Nutrition for Swimming

Article *in* International journal of sport nutrition and exercise metabolism · June 2014

DOI: 10.1123/ijsnem.2014-0015 · Source: PubMed

4 authors, including:

Greg Shaw
Australian Institute of Sport (AIS)

Louise Mary Burke
Australian Institute of Sport (AIS)

International Journal of Sport Nutrition and Exercise Metabolism, 2014, 24, 360-372
http://dayx.doi.org/10.1123/ijsnem.2014-0015

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

Nutrition for Swimming

Gregory Shaw, Kevin T. Boyd, Louise M. Burke, and Anu Koivisto

Swimming is a sport that requires considerable training commitment to reach individual performance goals. Nutrition requirements are specific to the macrocycle, microcycle, and individual session. Swimmers should ensure suitable energy availability to support training while maintaining long term health. Carbohydrate intake, both over the day and in relation to a workout, should be manipulated (3–10g/kg of body mass/day) according to the fuel demands of training and the varying importance of undertaking these sessions with high carbohydrate availability. Swimmers should aim to consume 0.3g of high-biological-value protein per kilogram of body mass immediately after key sessions and at regular intervals throughout the day to promote tissue adaptation. A mixed diet consisting of a variety of nutrient-dense food choices should be sufficient to meet the micronutrient requirements of most swimmers. Specific dietary supplements may prove beneficial to swimmers in unique situations, but should be tried only with the support of trained professionals. All swimmers, particularly adolescent and youth swimmers, are encouraged to focus on a well-planned diet to maximize training performance, which ensures sufficient energy availability especially during periods of growth and development. Swimmers are encouraged to avoid rapid weight fluctuations; rather, optimal body composition should be achieved over longer periods by modest dietary modifications that improve their food choices. During periods of reduced energy expenditure (taper, injury, off season) swimmers are encouraged to match energy intake to requirement. Swimmers undertaking demanding competition programs should ensure suitable recovery practices are used to maintain adequate glycogen stores over the entirety of the competition period.

Keywords: swimmer, carbohydrate, adaptation, consensus, training, competition

Swimming is a foundation Olympic sport included at every Summer Games since 1896. Competitive races are held for the four swimming strokes (freestyle, backstroke, butterfly, breaststroke), individually or in combination (medley). With events lasting from 20 s to 16 min (50 m–1500 m), swimming is a highly technical sport demanding power and endurance underpinned by different combinations of anaerobic and aerobic fuel systems. Relays add the dimension of a team sport to the competition format. Race programs vary from a single day of competition to multiday meets in which swimmers often compete in multiple events of varying distance and stroke over a number of heats, semifinals, and finals.

Swimmers traditionally learn to swim at an early age and transition into formal training soon afterward. It is not uncommon for large training volumes to be undertaken by young swimmers to ensure that they develop optimal biomechanical technique, physiological capacity and race skills to allow them to compete at the elite level by adolescence. Indeed, it is possible for swimmers (particularly female swimmers) to achieve high levels of success before full pubertal development. Combinations of advanced training techniques, competition opportunities, and greater commercial rewards have extended the lifespan of a swimmer, and some elite swimmers now compete into their early 30s.

The physiological and biomechanical principles underpinning the movement of swimming have been reviewed elsewhere (Pyne & Sharp, 2014), as have the principles of the training required to prepare an athlete to compete in aquatic sports (Mujika et al., 2014). The aim of the current review is to specifically investigate the training and competition characteristics of pool swimming and to discuss nutritional strategies that are important in optimizing the outcomes of each component.

An Overview of the Periodized Training and Competition Calendar

Until recently, large training volumes were the hallmark of the preparation of swimmers (Mujika et al., 2014). Indeed, Stewart and Hopkins (2000) observed that a large portion of the training of age group swimmers was completed at low intensities in a nonspecialty stroke (i.e., freestyle), simply for the purpose of making up volume. Traditionally, such training was undertaken for large portions of the year, punctuated by an annual program of large national and international competitions. Prepara-

Shaw and Burke are with the Dept. of Sports Nutrition, Australian Institute of Sport, Canberra, Australia. Boyd is with the Dept. of Sport & Exercise Medicine, University Hospitals of Leicester, United Kingdom. Koivisto is with The Norwegian Olympic Sports Center (Olympiatoppen), Oslo, Norway. Address author correspondence to Greg Shaw at greg.shaw@ausport.gov.au.

tion for these events included a significant taper period followed by short periods of often significant detraining before the program commenced again. A greater discussion of the limitations of this periodization model is provided by Mujika et al. (2014).

The increased frequency of domestic and international competition opportunities for contemporary swimmers has contributed to an evolution in training philosophy, with the volumes and intensities of training now more accurately reflecting the physiological demands of competition performance. There is also a more marked periodization of the annual swimming program, with training focused on achieving high-level competition performances at regular points throughout the year. Training cycles vary between periods of moderate-high volume with the focus on low-moderate intensity workouts and a smaller proportion of workouts done at very high-intensities, to periods during which there is a larger focus on high-intensity work. These may include blocks of specialized training (e.g., altitude training) or shorter domestic/international competitions (e.g., FINA World Cups). Before major competitions, there is a more pronounced taper, with a reduction in training volume but maintenance of training at high intensities and race pace. For further reviews on the periodization of these macrocycles and the nutritional adjustments, see Mujika et al. (2014) and Burke and Shaw (2013).

The weekly training program of an elite swimmer typically involves 1–3 sessions per day and includes a range of different types of pool sessions, supplemented by "dry-land" activities such as yoga, core training, resistance training and cross-training. Examples of the training schedules for different parts of the training calendar are summarized in Table 1a (a summary of different types of training and nutritional strategies included in a swimmer's program), Table 1b (an illustration of an example training week during a high-volume, low/moderate-intensity phase) and Table 1c (illustration of an example training week during a moderate-volume, high-intensity phase). The nutritional support for such training, which will be

Table 1a Description of Pool Sessions Undertaken by Swimmers and Potential Nutrition Interventions for Enhancing Performance and/or Adaptation in Training

Training Characteristics				
Pool Sessions	**Pace (Rest Intervals)**	**Heart Rate (BBM)**	**Key Energy source**	**Lactate (mmol/L)**
A1: skills		<60 BBM	Aerobic: fat	< 1
A2		≈ 40–50 BBM	Aerobic: fat-CHO	≈ 1
A3	> 2,000-m pace	≈ 20–30 BBM	Aerobic: fat-CHO	≈ 3
Threshold/heart rate	2,000-m pace	≈ 10 BBM	Aerobic and anaerobic: CHO	≈ 4
VO_{2max}	400-m pace (Longer duration efforts, medium to low rest)	Max	Aerobic and anaerobic: CHO	≈ 6–8
Tolerance	> 200-m pace (High intensity with medium rest)	Max	Aerobic and anaerobic: CHO	> 8
Speed development	> 50-m Pace (High intensity with long rest)	N/A	PCr/anaerobic:CHO	N/A
Nutrition Strategies				
Strategy	**Description**	**Explanation**		
HCHO-A	High CHO availability	High starting glycogen stores to meet fuel needs of session		
LCHO-A	Low CHO availability	Low glycogen stores at commencement of training or overnight fasting		
CHO central	CHO for central drive	Frequent carbohydrate mouth wash or intake during session to enhance central drive via CHO-sensing receptors in oral cavity (25-ml boluses of sports drink or other carbohydrate source)		
Protein	Postexercise protein	High biological value protein (0.3 g/kg fat free mass) after session to enhance muscle protein synthesis after session		
Creatine	Creatine loading	Optimization of muscle Cr and PCr stores to support interval/resistance training		
β-Alanine	β-Alanine loading	Optimization of muscle carnosine content to increase muscle buffering capacity and other functions		
Caffeine	Caffeine	Caffeine may help rescue the lower performance levels of LCHO-A sessions		
Sports foods	Sports foods/drinks	Use of sports foods and drinks to deliver target amounts of fluid and key macronutrients during and after session		

Notes. A1 = Aerobic 1 A2 = Aerobic 2. A3 = Aerobic 3. BBM = beats below max. VO_{2max} = maximum oxygen consumption. CHO = carbohydrate. HCHO-A = high carbohydrate availability. LCHO-A = low carbohydrate availability. PCr = phosphocreatine. Cr = creatine. N/A = not applicable.

Table 1b Example of High-Volume, Low- to Moderate-Intensity Training Week

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Nutrition Focus Range
AM session	A1	Threshold + RE (gym)	Threshold	A1	VO_{2max}	RE (gym)	Rest Day	Energy: 170–350 kJ/kg/day
				RE (gym)		Speed		40–75 kcal/kg/day
Session nutrition focus		Protein	LCHO-A	Protein	HCHO-A or CHOcentral	Protein		CHO: 3–7 g/kg/day
PM session	Tolerance/ Quality	A1	Speed/ Tolerance	A2/A3	Tolerance/A2 recovery	Off		Protein: 1.5–1.8 g/kg/day
Session nutrition focus	HCHO-A or CHO central		HCHO-A		HCHO-A or CHO central			Supplements Sports foods and drinks Caffeine
Examples of daily Nutrition strategies	CHO recovery after AM session	Protein snack post-RE session and regularly throughout day	CHO recovery and throughout day for HCHO-A at PM session	Protein snack post RE session and regularly throughout day	High daily CHO and energy requirements	Protein snack post-RE session and regularly throughout day	Reduce Energy and CHO to meet nontraining requirements	
	CHO intake during PM session	Restrict refueling after PM session for LCHO-A for AM session			CHO intake during AM and PM sessions			

Notes. A1 = Aerobic 1. RE = Resistence exercise. CHO = carbohydrate. VO_{2max} = maximum oxygen consumption. HCHO-A = high carbohydrate availability. LCHO-A = low carbohydrate availability. Adapted from Burke and Shaw (2013).

covered over this review, includes a periodization to include the needs of each session, recovery and adaptation between sessions, and adjustments to suit the larger goals of a training block. This will mean adjustment of total energy and carbohydrate intake according to general fuel needs and goals of physique manipulation, as well as specific arrangement of carbohydrate, fluid and protein intake around sessions to optimize training performance and/or adaptation.

Energy Requirements=

The changing energy needs of a swimmer chiefly reflect his or her training/racing volume, growth or goals to alter physique, and, in the case of nonelite competitors, other lifestyle activities. Typical values for the self-reported energy intakes of male and female swimmers are 15–20 MJ/day (3600–4800 Kcal/day) and 8–11 MJ/day (1900–2600 Kcal/day), respectively. The dietary survey literature on swimmers, summarized in Table 2, includes examples in which training blocks are completed in apparent energy balance (Alméras et al., 1997; Ousley-Pahnke et al., 2001; Vallieres, 1989). However, other studies report apparent large mismatches between energy intake and energy expenditure (up to 10 MJ/day or 2,400 kcal/day) when training volumes and intensities are extreme (Trappe et al., 1997).

There appears to be a sex-difference in the ability to match energy needs to expenditure during different swimming volumes (Berning et al., 1991; Kabasakalis et al., 2007; Noland et al., 2001). Male swimmers can appropriately increase their energy intake during periods of increased training, mainly by increasing their carbohydrate consumption to match increased fuel needs (Barr & Costill, 1992), although this is not always the case (Costill et al., 1988). Conversely, female swimmers have been reported to be less capable of spontaneously making such adjustments. Female collegiate swimmers who were tracked over an entire season were unable to adjust energy intake according to fluctuations in training

Table 1c Example of Moderate-Volume, Moderate- to High-Intensity Training Week

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Nutrition Focus Range
AM session	A1 + RE (gym)	VO_{2max}	RE (gym)	Threshold	A2/A3 + RE (gym)	Threshold	Rest day	Energy: ≥150–230 kJ/kg/day
								35–55 kcal/kg/day
Session nutrition focus	Prot	HCHO-A or CHO central	Protein	LCHO-A	Protein	LCHO-A		CHO: 3–8 g/kg/day
PM session	Speed	A1	Tolerance/A2 recovery	A1	Tolerance/A2 recovery	Off		Protein: 1.7–2.0 g/kg/day
Session nutrition focus	HCHO-A or CHO central		HCHO-A or CHO central		HCHO-A or CHO central			Supplements
	Protein		Protein		Protein			Protein
								β-Alanine
								Sports foods and drinks
								Caffeine
Examples of daily Nutrition strategies	Protein snack post-RE session and regularly throughout day	CHO intake during AM session	Protein snack post-RE session and regularly throughout day	CHO recovery over next 36 hr	Protein snack post-RE session and regularly throughout day	CHO recovery over next 48 hr before restarting	Reduce energy and CHO to meet nontraining requirements	
	CHO and protein recovery meal for glycogen resynthesis overnight		Restrict refueling after PM session for LCHO-A for AM session		Restrict refueling after PM session for LCHO-A for AM session			

Notes. A1 = Aerobic 1. RE = Resistance exercise. CHO = carbohydrate. VO_{2max} = maximum oxygen consumption. HCHO-A = high carbohydrate availability. LCHO-A = low carbohydrate availability. Adapted from Burke and Shaw (2013).

volume, with a noticeable gain in body fat during the off-season (Alméras et al., 1997). Indeed, the estimated energy cost of this body composition change was similar to the notional energy expenditure of the missed training sessions. However, within swimming circles, there is also discussion that female swimmers appear to be able to undertake training volumes similar to those of male swimmers but with unexpectedly lower energy intakes.

The appearance of "energy efficiency" in female swimmers who report energy intakes that are less than expected or less than their male counterparts while undertaking training with stable body composition has often been questioned. Explanations for this phenomenon include lower levels of lean muscle mass (Jones & Leitch, 1993; Van Handel et al., 1984), enhanced efficiency of swimming (Costill et al., 1985; Zamparo et al., 2011), and underreporting of dietary intake, particularly related to concerns about body composition. Athletes in other weight-conscious sports are often described as underreporting their dietary intakes on self-reported food diaries (Jonnalagadda et al., 2000). A significant negative energy balance is of concern when it affects health and performance.

Low energy availability, defined as an energy intake that is too low to support the body's energy needs for optimal function once the energy cost of exercise is subtracted, is known to have a large number of negative health consequences. These include reductions in meta-

Table 2 Summary of Energy Balance in Swimmers From Self-Reported Energy Intake and Estimated Energy Expenditures

Study	Methods for Measuring Energy Intake (EI) or Energy Expenditure (EE)	Swimming Population	Training Volume	Energy Intake [MJ/day (kcal/day)]	Energy Expenditure [MJ/day (kcal/day)]
Vallieres et al. 1989	30-day training period	Canadian collegiate	15 hr/week	Week 1: 10.4 ± 3.2 (2,500 ± 800)	Week 1: 12 ± 2.4 (2,900 ± 600)
	EI: 3-day food diary @ Weeks 1 & 4	(*n* = 6 F)	(3.3 ± 0.3 km/session)	Week 4: 10.2 ± 2.9 (2,400 ± 700)	Week 4: 10.5 ± 1.5 (2,500 ± 400)
	EE: Activity records, RMR and swimming EE via indirect calorimetry				
Jones & Leitch 1993	10-day taper	Canadian collegiate	90–120 min/day	16.3 ± 2.6 (3,895 ± 621)	14.6 ± 3.7 (3,556 ± 1,025)
	EE: Doubly labeled water	(*n* = 5 M, 3 F)	Day 6 intercollegiate championships		
	EI: Standardized diet provided and correlated to detailed weighed food records				
Alméras et al. 1997	13-month training period with	Canadian collegiate	18.8 hr/week	Baseline 11.0 ± 3.3 (2,600 ± 800)	PAR 12.0 ± 3.1 (2,900 ± 700 PAR 12.0 ± 2.7 (2,900 ± 600)
	3 × measurements throughout and after 2 months of detraining.		(range = 10–35 hr/week)	Part 1 10.5 ± 3.4 (2,500 ± 800)	HR-VO_2 12.7 ± 6.4 (3,000 ± 1,500)
	EE: Physical activity record (3 day) and HR-VO_2 method (2 day, 24-h HR measurement)			Part 2 11.1 ± 3.0 (2,600 ± 700)	PAR 13.2 ± 2.4 (3,100 ± 600) HR-VO_2 12.4 ± 3.6 (2,900 ± 900)
	EI: 3-day food diary			Part 3 9.2 ± 3.0 (2,200 ± 700)	PAR 12.7 ±2.2 (3,000 ± 500) HR-VO_2 13.1 ± 4.0 (3,100 ± 1,000)
Trappe et al. 1997	5-day training camp	U.S. national	5 day @ 2/day (5–6 h/day)	13.1 ± 0.9 (3,136 ± 227)	23.4 ± 2.1 (5,593 ± 495)
	EE: Doubly labeled water	(*n* = 5 F)	Training distance		
	EI: 2-day food diary		17,500 ± 1,000 m/day		
Ousley-Pahnke et al. 2001	Taper phase	U.S. collegiate	6 day @ 4,300 m/day	9.5 ± 2.8 (2,275 ± 665)	9.8 ± 0.7 (2,342 ± 158)
	EE: Activity diary & equations.	(*n* = 15 F)			
	EI: 4-day food diary				
Hassapidou & Manstrantoni 2001	Data collection during training and competitive season	Greek club teams	2–3 hr/day during non-competitive season, ≥ 0.5 hr racing during competitive season	Training: 8.4 ± 2.3 (2,015 ± 542)	Training: 10.5 ± 1.3 (2,520 ± 304)
	EE: 7-day activity records and equations	(*n* = 9 F)		Competition:	Competition:
	EI: 7-day weighed dietary records			7.9 ± 3 (1,890 ± 709)	10.7 ± 0.9 (2,550 ± 210)

(continued)

Table 2 *(continued)*

Study	Methods for Measuring Energy Intake (EI) or Energy Expenditure (EE)	Swimming Population	Training Volume	Energy Intake [MJ/day (kcal/day])]	Energy Expenditure [MJ/day (kcal/day])]
Sato et al. 2011	7-day preparation period	Japanese university	Preparation	Preparation:	Preparation:
			M: 3,528± 0 m/day	M:13.1 ± 3.1 (3,158 ± 733)	M:11.1 ± 0.4 (2,646 ± 146)
	7-day intense training period	(*n* = 6 M, 13 F)	F: 3,429 ± 242 m/day	F: 11.3 ± 1.8 (2,710 ± 431)	F: 8.7 ± 1.4 (2,085 ± 326)
	EE: RMR, activity factor, and VO_2 estimations		Intense	Intense	Intense
			M: 6,327 ± 554 m/day	M: 13.9 ± 1.6 (3,322 ± 378	M: 12.3 ± 1.4 (2,932 ± 335)
	EI: 3-day food records		F: 6,993 ± 330 m/day	F: 12.0 ± 1.7 (2,880 ± 408)	F: 11.3 ± 1.8 (2,562 ± 372)
Slattery et al. 2012	4-day training block	Australian national	Range = ≥ 191–130 min/day	16.6 ± 3.4 (3,995 ± 789)	16.7 ± 3.3 (3,969 ± 821)
	EI: 4 × 24-hr recall	(*n* = 4 M, 2 F)			
	EE: HR calculation				

Notes. HR = heart rate. VO_2 = oxygen consumption. RMR = resting metabolic rate. M = male. F = female. PAR = physical activity record.

bolic rate, hormonal disturbances, menstrual dysfunction, suboptimal bone health, and an increased risk of illness and injury (Burke, 2014; Melin et al., 2014). Recently, a study highlighted the impact of a low energy availability specifically on swimmers (VanHeest et al., 2014). Elite junior female swimmers were monitored over 12 weeks of training that included a period of increased volume, and a subgroup of swimmers who had regular menstrual function was compared with another subgroup in which ovarian suppression of their cycles occurred. This subgroup had higher body fat levels than their counterparts and maintained a stable weight over the course of the study, despite reporting a lower energy intake, while completing the same training as the regularly menstruating group. Energy deficiency was confirmed among these swimmers via measurements of resting energy expenditure (depressed) and triiodothyronine and insulin-like growth factor concentrations (dropped over the course of the study). Consequently, the two groups of swimmers were matched for performance (400-m swim time) at the commencement of the study; however, after 12 weeks of training, only the healthy group experienced an improvement (8% increase in speed); the energy-deprived swimmers showed a 10% decline in swimming speed.

Therefore, a major focus of a swimmer's diet should be the manipulation of energy intake to meet daily training requirements. This should be achieved through the manipulation of macronutrients according to the intensity, frequency, and volume of sessions (see Tables 1b and 1c). Swimmers should be educated on practical nutrition skills that allow them to easily transition between low to potentially high energy intakes. A strategy that assists with energy matching as well as providing direct nutrition support for workouts is to organize nutrient intake before, during, and after the training session. However, the regulation of appetite also plays a critical role in the success of such strategies.

Swimming has been associated anecdotally with an increased appetite and risk of overeating compared with other sports activities; the potential mechanism involves reduced thermoregulatory stress because of dissipation of heat into the cool water environment. Indeed, 1 hr of running undertaken in cold conditions (10 °C) has been shown to increase ad libitum food intake and reduce satiety compared with exercise in temperate (20 °C) environmental conditions. Conversely, the same bout of exercise in the heat (30 °C) reduced feelings of hunger and prospective food consumption (Wasse et al., 2014). Lambert et al. (1990) failed to find a difference in appetite and ad libitum intake after bouts of swimming and running matched for energy expenditure and intensity (≤70% VO2max); the pool temperature during the swimming session was 29 °C. Other studies of cool water (20 °C) exercise have found a 40% increase in postexercise energy intake compared with exercise in thermoneutral or control situations (White et al., 2005). Whether the mechanism for an increased food intake after exercise in water is associated with core temperature regulation or some other mechanism remains unknown, and more research is needed. However, it is logical to recommend that swimmers undertaking low-intensity training sessions, even in pools with controlled temperatures, require significant education regarding dietary strategies to control energy intake at times when appetite may be artificially amplified. Conversely, they should endeavor to use foods that are appetizing and easier to consume in situations in which appetite is suppressed (e.g., after completing high-intensity sessions in hot pools/environments).

Carbohydrate Requirements

Swimming training can significantly deplete muscle glycogen stores (Costill et al., 1988b); the completion of high-volume training blocks is reliant on the consumption of adequate carbohydrates (Costill et al., 1988a). The classic study by Costill et al. (1988a) demonstrated that swimmers who failed to increase carbohydrate intake in response to a sudden increase in training volume reported greater fatigue, muscle soreness, and inability to complete designated workouts compared with counterparts who spontaneously increased their carbohydrate intake (8.2 vs. 5.3 g/kg of body mass, or BM, per day) to maintain muscle glycogen stores. Even a minor degree of suboptimal refueling may interfere with performance: A group of well-trained swimmers who reduced daily carbohydrate intake by 10% over 3 days reported a reduction in performance over a distance of 400 yards (365 m). Conversely, a similar increase (10%) in dietary carbohydrate led to performance enhancement over 100- and 400-yard (91.5 and 365 m) swimming time trials (Reilly & Woodbridge, 1999). This does not suggest that the training diet should be high in carbohydrate per se. Rather, when high quality/intensity training is required, carbohydrate intakes should allow muscle glycogen restoration ("high carbohydrate availability"). Indeed, another study of swimmers undertaking a moderate training load found that a carbohydrate intake of 6 g/kg of BM/day met requirements for glycogen restoration and that no performance advantage was gained by consuming a greater amount (12 g/kg of BM/day; Lamb et al., 1990).

Daily carbohydrate intake should be periodized to match the changing fuel requirements of the training program to permit training at high intensities. Tables 1A, 1B, and 1C illustrate the carbohydrate-dependent workouts and how total carbohydrate could be periodized over the week and within a day to ensure high carbohydrate availability for key sessions. Other sessions may tolerate lower carbohydrate availability, which will be inevitable when several sessions are undertaken in close succession during high-volume training weeks. In fact, some sessions might be deliberately undertaken with low carbohydrate availability (low muscle glycogen stores and/or overnight fasting) to expose the muscle to a higher training stimulus and, therefore, to promote a greater metabolic adaptation. For a detailed review of such practices in swimming, see Mujika et al. (2014). Such interventions should be carefully programmed into a swimmer's yearly training plan to ensure low carbohydrate availability is used at appropriate times and does not compromise the outcome of strength and power blocks or immune health.

Carbohydrate intake can be increased in the total diet by including carbohydrate-rich foods at meals and snacks and by consuming carbohydrate sources before and during workouts and in the recovery afterward (Burke et al., 2014). There has been little specific investigation of the effect on immediate and cumulative performance of consuming carbohydrates before and during a swimming session. In fact, in the only directly applicable research, swimmers consuming carbohydrates (1g/kg BM) during a training session failed to achieve a significant benefit to their performance of a set of 10 × 100 yd (91.5 m) sprints completed at the end of a standardized training session (O'Sullivan et al., 1994). However, the general sports nutrition literature supports the value of consuming carbohydrates during prolonged exercise (> 90 min) to promote performance by providing an additional muscle fuel source (Burke et al., 2011). Of particular interest to shorter and/or technical sessions is the recent evidence of enhanced central drive and improved pacing strategies arising from carbohydrate intake; more specifically, there is evidence for contact of carbohydrate with receptors in the oral cavity (Jeukendrup, 2013), even during sprint exercise (Beaven et al., 2013). Specifically, the frequent exposure of the mouth to small amounts of carbohydrates during non–carbohydrate-dependent exercise bouts (< 60 min) enhances reward center functioning in the brain and consistently enhances performance (Jeukendrup, 2013). This phenomenon is discussed in more detail in the review of race practices for open-water swimming (Shaw, 2014) but could also be of use in a training scenario. It should be noted that the intake of carbohydrates before and during a swimming workout changes the relationship of lactate to swim velocity to indicate a greater contribution of anaerobic carbohydrate utilization for fuel use. For example, in a group of well-trained swimmers, the ingestion of 12 ml/kg BM of a 6% sucrose/glucose sport drink before undertaking a graded exercise capacity test in the pool resulted in significantly higher concentrations of blood lactate during the early stages of this test (35–50% at step 2) compared with a placebo trial (Millard-Stafford et al., 2010). This observation is important to understand because this relationship is traditionally monitored over a training cycle as a sign of the adaptive response; a lower lactate level for a given swimming speed is considered to indicate a positive training effect. This does not undermine the general relationship between fast swimming performances in competition and high levels of lactate production but shows the limitations of using lactate monitoring without dietary control as an indicator of training performance and prescription (Millard-Stafford et al., 2010; Reilly & Woodbridge, 1999).

Finally, high-intensity exercise has been shown to reduce the effectiveness of the body's immune defenses, particularly after exercise, when blood concentrations of glucose are low and cortisol is increased (Pyne et al., 2014). This review suggests that the consumption of carbohydrates during prolonged and/or high-intensity exercise may attenuate the reduction in immune system activity and reduce the risk of illness. Therefore, swimmers are encouraged to consume carbohydrate-containing foods and drinks, either immediately before or in small frequent amounts during key performance workouts, to optimize long-term training adaptations (see Tables 1B and 1C). Strategies to enhance refueling after glycogen-depleting workouts are discussed in more detail by Burke et al. (2014); there is also a discussion of tactics to enhance glycogen synthesis when the interval between carbohydrate-dependent workouts is short (< 8 hr) and/or total energy intake needs to be monitored (i.e., when loss of body fat is desired).

Protein Requirements

Protein intake is an important consideration in the achievement of optimal training adaptations. Dietary surveys of swimmers typically report intakes of more than 1.2–1.6 g/kg BM/day (Burke, 2007), which meets the suggested increase in daily protein requirements associated with sport. However, the current research focus concerns recommendations for the optimal timing, type, and amount of protein to promote adaptation and recovery from the specific stimulus of each exercise bout (Burke et al., 2014). Swimming is a challenging sport because the periodized training program includes endurance exercise, intermittent high-intensity sprints, and resistance training (Tables 1B and 1C). It has been suggested that the undertaking of mixed training stimuli in close proximity, as often occurs in the swimmer's training program (e.g., a pool session undertaken before or after a resistance workout) could produce interference with the net training stimulus. Nevertheless, a study of elite female swimmers who undertook a combination of an interval training session and a resistance workout found an effective increase in muscle protein synthesis (Tipton et al., 1996). Therefore, to maximize the early protein synthetic response to the exercise stimulus, swimmers should follow the current guidelines to consume 0.3g/kg BM of protein (~20–25 g of high-quality protein) soon after a key workout, resistance exercise sessions, or a race (Moore et al., 2009; Witard et al., 2014). They should continue to consume similar amounts of protein at 4–5 opportunities, including meals and snacks spread over the day and before bed, when trying to maximize the training response and/or increase muscle mass (Areta et al., 2013). Strategies are covered in more detail by Burke et al. (2014).

Micronutrient Requirements

A moderate to high energy intake and a wide variety of nutrient-rich foods generally guarantees a generous supply of micronutrients and phytochemicals. Because male swimmers are regularly reported to have high energy intake (Table 2), they are typically not considered to be a group at risk for low micronutrients. Reports of suboptimal micronutrient status are generally limited to female swimmers and concern iron (Farajian et al., 2004; Kabasakalis et al., 2007; Vallieres, 1989; Van Handel et al., 1984) and calcium (Farajian et al., 2004; Paschoal & Amancio, 2004). These findings are typically associated with restrained eating practices and inadequate food variety. In fact, in one study of female swimmers (Petersen et al., 2006), an improvement in iron status over a training season was associated with an improvement in the quality and quantity of dietary choices. This suggests that through the quality of food choices and by ensuring appropriate energy availability, good micronutrient status can be achieved.

Vitamin D is a micronutrient in the current spotlight because of its importance to health and performance and the risk of inadequate status in people who do not have adequate exposure to sunshine. Vitamin D insufficiency may be an issue for swimmers who train indoors or in environments in which exposure to ultraviolet B radiation is minimal. Indeed, one third of a group of Israeli swimmers who trained indoors were found to have 25(OH) vitamin D levels below 30 ng/ml (75 nmol/L), a level considered to be insufficient for optimal health and performance (Constantini et al., 2010). Likewise, swimmers were among a group of indoor-training American college athletes who were found to have significantly lower vitamin D levels than athletes who trained outdoors (Halliday et al., 2011). Recently, the supplementation of 4,000 IU (100 mg) of vitamin D in National Collegiate Athletic Association swimmers and divers who were at risk (living above 38° north latitude), but not deficient, was effective in maintaining (+1 ng/ml) plasma 25(OH) vitamin D over a winter training season. Those receiving a placebo saw a nonsignificant drop of 20 ng/ml (50 nmol/L; Lewis et al., 2013). Therefore swimmers who fall into the high-risk groups for insufficient sunshine exposure are encouraged to monitor their vitamin D status and to seek appropriate interventions, including supplementation, to enhance stores if they are found to be insufficient (Powers et al., 2011).

Physique and Performance in Swimming

Swimming performance is based on the ability to generate forward propulsion while minimizing drag through the water and is aided by a fine balance between muscle mass and appropriate morphology (e.g., surface area and body fat; Sharp et al., 2014). Typically, sprinters and high-level swimmers are taller and heavier than long-distance or less successful swimmers; female long-distance swimmers traditionally have significantly higher skinfold thicknesses than all other swimmers (Carter & Ackland, 1994). Ideally, training should be associated with periodized increases in lean tissue and reductions in fat mass across the swimming season (Alméras et al., 1997; Anderson et al., 2006; Petersen et al., 2006; Pyne et al., 2006), taking into account the physique changes associated with puberty, particularly in girls. Specific information on the ideal physique for swimming or the effect of body composition on swimming performance is limited and hard to interpret. For a period at least, the importance of physique was skewed by the mitigating effects of bodysuits on drag. The recent banning of these suits is likely to have increased the interest in manipulating the body composition of swimmers.

Although it would be valuable to undertake cross-sectional and longitudinal studies of performance and physique in swimming, the limitations of such data in determining cause and effect must be acknowledged. For example, in the case of observations of the extreme leanness of certain elite swimmers or improvements in performance associated with physique changes, it is hard to distinguish between the effects of body fat or lean mass on performance, per se, and the influence of the training or dietary commitment that were involved in the achievement of such a physique. It is most likely that ideal physique is individual to each swimmer (influenced by developmental age, chosen stroke, and competition distance) and that each swimmer has a range of desirable physical characteristics within which they maintain good health while training and performing well. The swimmer should aim to achieve their optimal body composition over a number of years as well as periodize it over the season.

Gain of body fat, whether as a natural consequence of adolescence or during the off-season, is a consistent concern for many female swimmers and their coaches. Clearly, an excessive amount or rate of increase of body fat is detrimental to performance, presumably because of the sudden change in the fluid dynamics and biomechanics of swimming. There is both research and anecdotal evidence of a worrying prevalence of weight-control phobias among female swimmers, accompanied by disordered eating or pathogenic weight loss behaviors (Benson, 1991). It is now recognized that a risk factor for the development of disordered eating among athletes is the necessity to wear figure-revealing or skimpy sports clothing (Otis et al., 1997). The constant display of a changing body shape is likely to be a particularly stressful activity for the adolescent female swimmer with self-esteem and body-image problems. Clearly, a complex array of factors contributes to the pressure felt by many female swimmers with regard to weight and body fat levels. Although not as prominent in the literature, male athletes in some sports may also be susceptible to body-image pressures. The consequences of strategies used to achieve sporting norms can have similar significant negative performance and health consequences as female athletes (Hagmar et al., 2013). Coaches and support personnel should be aware of their role and responsibilities around the appropriate discussion of body composition with swimmers. These populations should be targeted for sound professional advice regarding the setting and achievement of long-term goals for ideal physique. The problem of disordered eating and eating disorders within aquatic sports is covered in more detail by Melin et al. (2014).

Nutrition for Racing

Nutrition for racing encompasses two major themes: addressing the nutrition-related factors that underpin fatigue in the swimmers' specific event or competition schedule, as well as managing the practical issues associated with the competition lifestyle and environment. The latter challenges are discussed in more detail in the review by Stellingwerff et al. (2014) and are often encountered during the reduced energy expenditure associated with the pronounced training taper before major events and the racing commitment itself. To circumvent a gain of substantial amounts of body fat, swimmers should be aware of their changing nutrient and energy needs and undertake mindful eating within the competition environment (Stellingwerff et al., 2014).

Although there are different event formats, swimming competitions typically involve a multiday meet; the Fédération Internationale de Natation (FINA) World championships and Olympic Games program extend to 8 days, with heats conducted in the morning session and semifinals and finals in the evening. The variability in competition load between swimmers can be significant. Elite breaststrokers, for example, rarely swim other strokes and may compete in only a single event at a major championship. Conversely, talented swimmers can undertake a substantial race program that involves several races within single-session and multiple events across different strokes in both heats and finals sessions over a period of 8 days. Single-event swimmers are unlikely to challenge their fuel stores, but multievent swimmers face significant barriers to timely fuel maintenance and postrace recovery. A well planned approach is required, using the principles reviewed by Burke et al. (2014) to organize a schedule of meals and postrace snacks to achieve race preparation and recovery goals.

Large multievent programs undertaken over consecutive days require a planned approach to race eating, especially when the athlete is competing in events away from his or her home base. A competition-day nutrition plan should include a familiar and well-tolerated carbohydrate-rich prerace meal, consumed 1–3 hr before warm-up. During and after warm-ups, and in recovery between events on the same program, carbohydrate-containing drinks (e.g., sport drinks) and light carbohydrate foods (fruit, cereal bars, sport bars) will help to maintain body carbohydrate supplies and fluid balance and prevent hunger. Carbohydrate- and protein-rich food and formulated sport food choices such as liquid meal supplements, flavored and unflavored milk, or meat sandwiches are useful at the end of competition sessions to promote repair and adaptation, and when carbohydrate intake is suboptimal, to promote glycogen resynthesis (Burke et al., 2014). For swimmers competing in whole-day meets, intake should be targeted to the amount of time between races. When the time between races is less than 60 min, swimmers should focus on carbohydrate sources that are unlikely to cause gastrointestinal upset. As the time between races increases, more substantial meals, including protein and other nutrients, can be consumed to aid recovery and improve overall race-day food quality.

Swimmers should plan for all eventualities and carry suitable food choices with them to the pool for periods of reduced food access. Swimmers should pay particular attention to the use of supplements or foods containing caffeine. Although little evidence exists to link one poor night of sleep to reduced performance on the subsequent day, the frequent use of caffeine over a multiple-day competition can lead to accumulated sleep loss, which may reduce performance toward the end of the meet, or to a cyclical misuse of sleeping aids followed by more caffeine intake.

Supplements and Sports Foods

Swimmers are regularly reported as enthusiastic supplement consumers. Data collected at doping control at the Sydney 2000 Olympic Games reported swimming among the sports with the greatest prevalence of supplement use (Corrigan & Kazlauskas, 2003). Baylis et al. (2001) looked specifically at the supplement practices of high-level swimmers and reported that 99% of swimmers used dietary supplements (including formulated sports foods); 94% used at least one non–food-based dietary supplement, and one swimmer reported using 27 different products. The current authors (Shaw, 2013) have measured supplement practices in a similar group of elite Australian swimmers (2009 World championship participants), noting a continued high prevalence of use (97%). However, the influence of a more expansive and visible supplement industry was seen in this 2009 group, with a greater number of supplements (9.2 ± 3.7 vs 5.9 ± 2.9) from a greater number of individual manufacturers (7.6 ± 2.9 vs 5.6 ± 2.7). Swimmers in 2009 focused their practices on supplements with sound evidence of performance enhancing effects (such as caffeine, sodium bicarbonate and sports foods; Shaw, 2013).

The general issues involved with the use of supplements and sports foods are discussed by Maughan et al. (2014). Even when there is evidence for the use of such products, the swimmer is advised to be aware of the appropriate situations and protocols of use and to take into account the "cost" of products in terms of financial outlay and the small but real risk of an inadvertent doping outcome (Maughan et al., 2014). To avoid adverse outcomes of supplement use, swimmers are encouraged to practice dietary-supplement protocols in multiple situations before major competition use.

The Adolescent Swimmer

Swimming training and competition can start at a young age; many young swimmers complete large training volumes by their early teens. Parents and coaches of these swimmers need to be aware of the unique nutrition requirements of this group. Increased energy needs of growth and development should be accounted for by an increased intake of a variety of food sources. Because of their training immaturity and lower level of metabolic adaptations, carbohydrate requirements for a given workout may be relatively higher. From Current sentence to Protein requirements (grams per kilogram of BM) of adolescent swimmers are likely to be increased because of growth. These requirements can be suitably met by choosing a variety of protein containing foods, as part of a high energy intake. It is unknown whether adolescent swimmers have higher than normal micronutrient requirements. However, they are encouraged to choose a wide variety of foods within a diet that meets their energy needs to ensure micronutrient intakes are suitable. Parents and coaches can support adolescent swimmers by establishing good meal patterns at home, reinforcing the education pathway described in the section below in the home environment, and ensuring the availability of appropriate and convenient whole-food options around the workouts.

Nutrition Knowledge and Practices in Swimmers

The ability to follow the practices outlined in this review requires significant nutrition knowledge and food literacy. Although athletes typically have similar general nutrition knowledge, and greater sports nutrition knowledge than their nonathletic peers (Heaney et al., 2011), swimmers are often reported to consume diets that are suboptimal (Farajian et al., 2004; Kabasakalis et al., 2007; Petersen et al., 2006). Furthermore, the experience of the current authors is that it takes a carefully designed education program to progressively develop nutrition knowledge and practice across a swimmer's career. Nutrition education should focus on nutrition for health at a learn-to-swim level and then progress to the manipulation of specific nutrients for adaptation and performance goals. Sports nutrition concepts should be introduced with a focus on whole foods consumed for performance purposes, evolving as the swimmers become more elite into education around single nutrients or use of supplements and specialized sports foods. "Hands on" education of skills such as meal planning, shopping, and food preparation are paramount to a swimmer's ability to turn knowledge into practice. Without these skills and food literacy, swimmers are ill-equipped to achieve the complex dietary strategies and nutrient periodization promoted in reviews such as this.

Summary

Like the other aquatic sports, swimming provides considerable nutritional challenges in both training and competition phases. Energy and carbohydrate needs can vary greatly between swimmers and across the various components of a week, macrocycle, annual program, or swimming career. To achieve the best outcomes, swimmers need to learn the skills to vary their food intake accordingly, especially to periodise optimal nutritional support before, during, and after workouts. The achievement of ideal physique can be challenging, particularly for female swimmers. Competition nutrition requires a special eating plan to promote recovery between races, especially for swimmers who race in multiple events.

Some supplements and sports foods can be used by swimmers to achieve their nutritional goals and optimal performance. Many of the recommendations for swimmers are based on evidence gained from research on other sports with similar characteristics. More swimming-centered studies are needed to provide specific support for these guidelines or to evolve new practices.

Acknowledgments

The authors have no conflicts of interest to declare.

References

Alméras, N., Lemieux, S., Bouchard, C., & Tremblay, A. (1997). Fat gain in female swimmers. *Physiology & Behavior, 61,* 811–817. PubMed doi:10.1016/S0031-9384(96)00559-8

Anderson, M.E., Hopkins, W.G., Roberts, A.D., & Pyne, D.B. (2006). Monitoring seasonal and long-term changes in test performance in elite swimmers. *European Journal of Sport Science, 6,* 145–154. doi:10.1080/17461390500529574

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

Barr, S.I., & Costill, D.L. (1992). Effect of increased training volume on nutrient intake of male collegiate swimmers. *International Journal of Sports Medicine, 13,* 47–51. PubMed doi:10.1055/s-2007-1021233

Baylis, A., Cameron-Smith, D., & Burke, L.M. (2001). Inadvertent doping through supplement use by athletes: assessment and management of the risk in Australia. *International Journal of Sport Nutrition and Exercise Metabolism, 11,* 365–383. PubMed

Beaven, C.M., Maulder, P., Pooley, A., Kilduff, L., & Cook, C. (2013). Effects of caffeine and carbohydrate mouth rinses on repeated sprint performance. *Applied Physiology, Nutrition, and Metabolism, 38,* 633–637. PubMed doi:10.1139/apnm-2012-0333

Benson, R. (1991). Weight control among elite women swimmers. In D.R. Black (Ed.). *Eating disorders among athletes: Theory, issues, and research* (pp. 97–109). Reston, VA: American Alliance for Health, Physical Education, Recreation, and Dance.

Berning, J.R., Troup, J.P., VanHandel, P.J., Daniels, J., & Daniels, N. (1991). The nutritional habits of young adolescent swimmers. *International Journal of Sport Nutrition, 1,* 240–248. PubMed

Burke, L.M. (in press). An updated view on low energy availability in athletes. *British Journal of Sports Medicine*.

Burke, L.M., Hawley, J.A., Wong, S.H., & Jeukendrup, A.E. (2011). Carbohydrates for training and competition. *Journal of Sports Sciences, 29*(Suppl. 1), S17–S27. PubMed doi:10.1080/02640414.2011.585473

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

Burke, L.M., & Shaw, G. (2013). Swimming. In Maughan, R.J. (Ed.). *The encyclopaedia of sports medicine: An IOC medical commission publication. Volume XIX. Sports nutrition* (pp. 607–618). Chichester, UK: John Wiley & Sons Ltd.

Carter, J.E.L., & Ackland, T.R. (Eds.). (1994). *Kinanthropometry in aquatic sports: A study of world class athletes*. Champaign, IL: Human Kinetics.

Constantini, N.W., Arieli, R., Chodick, G., & Dubnov-Raz, G. (2010). High prevalence of vitamin D insufficiency in athletes and dancers. *Clinical Journal of Sport Medicine, 20,* 368–371. PubMed doi:10.1097/JSM.0b013e3181f207f2

Corrigan, B., & Kazlauskas, R. (2003). Medication use in athletes selected for doping control at the Sydney Olympics (2000). *Clinical Journal of Sport Medicine, 13,* 33–40. PubMed doi:10.1097/00042752-200301000-00007

Costill, D.L., Flynn, M.G., Kirwan, J.P., Houmard, J.A., Mitchell, J.B., Thomas, R., & Park, S.H. (1988a). Effects of repeated days of intensified training on muscle glycogen and swimming performance. *Medicine & Science in Sports & Exercise, 20,* 249–254. PubMed doi:10.1249/00005768-198806000-00006

Costill, D.L., Hinrichs, D., Fink, W.J., & Hoopes, D. (1988b). Muscle glycogen depletion during swimming interval training. *Journal of Swimming Research, 4,* 15–18.

Costill, D.L., Kovaleski, J., Porter, D., Kirwan, J., Fielding, R., & King, D. (1985). Energy expenditure during front crawl swimming: predicting success in middle-distance events. *International Journal of Sports Medicine, 6,* 266–270. PubMed doi:10.1055/s-2008-1025849

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

Farajian, P., Kavouras, S.A., Yannakoulia, M., & Sidossis, L.S. (2004). Dietary intake and nutritional practices of elite Greek aquatic athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 14,* 574–585. PubMed

Hagmar, M., Berglund, B., Brismar, K., & Hirschberg, A.L. (2013). Body composition and endocrine profile of male olympic athletes striving for leanness. *Clinical Journal of Sport Medicine, 23,* 197–201. PubMed doi:10.1097/JSM.0b013e31827a8809

Halliday, T.M., Peterson, N.J., Thomas, J.J., Kleppinger, K., Hollis, B.W., & Larson-Meyer, D.E. (2011). Vitamin D status relative to diet, lifestyle, injury, and illness in college athletes. *Medicine & Science in Sports & Exercise, 43,* 335–343. PubMed doi:10.1249/MSS.0b013e3181eb9d4d

Hassapidou, M.N., & Manstrantoni, A. (2001). Dietary intakes of elite female athletes in Greece. *Journal of Human Nutrition and Dietetics, 14,* 391–396. PubMed doi:10.1046/j.1365-277X.2001.00307.x

Heaney, S., O'Connor, H., Michael, S., Gifford, J., & Naughton, G. (2011). Nutrition knowledge in athletes: A systematic review. *International Journal of Sport Nutrition and Exercise Metabolism, 21,* 248–261. PubMed

Jeukendrup, A.E. (2013). Oral carbohydrate rinse: Placebo or beneficial? *Current Sports Medicine Reports, 12,* 222–227. PubMed doi:10.1249/JSR.0b013e31829a6caa

Jones, P.J., & Leitch, C.A. (1993). Validation of doubly labeled water for measurement of caloric expenditure in collegiate swimmers. *Journal of Applied Physiology, 74,* 2909–2914. PubMed

Jonnalagadda, S.S., Bernardot, D., & Dill, M.N. (2000). Assessment of under-reporting of energy intake by elite female gymnasts. *International Journal of Sport Nutrition and Exercise Metabolism, 10,* 315–325. PubMed

Kabasakalis, A., Kalitsis, K., Tsalis, G., & Mougios, V. (2007). Imbalanced nutrition of top-level swimmers. *International Journal of Sports Medicine, 28,* 780–786. PubMed doi:10.1055/s-2007-964907

Lamb, D.R., Rinehardt, K.F., Bartels, R.L., Sherman, W.M., & Snook, J.T. (1990). Dietary carbohydrate and intensity of interval swim training. *American Journal of Clinical Nutrition, 52,* 1058–1063. PubMed

Lambert, C., Robergs, R., Pascoe, D., Zachwieja, J., & Costill, D. (1990). 492. Does increased training volume improve indices of swimming performance? [Abstract]. *Medicine & Science in Sports & Exercise, 22,* S82. doi:10.1249/00005768-199004000-00492

Lewis, R.M., Redzic, M., & Thomas, D.T. (2013). The effects of season-long vitamin D supplementation on collegiate swimmers and divers. *International Journal of Sport Nutrition and Exercise Metabolism, 23,* 431–440.

Melin, A., Torstveit, M.K., Burke, L.M., Marks, S., & Sundgot-Borgen, J. (2014). Disordered eating and eating disorders in aquatic sports. *International Journal of Sport Nutrition and Exercise Metabolism, 24*, 450-459.

Millard-Stafford, M.L., Brown, M.B., & Snow, T.K. (2010). Acute carbohydrate ingestion affects lactate response in highly trained swimmers. *International Journal of Sports Physiology and Performance, 5,* 42–54. PubMed

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. doi:10.3945/ajcn.2008.26401

Mujika, I., Stellingwerff, T., & Tipton, K. (2014). Nutrition and training adaptations in aquatic sports. *International Journal of Sport Nutrition and Exercise Metabolism, 24*, 414-424.

Noland, R.C., Baker, J.T., Boudreau, S.R., Kobe, R.W., Tanner, C.J., Hickner, R.C., McCammon, M.R. & Houmard, J.A. (2001). Effect of intense training on plasma leptin in male and female swimmers. *Medicine & Science in Sports & Exercise*, 33, 227-231.

O'Sullivan, S., Sharp, R., & King, D.S. (1994). Carbohydrate ingestion during competitive swimming training. *Journal of Swimming Research, 10,* 35–40.

Otis, C.L., Drinkwater, B., Johnson, M., Loucks, A., & Wilmore, J. (1997). American College of Sports Medicine position stand. The Female Athlete Triad. *Medicine & Science in Sports & Exercise, 29,* i–ix. PubMed doi:10.1097/00005768-199705000-00037

Ousley-Pahnke, L., Black, D.R., & Gretebeck, R.J. (2001). Dietary intake and energy expenditure of female collegiate swimmers during decreased training prior to competition. *Journal of the American Dietetic Association, 101,* 351–354. PubMed doi:10.1016/S0002-8223(01)00091-8

Paschoal, V.C., & Amancio, O.M. (2004). Nutritional status of Brazilian elite swimmers. *International Journal of Sport Nutrition and Exercise Metabolism, 14,* 81–94. PubMed

Petersen, H.L., Peterson, C.T., Reddy, M.B., Hanson, K.B., Swain, J.H., Sharp, R.L., & Alekel, D.L. (2006). Body composition, dietary intake, and iron status of female collegiate swimmers and divers. *International Journal of Sport Nutrition and Exercise Metabolism, 16,* 281–295. PubMed

Powers, S., Nelson, W.B., & Larson-Meyer, E. (2011). Antioxidant and Vitamin D supplements for athletes: Sense or nonsense? *Journal of Sports Sciences, 29*(Suppl. 1), S47–S55. PubMed doi:10.1080/02640414.2011.602098

Pyne, D.B., Anderson, M.E., & Hopkins, W.G. (2006). Monitoring changes in lean mass of elite male and female swimmers. *International Journal of Sports Physiology and Performance, 1,* 14–26. PubMed

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.

Reilly, T., & Woodbridge, V. (1999). Effects of moderate dietary manipulations on swim performance and on blood lactate-swimming velocity curves. *International Journal of Sports Medicine, 20,* 93–97. PubMed doi:10.1055/s-2007-971099

Sato, A., Shimoyama, Y., Ishikawa, T., & Murayama, N. (2011). Dietary thiamin and riboflavin intake and blood thiamin and riboflavin concentrations in college swimmers undergoing intensive training. *International Journal of Sport Nutrition and Exercise Metabolism, 21,* 195–204. PubMed

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

Shaw, G. (2013). Supplement practice of Elite Swimmers: The implications of a global education and local provision program on dietary supplement practices. University of the Sunshine Coast, Queensland, Australia.

Slattery, K.M., Coutts, A.J., & Wallace, L.K. (2012). Nutritional practices of elite swimmers during an intensified training camp: with particular reference to antioxidants. *Journal of Sports Medicine and Physical Fitness, 52,* 501–505. PubMed

Stellingwerff, T., Pyne, D.B., & Burke, L.M. (2014). Nutrition considerations in special environments for aquatic sports. *International Journal of Sport Nutrition and Exercise Metabolism, 24*, 470-479.

Stewart, A.M., & Hopkins, W.G. (2000). Seasonal training and performance of competitive swimmers. *Journal of Sports Sciences, 18,* 873–884. PubMed doi:10.1080/026404100750017805

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

Trappe, T.A., Gastaldelli, A., Jozsi, A.C., Troup, J.P., & Wolfe, R.R. (1997). Energy expenditure of swimmers during high volume training. *Medicine & Science in Sports & Exercise, 29,* 950–954. PubMed doi:10.1097/00005768-199707000-00015

Vallieres, F.T., Tremblay, A., & St-Jean, L. (1989). Study of the energy balance and the nutritional status of highly trained female swimmers. *Nutrition Research, 9,* 699–708. doi:10.1016/S0271-5317(89)80013-2

Van Handel, P., Cells, K., Bradley, P., & Troup, J. (1984). Nutritional status of elite swimmers. *Journal of Swimming Research, 1,* 27–31.

VanHeest, J.L., Rodgers, C.D., Mahoney, C.E., & De Souza, M.J. (2014). Ovarian suppression impairs sport performance in junior elite female swimmers. *Medicine & Science in Sports & Exercise*, *46,* 156–166. PubMed doi:10.1249/MSS.0b013e3182a32b72

Wasse, L.K., King, J.A., Stensel, D.J., & Sunderland, C. (2014). Effect of ambient temperature during acute aerobic exercise on short-term appetite, energy intake, and plasma acylated ghrelin in recreationally active males. *Applied Physiology, Nutrition, and Metabolism, 38,* 905–909. PubMed doi:10.1139/apnm-2013-0008

White, L.J., Dressendorfer, R.H., Holland, E., McCoy, S.C., & Ferguson, M.A. (2005). Increased caloric intake soon after exercise in cold water. *International Journal of Sport Nutrition and Exercise Metabolism, 15,* 38–47. PubMed

Witard, O.C., Jackman, S.R., Breen, L., Smith, K., Selby, A., & Tipton, K.D. (2014). 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

Zamparo, P., Capelli, C., & Pendergast, D. (2011). Energetics of swimming: A historical perspective. *European Journal of Applied Physiology, 111,* 367–378. PubMed doi:10.1007/s00421-010-1433-7