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Energy and carbohydrate for training and recovery

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Abstract

Soccer players should achieve an energy intake that provides sufficient carbohydrate to fuel the training and competition programme, supplies all nutrient requirements, and allows manipulation of energy or nutrient balance to achieve changes in lean body mass, body fat or growth. Although the traditional culture of soccer has focused on carbohydrate intake for immediate match preparation, top players should adapt their carbohydrate intake on a daily basis to ensure adequate fuel for training and recovery between matches. For players with a mobile playing style, there is sound evidence that dietary programmes that restore and even super-compensate muscle glycogen levels can enhance activity patterns during matches. This will presumably also benefit intensive training, such as twice daily practices. As well as achieving a total intake of carbohydrate commensurate with fuel needs, the everyday diet should promote strategic intake of carbohydrate and protein before and after key training sessions to optimize the adaptations and enhance recovery. The achievement of the ideal physique for soccer is a long-term goal that should be undertaken over successive years, and particularly during the off-season and pre-season. An increase in lean body mass or a decrease in body fat is the product of a targeted training and eating programme. Consultation with a sports nutrition expert can assist soccer players to manipulate energy and nutrient intake to meet such goals. Players should be warned against the accidental or deliberate mismatch of energy intake and energy expenditure, such that energy availability (intake minus the cost of exercise) falls below 125 kJ (30 kcal) per kilogram of fat-free mass per day. Such low energy availability causes disturbances to hormonal, metabolic, and immune function.

Keywords: *Glycogen, refuelling, low energy availability, female athlete triad*

Introduction

During a typical training week, a soccer player undertakes individual and team-based sessions encompassing endurance, speed and strength conditioning, skills practice, tactical drills, and match-play (Bangsbo, Mohr, & Krustrup, 2006). The nature, volume, and intensity of the training programme vary according to the time of the season, the calibre of player, and the player's position and individual goals. For professional players, pre-season camps may involve a schedule of twice daily practices. During the competitive season, the week may also include one or two matches. This review will cover the players' needs for energy and carbohydrate to fuel, recover, and optimize the adaptations from these sessions. Ideas for future research in which the timing and macronutrient composition of energy intake might be manipulated to further enhance training adaptations are covered by Hawley, Tipton and Millard-Stafford (2006). The present review is limited to strategies for which there is good support for positive outcomes, and warns against strategies for which there is clear evidence of detrimental outcomes. It will also focus on research undertaken over the last decade, and thus on the enhancements in our knowledge since the 1994 Consensus on Food, Nutrition and Soccer Performance.

Energy needs

The total energy expenditure and requirements of each soccer player are unique, arising from the contribution of basal metabolic rate, thermic effect of food, thermic effect of activity, and in some cases growth (Manore & Thompson, 2006). For many athletes, and in particular professional players undertaking multiple training sessions in a day or more than one match in a week, the energy cost of training and games is substantial. The importance of adequate energy intake in underpinning the nutritional goals of training is emphasized in other sections of

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this review. In the scientific literature there are several reports of the energy expenditure of particular groups of soccer players, derived from techniques such as doubly labelled water (Ebine *et al.*, 2002) and indirect calorimetry (Fogelholm *et al.*, 1995). However, the expense and complex technology involved in these techniques confine them to the realms of research.

In the field, an accessible and practical way to assess the daily energy expenditure of an athlete is to use prediction equations based on assessments of resting metabolic rate and the energy cost of daily activities (Manore & Thompson, 2006). Once resting metabolic rate is estimated from one of the available prediction equations, it is then multiplied by various activity factors to determine the daily total energy expenditure. Most simply, a general activity factor is applied to the whole day to represent the athlete's typical exercise level. More complex, an athlete might complete an intricate activity diary, with the predicted or measured energy cost of each activity undertaken over the day being summed to predict total daily energy expenditure. While this "factorial method" can provide a general estimation of a soccer player's energy requirements, there is considerable potential for error.

An alternative field method is the "energy availability model" (Loucks, 2004) in which the amount of energy available to the body to undertake its physiological processes is considered. Energy availability is calculated as total energy intake minus the energy cost of the daily exercise programme. Typically, energy balance in normal, healthy adults is achieved at a mean energy availability of $\sim$45 kcal per kilogram of fat-free mass (FFM) (189 kJ $\cdot$ kg FFM^{-1}). Since information about the energy expended in exercise can be provided by various commercial heart rate monitors, calculations of energy availability may be simple to undertake and interpret. The Appendix to this review compares the concepts of energy balance and energy availability, demonstrating the utility of the energy availability model.

Whether it is assessed in absolute terms or in comparison to estimates of energy requirement, the energy intake of a soccer player is of interest for several reasons (Burke, 2001):

1. It sets the potential for achieving the player's requirements for energy-containing macronutrients such as protein and carbohydrate, and the food needed to provide vitamins, minerals, and other non-energy-containing dietary compounds required for optimal function and health.
2. It assists the manipulation of muscle mass and body fat to achieve the specific physique that is ideal for training and match performance.
3. It affects the function of the hormonal and immune systems.
4. It challenges the practical limits to food intake set by issues such as food availability and gastrointestinal comfort.

The available information on intakes of energy and macronutrients in the everyday diets of adult soccer players, ranging from collegiate to elite/professional players, is summarized in Table I. These data were collected by self-reported prospective techniques that are limited by errors of accuracy and reliability (how well they represent usual intake) (for a review, see Burke *et al.*, 2001). In addition, only three of the studies attempted to measure energy balance (intake vs. expenditure) in their groups. One study of Japanese male professional soccer players found that mean reported energy intake accounted for only 88% of energy expenditure, estimated from doubly labelled water techniques (Ebine *et al.*, 2002). The authors concluded that this discrepancy was due to under-reporting; this is the usual error in self-reported dietary intake. Another study that used daily activity records to assess energy expenditure found closer agreement with estimates of energy intake and expenditure of a group of players from the Olympic team of Puerto Rico (Rico-Sanz *et al.*, 1998).

Although the spread of time periods of data collection makes it difficult to make firm conclusions about the dietary practices of contemporary soccer players, it appears that the reported energy intake of the typical male player is about 13 – 16 MJ $\cdot$ day^{-1}, equivalent to approximately 160 – 200 kJ $\cdot$ kg^{-1} $\cdot$ day^{-1}. This would appear to reflect high levels of activity during game play and the conditioning required to achieve or maintain fitness, especially among professional players (Bangsbo, Norregaard, & Thorsoe, 1992; Jacobs, Westlin, Karlsson, Rasmusson, & Houghton, 1982; Rico-Sanz *et al.*, 1998). Data for female soccer players are scarce, but tend to show the usual phenomenon of a lower energy intake relative to body mass in female players than in their male counterparts. Of course, the training demands of female players are likely to be substantially less than those of male players, since the opportunities for elite competition are fewer. The one study to investigate energy balance in female soccer players during the post-season (Fogelholm *et al.*, 1995) found reasonable agreement between reported energy intake and energy expenditure (using indirect calorimetry to estimate resting metabolic rate). However, energy expenditure was not different from that of sedentary controls, raising some doubts about the appropriateness of the techniques or the timing of the investigation. Alternatively, resting metabolism may have been suppressed by chronic energy deficiency in the soccer players.

Table I. Reported dietary intakes of male soccer players during training (mean daily intake ± *s*) (adapted from Burke, 2006).

Reference	Team population	Survey method	Age (years)	BM (kg)	Energy MJ	Energy $kJ \cdot kg^{-1}$	CHO g	CHO $g \cdot kg^{-1}$	CHO % Energy	Protein g	Protein $g \cdot kg^{-1}$	Protein % Energy	Fat g	Fat % Energy
Jacobs *et al.* (1982)	Swedish professional players ($n = 15$)	7 day food diary (household measures)	24	74	20.7 ± 4.7	282	596 ± 127	8.1	47 ± 3	170 ± 27	2.3	13.5 ± 1.5	217 ± 36	29 ± 8
Short and Short (1983)	US collegiate players ($n = 8$)	3 day food diary (household measures)			12.4		320		43	113		16	135	41
Hickson *et al.* (1987)	US collegiate players	3 day food diary (household measures)	20	72										
	– conditioning on campus ($n = 17$)				18.7	260	596	8.3	52			14		34
	– season on campus ($n = 8$)				15.99 ± 2.7	221	487 ± 107	6.8	52 ± 11			16		32 ± 9
	– season off campus ($n = 9$)				12.8 ± 4.9	178	306 ± 118	4.2	42 ± 15			16		42 ± 18
Van Erp-Baart *et al.* (1989)	Dutch international players ($n = 20$)	4–7 day food diary (household measures)	20	74	14.3	192	420	5.6	47	111	1.5	13	134	35
Caldarone *et al.* (1990)	Italian professional players ($n = 33$)	7 day dietary recall (household measures)	26	76	12.8 ± 2.4	169	449	5.9	56					
Bangsbo *et al.* (1992)	Danish professional players ($n = 7$)	10 day food diary (household measures)	23	77	15.7	204	426	5.5	46	144	1.9	16	152	38
Schena *et al.* (1995)	Italian national players ($n = 16$)	7 day food diary (household measures)	25	74	13.4 ± 1.5	180	454 ± 32	6.1	57	86 ± 16	1.2	19	90 ± 14	24
Zuliani *et al.* (1996)	Italian professional players ($n = 25$)	4 day food diary (household measures)	25	71	15.3 ± 1.8	213	532	7.4	56					
Maughan (1997)	Scottish professional players from two clubs ($n = 51$)	7 day weighed food diary	23	80	11.0 ± 2.6	137	354 ± 95	4.4	51 ± 8	103 ± 26	1.3	16 ± 2	93 ± 33	31 ± 5
			26	75	12.8 ± 2.2	171	397 ± 94	5.3	48 ± 4	108 ± 20	1.4	14 ± 2	118 ± 24	35 ± 4
Rico-Sanz *et al.* (1998)	Puerto Rican Olympic team players ($n = 8$)	12 day food diary (household measures)	17	63	16.5 ± 4.5	260 ± 50	526 ± 62	8.3	53 ± 6	143 ± 23	2.3	14 ± 2	142 ± 17	32 ± 4
Ebine *et al.* (2002)	Japanese professional players ($n = 7$)	7 day food diary (household measures)	22	70	13.0 ± 2.4	186	–	–	–	–	–	–	–	–
Reeves and Collins (2003)	English professional players ($n = 21$)	7 day food diary (household measures)	20	74	12.8 ± 0.8	173	437 ± 40	5.9	57 ± 4	115 ± 2	1.6	15 ± 2	94 ± 1	27 ± 3
Ruiz *et al.* (2005)	Basque club players ($n = 24$)	3 day weighed food diary	21	73	12.7 ± 2.9	173 ± 43	334 ± 78	4.7 ± 1.0	45	133 ± 31	1.8 ± 0.5	18	128 ± 49	38

Abbreviations: BM = body mass, CHO = carbohydrate.

Manipulating energy balance and body composition

Energy balance is not the objective for many athletes, at least for some portions of the season or their athletic career. Instead, the athlete may wish to manipulate body composition (lean body mass or body fat) and fuel stores (glycogen stores), and these changes might require temporary periods of energy deficit or surplus, or manipulation of multiple components of these body compartments in apparently conflicting directions (for a review, see Loucks, 2004). The optimal physique for a soccer player in terms of lean body mass and body fat varies according to the position and playing style of the individual. However, there is at least anecdotal evidence that elite modern players are leaner and stronger than players from previous times or those who compete at a lower standard (Reilly, 2005). Mean body fat values in high-level adult male soccer players using a variety of methods (dual-energy X-ray absorptiometry; skinfold thicknesses) and prediction equations have been reported to range from 8.2 to 13.0% (Kraemer *et al.*, 2004; Maughan, 1997; Reilly & Gregson, 2006; Wittich, Oliveri, Rotemberg, & Mautalen, 2001). Data for top-class female players are limited. Using hydrostatic weighing, Clark, Reed, Crouse and Armstrong (2003) reported percent body fat to be approximately 16% in US collegiate division 1 players (see Table II).

The best time to undertake conditioning programmes aimed at increasing lean body mass and/or reducing body fat is during the off-season or preseason. At lower levels of competition, achievement of the desired body composition for the playing season may also require a dedicated effort to reduce the loss of conditioning caused by a long off-season that is often marked by inactivity, poor eating, and excessive intake of alcohol. The off-season for elite players is usually brief (about 6 weeks) and generally involves a player- or club-determined conditioning programme. However, breaks required for the treatment and rehabilitation of injuries in elite players also present a risk for deconditioning.

Optimizing lean body mass and body fat requires manipulation of both training and dietary strategies. Adequate energy intake, including perhaps an increase in energy intake, appears to be important in promoting the gains from a resistance training programme (Gater, Gater, Uribe, & Bunt, 1992), although information pinpointing the optimal intake of energy and the macronutrient contribution to this intake is lacking. There is emerging evidence that resistance training may be assisted by strategic intake of protein and carbohydrate before, during, and after the session (Hawley *et al.*, 2006). Guidelines to assist players to increase their energy intake to meet high

Table II. Reported dietary intakes of female soccer players during training (mean daily intake ± s) (adapted from Burke, 2006).

Reference	Team population	Survey method	Age (years)	BM (kg)	Energy		CHO			Proteing			Fat	
					MJ	$kJ \cdot kg^{-1}$	g	$g \cdot kg^{-1}$	% Energy	g	$g \cdot kg^{-1}$	% Energy	g	% Energy
Fogelholm *et al.* (1995)	Finnish national players ($n = 12$)	7 day food diary (household measures)	18	61	9.0 ± 1.7	147								
Clark *et al.* (2003)	US collegiate players ($n = 13$)	3 day food diary (household measures)	20	62										
		−season			9.6 ± 1.3	155	320 ± 70	5.2 ± 1.1	55 ± 8	87 ± 19	1.4 ± 0.3	15 ± 3	75 ± 13	29 ± 6
		−post- season			7.8 ± 2.2	126	263 ± 71	4.3 ± 1.2	57 ± 7	59 ± 17	1.0 ± 0.3	13 ± 2	66 ± 29	31 ± 7
Gropper *et al.* (2003)	US collegiate players ($n = 15$)	3 day food diary (household measures)	19	59	8.5 ± 2.5	143				71 ± 29	1.3	14		

Abbreviations: BM = body mass, CHO = carbohydrate.

energy requirements or to provide nutritional support at strategic times in relation to training or a match are summarized in Table III. These strategies may be useful to support an increase in lean body mass during the pre-season or a growth spurt in adolescent players, or to meet high energy requirements during a demanding schedule of training or matches.

A reduction in body fat is achieved by manipulation of diet and training to create a negative fat balance and negative energy balance over the total day or for substantial portions of the day. Guidelines to achieve this outcome with minimal interference with other goals of training or performance are outlined in Table III. There is considerable evidence that a low availability of energy, previously defined as total energy intake minus the energy cost of the athlete's exercise programme, has serious consequences on the hormonal, immunological, and health status of the athlete (see Loucks, 2004). This is best demonstrated in female athletes and the characterisation of the female athlete triad in which low energy availability, impaired menstrual status, and poor bone health are interrelated (Loucks & Nattiv, 2005; Otis, Drinkwater, Johnson, Loucks, & Wilmore, 1997). Many female athletes develop metabolic, reproductive, and bone disruptions because they over-restrict their energy intake to achieve loss of body fat. Incremental changes in energy availability (Loucks & Thuma, 2003) lead to a dose-dependent relationship between energy restriction and metabolic and hormonal function; the threshold for maintenance of normal menstrual function in females is an energy availability of above 30 kcal (125 kJ) per kilogram of fat free mass. The Appendix to this paper illustrates the concepts of low and normal energy availability.

Although team sport athletes, and soccer players in particular, are generally not identified in the literature as being at high risk of over-zealous dieting or the pursuit of inappropriate thinness, practitioners who work with soccer teams will be familiar with individual players to whom this does apply. The prevalence of this concern may increase as an

Table III. Guidelines for adjusting energy intake according to goals of training or physique.

Recommendations for

- Soccer players should adjust their energy intake according to their activity level and goals for growth, increased lean body mass, or loss of body fat. These goals are specific to the individual player and will vary over the season and over the player's career. An energy surplus will occur if energy intake is not reduced when a player who normally undertakes a heavy training programme becomes suddenly inactive, such as during the off-season or when injured.
- The ideal physique for match performance is individual to each player and should be achieved gradually as the player matures in age and training history. The achievement of the ideal physique should not compromise health, long-term performance, sound eating practices, or the enjoyment of food. Major programmes to manipulate muscle mass and body fat should be confined to the pre-season or off-season.
- Soccer players should not monitor body mass as a measure of physique. Rather, they should monitor changes in objective measures of body fat (e.g. skinfold thickness) or functional capacity (e.g. strength), taking into account the reliability and relevance of these measures.
- An increase in lean body mass is the product of appropriate resistance training and a diet providing adequate energy and nutrients. Strategic intake of protein and carbohydrate before and after a workout may enhance the adaptations achieved by the session, as well as increasing total energy intake to meet higher energy requirements
- Other strategies that may assist the soccer player to meet high energy needs include:
  - Planning food intake with appropriate supplies organized for consumption at key times
  - Consuming small, frequent meals and snacks throughout the day
  - Avoiding excessive intake of low energy-dense and fibre-rich foods when these foods would reduce appetite or impair total food intake
  - Making use of energy- and nutrient-dense fluids such as fortified milk drinks and liquid meal supplements
- Loss of body fat is achieved by careful planning of training and food intake to achieve a negative fat balance and a negative energy balance. A strategic spread and choice of foods over the day and in relation to training should achieve these goals while maintaining adequate intake of fuel and nutrients and avoiding hunger.
  - Fat intake should be moderated, especially saturated fats
  - Foods that are energy-dense but low in nutrient density should be avoided
  - Priority should be given to foods that are high in nutrient density so that nutrient needs are meet from a lower intake of energy
  - Foods that are low in energy density or high in satiety value (e.g. low glycaemic index or protein-containing) should be chosen to manage hunger
- Soccer players should consult a sports nutrition expert for an individualised eating plan to assist with goals of fat loss or increased muscle mass. Players who are seen to be following unsound nutritional practices, especially those related to weight loss, should be referred to appropriate specialists for early intervention.

Recommendations against

- Soccer players should not undertake a diet and exercise programme that allows or specifically promotes a substantial energy deficit. In particular, daily energy availability (total energy intake minus the cost of exercise) should not be less than about 125 kJ (30 kcal) per kilogram of fat-free mass daily. This may happen unintentionally when food intake is not sufficiently increased to compensate for a sudden increase in training. More often, however, this situation is the outcome of restricted energy intake to achieve fat loss goals.
- A low-carbohydrate diet is not a suitable weight-loss programme for an active soccer player. Low carbohydrate availability may underpin some of the metabolic disturbances seen in instances of low energy availability.

outcome of the general increase in the leanness achieved by elite soccer players. Anecdotally, we have noted that the imposition of lycra "body suit" uniforms on female competitors in some team sports has increased the concerns related to body image and body fatness in these populations. Indeed, the wearing of a figure-hugging or revealing uniform has been identified as a risk factor for the development of disordered eating among athletes (Otis *et al.*, 1997). The suggestion that women's soccer should follow this fashion statement in an attempt to increase the television interest and popularity of the sport must be balanced by consideration of the possible harmful outcomes from such a change (Burke, 2006).

It is likely that male athletes who expose themselves to periods of low energy availability will also suffer from metabolic and reproductive disturbances (Friedl *et al.*, 2000). Of course, not all cases of low energy availability in males, or females, are due to deliberate restriction of energy to reduce body mass and body fat. It can be due to the practical challenges faced by the soccer player with high energy requirements, an over-committed daily timetable and travel schedule, and poor nutrition knowledge. The guidelines in Table III address the needs of these players.

Carbohydrate needs for training and recovery between games

The "training" diet of a soccer player must include strategies to refuel effectively between matches undertaken every 4 – 7 days during the competition season, as well as the conditioning sessions undertaken between matches or during pre-season preparation. The fuel needs of training and matches, including the effects of inadequate fuel stores on performance, are reviewed by Bangsbo *et al.* (2006). We now consider the effect of dietary interventions that manipulate muscle glycogen content on the outcomes of actual or simulated soccer match-play. While some strategies to promote fuel availability for match-play and prolonged training sessions are achieved by nutritional practices on the day (Williams & Serratosa, 2006), tactics to restore or even super-compensate muscle glycogen content must commence in the 24 – 48 h before a game. As such, they form a cycle of recovery between activities in the training week.

The value of "fuelling up" before a match has been demonstrated in laboratory studies. In the study of Balsom, Gaitanos, Soderlund and Ekblom (1999a), participants followed 48 h of either a high- or low-carbohydrate diet before short-term (< 10 min) and prolonged (> 30 min) protocols of intermittent exercise (6 s bouts at 30 s intervals). Muscle glycogen concentrations were reduced by at least 50% in the low-carbohydrate trial compared to the high-carbohydrate trial, and were associated with a dramatic reduction in the work performed in both exercise protocols. In another study (Bangsbo *et al.*, 1992), professional soccer players completed an intermittent high-intensity protocol of field and treadmill running lasting approximately 90 min, after 48 h on a high-carbohydrate ($\sim 8\,g \cdot kg^{-1} \cdot day^{-1}$) or control ($\sim 4.5\,g \cdot kg^{-1} \cdot day^{-1}$) diet. Intermittent running to fatigue at the end of the protocol was increased by about 1 km by the high-carbohydrate diet ($P < 0.05$), although the performance enhancement was more marked in some participants than others. These studies show that higher pre-exercise glycogen stores enhance the capacity to undertake repeated bouts of exercise, even when these are as short as 6 s in duration.

Other studies using applied or real-life protocols in prolonged team sports have confirmed these findings. Balsom, Wood, Olsson and Ekblom (1999b) undertook movement analysis of a four-a-side indoor game lasting 90 min, following 48 h of high ($\sim 8\,g \cdot kg^{-1} \cdot day^{-1}$) or moderate ($\sim 3\,g \cdot kg^{-1} \cdot day^{-1}$) carbohydrate intake. Compared with the control trial, the high-carbohydrate diet increased muscle glycogen content by 38% and allowed the soccer players to complete approximately 33% more high-intensity work during the game. In another investigation, Akermark, Jacobs, Rasmusson and Karlsson (1996) found that elite ice hockey players who "carbohydrate-loaded" ($8.4\,g \cdot kg^{-1} \cdot day^{-1}$) during the 3 day recovery between two games were able to skate for longer distances and at higher intensities than when their normal dietary preparation ($6.2\,g \cdot kg^{-1} \cdot day^{-1}$) was followed. Muscle glycogen concentrations were reduced after the first game for all players (43 mmol · kg wet weight^{-1}), but restoration levels were 45% higher in the carbohydrate-loaded players before the next game (99 vs. 81 mmol · kg wet weight^{-1}; $P < 0.05$). Distance skated, number of shifts skated, amount of time skated within shifts, and skating speed were all increased in the carbohydrate-loaded players compared with the control group, with the differences being most marked in the third period. Individual differences in performance were thought to be related to muscle glycogen metabolism (Akermark *et al.*, 1996).

Twenty-four hour recovery was studied in team sport players who undertook a 60 min treadmill test involving multiple sprints, and were then randomized into groups of low (12% of energy), normal (47% of energy), and high (79% of energy) carbohydrate intake (Nevill, Williams, Roper, Slater, & Nevill, 1993). Power outputs during 6 s sprints interspersed over the 60 min declined over the duration of the test on day 1, and were even lower when repeated on day 2. Performance on day 2 was not different between dietary groups for the total

60 min; performance declined by 5%, 0.5%, and 0.2% compared with day 1 for the low, normal, and high carbohydrate trials respectively, but this was not statistically significant. However, over the first 20 min of the test on day 2, the high-carbohydrate group did perform better than the low-carbohydrate group. This study shows the difficulty of repeating performance of high-intensity exercise on successive days, but suggests that better restoration of muscle carbohydrate stores can enhance recovery.

Whether enhanced muscle fuel status will prevent the apparent deterioration of skills towards the end of a soccer game is hard to determine. Abt, Zhou and Weatherby (1998) attempted to address this question by having recreational soccer players consume different carbohydrate intakes (8 vs. $4\,g \cdot kg^{-1} \cdot day^{-1}$) in the 48 h before a simulated match. Shooting and dribbling tasks were undertaken before and after a 60 min intermittent treadmill run. There was no deterioration in the performance of these drills over time in the control trial. It is not surprising, therefore, that the high-carbohydrate treatment did not change the outcome. The authors concluded that either their treadmill protocol failed to achieve sufficient glycogen degradation to impair the execution of skills, or that factors other than fuel depletion are responsible for the decline that occurs during real match-play (Abt *et al.*, 1998). However, the ability of the test protocol to provide a reliable and valid measure of match skills in these players must also be questioned.

Overall, the literature supports the value of restoring glycogen between matches, and of providing adequate fuel for training sessions requiring high-intensity intermittent exercise. However, there has been little systematic study of the amounts of dietary carbohydrate needed to achieve optimal refuelling of soccer players. Early studies suggested that professional players were unable to replete muscle glycogen during the 48 h after a match, despite minimal training and a mean daily carbohydrate intake of $8\,g \cdot kg^{-1}$ (Jacobs *et al.*, 1982). Muscle glycogen concentrations determined from biopsy samples increased from ~46 to ~69 mmol · kg wet weight^{-1} during the first 24 h of sedentary recovery, with restoration correlated to the extent of depletion at the end of the game. However, no further refuelling appeared to take place during the second 24 h recovery period that included light training; muscle glycogen concentrations were 73 mmol · kg wet weight^{-1} at the end of this period. It should be noted that the reported values for glycogen content in this study are low in comparison to other values in the literature for well-trained and rested athletes, and are in contrast to more recent studies that suggest that the well-trained muscle can normalize or even super-compensate glycogen stores within 24 – 36 h of the last exercise bout (Bussau, Fairchild, Rao, Steele, & Fournier, 2002). This may reflect an artifact of the study or a specific impairment of glycogen resynthesis in team sport players – for example, as a result of muscle damage from high-intensity running or contact injuries.

In contrast, a study using magnetic resonance spectroscopy monitored muscle glycogen utilization during a simulated soccer match and its repletion over 24 h of recovery while players consumed their habitual diet (Zehnder, Rico-Sanz, Kuhne, & Boutellier, 2001). Mean muscle glycogen content decreased from 134 to 80 mmol · kg wet weight^{-1} over the exercise protocol, but was almost restored to pre-"match" values (122 mmol · kg wet weight^{-1}) after 24 h. Players reported an intake of 327 g carbohydrate (4.8 g · kg body mass^{-1}) during this period. Whether this is a suitable simulation of the true fuel demands of match-play, and whether players would benefit from a higher carbohydrate intake to ensure full glycogen repletion, was not addressed by this study.

Carbohydrate intake guidelines for daily training and preparation for games

Further study is needed before clear guidelines for daily carbohydrate intake can be provided to soccer players. In addition, the variability in the fuel needs of different players, even in the same team, causes additional complexity in formulating and implementing such guidelines. However, in at least some circumstances it is prudent to undertake strategies that optimize muscle glycogen storage – these factors were addressed by the 2003 International Olympic Committee Consensus on Nutrition for Athletes (Burke, Kiens, & Ivy, 2004). The outcomes of this consensus regarding daily fuel needs have been translated into guidelines appropriate for soccer players (see Table IV).

The major dietary factor involved in post-exercise refuelling is the amount of carbohydrate consumed. As long as total energy intake is adequate (Tarnopolsky *et al.*, 2001), increasing amounts of dietary carbohydrate promote increased muscle glycogen storage until the upper limit for glycogen synthesis is reached at intakes of about $10\,g \cdot kg^{-1} \cdot day^{-1}$ (see Burke *et al.*, 2004). Each player needs to match daily carbohydrate intake to the fuel needs of the schedule of training and the competition programme, including the weekly and seasonal variations that occur. A reasonable target range for carbohydrate intake by high-level players in less mobile roles, or teams or individuals with a less demanding training and competition schedule, is 5 – $7\,g \cdot kg^{-1} \cdot day^{-1}$. For mobile players who want to maximize muscle glycogen refuelling, in preparation for matches or for recovery during an intensive

Table IV. Guidelines for the intake of carbohydrate in the everyday or training diets of soccer players (based on Burke *et al.*, 2004).

Recommendations for

- Soccer players should aim to achieve a carbohydrate intake that meets the fuel requirements of their training programme and optimizes restoration of muscle glycogen stores between training sessions and before matches. General recommendations can be provided, but these should be fine-tuned with individual consideration of total energy needs, specific training needs, and feedback from training/match performance.
  - Moderate daily recovery and match preparation (e.g. less mobile players, moderate training programme, periods of energy restriction for fat loss) = $5-7\,g \cdot kg^{-1} \cdot day^{-1}$
  - Enhanced daily recovery and match preparation (e.g. heavy training such as twice daily practices, or fuelling up for matches, in mobile players) = $7-12\,g \cdot kg^{-1} \cdot day^{-1}$
- Players should recognize that their fuel requirements will vary over the week, over the season, and over their career. They should be prepared to adjust their carbohydrate intake accordingly. Many soccer clubs provide opportunities for players to eat together (e.g. pre-match meals, post-match or post-training recovery eating, catering during camps or travel). Menus and food choices on these occasions should be sufficiently flexible to provide for the range of energy and carbohydrate needs of various players.
- Soccer players should give priority to nutrient-rich carbohydrate foods and may need to add other foods to recovery meals and snacks to provide a good source of protein and other nutrients. These nutrients may assist in other recovery processes. The soccer club should invest in resources, such as the services of a sports nutrition expert, to help young players to develop nutrition knowledge and the practical skills required to eat well.
- When the period between exercise sessions is less than about 8 h, players should consume carbohydrate as soon as practical after the first workout to maximize the effective recovery time between sessions. There may be some advantages in meeting carbohydrate intake targets as a series of snacks during the early recovery phase.
  - Carbohydrate intake target for immediate recovery after a match or training session (0–4 h) = $1.0-1.2\,g \cdot kg^{-1} \cdot h^{-1}$ consumed at frequent intervals
- During longer recovery periods (24 h), soccer players should organize the pattern and timing of carbohydrate-rich meals and snacks according to what is practical and comfortable for them individually. There is no difference in refuelling when liquid or solid forms of carbohydrate are consumed.
- Carbohydrate-rich foods with a moderate to high glycaemic index provide a readily available source of carbohydrate for muscle glycogen synthesis, and should be the major carbohydrate choices in recovery meals.
- Adequate energy intake is also important for optimal glycogen recovery; the restrained eating practices of some players, particularly females, make it difficult to meet carbohydrate intake targets and to optimize glycogen storage from this intake.

Recommendations against

- Guidelines for carbohydrate (or other macronutrients) should not be provided in terms of percentage contributions to total dietary energy intake. Such recommendations are neither user-friendly nor strongly related to the muscle's absolute needs for fuel
- Soccer players should not consume excessive amounts of alcohol after training or matches, since this is likely to interfere with their ability or interest to follow guidelines for post-exercise eating. Players should follow sensible drinking practices at all times, but particularly in the period after exercise.

training schedule, a target of $7-10\,g \cdot kg^{-1} \cdot day^{-1}$ may be required (see Table IV). Historically, many team sport players have considered carbohydrate intake as a priority for the night before the game or for the pre-game meal only. It may take a change in culture for some modern players to eat adequate carbohydrate to keep pace with the *daily* fuel demands of training and match-play. The limited range of dietary surveys of serious soccer players (Table I) shows that only a few groups of players (Rico-Sanz *et al.*, 1998; Zuliani *et al.*, 1996), and perhaps some individuals within groups, report daily carbohydrate intakes that fall within these higher target ranges.

Manipulation of the timing of intake and type of carbohydrate may provide some practical or metabolic advantages for refuelling. Carbohydrate-rich foods with a moderate or high glycaemic index (GI) appear to have some advantages over low-GI choices in promoting glycogen synthesis (Burke, Collier, & Hargreaves, 1993), but the form of the carbohydrate – fluids or solids – does not appear to affect glycogen synthesis (Keizer, Kuipers, Van Kranenburg, & Guerten, 1986). The highest rates of muscle glycogen storage occur during the first hour after exercise, due to enhancement of glucose delivery and enzyme activity within the muscle. While carbohydrate intake immediately after exercise appears to take advantage of these effects (Ivy, Katz, Cutler, Sherman, & Coyle, 1988), failure to consume carbohydrate in the immediate phase of post-exercise recovery leads to very low rates of glycogen restoration until feeding occurs. Early intake of carbohydrate following strenuous exercise is valuable because it provides an immediate source of substrate to the muscle cell to start effective recovery. This may be important when there is only 4 – 8 h between exercise sessions (Ivy *et al.*, 1988), such as when training twice a day, but may have less impact over a longer recovery period (Parkin, Carey, Martin, Stojanovska, & Wilmore, 1997).

The pattern of food intake does not appear to affect glycogen storage in overall daily recovery as long as total carbohydrate needs are met (Burke *et al.*, 1996;

Costill *et al.*, 1981). However, rapid refuelling during the first hours of recovery may be achieved by a total carbohydrate intake of approximately 1.0 – 1.2 g · $^{h-1}$, perhaps as a series of small snacks every 15 – 30 min (see Jentjens & Jeukendrup, 2003). The effect of the co-ingestion of protein with carbohydrate on refuelling has been debated (see Burke *et al.*, 2004), but any enhancement of glycogen storage appears to be limited to the first hour of recovery (Ivy *et al.*, 2002) or to when the total amount of carbohydrate or pattern of intake is below the threshold for maximal glycogen synthesis and when the protein is consumed as an additional energy source. There may be some merit in investigating further the effects of consuming large amounts of carbohydrate with or without protein during the half-time interval of a soccer match. In general, the intake of protein within carbohydrate-rich recovery meals is encouraged and may allow the players to meet other nutritional goals, including the enhancement of net protein balance after exercise. Excessive alcohol intake during the post-game period is likely to interfere with refuelling goals, particularly by its indirect effects on behaviour and commitment to optimal nutrition strategies (Burke *et al.*, 2003; Maughan, 2006).

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Appendix

Energy considerations using energy balance

Consider a healthy, adult athlete with an energy intake (EI) sufficient to maintain all the body's physiological processes and an exercise energy expenditure (EEE) of $15\,\text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1}$. The athlete's energy balance (EB) is calculated in terms of resting metabolic rate (RMR), the thermic effect of food (TEF), and non-exercise activity thermogenesis (NEAT) as:

$$\begin{aligned} \text{EB} &= \text{EI} - (\text{RMR} + \text{TEF} + \text{NEAT}) - \text{EEE} \\ &= 60 - (30 + 6 + 9) - 15\ \text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \\ &= 0\ \text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \end{aligned}$$

The athlete's energy availability (EA) is:

$$\begin{aligned} \text{EA} &= \text{EI} - \text{EEE} \\ &= 60 - 15\ \text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \\ &= 45\ \text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \end{aligned}$$

Thus, at an energy availability of $45\,\text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1}$, the athlete is in energy balance.

Now consider the energy balance of the same athlete after energy intake has been restricted to $35\,\text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1}$ for a month:

$$\begin{aligned} \text{EB} &= \text{EI} - (\text{RMR} + \text{TEF} + \text{NEAT}) - \text{EEE} \\ &= 35 - (24 + 3.5 + 9) - 15\ \text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \\ &= -16.5\ \text{kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \end{aligned}$$

Note that the thermic effect of food is still 10% of energy intake and that resting metabolic rate has declined by 20% because reproductive function, bone turnover, and other physiological processes have been suppressed.

By comparison, the athlete's energy availability is:

$$\begin{aligned} EA &= EI - EEE \\ &= 35 - 15 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \\ &= 20 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \end{aligned}$$

By calculating differences in energy balance, the athlete's energy deficiency appears to be:

$$\begin{aligned} EB_{\text{final}} - EB_{\text{initial}} &= -16.5 - 0 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \\ &= -16.5 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \end{aligned}$$

but this does not account for the suppression of physiological systems. By calculating differences in energy availability, the athlete's actual energy deficiency is found to be:

$$\begin{aligned} EA_{\text{final}} - EA_{\text{initial}} &= 20 - 45 \text{ kcal} \cdot \text{kgFFM}^{-1} \cdot \text{day}^{-1} \\ &= -25 \text{ kcal} \cdot \text{FFM}^{-1} \cdot \text{day}^{-1} \end{aligned}$$

In this example, energy balance underestimates the athlete's energy deficiency by 100 * (25 − 16.5)/25 = 34%.

Now, suppose the chronically undernourished athlete consults a nutritionist to correct his or her energy deficiency. If the nutritionist's approach is to measure the athlete's resting metabolic rate and then to multiply that by a factor (F) related to the athlete's level of physical activity, the nutritionist will assess the athlete's physical activity and pick the corresponding activity factor (F) from a standard table, *which was developed from data on adequately nourished individuals*. Therefore, if the nutritionist correctly assesses the athlete's level of physical activity, the nutritionist will pick:

$$\begin{aligned} F &= EI/RMR \\ &= 60 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} / \\ &\quad \times 30 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} = 2.0 \end{aligned}$$

The nutritionist will then multiply the undernourished athlete's measured resting metabolic rate by this value to arrive at a recommended energy intake of:

$$\begin{aligned} EI = F^{*}RMR &= 2.0^{*}24 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \\ &= 48 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \end{aligned}$$

which perpetuates the athlete's undernutrition by 100*(60 − 48)/60 = 20%.

Sports nutrition by reference to energy availability

The energy availability approach to sports nutrition assumes that energy intake must exceed exercise energy expenditure by 45 kcal · kg FFM^{-1} · day^{-1} for all physiological systems to function normally, because 45 kcal · kg FFM^{-1} · day^{-1} is the average energy intake of healthy, young sedentary adults in energy balance.

By this approach, the nutritionist in the above example would measure the undernourished athlete's exercise energy expenditure as 15 kcal · kg FFM^{-1} · day^{-1} and recommend:

$$\begin{aligned} EI = EA + EEE &= 45 + 15 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \\ &= 60 \text{ kcal} \cdot \text{kg FFM}^{-1} \cdot \text{day}^{-1} \end{aligned}$$

which is the amount required to provide sufficient metabolic fuels for all physiological processes.

Data consistent with this example are reported in Myerson *et al.* (1991).