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CARBOHYDRATE NUTRITION AND TEAM SPORTS PERFORMANCE

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KEY POINTS

- To succeed in team sports, players must have endurance, strength, speed and power, as well as a range of sport-specific skills that can be executed accurately and rapidly during competition.
- Team-sport players spend about half of their time performing low- to moderate-speed running from which they are able to perform multiple sprints to support scoring opportunities or to prevent the opposition from scoring.
- Unlike traditional endurance sports in which athletes run, cycle or swim in one direction, team-sport players have to constantly change direction as well as make rapid changes in pace. The distances covered and the number and frequency of directional changes are largely unpredictable and vary with each team sport and even between playing positions in each sport.
- In team sports that involve whole body contact such as American football, rugby and Australian Rules football, players have to be strong enough to tackle as well as wrestle their opponents for ball possession. To cope with the demands of training and competition, the nutrition of players has to be designed to cover their energy expenditures as well as sustain good health. Central in nutritional planning for team-sports players is the quantity and type of carbohydrate in their diets because of the essential contribution made by this macronutrient to energy metabolism during high-intensity exercise.
- Each sprint performed generally lasts no more than 2-4 s and relies on the phosphocreatine (PCr) and glycogen stores of skeletal muscles. Recovery between each sprint can vary from a few seconds to as much as several minutes when there is a break in play.
- Frequent sprints with inadequate recovery drain PCr and muscle glycogen concentrations, especially in full-contact team sports.
- Replenishing liver and muscle glycogen stores before training and competition has a positive impact on performance whereas failure to undertake this dietary preparation results in under-performance.
- Ingesting carbohydrate during exercise not only helps support performance, but appears to preserve sports skills to a greater extent than drinking only water.
- Successful recovery from team-sport training and competition requires players to consume an adequate quantity (~9 g/kg body mass) of high glycemic carbohydrates. There is also some evidence that carbohydrate-protein mixtures may reduce the delayed onset of muscle soreness commonly experienced by team-sport players.

INTRODUCTION

Successful performance in team sports such as American football, soccer, rugby, field and ice hockey, and basketball depends on the mutual cooperation of team players to score more goals/points than the opposing team. Although each of these sports has different rules for the duration of play, equipment and substitutions, they share a common pattern of play. All of these team sports involve brief periods of high-intensity activity interspersed with lower-intensity activities that support play as well as provide brief recovery opportunities.

Changes in pace and direction – and in some sports, physical contests for the possession of the ball – make large demands on the players' energy stores, particularly skeletal muscle glycogen (Balsom et al., 1999b; Nicholas et al., 1999). These multiple physical demands precipitate the onset of fatigue that is evident not only as a decrease in running speed and distance covered late in a match, but also as a decrease in skill performance.

Therefore, in order to cope with the demands of training and competition, the nutrition of players has to be designed to cover their energy expenditures and to sustain good health. Central in nutritional planning for team-sports players is the quantity and type of carbohydrate in their diets because of the essential contribution made by this macronutrient to energy metabolism during high-intensity exercise (Burke et al., 2011). Therefore, the aim of this article is to explore the links between carbohydrate nutrition and team-sport performance by examining the available research literature on this topic.

PHYSICAL DEMANDS OF TEAM SPORTS

The common characteristic of team sports is the "stop-go" pattern of play in which players perform repeated bouts of brief high-intensity exercise punctuated by periods of lower-intensity activities. However, there is considerable variation between team sports, and even within a sport, in the type, intensity and duration of activities between the periods of high-speed running. Quantitative descriptions of the activity patterns of several team sports are now available as a result of studies using GPS and video analysis. For example, analyses of the activity patterns of elite female field hockey players during international matches showed that low-level activities (walking and standing) amounted to 55%, jogging and running occupied about 38% whereas the proportion of fast running and sprinting was 5% and 1.5% of match time (Macutkiewicz & Sunderland, 2011). Players performed, on average, 17 sprints with an overall heart rate of 172 bpm and they covered 5,541 m. A similar analysis of elite women soccer players showed that the average distance covered was 10.3 km, of which 1.31 km was by high-speed running (Krustrup et al., 2005). Standing and walking occupied 50% and low-speed running 34% of match time. The remaining time was spent in high-speed running during which there was an average of 25 sprints that varied according to the position of each player.

In contact sports such as rugby, 85% and 15% of the game is spent in low- and high-intensity activities, respectively (Duthie et al., 2003). The high-intensity activities involve about 6% running and 9% tackling and wrestling for ball possession. The total distance covered in a rugby match is about 6 km, which is less than the 10-11 km covered in matches played by elite soccer players (Mohr et al., 2003), but the overall energy expenditure is probably greater because of the frequent whole body tackles. In American football each team is made up of two squads, one for defence and another for offence, so there are frequent substitutions that are dictated by which team has possession of the ball. Although each squad spends less time on the field than in rugby football, the energy expenditures during the high-intensity tackles and contests for ball possession are underestimated by analyses of activity patterns alone (Hoffman et al., 2002). These studies also show that there are significant inter-positional differences in the amount of running and tackles completed by players during match-play. The differences in overall energy expenditures will also be compounded by players' stature, body mass and fitness.

The duration of each sprint in team sports is rarely longer than 2-4 s and recovery is often as little as several seconds and only extends to several minutes during breaks in play (Spencer et al., 2005). During the low-level activities players attempt to recover from the last passage of play while moving into spaces to contribute to scoring opportunities or to defend against their opponent's scoring opportunities.

In non-contact sports such as field hockey, soccer and basketball, gaining possession of the ball routinely involves whole-body collisions. In contrast, whole-body tackling and collisions and wrestling the puck or ball away from opponents is the accepted method of gaining possession in the full contact sports of ice hockey, American football and in all codes of rugby.

One of the common features of playing team sports is the occurrence of post-exercise muscle soreness, and in full-body contact sports, it's the high risk of injury. Therefore, recovery from competition and training includes coping with excessive muscle soreness and injury (Bailey et al., 2007; Thompson et al., 1999).

In order to cope with the large energy expenditures of physically demanding training and competition, the energy intakes of team-sport players should match these demands. Because of the large and essential contribution of carbohydrate (CHO) metabolism to energy production during high-speed running as well as the whole-body contacts, special attention is given to this essential macronutrient in players' diets (Burke et al., 2011).

ENERGY METABOLISM DURING HIGH-INTENSITY EXERCISE

Our ability to exercise at high intensity depends on the capacity of our skeletal muscles to rapidly replace the adenosine triphosphate (ATP) used to support all energy-demanding processes during exercise. The two metabolic systems that generate ATP in skeletal muscle are described as "anaerobic" and "aerobic." In order to avoid misunderstanding the function of these two energy systems, it is important to recognize that they work in concert, not in isolation. For example, during a short sprint, the high rate of ATP production in skeletal muscle is provided by anaerobic energy metabolism whereas at the same time, aerobic metabolism continues to supply ATP to, for example, the heart and other organs to support their physiological functions.

The anaerobic production of ATP is fuelled by the degradation of intra-muscular phosphocreatine (PCr) and glycogen, a polymer of glucose. PCr is a high-energy molecule that rapidly converts the breakdown product of ATP, i.e., adenosine diphosphate (ADP), back to ATP. Muscle contains about 4-5 times more PCr than its small concentration of ATP. For example in a 6-s sprint, PCr and glycogen contribute in almost equal amounts to ATP turnover (Gaitanos et al., 1993) (Figure 1).

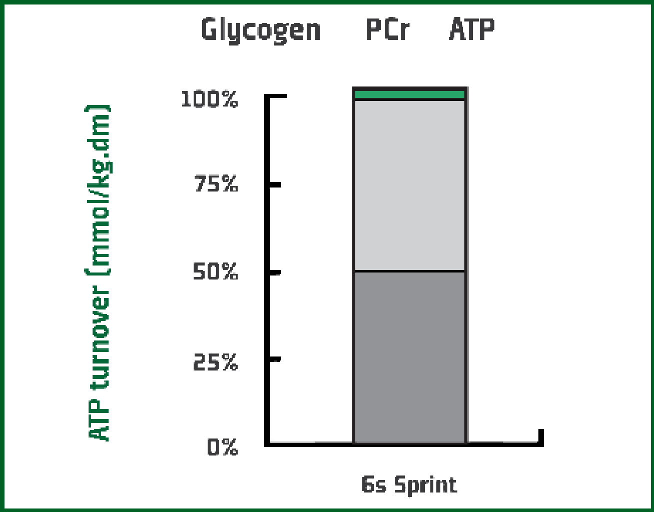

Figure 1. Contributions to ATP production during a 6-s sprint on a non-motorized treadmill. PCr, phosphocreatine; dm, dry muscle. Adapted from Gaitanos et al. J. Appl. Physiol. 1993.

While the aerobic degradation of glycogen is a slower process, it produces about 12 times more ATP per glucose molecule (~36 mmol) than during its anaerobic degradation. Even more ATP is produced by the oxidation of fatty acids (~140 mmol). However, while aerobic metabolism is too slow to support the high rate of ATP turnover required during short sprints, it does provide players with the energy necessary to perform the range of lower-intensity activities that occur between sprints. In addition, it is the aerobic metabolism of glycogen and fatty acids, during recovery between sprints, that is responsible for resynthesizing PCr. As the game progresses and the number of sprints increase, there is an even greater contribution of aerobic metabolism, especially during the lower-intensity activities between sprints (Balsom et al., 1999b; Parolin et al., 1999). Most training programs for team-sport players complement their sprint work with sessions that are designed to improve the aerobic capacity. While adequate carbohydrate nutrition ensures optimum performance during training and competition, periodic pre-exercise training in the fasted state provides an additional means of “stressing” mitochondrial oxidative systems to improve their capacity for ATP production (Bartlett et al., 2014).

PROTOCOLS FOR STUDYING TEAM SPORTS

Although traditional laboratory studies continue to provide insight into the importance of dietary interventions on exercise performance, they do not reproduce the demands of “stop-go” sports that include acceleration, deceleration and running at a range of speeds. Several studies of intermittent variable-speed running have based their methods on 20-m shuttle running (Leger & Lambert, 1982). One such method is the Loughborough Intermittent Shuttle Running Test (LIST) that was designed to simulate the activity pattern characteristic of soccer and other stop-go sports (Nicholas et al., 2000). The protocol consists of two parts: Part A is a fixed period of variable-speed shuttle running over a distance of 20 m; Part B consists of continuous running, alternating every 20 m between 95% and 55% of maximal oxygen uptake (VO_2max) until volitional fatigue. Part A consists of five 15-min blocks of activity with a 3-min recovery between each block. In each 15-min block, runners complete the following cycle of activities: a walk, a sprint, a jog (55% VO_2max) and a run (95% VO_2max), and each cycle is repeated 11-12 times. An audible computer-generated “bleep” helps participants maintain their predetermined pace with the exception of the sprints. Times for 15 m of the 20-m sprint are recorded by computer using photo-electric timing gates. The physiological responses and distances covered during the 90-min LIST compare well with those recorded for professional soccer matches.

The LIST protocol has also been modified to simulate activities that are common in basketball and have also included several tests of cognition (Welsh et al., 2002; Winnick et al., 2005). Bangsbo and colleagues (2006) extended the shuttle running protocol to include a full range of soccer-related activities in addition to sprinting, running and walking. The Copenhagen Soccer Test (CST) includes a comprehensive coverage of soccer-related activities that compares very well with the physiological and metabolic demands of a soccer match (Bendiksen et al., 2012). For example, they showed that completion of the CST reduced muscle glycogen contents to similar values as recorded during competitive soccer matches. Muscle glycogen contents following competitive soccer matches are reduced by 50-60% of pre-match values. They and others noted that the loss of glycogen during intermittent variable-speed running is not equal across type 1 and type 2 fibres (Bendiksen et al., 2012; Nicholas et al., 1999). In general, the decrease in muscle glycogen concentration is accompanied by, and is probably responsible for, a parallel fall in the performance of multiple sprints (Gaitanos et al., 1993).

It is important to acknowledge that in these studies the exercise intensity is prescribed with only the sprint speeds being self-selected, whereas in competitive games the players pace themselves in order to avoid exhaustion. This limitation to the LIST protocol has recently been addressed with the addition of “self-paced” sections to the protocol (Ali et al., 2014). This improves the ecological validity of the test and also allows the performances of players to be monitored more closely during the gradual onset of fatigue.

CARBOHYDRATE NUTRITION AND TEAM SPORT PERFORMANCE

Of all the team sports, the performance of soccer players and their underpinning physiological and metabolic changes have been most widely studied. Early studies on muscle glycogen and activity patterns of players during soccer matches showed that those with low pre-match contents covered less ground than those with high values (Bangsbo et al., 2006; Rollo, 2014). These observations resulted in the recommendation for team-sport players to restock their CHO stores before competition as well as during recovery between training sessions. When there are several days between matches, the tapered training and increased CHO intake in the days before competition is now a well-accepted method of restoring muscle and liver glycogen contents (Burke et al., 2011; Sherman et al., 1981). Although there are several seminal running and cycling studies that show the benefits of undertaking exercise with well-stocked glycogen stores, there are fewer studies on team-sport performance.

Pre-Exercise Carbohydrate Feeding

Recognizing that fatigue during prolonged high-intensity exercise is closely associated with the depletion of skeletal muscle glycogen, it is not surprising that the performance benefits of increasing dietary carbohydrate have received much attention, particularly in preparation for endurance exercise. However, dietary interventions prior to training and competition for team sports have received less attention.

Addressing this question for ice hockey, Akermark and colleagues (1996) examined the impact of a CHO-enriched (60%) and a mixed (CHO 40%) diet on two groups of players during the 3 days between two games. They found that the group on the high-CHO diet skated significantly longer (30%) and covered a greater distance (~5 km vs. ~3.5 km) during the second game than the players on the lower CHO diet. In a similar field study, Balsom and colleagues (1999a) examined the impact of CHO loading on performance during a 90-min, four-aside soccer match. They lowered the players' glycogen stores 48 h earlier by variable-speed shuttle running and then changed the CHO content of their diet to either one with 65% or 30% of daily energy intake. Analysis of the movement patterns during the soccer match showed that players performed 30% more high-intensity running after the high- vs. low-CHO pre-match diet.

Eating a high-CHO pre-exercise meal ~2-3 h before training and competition helps restore liver glycogen, which is reduced after an overnight fast as well as producing a small increase in muscle glycogen content. High-CHO meals that provide about 2.5 g/kg body mass (BM) consumed 3 h before exercise increase muscle glycogen content by ~11% (Chryssanthopoulus et al., 2004). This relatively small increase in muscle glycogen is a consequence of the take-up of glucose by the liver and some delay in absorption and digestion especially when the meal is eaten only 2 h before exercise.

Does the type of CHO consumed in the pre-exercise meal have an influence on subsequent exercise performance? There have been several studies comparing the potential advantages of high glycemic index (HGI) and low glycemic index (LGI) CHO pre-exercise meals. One study suggested that a LGI carbohydrate pre-exercise meal eaten 3 h before exercise improved endurance capacity during submaximal treadmill running (Wu & Williams, 2006). In this study, fat metabolism was greater after the LGI than after the HGI meal. However, this potential advantage does not translate to improvements in performance during brief periods of sprinting (Erith et al., 2006) because fat metabolism cannot provide ATP fast enough to support high-intensity exercise. Furthermore, when consuming energy-matched HGI and LGI carbohydrate meals (2.5 g/kg BM) after an overnight fast, only the HGI breakfast increases muscle glycogen (11–15%) 3 h later (Wee et al., 2005).

Carbohydrate Feeding During Exercise

Although the benefits of ingesting a carbohydrate-electrolyte (CHO-E) solution during endurance running are well established, less attention has been paid to prolonged intermittent exercise. Therefore, Nicholas and colleagues (1995) provided games players with either a 6.5% CHO-E or a taste- and color-matched placebo (P) solution between each 15-min block of the LIST. After performing 5 blocks of the LIST, the games players completed Part B, i.e., alternating 20-m sprints with jogging recoveries to fatigue. Ingesting the CHO-E solution resulted in a 33% greater running time, i.e., beyond the 75 min taken to complete the 5 blocks of the LIST, than when players ingested the P solution. A similar result was obtained by Davis and colleagues (2000) using a modified form of the LIST to examine the influences of ingesting a 6% CHO-E solution with and without chromium supplementation on endurance intermittent shuttle running performance. Ingesting a 6% CHO-E solution improved shuttle running time by 32% compared with ingesting a placebo, but there was no added benefit from including chromium. Similar improvements in performance have been reported when games players ingested CHO gels. The two published studies on the impact of ingesting CHO gels on performance on variable speed shuttle running both reported improved endurance running capacity (Patterson & Gray, 2007; Phillips et al., 2012).

In many team games, several minutes are added to playing time because of stoppages due to injury. For example, in international soccer matches an additional 30 min is played when scores are equal at full time. This "extra time" presents a range of challenges that include the onset of fatigue that is associated with depletion of muscle glycogen. Refuelling during the brief break prior to playing "extra time" has only a modest effect on the players' recovery. An additional strategy is to ensure that liver and muscle glycogen contents are restored, after training and prior to competition, by CHO loading. In order to test this hypothesis, university-level soccer players completed 6 blocks of the LIST (90 min) and then consumed a high-CHO diet for 48 h before repeating the LIST to fatigue (Foskett et al., 2008). Carbohydrate loading increased muscle glycogen content by about 50% more than the normal values for these games players. During subsequent performance of the LIST, they ingested either a 6.5% CHO-E solution or a colored-taste matched placebo throughout exercise. At the end of 90 min, the games players who were running with a "fitness-matched" partner continued to complete standard 15-min blocks of activities to the point of fatigue. The total exercise time during the CHO-E trial was significantly longer (158 min) than during the placebo trial (131 min).

In hot environments, the rapid rise in body temperature rather than glycogen depletion is the cause of a reduction in performance during prolonged intermittent variable-speed running (Mohr et al., 2010; Morris et al., 2005). Avoiding severe dehydration by adopting an appropriate drinking strategy is the accepted approach to training and competing in the heat. Therefore, is there a benefit from drinking a CHO-E solution rather than water during playing team sports in the heat? Addressing this question, Morris and colleagues (2003) found no performance benefits when unacclimatized games players undertook the LIST protocol in an environmental temperature of 30°C while drinking either a 6.5% CHO-E solution or a flavor- and color-matched placebo. However, it is important to note that in this study, the pace of the players was dictated for all but the sprint section of the protocol – when their core temperatures reached critically high values the players simply stopped running. In the real world of competitive sport, these games players would have paced themselves to avoid early onset of fatigue and/or to avoid being substituted. Under these conditions, it is reasonable to speculate that ingesting a CHO-E solution would have benefits over ingesting water alone. These include maintaining blood glucose concentration, delaying glycogen depletion, preserving skill levels and not forgetting the potential impact on brain metabolism and the link with motivation (Rollo & Williams, 2011).

CARBOHYDRATE FEEDING AND SKILL PERFORMANCE

An essential component of team sport performance is the execution of high levels of skill. The variety and complexity of skill varies significantly between team sports and players. However, as the match progresses and the players become fatigued, there is a decrease in skill levels (Sunderland & Nevill, 2005). Nevertheless, the level of skill proficiency that a player can achieve, especially when performed at speed, is a distinguishing factor between the recreational and professional player. Not surprisingly, studies observing professional team sport have found that teams that better maintain their skill performance over the duration of a match finish the season in a higher position in their league (Rampinini et al., 2009). Unfortunately, there is very little information on skill performance in many team stop-go sports largely because of the difficulty in establishing tests that are reliable and ecologically valid (Ali et al., 2009). The majority of studies on sports-specific skills are those on basketball and soccer.

For example, in a soccer-skill study, the ingestion of 6.0-7.5% CHO solutions, providing ~30-60 g CHO/h was associated with superior skill performance in the latter stages of play than following the ingestion of a placebo solution (Ali et al., 2007; 2009; Russell & Kingsley, 2014). Currell and colleagues (2009) also reported a significant improvement in soccer ball dribbling performance when players ingested 55 g CHO/h compared to a taste-matched placebo. Studies examining goal shooting and soccer passing performance after completing 90 min of the LIST showed that ingesting a CHO-E solution (~52 g/h) tended to preserve skill performance to a greater extent than when ingesting a taste-color matched placebo (Ali et al., 2007).

In an attempt to examine the influences of ingesting a CHO-E solution on skill and mood changes, Welsh and colleagues (2002) modified the LIST protocol to more closely resemble the activity periods in basketball. They included four 15-min blocks (quarters) of running, walking and vertical jumps with a 20-min resting "half-time" between the second and third quarters. At the end of the fourth quarter, the players completed 20-m intervals of shuttle running, alternating between 120% VO_2max and 55% VO_2max to voluntary fatigue. In the brief rest periods between each 15-min block, the players also completed a set of mental and physical tests, namely: vertical jumps, a modified hop-scotch test to assess whole body motor skill and mental function tests, i.e., Stroop color word test as well as completing a mood state questionnaire (POMS). The games players ingested either a 6% CHO-E solution or a taste- and color-matched placebo immediately before and throughout exercise. Shuttle running time to fatigue was 37% greater when the players ingested the CHO-E solution and sprint times were better maintained during the last quarter than during the placebo trial. This study was extended with a larger number of male and female games players to examine the impact of ingesting a 6% CHO-E on peripheral and CNS function. Again they found faster 20-m sprint times, enhanced motor skills and improved mood state during the last quarter when the games players ingested the CHO-E solution (Winnick et al., 2005). Similar beneficial improvements were reported in a basketball study on shooting skill of young players following the ingestion of a CHO-E solution (6% solution: 70-73 g/h) during a 4-quarter simulated game (Dougherty et al., 2006).

It is important to note that unlike laboratory studies on skill performance where the frequency and amount of CHO-E ingestion is carefully controlled, there are limited opportunities to drink during soccer matches. In basketball, the opportunities to drink during breaks in match-play are somewhat greater. Nevertheless, the available evidence suggests that players should seek opportunities to ingest CHO-E solutions during breaks in play when they occur throughout matches.

CARBOHYDRATE FEEDING AND RECOVERY OF PERFORMANCE

Consuming carbohydrate immediately after exercise increases the repletion rate of muscle and liver glycogen (Casey et al., 2000; Ivy, 1998). However, the restoration of glycogen appears to be slower after stop-go sports possibly because they include a large number of damaging eccentric contractions in skeletal muscles (Asp et al., 1998). More recent evidence confirms that glycogen resynthesis is slower after both a 60-min simulated soccer match and after a 90-min match but casts doubt on the link with eccentric exercise (Gunnarsson et al., 2013).

Although the mechanisms underlying the restoration of muscle glycogen following participation in stop-go sports have yet to be explained, the pragmatic question is whether or not high-CHO recovery diets restore performance during subsequent exercise. To address this question, Nicholas and colleagues (1997) recruited games players who performed 5 blocks of the LIST (75 min) followed by alternate 20-m sprints with jogging recovery to fatigue and then repeated their performance 22 h later. During the recovery, they consumed either their normal diet with either additional CHO to achieve a total intake of 9 g/kg BM or their normal CHO intake (5 g/kg BM) plus extra protein so as to match energy intake of the CHO diet. After the high-CHO recovery diet, the games players were able to match their previous day's performance. In contrast, when they consumed their normal amount of CHO and an equal energy intake, the players failed to reproduce their previous day's performance.

It has been suggested that adding protein to CHO during recovery increases the rate of glycogen resynthesis and so improves subsequent exercise capacity. However, not all studies support these findings either after treadmill running (Betts & Williams, 2010) or after a competitive soccer match (Gunnarsson et al., 2013). Nevertheless, there may be a case for the consumption of CHO-protein mixtures after exercise. For example, in order to achieve the optimum rate of post-exercise glycogen synthesis, players must consume a large amount of CHO (~1.2 g/kg body mass), which they may find intolerable. Energy-matched CHO-protein mixtures contain less CHO yet result in a similar rate of glycogen resynthesis as CHO alone.

Thus, the available information shows that successful recovery is achieved by initiating glycogen resynthesis immediately after exercise. Furthermore, consuming HGI carbohydrates after exercise exploits the cellular biochemistry that is up-regulated to rapidly replace liver and muscle glycogen stores, to a greater extent than consuming LGI carbohydrates (Burke et al., 1993). Post-exercise ingestion of CHO-electrolyte solutions have the advantage of not only contributing to glycogen resynthesis, but also contributing to rehydration. Furthermore, while a post-exercise CHO-protein mixture may not result in greater glycogen storage, there are suggestions that they may help reduce the delayed onset of muscle soreness experienced by players in many team sports (Cockburn et al., 2010) though this is not a consensus view (Pasiakos et al., 2014). However, there is general agreement that ingesting protein after exercise provides substrate for an increased protein synthesis (Pasiakos et al., 2014; Phillips, 2011).

PRACTICAL IMPLICATIONS

- During prolonged intermittent, brief high-intensity running there is a gradual reduction in performance as the match progresses, which is largely the result of a decrease in glycogen contents in skeletal muscles.
- Consuming carbohydrate-electrolyte solutions (60-90 g/h) during prolonged exercise has several performance advantages:
    - It extends running time beyond that achieved when drinking water.
    - It preserves sprint speed beyond that achieved when drinking water.
    - It tends to preserve sport-specific skills than when drinking water.
- Consuming carbohydrate following team-sport playing is essential for successful recovery.
    - Consuming carbohydrate immediately after exercise exploits the up-regulation of glycogen synthesis in skeletal muscle.
    - Recovery and pre-exercise diets merge when players train twice a day and so nutritional planning is essential to achieve optimum performance.
    - Individual food preferences should be included in dietary planning for players with the acknowledgement of their overall energy expenditures during training and competition.
    - When players complete heavy daily training they require a recovery diet that includes 9-10 g CHO/kg BM in order to restore performance.
    - Carbohydrate-protein mixtures consumed during recovery may help reduce delayed onset of muscle soreness post-exercise.

SUMMARY

In summary, a pragmatic approach is needed to ensure that players' carbohydrate intakes adequately match the demands of training and competition. In the absence of reliable information on players' energy expenditure, the focus should be on three elements; (1) the diet of players, ensuring a sufficient intake of carbohydrate and protein, (2) monitoring variations in body mass and composition to ensure that players are not losing or gaining body mass and (3) their ability to cope with training and competition as reflected by their own and their coach's perceptions of their performance. Combining these observations with routine dietary monitoring allows the diets of players to be adjusted so that they are able to cope with the demands of training and competition as well as maintain good health. This approach is a positive step toward customizing the carbohydrate needs of sports team players (Jeukendrup, 2014).

REFERENCES

Akermark, C., I. Jacobs, M. Rasmusson, and J. Karlsson (1996). Diet and muscle glycogen concentration in relation to physical performance in Swedish elite ice hockey players. Int. J. Sport Nutr. 6:272-284.

Ali, A., C. Williams, C. Nicholas, and A. Foskett (2007). The influence of carbohydrate-electrolyte ingestion on soccer skill performance. Med. Sci. Sports Exerc. 39:1969-1976.

Ali, A., C. Williams, M. Hulse, A. Strudwick, J. Reddin, L. Howarth, J. Eldred, M. Hirst, and S. McGregor (2009). Reliability and validity of two tests of soccer skill. J. Sports Sci. 25:1461-1470.

Ali, A., A. Foskett, and N. Gant (2014). Measuring intermittent exercise performance using shuttle running. J. Sports Sci. 32:601-609.

Asp, S., J. Daugaard, S. Kristiansen, B. Kiens, and E. Richter (1998). Exercise metabolism in human skeletal muscle exposed to prior eccentric exercise. J. Physiol. 509:305-313.

Bailey, D., S. Erith, J. Griffin, T. Dowson, D. Brewer, N, Gant, and C. Williams (2007). Influence of cryotherapy on indices of muscle damage following prolonged intermittent shuttle-running exercise. J. Sports Sci. 25:1163-1170.

Balsom, P., K. Wood, P. Olsson, and B. Ekblom (1999a). Carbohydrate intake and multiple sprint sports: with special reference to football (soccer). Int. J. Sports Med. 20:48-52.

Balsom, P., G. Gaitanos, K. Soderlund, and B. Ekblom (1999b). High intensity exercise and muscle glycogen availability in humans. Acta Physiol. Scand. 165:337-345.

Bangsbo, J., M. Mohr, and P. Krustrup (2006). Physical and metabolic demands of training and match play in the elite player. J. Sports Sci. 24:665-674.

Bartlett, J.D., J.A. Hawley, and J.P. Morton (2014). Carbohydrate availability and exercise training adaptation: Too much of a good thing? Eur. J. Sport Sci. 19:1-10.

Bendiksen, M., R. Bischoff, M. Randers, M. Mohr, I. Rollo, C. Suetta, J. Bangsbo, and P. Krustrup (2012). The Copenhagen soccer test: Physiological response and fatigue development. Med. Sci. Sports Exerc. 44: 1595–1603.

Betts, J., and C. Williams (2010). Short-term recovery from prolonged exercise: Exploring the potential for protein ingestion to accentuate the benefits of carbohydrate supplements. Sports Med. 40:941-959.

Burke, L.M., G.R. Collier, and M. Hargreaves (1993). Muscle glycogen storage after prolonged exercise: effect of the glycemic index of carbohydrate feedings. J. Appl. Physiol. 75:1019-1023.

Burke, L., J. Hawley, S. Wong, and A. Jeukendrup (2011). Carbohydrates for training and competition. J. Sports Sci. 29:S17-S27.

Casey, A., R. Mann, K. Banister, J. Fox, P.G. Morris, I. Macdonald, and P.L. Greenhaff (2000). Effect of carbohydrate ingestion on glycogen resynthesis in human liver and skeletal muscle, measured by 13C MRS. Am. J. Physiol. 278:E65-E75.

Cockburn, E., E. Stevenson, P. Hayes, P. Robson-Ansley, and G. Howatson (2010). Effect of milk-based carbohydrate-protein supplement timing on the attenuation of exerciseinduced muscle damage. Appl. Physiol. Nutr. Metab. 35:270-277.

Chryssanthopoulos, C., C. Williams, A. Nowitz, and G. Bogdanis (2004). Skeletal muscle glycogen concentration and metabolic responses following a high glycaemic carbohydrate breakfast. J. Sports Sci. 22:1065-1071.

Currell, K., S. Conway, and A. Jeukendrup (2009). Carbohydrate ingestion improves performance of a new reliable test of soccer performance. Int. J. Sport Nutr. Exerc. Metab. 19:34-46.

Davis, J., R. Welsh, and N. Alderson (2000). Effects of carbohydrate and chromium ingestion during intermittent high-intensity exercise to fatigue. Int. J. Sport Nutr. Exerc. Metab. 10:476-485.

Dougherty, K., L. Baker, M. Chow, and L. Kenney (2006). Two percent dehydration impairs and six percent carbohydrate drink improves boys basketball skills. Med. Sci. Sports Exerc. 38:1650-1658.

Duthie, G., D. Pyne, and S. Hooper (2003). Applied physiology and game analysis of rugby union. Sports Med. 33:973-991.

Erith, S., C. Williams, E. Stevenson, S. Chamberlain, P. Crews, and I. Rushbury (2006). The effect of high carbohydrate meals with different glycemic indices on recovery of performance during prolonged intermittent high-intensity shuttle running. Int. J. Sport Nutr. Exerc. Metab. 16:393-404.

Foskett, A., C. Williams, L. Boobis, and K. Tsintzas (2008). Carbohydrate availability and muscle energy metabolism during intermittent running. Med. Sci. Sports Exerc. 40:96-103.

Gaitanos, G.C., C. Williams, L.H. Boobis, and S. Brooks (1993). Human muscle metabolism during intermittent maximal exercise. J. Appl. Physiol. 75:712-719.

Gunnarsson, T., M. Bendiksen, R. Bischoff, P. Christensen, B. Lesivig, K. Madsen, F. Stephens, P. Greenhaff, P. Krustrup, and J. Bangsbo (2013). Effect of whey protein- and carbohydrate-enriched diet on glycogen resynethesis during the first 48 h after a soccer game. Scand. J. Med. Sci. Sports. 23:508-515.

Hoffman, J., C. Maresh, R. Newton, M. Ruben, D. French, J.S. Volek, J. Sutherland, N. Robertson, A.L. Gomez, N.A. Ratamess, J. Kang, and W.J. Kraemer (2002). Performance, biochemical and endocrine changes during a competitive football game. Med. Sci. Sports Exerc. 34:1845-1853.

Ivy, J. (1998). Glycogen resynthesis after exercise: effect of carbohydrate intake. Int. J. Sports Med. 19:S142-S145.

Jeukendrup, A. (2014). A step towards personalized sports nutrition: carbohydrate intake during exercise. Sports Med. 44:S25-S33.

Krustrup, P., M. Mohr, H. Ellingsgaard, and J. Bangsbo (2005). Physical demands during an elite female soccer game: importance of training status. Med. Sci. Sports Exerc. 37:1242-1248.

Leger, L., and J. Lambert (1982). A maximal multistage 20-m shuttle run test to predict V02max. Eur. J. Appl. Physiol. 49:1-12.

Macutkiewicz, D., and C. Sunderland (2011). The use of GPS to evaluate activity profiles of elite women hockey players during match play. J. Sports Sci. 29:967-973.

Mohr, M., P. Krustrup, and J. Bangsbo (2003). Match performance of high-standard soccer players with special reference to development of fatigue. J. Sports Sci. 21:519-528.

Mohr, M., I. Mujika, J. Santisteban, M. Randers, R. Bischoff, R. Solano, A. Hewitt, A. Zubillaga, E. Peltola, and P. Krustrup (2010). Examination of fatigue development in elite soccer in a hot environment: a multi-exerimental approach. Scand. J. Med. Sci. Sports. 20:S125-S132.

Morris, J., M. Nevill, D. Thompson, J. Collie, and C. Williams (2003). The influence of a 6.5% carbohydrate-electrolyte solution on performance of prolonged intermittent high intensity running at 30 OC. J. Sports Sci. 31:371-381.

Morris, J., M. Nevill, L. Boobis, I. Macdonald, and C. Williams (2005). Muscle metabolism, temperature, and function during prolonged intermittent high intensity running in air temperatures of 33 oC and 17oC. Int. J. Sport Med. 26:805-814.

Nicholas, C., C. Williams, H. Lakomy, G. Phillips, and A. Nowitz (1995). Influence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high intensity shuttle running. J. Sports Sci. 13:283-290.

Nicholas, C., P. Green, R. Hawkins, and C. Williams (1997). Carbohydrate intake and recovery of intermittent running capacity. Int. J. Sport Nutr. 7:251-260.

Nicholas, C., C. Williams, L. Boobis, and N. Little (1999). Effect of ingesting a carbohydrate-electrolyte beverage on muscle glycogen utilisation during high intensity, intermittent shuttle running. Med. Sci. Sport Exec. 31:1280-1286.

Nicholas, C., F. Nuttall, and C. Williams (2000). The Loughborough Intermittent Shuttle Test: A field test that simulates the activity pattern of soccer. J. Sports Sci. 18:97-104.

Parolin, M., A. Chesley, M. Matsos, L. Spriet, N. Jones, and G. Heigenhauser (1999). Regulation of skeletal muscle glycogen phosphorylase and PDH during maximal intermittent exercise. Am. J. Physiol. 277:E890-E900.

Pasiakos, S., H. Lieberman, and T. McLellan (2014). Effects of protein supplements on muscle damage, soreness and recovery of muscle function and physical performance: a systematic review. Sports Med. 44:665-670.

Patterson, S., and S. Gray (2007). Carbohydrate-Gel supplementation and endurance performance during intermittent high-intensity shuttle running. In.t. J Sport Nutr. Exerc, Metab. 17:445-455.

Phillips, S. (2011). Exercise and protein nutrition: The science of muscle hypertrophy: making dietary protein count. Proc. Nutr. Soc. 70:100-103.

Phillips, S.M., A.P. Turner, M.F. Sanderson, and J. Sproule (2012). Carbohydrate gel ingestion significantly improves the intermittent endurance capacity, but not sprint performance, of adolescent team games players during a simulated team games protocol. Eur. J. Appl. Physiol. 112:1133-1141.

Rampinini, E., F. Impellizzeri, A. Castagna, J. Coutt, and U. Wisloff (2009). Technical performance during soccer matches of the Italian Serie A league effect of fatigue and competitive level. J. Sci. Med. Sport. 120:227-233.

Rollo, I., and C. Williams (2011). Effect of mouth-rinsing carbohydrate solutions on endurance performance. Sports Med. 41:449-461.

Rollo, I. (2014). Carbohydrate: The football fuel. Sports Sci. Exchange. 27(127):1-8.

Sherman, W., D. Costill, W. Fink, and J. Miller (1981). Effect of exercise-diet manipulation on muscle glycogen and its subsequent utilization during performance. Int. J. Sports Med. 2:114-118.

Russell, M., and M. Kingsley (2014). The efficacy of nutritional interventions on soccer skill performance. Sports Med. 44:957-970.

Spencer, M., D. Bishop, B. Dawson, and C. Goodman (2005). Physiology and etabolic responses of repeated-sprint activities. Sports Med. 35:1025-1044.

Sunderland, C., and M.E. Nevill (2005). High intensity intermittent running and field hockey skill performance in the heat. J. Sports Sci. 23:531-540.

Thompson, D., C. Nicholas, and C. Williams (1999). Muscle soreness following prolonged intermittent high intensity shuttle running. J. Sports Sci. 17:387-395.

Wee, S., C. Williams, K. Tsintzas, and L. Boobis (2005). Ingestion of a high-glycemic index meal increases muscle glycogen storage at rest but aguments its utilization during subsequent exercise. J. Appl. Physiol. 99:707-714.

Welsh, R., M. Davis, J. Burke, and H. Williams (2002). Carbohydrates and physical/mental performance during intermittent exercise to fatigue. Med. Sci. Sports Exerc.34:723-731.

Winnick, J., J. Davis, R. Welsh, and M. Carmichael (2005). Carbohydrate feedings during team sport exercise preserve physical and CNS function. Med. Sci. Sports Exerc. 37:306-315.

Wu, C.-L., and C. Williams (2006). A low glycemic index meal before exercise improves running capacity in man. Int. J. Sport Nutr. Exerc. Metab. 16:510-527.