SSE #242

Sports Science Exchange (2023) Vol. 36, No. 242, 1- 6

GATORADE SPORTS SCIENCE INSTITUTE

CARBOHYDRATE NUTRITION AND SKILL PERFORMANCE IN SOCCER

Ian Rollo, Ph.D.,[1,2] Clyde Williams, Ph.D.[2]
[1]Gatorade Sports Science Institute, PepsiCo Life Sciences, Global R&D, UK
[2]School of Sports Exercise and Health Sciences, Loughborough University, UK

KEY POINTS

- Skilled actions are an essential requirement for soccer performance.
- Physical and mental fatigue experienced by players during team sport have a negative impact on the performance of soccer-specific skills.
- Increasing muscle and liver glycogen stores before and ingesting carbohydrate during competition delays the onset of fatigue and is conducive to maintaining the execution of soccer-specific skills.
- The ingestion of carbohydrate may also counter negative subjective feelings and improve player concentration to help maintain skill execution over the duration of training or a match.

INTRODUCTION

In soccer, skill is an umbrella term that encapsulates not only the physical performance of a particular skill but also the complex interaction of cognitive and technical ability to respond to the multitude of scenarios present in every match. While technical skills can be learned to the point of being autonomous, the cognitive skill of 'reading the game' is one that is developed by successful players over the duration of their playing careers.

At all levels of sport, the quality of the skill performed is likely influenced by the preceding volume of exercise completed (attacking and defending) over the duration of the match. For example, the higher the tempo of a match, the sooner players begin to experience both physical (run, sprint, jump) and mental (concentration, decision making) effects of fatigue, which often results in a 15% increase in the speed of the match (Wallace & Norton, 2014). These observations highlight the increased physical and technical demands placed on professional soccer players.

While team metrics are hugely informative, the impact of training, rehabilitation and nutritional intervention on individual players may be better understood by assessing their skills via objective assessments. Desirable as this is, it remains challenging to design and implement objective skill tests that reproduce the demands of a match. As a result, some studies have used isolated tests of soccer skills, for example, ball juggling (Hoare & Warr, 2000), wall volley (Vanderford et al., 2004), heading (Rosch et al., 2000), shooting (Ali & Williams, 2009: Haaland & Hoff, 2003), passing (Ali & Williams, 2009: Bendiksen et al., 2012: Rodriguez-Giustiniani et al., 2019: Rostgaard et a., 2008) and dribbling (Harper et al., 2017).

Laboratory-based studies provide controlled environments to investigate isolated skills, whilst also simulating the physical demands of the sport. For example, the Soccer Match Simulation (SMS) protocol embeds soccer-specific skills to enhance the ecological validity of a previously validated simulated assessment replicating the energy demands of a soccer match (Nicholas et al., 2000: Russell et al., 2011). However, while objective tests of skill have many advantages they are not without several limitations. For example, playing surface is an important consideration in the ecological validity of soccer skill tests (Harper et al., 2017: Rodriguez-Giustiniani et al., 2019). Furthermore, the footwear worn for different surfaces may not be conducive for the skill under assessment, i.e. boots versus trainers when testing shooting skill. Ali (2011) has reviewed the strengths and limitations of soccer skill performance tests.

The purpose of this Sports Science Exchange (SSE) article is to review the recent studies investigating carbohydrate ingestion on soccer-specific skills. In addition, the article will discuss the possible role that carbohydrate ingestion plays in negating the impact that more recently reported mental fatigue has on skill performance.

CARBOHYDRATE INGESTION AND SKILL

While adopting nutritional strategies to delay a rapid loss of the body's glycogen stores helps players maintain their work rate during matches, the question is whether it also helps prevent a loss of skill? A simple answer would be that if players tire less readily, after implementing a carbohydrate feeding strategy, then they are likely to better execute the necessary skills in match play. Unfortunately, there are too few studies to provide a definitive answer to this question. However, one study reported that when male professional soccer players ingested either a 7% carbohydrate-electrolyte or placebo beverage before (5 ml·kg body mass^{-1}(BM)) and every 15 min (2 ml·kg BM^{-1}) during a 90 min on-field soccer match and then completed the assessment of four skills (dribbling speed, coordination, precision, and power), there was a significant improvement in dribbling speed and precision following carbohydrate ingestion (Ostojic & Mazic, 2002). The appropriate type, timing, and quantity of carbohydrate to be ingested during team sports, have led to

<table>
<tr><th>Team sport exercise scenario</th><th>Objectives</th><th>Desired adaptation/ outcome</th><th>Suggested daily carbohydrate ingestion range</th><th>Considerations</th></tr>
<tr><td>In-Season Training
(1 game per week)</td><td rowspan="2">• Delay physical and mental fatigue
• To maintain physical qualities (and improve where possible/appropriate)
• To keep players injury and illness free</td><td rowspan="2">• To maintain aerobic and anaerobic fitness
• To at least maintain strength, power, speed
• To maintain lean body mass
• Support physical and technical performance</td><td>4-8 g/kg body mass</td><td>Range accommodates variations in loads across the micro-cycle (e.g. low load days and Match Day-1 carbohydrate loading protocols) as well as individual training goals (e.g. manipulation of body composition to accommodate weight loss and fat loss or weight gain and lean mass gain).
Practice competition carbohydrate ingestion regime.</td></tr>
<tr><td>Match Day-1, Match Day and Match Day +1</td><td>6-8 g/kg body mass to elevate muscle glycogen stores.</td><td>Ingest 1-3 g of carbohydrate/kg body mass 3-4 hrs before a match to replenish liver glycogen stores.
Ingest 30 g of carbohydrate following the warm-up and during the half-time interval.
Ingest 1 g carbohydrate/kg body mass/hr with fluids after a match to start restoration of glycogen and rehydration.</td></tr>
</table>

Table 1: Carbohydrate Intake Recommendations for Soccer (from Rollo et al., 2014; 2021).

tried and tested recommendations (Anderson et al., 2016; Burke et al., 2011; Collins et al., 2021; Funnell et al., 2017; Harper et al., 2017; Moss et al., 2020; Rollo et al., 2021; Thomas et al., 2016) (Table 1).

In an innovative study on the impact of carbohydrate ingestion on skill, tests were undertaken on players' dominant and non-dominant limbs. Using a soccer-specific protocol, higher passing scores were achieved by both dominant and non-dominant feet following an ecologically valid carbohydrate ingestion regime (30 g, before and at half time, compared with placebo whilst drinking water ad-libitum) (Rodriguez-Giustiniani et al., 2019). This effect was evident in the final 30 min of the 90 min protocol. Importantly, improved performance was attained without loss of passing speed, which was better maintained in the non-dominant foot with carbohydrate ingestion. This observation is of interest because it is consistent with other studies in sports such as tennis, where non-dominant or weaker sides (backhand) shots respond positively to carbohydrate ingestion, especially when fatigued (McRae et al., 2012). The assessment of complex skilled actions on the non-dominant side may require greater activation of the central nervous system (CNS) and therefore be more susceptible to fatigue (Rodriguez-Giustiniani et al., 2019). Furthermore, non-dominant skilled actions may be more likely influenced by the arousal level of the player (McMorris & Graydon, 1997). Thus, the assessment of players' non-dominant sides seems to have a greater sensitivity to carbohydrate ingestion, even though the "non-dominant" side is likely to be inferior in performing skills.

CARBOHYDRATE INGESTION AND MENTAL FATIGUE

A recent model of motor or cognitive task-induced fatigue proposes that no single factor is responsible for declines in skill performance. Instead, fatigue is considered a psychophysiological condition (Enoka et al., 2011). Motor fatigue and perceived fatigue are interdependent but hinge on various determinants and depend on modulating factors such as age, sex, and specific skill characteristics (Behrens et al., 2022). Mental fatigue is defined as a psychobiological state that develops during prolonged demanding cognitive activity and results in an acute feeling of tiredness and/or a decreased cognitive ability as well as mood changes (Habay et al., 2021; Roelands et al., 2022). Mental fatigue has been recognized as a key consideration in team sports, due to the associated negative impact on physical, technical, decision-making, and tactical performance (Smith et al., 2018). Contributing factors to mental fatigue in team sport environments include but are not limited to; prolonged cognitive demands, team meetings, travel, and the inability to "switch off" (Thompson et al., 2020; 2022). To emphasise the potential impact on performance, mental fatigue has been found, in one review (n=92), to have a negative influence on 37% of soccer-specific skills (Habay et al., 2021).

Monitoring mental fatigue is recommended in team sport to provide an indicator of how players are coping with the demands of competition and or training (Thompson et al., 2019). Strategies are also recommended to help avoid mental fatigue, such as displacement activities, changes in training routines and environment, and of course, adequate rest and recovery. Increasing dietary carbohydrate while improving exercise capacity both in training and competition may also be a mood-changing counter-measure to mental fatigue (Achten et al., 1994; Killer et al., 2017). If players are feeling good rather than bad (pleasure–displeasure) and energized (i.e., an activated state) before and during matches, then they are more likely to perform better (Acevedo et al., 1996;

McMorris & Graydon, 1997). Backhouse and colleagues reported that the ingestion of carbohydrate elevated perceived activation during the final 30 min of 120-min intermittent running exercise (Backhouse et al., 2007), and also attenuated the decline in pleasure–displeasure during a 120-min bout of cycling (Backhouse et al., 2005). Administering both a Feeling Scale (FS) and a rating of perceived exertion (RPE) scale allows a measure of not only "what" (RPE) but "how" (FS) a person feels (Hardy & Rejeski, 1989), but is rarely administered during skill intervention studies or in applied soccer environments.

A recent review identified mouth rinsing and expectorating a carbohydrate beverage as a potential acute countermeasure to mental fatigue (Proost et al., 2022). The recognition of carbohydrate in the mouth, when administered immediately after a mentally fatiguing task, was linked to increased excitability of corticomotor pathways (Bailey et al., 2021; Gant et al., 2010). Furthermore, there appears to be a direct link between improvements in task-specific activity and activation within the primary sensorimotor cortex in response to oral carbohydrate signalling (Turner et al., 2014). These results contribute to a possible explanation for improved performance in response to mouth rinsing a carbohydrate beverage (see Rollo & Williams, 2011).

These responses to carbohydrate ingestion may not be surprising bearing in mind that glucose is the main fuel for the brain and the CNS (Mergenthaler et al., 2013). The optimum functioning of the brain and CNS requires glucose homeostasis to be maintained during a wide range of conditions. If blood glucose falls to hypoglycemic concentrations, then the neural drive to skeletal muscles will be compromised, although function is restored following the ingestion of carbohydrate (Nybo, 2003). During exercise, the rate of glucose release from the liver into the blood increases to match the glucose uptake by contracting muscle (Wasserman, 2009). In most team sports, blood glucose concentrations are well maintained over the duration of competition (~80-90 min) and extra time (120 min in soccer) in well-fed individuals (Harper et al., 2016). Nevertheless, carbohydrate ingestion at the onset of exercise is an effective strategy not only to top up liver and muscle glycogen stores but to also temporarily inhibit hepatic glucose release in a dose-dependent manner, thereby conserving liver glycogen stores (Jeukendrup et al., 1999). Carbohydrate ingestion, as a means of preserving the finite store of liver glycogen, will maintain blood glucose concentrations and performance late in exercise. This strategy is particularly beneficial when soccer matches go to extra time, which is becoming a common occurrence in International and major cup competitions (Field et al., 2022; Mohr et al., 2023).

Of interest, is the observation that elevated blood glucose concentrations are associated with improved skill performance in comparison to euglycemia (Ali & Williams, 2009; Ali et al., 2007; Harper et al., 2017; Rodriguez-Giustiniani et al., 2019). An immediate explanation for this observation is not apparent other than glucose is a fuel for the brain (Lopez-Gambero et al., 2019; van Praag et al., 2014). The brain is sensitive to changes in blood glucose and thus the rate of change may act to monitor the availability of whole-body carbohydrate stores.

Dietary carbohydrate	Consideration
Sports drink	Contributes to hydration plan
Banana	Ensure fruit is ripe
Sweets/ Confectionary	Check carbohydrate content, ensure not over consumed by non-starters/impact players (substitutes)
Sports Gel	Check carbohydrate content, consume with water as part of hydration plan
Rice cakes (x4)	Check carbohydrate content
Cereal bar	Check carbohydrate content

Table 2: Examples of dietary options providing approximately 30 g of carbohydrate, recommended before, at half time, and before any extra time periods. Carbohydrate ingestion should be planned in concert with the players individualized hydration strategy.

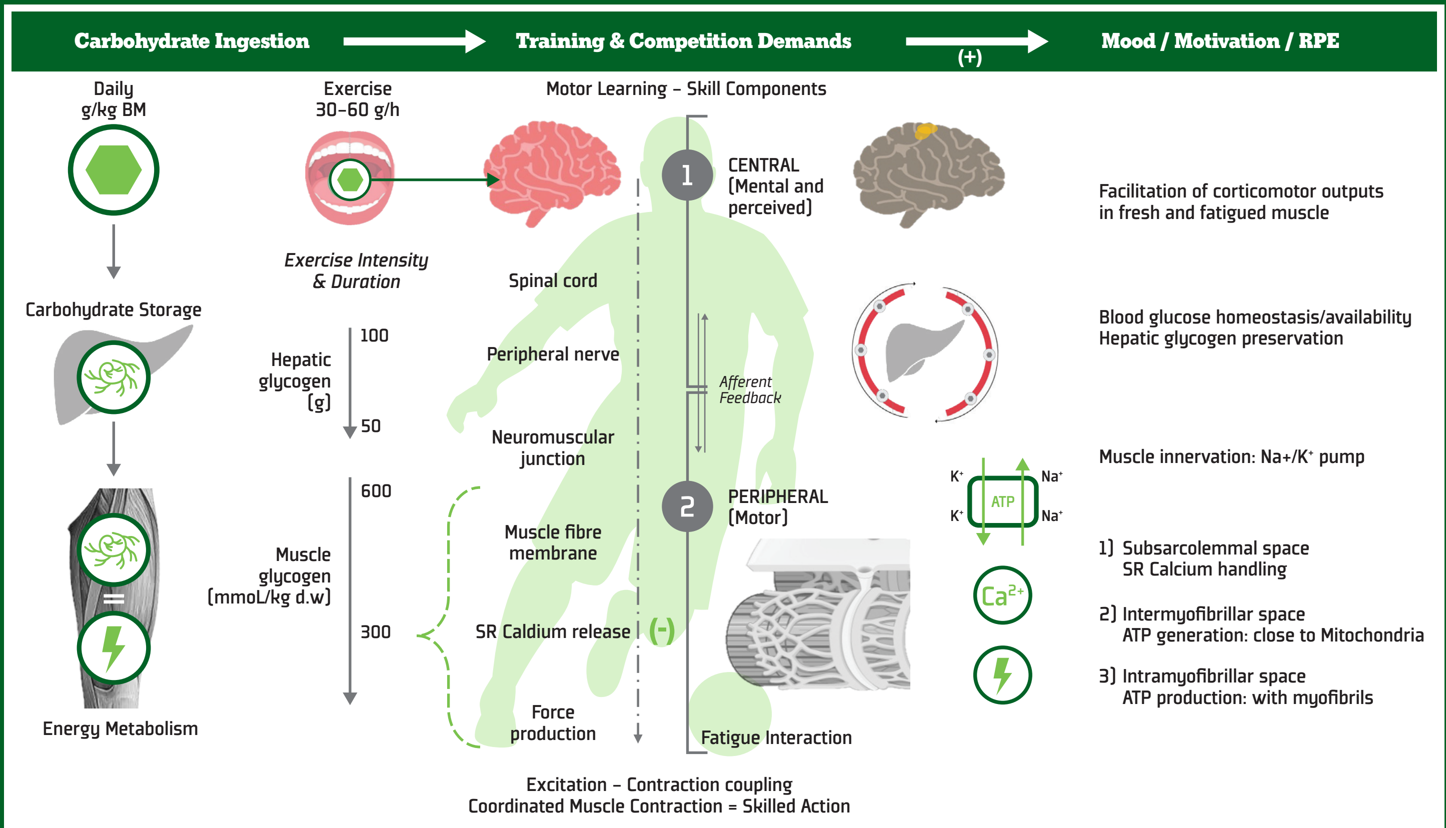

Figure 1: Translating thoughts into skilled actions. The electro-chemical chain of events between the brain and skeletal muscles, that carbohydrate ingestion may impact skill performance. BM=Body Mass, SR= sarcoplasmic reticulum, Ca+ = Calcium, Na+/K+ = Sodium, potassium pump, ATP = adenosine triphosphate. + = positive influence upon, - = negative influence upon. Mood, Motivation, RPE (Jeukendrup et al., 1999: Nybo, 2003; Turner et al., 2014), Facilitation of corticomotor outputs (Ali et al., 2007; Mohr et al., 2023), blood glucose availability, hepatic glycogen preservation (Fuchs et al., 2016; Gonzalez et al., 2016; Jeukendrup et al., 1999: Newell et al., 2018), Muscle Innervation: SR calcium handling (Ortenblad et al., 2011), ATP generation (Duhamel et al., 2007; Nielsen et al. 2011; Ortenbald et al., 2011). Figure taken from Rollo and Williams (2023), with permission.

SUMMARY AND PRACTICAL RECOMMENDATIONS

Soccer players experience, to different degrees, physical and mental fatigue that can negatively impact the performance of sports-specific skills. Figure 1 summarizes the complex series of events between brain and skeletal muscle that interact to minimize the impact of physical and mental fatigue on the performance of skills during exercise, following carbohydrate feedings. It is important to note that the guidance on carbohydrate intake (Table 1) can be achieved by ingesting a variety of different dietary sources of carbohydrate. Players should be encouraged to consume a variety of different foods to meet daily carbohydrate goals, whilst achieving other important nutrition objectives related to protein, hydration, and fats. Around the exercise occasion, the ingestion of 30 g of carbohydrate can be achieved by ingesting one or a combination of different carbohydrate foods, mixed and matched to the players' preference (Table 2).

We would like to acknowledge and thank all previous and existing colleagues and collaborators. Ian Rollo is an employee of the Gatorade Sports Science Institute, a division of PepsiCo, Inc. The views expressed in this manuscript are those of the author and do not necessarily reflect the position or policy of PepsiCo Inc.

REFERENCES

Acevedo, E., D. Gill, A. Goldfarb, and B. Boyer (1996). Affect and perceived exertion during a two-hour run International J. Sport Psychol. 27:286-292.

Achten, J., S.L. Halson, L. Moseley, M.P. Rayson, A. Casey, and A.E. Jeukendrup (2004). Higher dietary carbohydrate content during intensified running training results in better maintenance of performance and mood state. J. Appl. Physiol. 96:1331-1340.

Ali, A. (2011). Measuring soccer skill performance: a review. Scand. J. Med. Sci. Sports. 21:170-183.

Ali, A. and C. Williams (2009). Carbohydrate ingestion and soccer skill performance during prolonged intermittent exercise. J. Sports Sci. 27:1499-1508.

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

Anderson, L., P. Orme, R. Di Michele, G.L. Close, R. Morgans, B. Drust, and J.P. Morton (2016). Quantification of training load during one-, two- and three-game week schedules in professional soccer players from the English Premier League: Implications for carbohydrate periodisation. J. Sports Sci. 34:1250-1259.

Andrzejewski, M., J.M. Oliva-Lozano, P. Chmura, J. Chmura, S. Czarniecki, E. Kowalczuk, A. Rokita, J.M. Muyor, and M. Konefal (2022). Analysis of team success based on match technical and running performance in a professional soccer league. BMC Sports Sci. Med. Rehabil. 14:82.

Backhouse, S.H., N.C. Bishop, S.J. Biddle, and C. Williams (2005). Effect of carbohydrate and prolonged exercise on affect and perceived exertion. Med. Sci. Sports Exerc. 37:1768-1773.

Backhouse, S.H., A. Ali, S.J. Biddle, and C. Williams (2007). Carbohydrate ingestion during prolonged high-intensity intermittent exercise: Impact on affect and perceived exertion. Scand. J. Med. Sci. Sports 17:605-610.

Bailey, S.P., G.K. Harris, K. Lewis, T.A. Llewellyn, R. Watkins, M.A. Weaver, B. Roelands, J. Van Cutsem, and S.F. Folger (2021). Impact of a carbohydrate mouth rinse on corticomotor excitability after mental fatigue in healthy college-aged subjects. Brain Sci. 11:972.

Behrens, M., M. Gube, H. Chaabene, O. Prieske, A. Zenon, K.C. Broscheid, L. Schega, F. Husmann, and M. Weippert (2023). Fatigue and human performance: An updated framework. Sports Med. 53:7-31.

Bendiksen, M., R. Bischoff, M.B. 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.

Bradley, P.S., C. Lago-Penas, E. Rey, and A. Gomez Diaz (2013). The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. J. Sports Sci. 31:1261-1270.

Burke, L.M., J.A. Hawley, S.H. Wong, and A.E. Jeukendrup (2011). Carbohydrates for training and competition. J. Sports Sci. 29 (Suppl 1):S17-S27.

Collins, J., R.J. Maughan, M. Gleeson, J. Bilsborough, A. Jeukendrup, J.P. Morton, S.M. Phillips, L. Armstrong, L.M. Burke, G.L. Close, R. Duffield, E. Larson-Meyer, J. Louis, D. Medina, F. Meyer, I. Rollo, J. Sundgot-Borgen, B.T. Wall, B. Boullosa, G. Dupont, A. Lizarraga, P. Res, M. Bizzini, C. Castagna, C.M. Cowie, M. D'Hooghe, H. Geyer, T. Meyer, N. Papadimitriou, M. Vouillamoz, and A. McCall (2021). UEFA expert group statement on nutrition in elite football. Current evidence to inform practical recommendations and guide future research. Br. J. Sports Med. 55:416.

Duhamel, T.A., R.D. Stewart, A.R. Tupling, J. Ouyang, and H.J. Green (2007). Muscle sarcoplasmic reticulum calcium regulation in humans during consecutive days of exercise and recovery. J. Appl. Physiol. 103:1212-1220.

Enoka, R.M., S. Baudry, T. Rudroff, D. Farina, M. Klass, and J. Duchateau (2011). Unraveling the neurophysiology of muscle fatigue. J. Electromyogr. Kines. 21:208-219.

Field, A., R.J. Naughton, M. Haines, S. Lui, L.D. Corr, M. Russell, R.M. Page, and L.D. Harper (2022). The demands of the extra-time period of soccer: A systematic review. J. Sport Health Sci. 11:403-414.

Fuchs, C.J., J.T. Gonzalez, M. Beelen, N.M. Cermak, F.E. Smith, P.E. Thelwall, R. Taylor, M.I. Trenell, E.J. Stevenson, and L.J. van Loon (2016). Sucrose ingestion after exhaustive exercise accelerates liver, but not muscle glycogen repletion compared with glucose ingestion in trained athletes. J. Appl. Physiol. 120:1328-1334.

Funnell, M.P., N.R. Dykes, E.J. Owen, S.A. Mears, I. Rollo, and L.J. James (2017). Ecologically valid carbohydrate intake during soccer-specific exercise does not affect running performance in a fed state. Nutrients 9:39.

Gant, N., C.M. Stinear, and W.D. Byblow (2010). Carbohydrate in the mouth immediately facilitates motor output. Brain Res. 1350:151-158.

Gonzalez, J.T., C.J. Fuchs, J.A. Betts, and L.J. van Loon (2016). Liver glycogen metabolism during and after prolonged endurance-type exercise. Am. J. Physiol. 311:E543-E553.

Haaland, E. and J. Hoff (2003). Non-dominant leg training improves the bilateral motor performance of soccer players. Scand. J. Med. Sci. Sports. 13:179-184.

Habay, J., J. Van Cutsem, J. Verschueren, S. De Bock, M. Proost, J. De Wachter, B. Tassignon, R. Meeusen, and B. Roelands (2021). Mental fatigue and sport-specific psychomotor performance: A systematic review. Sports Med. 51:1527-1548.

Hardy, C., J and W. Rejeski (1989). Not what, but how ones feels: The measurement of affect during exercise. J. Sport Exerc. Psychol. 11:304-317.

Harper, L.D., D.J. West, E. Stevenson, and M. Russell (2014). Technical performance reduces during the extra-time period of professional soccer match-play. PloS one 9:e110995.

Harper, L.D., M.A. Briggs, G. McNamee, D.J. West, L.P. Kilduff, E. Stevenson, and M. Russell (2016). Physiological and performance effects of carbohydrate gels consumed prior to the extra-time period of prolonged simulated soccer match-play. J. Sci. Med. Sport 19:509-514.

Harper, L.D., E.J. Stevenson, I. Rollo, and M. Russell (2017). The influence of a 12% carbohydrate-electrolyte beverage on self-paced soccer-specific exercise performance. J. Sci. Med. 12:1123-1129.

Hoare, D.G. and C.R. Warr (2000). Talent identification and women's soccer: an Australian experience. J. Sports Sci. 18:751-758.

Jeukendrup, A.E., A.J. Wagenmakers, J.H. Stegen, A.P. Gijsen, F. Brouns, and W.H. Saris (1999). Carbohydrate ingestion can completely suppress endogenous glucose production during exercise. Am. J. Physiol. 276:E672-E683.

Killer, S.C., I.S. Svendsen, A.E. Jeukendrup, and M. Gleeson (2017). Evidence of disturbed sleep and mood state in well-trained athletes during short-term intensified training with and without a high carbohydrate nutritional intervention. J. Sports Sci. 35:1402-1410.

Lopez-Gambero, A.J., F. Martinez, K. Salazar, M. Cifuentes, and F. Nualart (2019). Brain glucose-sensing mechanism and energy homeostasis. Mol. Neurobiol. 56:769-796.

McMorris, T. and J. Graydon (1997). The effect of exercise on cognitive performance in soccer-specific tests. J. Sports Sci. 15:459-468.

McRae, K.A. and S.D. Galloway (2012). Carbohydrate-electrolyte drink ingestion and skill performance during and after 2 hr of indoor tennis match play. Int. J. Sport Nutr. Exerc. Metab. 22:38-46.

Mergenthaler, P., U. Lindauer, G.A. Dienel, and A. Meisel (2013). Sugar for the brain: The role of glucose in physiological and pathological brain function. Trends Neurosci. 36:587-597.

Mohr, M., J.F. Vigh-Larsen, and P. Krustrup (2022). Muscle glycogen in elite soccer - A perspective on the implication for performance, fatigue, and recovery. Front. Sports Active Living 4:876534.

Mohr, M., G. Ermidis, A.Z. Jamurtas, J.F. Vigh-Larsen, A. Poulios, D. Draganidis, K. Papanikolaou, P. Tsimeas, D. Batsilas, G. Loules, A. Batrakoulis, A. Sovatzidis, J.L. Nielsen, T. Tzatzakis, C.K. Deli, L. Nybo, P. Krustrup, and I.G. Fatouros (2023). Extended match time exacerbates fatigue and impacts physiological responses in male soccer players. Med. Sci. Sports Exerc. 55:80-92.

Moss, S.L., R.K. Randell, D. Burgess, S. Ridley, C. ÓCairealláin, R. Allison, and I. Rollo (2020). Assessment of energy availability and associated risk factors in professional female soccer players. Eur. J. Sport Sci. 6:861-870.

Newell, M.L., G.A. Wallis, A.M. Hunter, K.D. Tipton, and S.D.R. Galloway (2018). Metabolic responses to carbohydrate ingestion during exercise: Associations between carbohydrate dose and endurance performance. Nutrients 10:37.

Nicholas, C.W., F.E. 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.

Nielsen, J., H.C. Holmberg, H.D. Schroder, B. Saltin, and N. Ortenblad (2011). Human skeletal muscle glycogen utilization in exhaustive exercise: Role of subcellular localization and fibre type. J. Physiol. 589:2871-2885.

Nybo, L. (2003). CNS fatigue and prolonged exercise: Effect of glucose supplementation. Med. Sci. Sports Exerc. 35:589-594.

Ortenblad, N., J. Nielsen, B. Saltin, and H.C. Holmberg (2011). Role of glycogen availability in sarcoplasmic reticulum Ca2+ kinetics in human skeletal muscle. J. Physiol. 589:711-725.

Ostojic, S.M. and S. Mazic (2002). Effects of a carbohydrate-electrolyte drink on specific soccer tests and performance. J. Sports Sci. Med. 1:47-53.

Proost, M., J. Habay, J. De Wachter, K. De Pauw, B. Rattray, R. Meeusen, B. Roelands, and J. Van Cutsem (2022). How to tackle mental fatigue: A systematic review of potential countermeasures and their underlying mechanisms. Sports Med. 52:2129-2158.

Rodriguez-Giustiniani, P., I. Rollo, O.C. Witard, and S.D.R. Galloway (2019). Ingesting a 12% Carbohydrate-electrolyte beverage before each half of a soccer match simulation facilitates retention of passing performance and improves high-intensity running capacity in academy players. Int. J. Sport Nutr. Exerc. Metab. 29:397-405.

Roelands, B., V. Kelly, S. Russell, and J. Habay (2022). The physiological nature of mental fatigue: current knowledge and future avenues for sport science. Int. J. Sports Physiol. Perf. 17:149-150.

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

Rollo, I., F.M. Impellizzeri, M. Zago, and F.M. Iaia (2014). Effects of 1 versus 2 games a week on physical and subjective scores of subelite soccer players. Int. J. Sports Physiol. Perf. 9:425-431.

Rollo, I., R.K. Randell, L. Baker, J.Y. Leyes, D. Medina Leal, A. Lizarraga, J. Mesalles, A.E.

Jeukendrup, L.J. James, and J.M. Carter (2021). Fluid balance, sweat na(+) losses, and carbohydrate intake of elite male soccer players in response to low and high training intensities in cool and hot environments. Nutrients 13:401.

Rollo I and C. Williams (2023). Carbohydrate Nutrition and Skill Performance in Soccer. Sports Med. 2023 Epub ahead of print.

Rosch, D., R. Hodgson, T.L. Peterson, T. Graf-Baumann, A. Junge, J. Chomiak, and J. Dvorak (2000). Assessment and evaluation of football performance. Am. J. Sports Med. 28(5 Suppl): S29-S39.

Rostgaard, T., F.M. Iaia, D.S. Simonsen, and J. Bangsbo (2008). A test to evaluate the physical impact on technical performance in soccer. J. Strength Cond. Res. 22:283-292.

Russell, M., G. Rees, D. Benton, and M. Kingsley (2011). An exercise protocol that replicates soccer match-play. Int. J. Sports Med. 32:511-518.

Smith, M.R., C. Thompson, S.M. Marcora, S. Skorski, T. Meyer, and A.J. Coutts (2018). Mental fatigue and soccer: Current knowledge and future directions. Sports Med. 48:1525-1532.

Thomas, D.T., K.A. Erdman, and L.M. Burke (2016). Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance. J. Acad. Nutr. Dietet. 116:501-528.

Thompson, C.J., J. Fransen, S. Skorski, M.R. Smith, T. Meyer, S. Barrett, and A.J. Coutts (2019). Mental fatigue in football: Is it time to shift the goalposts? An evaluation of the current methodology. Sports Med. 49:177-183.

Thompson, C.J., M. Noon, C. Towlson, J. Perry, A.J. Coutts, L.D. Harper, S. Skorski, M.R. Smith, S. Barrett, and T. Meyer (2020). Understanding the presence of mental fatigue in English academy soccer players. J. Sports Sci. 38:1524-1530.

Thompson, C.J., A. Smith, A.J. Coutts, S. Skorski, N. Datson, M.R. Smith, and T. Meyer (2022). Understanding the presence of mental fatigue in elite female football. Res. Quart. Exerc. Sport 93:504-515.

Turner, C.E., W.D. Byblow, C.M. Stinear, and N. Gant (2014). Carbohydrate in the mouth enhances activation of brain circuitry involved in motor performance and sensory perception. Appetite 80:212-219.

Vanderford, M.L., M.C. Meyers, W.A. Skelly, C.C. Stewart, and K.L. Hamilton (2004). Physiological and sport-specific skill response of olympic youth soccer athletes. J. Strength Cond. Res. 18:334-342.

van Praag, H., M. Fleshner, M.W. Schwartz, and M.P. Mattson (2014). Exercise, energy intake, glucose homeostasis, and the brain. J. Neurosci. 34:15139-15149.

Wallace, J.L. and K.I. Norton (2014). Evolution of World Cup soccer final games 1966-2010: game structure, speed and play patterns. J. Sci. Med. Sport 17:223-228.

Wasserman, D.H. (2009). Four grams of glucose. Am. J. Physiol. 296:E11-E21.

Williams, C., and I. Rollo (2015). Carbohydrate nutrition and team sport performance. Sports Med. 45 (Suppl 1):S13-S22.