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SYSTEMATIC REVIEW

The Efficacy of Acute Nutritional Interventions on Soccer Skill Performance

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Abstract

Background The use of nutritional ergogenic aids in team sports such as soccer is now commonplace. Aligned with the primary aim of soccer, which is to score more goals than the opposition within the allotted time, the quality of performance of technical actions (i.e., skills) executed during soccer-specific exercise is likely to determine success. However, when seeking to maintain soccer skill performance, information about the efficacy of nutritional interventions is lacking and factors which might modulate the efficacy of such strategies are unclear.

Objective This review aimed (i) to systematically evaluate the current research that examines the efficacy of nutritional interventions on soccer skills, and (ii) to provide a qualitative commentary on factors that have the potential to modulate the efficacy of such strategies.

Data Sources Relevant databases (PubMed and SPORTDiscus) were searched up to and including 1 July, 2013 for studies that investigated the efficacy of acute nutritional interventions on soccer skill performances.

Study Selection Overall, 279 records were retrieved. Articles were sequentially excluded from the review based on specific criteria, being: (A) articles that did not report outcomes directly relating to skilled performances in soccer, (B) articles that examined the influence of interventions that were not nutritional in origin and/or were nutritional in origin but provided >3 hours before skill testing commenced, (C) articles that were review papers, and (D) post-acceptance withdrawal of articles methods from database.

Study Appraisal and Synthesis Methods Articles were independently assessed for the quality of the methods employed based upon the Physiotherapy Evidence Database (PEDro) scale. Records achieving a minimum PEDro score of 5 out of 10 were included in this review. Qualitative appraisal of 13 articles was performed after the application of exclusion criteria and quality assurance processes. The majority ($n = 8$) of articles examined the influence of carbohydrates on technical performance whereas fewer studies investigated the influence of caffeine ingestion ($n = 2$) and fluid provision ($n = 3$).

Results Findings were reported for a total of 171 participants and all but one of the included articles used crossover study designs. Most participants (94 %) were male, highly trained (reported maximal aerobic capacity range 50–59 $ml \cdot kg^{-1} \cdot min^{-1}$) and exercised in temperate environments (reported temperature range 13–25 °C). Six of the eight studies reported that carbohydrates, consumed in the form of a 6–8 % solution of glucose, sucrose or maltodextrin at rates of 30–60 $g \cdot h^{-1}$, enhanced at least one aspect of skilled performance over the duration of exercise (75–90 min). Although some evidence exists to support the consumption of caffeine (6 $mg \cdot kg^{-1}$ body mass [BM]) and prescribed fluid to preserve skills performed during soccer-specific exercise, findings from the small number of included studies were inconsistent.

Limitations The outcome measures and methods used to quantify skilled performance were not consistent across studies; consequently, it was not possible to perform meta-analyses to produce pooled effect sizes in this review.

Conclusions The findings from this systematic review suggest that nutritional interventions, which provide carbohydrate,

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caffeine and fluid, have potential to preserve skills performed under conditions that induce soccer-specific fatigue. The weight of current evidence supports the consumption of carbohydrate, but is less conclusive with respect to caffeine and fluid provision. It is likely that the efficacy of a nutritional intervention will be modulated by factors including the dose consumed, the mode of administration, individual responsiveness to the intervention and interactions with other physiological changes occurring during soccer-specific exercise. Consequently, these factors should be considered when using carbohydrates, caffeine and fluid provision to maintain skilled performances in soccer. Future research should seek to optimise the nutritional strategies employed to maintain technical performance throughout match-play.

1 Introduction

Ergogenic aids have been defined as: "a technique or practice that can improve physical work capacity or athletic performance" [1], and have primarily been categorised as being mechanical, physiological, pharmacological, psychological or nutritional in origin [1]. As strategies that aim to improve athletic performance are appealing, especially those which are nutritional in origin, it is not surprising that the use of ergogenic aids is now synonymous with the preparation of athletes. For example, the analysis of a prospective survey of medications taken in the 3 days before soccer World Cup matches revealed that 57 % of active ingredients were classified as nutritional supplements [2]. Furthermore, some players reported consuming up to ten different supplements prior to competition [2]. Although most research relating to the efficacy of such substances has focused on physical indices of performance (e.g., time-trial or time-to-exhaustion protocols), the main aim of soccer is to score more goals than the opposition within the allotted time. Therefore, nutritional interventions that influence the quality of technical actions (i.e., skilled performances) might have an important role when seeking to optimise performance in soccer players.

Soccer skill performance is dependent upon cognitive, perceptual, and motor skills, which interact in rapidly changing environments [3]. Therefore, any strategy that can benefit one or more of these facets of skill performance is likely to be of considerable interest to soccer players and those responsible for the technical preparations of these athletes. A comprehensive review of the technical demands of soccer match-play is beyond the scope of this paper (interested readers are referred to references [4–6]). However, notational analysis has identified that the most frequent skills performed during match-play are passing and dribbling actions [5, 6]. Additionally, shooting is a crucial skill in soccer [7]. Therefore, proficiency in ball skills executed during soccer-specific exercise is likely to contribute to success in soccer, especially considering that the technical aspects of game-play appear more important than the performance of high-intensity physical activity [8] and that the completion of longer passing sequences was associated with more goals scored in successful teams [9].

Soccer-specific exercise appears to impair the quality of technical performance in soccer players, particularly for passing and shooting skills performed in the second half [10]. Using computerised notational analysis data collected over 23 home matches in the English Championship, it was observed that total possessions and the number of ball distributions were lower in the second versus the first half of match-play [11]. Furthermore, analysis across 15-min intervals revealed that transient reductions in the total number of ball possessions and distributions occurred in the final 15 min of match-play when compared with the opening phase of play [11]. These data support the conclusions of previous authors that the accumulated effects of match-related fatigue explain the reduction in short passing performance observed between the first and second halves in players competing in the Italian Serie A [5] and that more goals are conceded in the final 15 min of a match [12].

Match-related fatigue has been suggested to explain transient changes in physical performance over the course of a match, particularly in respect to high-intensity actions performed in the second half [13, 14]. Self-pacing strategies [15] and tactical modifications [16] have also been proposed to explain such changes. Although self-pacing could be a plausible explanation for conservation of physical performance, it is paradoxical to suggest that players would implement pacing strategies in relation to the quality of the skills that they execute in a sport which is determined by the number of goals scored. Additionally, despite the mechanisms regulating performance in soccer players being unclear, the volume of literature profiling the reduction in various facets of physical performance upon cessation of 90 min of match-play (for a review see Mohr et al. [17]) indicates that fatigue does explain some aspect of reduced performance in soccer players in the second half.

Saltin [18] observed that the muscle glycogen concentrations measured at half-time of soccer match-play were below that established for maintaining maximal glycolytic rate ($\sim$200 mmol·kg^{-1} dry mass; [19, 20]) in players who started exercise in a low pre-match muscle glycogen state. Additionally, diminished muscle glycogen concentrations were observed at full time in players who started the game with normal glycogen levels. More recently, depleted or almost depleted intramuscular glycogen concentrations have been identified in 50 % of muscle fibres following match-play [21]. Although a topic of considerable debate [22, 23], fatigue induced by high-intensity intermittent exercise may also be dependent upon hydration status, where increased core temperature, enhanced glycogen utilisation, altered metabolic function, modified central nervous system activity and increased cardiovascular strain have been associated with hypohydration [24, 25].

A combination of central (i.e., impaired function of the central nervous system) and peripheral (e.g., disturbance of acid-base balance, muscle damage, stored energy depletion) factors have been implicated in match-related fatigue [26]; however, research focusing on physical performances during intermittent exercise have primarily investigated strategies that seek to minimise the detrimental effects of stored energy depletion, hypohydration and central fatigue. From endurance exercise paradigms, it is well established that the ingestion of carbohydrates during prolonged exercise can increase the time to fatigue due to the maintenance of blood glucose levels and adequate supply of energy when muscle glycogen levels are low [27, 28]. More recently, the beneficial effects of carbohydrate-containing beverages have been reported in relation to qualities important in soccer, such as shuttle running endurance, sprinting and explosive lower body performances [29–33]. Notably, our research group has identified that a 9.6 % carbohydrate–caffeine–electrolyte ($\sim$6 mg·kg^{-1} body weight caffeine) solution and carbohydrate–electrolyte gels improved mean sprint performance by $\sim$3 % during the Soccer Match Simulation compared with a placebo [30].

Given the established role of selected nutritional interventions (e.g., carbohydrate, fluid and caffeine provision) in attenuating reductions in physical performance, it is not surprising that a growing body of literature is emerging about the role of such strategies for maintenance of skilled performances throughout the full duration of a match [7, 34–40]. To date, a systematic appraisal of literature examining the efficacy of such strategies is lacking. Furthermore, factors which have the potential to modulate the efficacy of nutritional ergogenic aids for the purpose of maintaining soccer skill performances have not been identified. With this in mind, the aim of this review was two-fold: (i) to systematically evaluate and summarise current research that examines the efficacy of nutritional interventions upon soccer skills, and (ii) to provide a qualitative commentary on factors that modulate the efficacy of such strategies.

2 Methods

This review was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [41]. Computerised literature searches were performed in PubMed and SPORTDiscus databases between November 2009 and July 2013. A search strategy incorporating the terms (soccer OR football) AND (carbohydrate OR ergogenic OR supplement OR caffeine OR nutrition OR hydration OR buffer OR citrate OR bicarbonate OR hypohydration OR dehydration OR hyperhydration OR beta alanine OR carnosine OR fluid) AND (skill OR technical OR performance OR shooting OR dribbling OR passing) was performed. Filters activated were: Clinical Trial, Comparative Study, Controlled Clinical Trial, Journal Article, Randomized Controlled Trial, Abstract available, Publication date from 1990/01/01 to 2013/07/01, Humans, English, Adult: 19+ years, Adolescent: 13–18 years. Additionally, studies were sourced from other means that included those previously known to the authors and from checking bibliographies for relevant articles.

2.1 Study Selection

To ensure that the results reflected the aims of this review, articles were sequentially excluded based on the following criteria: (A) articles that did not report outcomes directly relating to skilled performances in soccer, (B) articles that examined the influence of interventions that were not nutritional in origin and/or were nutritional in origin but were provided >3 hours before skill testing commenced, (C) articles that were review papers, and (D) post-acceptance withdrawal of articles from database.

2.2 Quality Assessment

Articles remaining after the application of the exclusion criteria were independently assessed for the quality of the methods employed based upon the Physiotherapy Evidence Database (PEDro) scale. Briefly, the critical appraisal tool for experimental studies contains eight criteria for assessing the internal validity of a study, and two criteria for assessing sufficiency of the statistical information. A single point is allocated when a criterion is achieved; therefore, all trials are scored out of a maximum of 10 points and the tool has previously been found to be reliable [42]. In agreement with previous reviews [43], only studies with a minimum PEDro score of 5 out of 10 were included to improve the credibility of the analyses.

3 Results

In total, 279 records were retrieved from the original search strategy. Following the removal of 102 duplicated records, the remaining 177 records were screened according to predefined exclusion criteria. Based on this screening, 164 records were removed, of which 126 records did not report outcomes directly relating to skilled performances in soccer (exclusion criteria A) whereas 36 records examined the

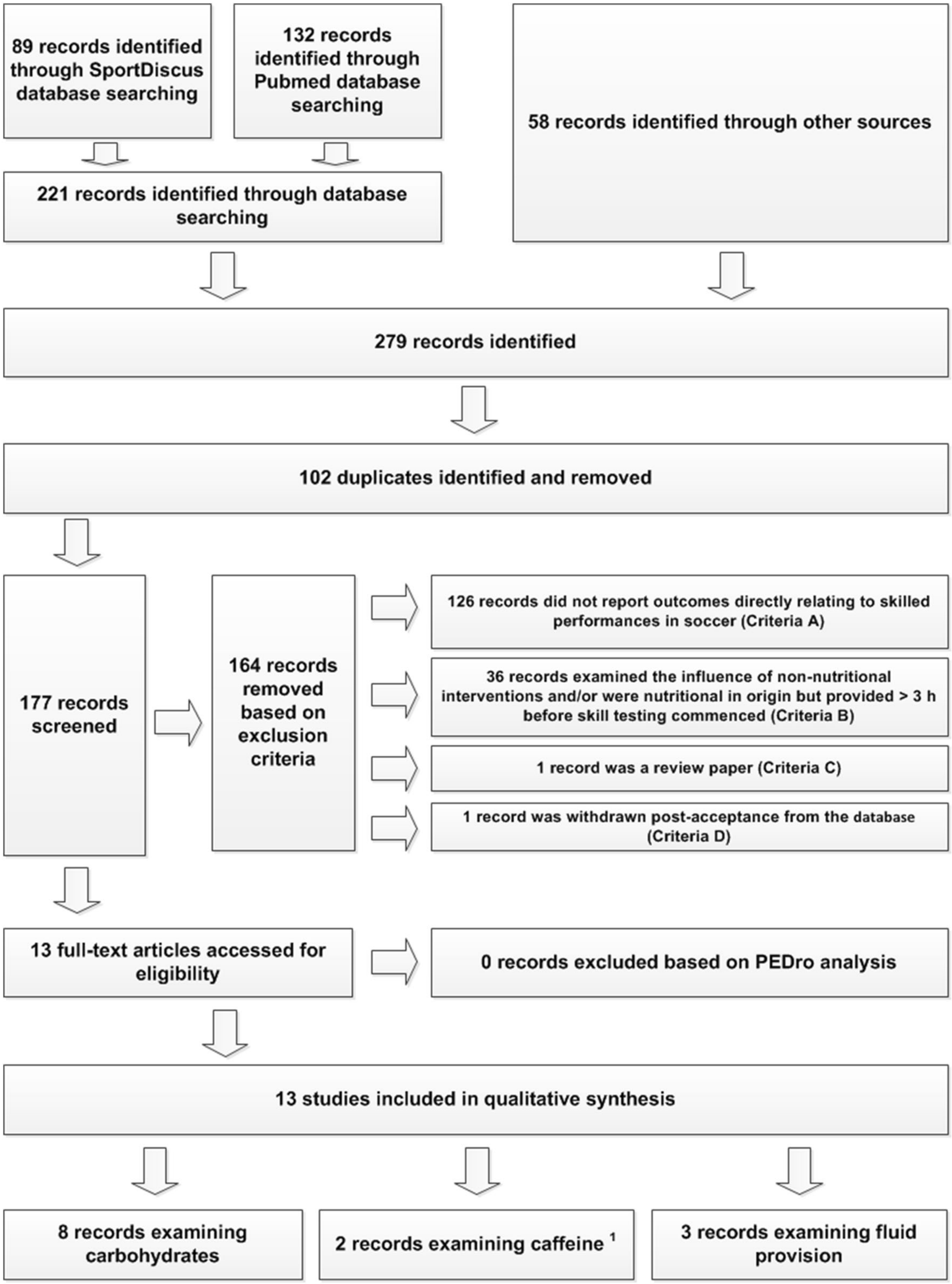

Fig. 1 Selection process for articles included in the systematic review. [1] Includes one paper [38] that reports caffeine co-ingested with carbohydrate

effects of non-nutritional interventions or those which were provided >3 hours before testing (exclusion criteria B). A single record was a review paper (exclusion criteria C) and one article was withdrawn post-acceptance (exclusion criteria D). Therefore, 13 articles were retained and included in the review commentary (Fig. 1).

Table 1 Studies examining the effects of carbohydrates on soccer skill performance included in the systematic review

Study	Players	$VO_{2\ max}$	Standard	Intervention	Mean trial temperature (°C)	Mode of intervention	Exercise	Skill measurement	Results
Zeederberg et al. [44]	11 males	NA	Highest pre-professional South African league	6.9 % glucose polymer-electrolyte or PL in a cross-over design	13.0–15.0	Beverage (swilling not reported)	90-min match	Subjective evaluation of tackling, controlling, passing, dribbling, heading and shooting	No effect of CHO on any skills
Northcott et al. [40]	10 males	NA	College team	8.0 % glucose-polymer or water PL in a cross-over design	NA	Beverage (swilling not reported)	90-min match simulation	Targets of various lengths for passing (10, 20 and 30 m) and shooting (15 m)	CHO ↑ skill proficiency in last 15 min compared with PL
Ostojic and Mazic [48]	22 males	55.2 ml·kg^{-1}·min^{-1}	Professional first Yugoslav league	7.0 % CHO-electrolyte or water PL in an independent groups design	24.5	Beverage (swilling not reported)	90-min match	Timed 18.0 m dribble test	CHO ↑ dribbling performance by 5.0 % compared with PL
Ali et al. [36]	16 males	56.0 ml·kg^{-1}·min^{-1}	Ex-professional and University team	6.4 % CHO-electrolyte or a non-electrolyte PL in a cross-over design	NA	Beverage (swilling not reported)	90-min match simulation	Loughborough Soccer Passing Test and Loughborough Soccer Shooting Test	CHO ↑ shooting performance compared with PL post-exercise. No effect of exercise or CHO on passing
Abbey and Rankin [47]	10 males	50.1 ml·kg^{-1}·min^{-1}	Experienced players	6.0 % CHO-electrolyte, 6.0 % honey-electrolyte or sweetened PL in a cross-over design	NA	Beverage (swilling not reported)	75-min match simulation and PSR	Shooting towards a target 7 m away	No effect of exercise or CHO on shooting
Ali and Williams [35]	17 males	59.0 ml·kg^{-1}·min^{-1}	Ex-professional and University team	6.4 % CHO-electrolyte or a non-electrolyte PL in a cross-over design	NA	Beverage (swilling not reported)	90-min match simulation	Loughborough Soccer Passing Test	CHO tended to ↑ passing performance in last 15 min over PL
Currell et al. [54]	11 males	NA	Recreational standard	7.5 % maltodextrin or PL in a cross-over design	NA	Beverage (swilling not reported)	90-min match simulation	Timed dribbling test, shooting target, and a maximum jump height heading task	CHO ↑ dribbling and shooting performances in each trial. Timing effects were non-significant
Russell et al. [34]	15 males	58.4 ml·kg^{-1}·min^{-1}	Professional academy standard	6.0 % sucrose-electrolyte or a fluid-electrolyte PL in a cross-over design	20.1–20.7	Beverage (swilling not reported)	90-min match simulation	Speed, precision, success and overall index of passing, shooting and dribbling skills	CHO ↑ shooting speed and performance by 10.0 % compared with PL. Exercise influenced speed and performance in shooting in PL

CHO carbohydrate, *NA* not applicable, *PL* placebo, *PSR* progressive shuttle run, $VO_{2\ max}$ maximal oxygen uptake, ↑ improved

Results were presented for a total of 171 participants, 94 % of whom were male, and all but one article reported cross-over, repeated measure study designs. Most participants were highly trained (reported maximal aerobic capacity range 50–59 ml·kg^{-1}·min^{-1}) and were tested in temperate environments (reported temperature range 13–25 °C). Considerable variation existed between studies in the soccer skills assessed (e.g., passing, shooting, dribbling, tackling, controlling and heading) and the method of skill assessment used (e.g., subjective evaluations, criterion-based measures according to the use of targets, and/or outcomes that were continuous in nature). The duration of soccer-specific exercise used in all trials ranged from 75 to 90 min.

3.1 Effect of Carbohydrates on Soccer Skill Performance

Of the 13 articles retained, the majority ($n = 8$) examined the influence of carbohydrates on indices of soccer skill performance. In 112 male players (individual study sample sizes ranging from 10 to 22 players), beverages with a carbohydrate concentration between 6 and 8 % and from a variety of sources (i.e., sucrose, maltodextrin, glucose polymer, honey) were ingested before and during soccer-specific exercise. Carbohydrates were reported to enhance at least one aspect of skilled performance for the majority of studies analysed (Table 1).

3.2 Effect of Caffeine on Soccer Skill Performance

Comparatively fewer studies have focused on the effects of caffeine ($n = 1$), and caffeine co-ingested with carbohydrate ($n = 1$) on technical performances in soccer. In 27 males (study sample sizes ranging from 12 to 15 players), caffeine was ingested in doses of 3.7 and 6.0 mg·kg^{-1} body mass (BM) in beverage and capsule form. Inconsistent effects of caffeine on skill performance have been observed (Table 2).

3.3 Effect of Fluid Provision on Soccer Skill Performance

The effect of fluid provision on soccer skill performance has been investigated in three studies. In 32 players, including 10 females (study sample sizes ranging from 9 to 13 players), fluid consumption (either *ad libitum* or prescribed intake) resulted in inconclusive and inconsistent effects on soccer skill performance (Table 3).

4 Discussion

A key purpose of this review was to systematically evaluate the current body of research that examines the efficacy

Table 2 Studies examining the effects of caffeine on soccer skill performance included in the systematic review

Study	Players	$VO_{2\ max}$	Standard	Intervention	Mean trial temperature (°C)	Mode of intervention	Exercise	Skill measurement	Results
Foskett et al. [37]	12 males	56.0 ml·kg^{-1}·min^{-1}	Premier division standard	6.0 mg·kg^{-1} BM caffeine or PL in a cross-over design	19.3	Capsules	90-min match simulation	Loughborough Soccer Passing Test	Caffeine ↑ passing performance by 4.3 % compared with PL
Gant et al. [38]	15 males	56.0 ml·kg^{-1}·min^{-1}	Premier grade standard	6.0 % CHO-electrolyte + 3.7 mg·kg^{-1} BM caffeine or 6.0 % CHO-electrolyte control in a cross-over design	18.9	Beverage (swilling not reported)	90-min match simulation	Loughborough Soccer Passing Test	No effect of caffeine on passing performance

BM body mass, *CHO* carbohydrate, *PL* placebo, $VO_{2\ max}$ maximal oxygen uptake, ↑ improved

Table 3 Studies examining the effects of fluid provision on soccer skill performance included in the systematic review

Study	Players	$VO_{2\ max}$	Standard	Intervention	Mean trial temperature (°C)	Mode of intervention	Exercise	Skill measurement	Results
McGregor et al. [39]	9 males	59.1 ml·kg^{-1}·min^{-1}	Semi-professional and University standard	No added sugar cordial or no-fluid control in a cross-over design	13.0–20.0	Beverage (swilling not reported)	90-min match simulation	Timed 18.0 m dribble test	Fluid ↑ dribbling performance by 5.0 % compared with PL
Ali et al. [46]	10 females	NA	Premier division standard	3.0 ml·kg^{-1} BM water every 15 min during exercise or no-fluid control in a cross-over design	18.0–20.0	Beverage (swilling not reported)	90-min match simulation	Loughborough Soccer Passing Test	No effect of exercise or fluid on passing performance
Owen et al. [101]	13 males	54 ml·kg^{-1}·min^{-1}	Semi-professional standard	Mineral water consumed *ad libitum*, prescribed according to sweat rate and no-fluid control in a cross-over design	19.4	Beverage (swilling not reported)	90-min match simulation and PSR	Loughborough Soccer Passing Test and Loughborough Soccer Shooting Test	Limited and inconsistent effects on passing and shooting skills

BM body mass, *NA* not applicable, *PL* placebo, *PSR* progressive shuttle run, $VO_{2\ max}$ maximal oxygen uptake, ↑ improved

of nutritional ergogenic aids upon the maintenance of soccer skill performance. Carbohydrate, caffeine and fluid ingestion were specific nutritional interventions that have been investigated by previous authors aiming to preserve the integrity of soccer skills. The ingestion of carbohydrates before and during exercise might assist in the maintenance of soccer skill performance, whereas the evidence is inconclusive for caffeine ingestion and fluid provision. It is probable that factors such as the supplement dose, individual responsiveness, interactions with other physiological changes occurring during soccer-specific exercise and/or individual responsiveness to the nutritional intervention modulate the efficacy of nutritional interventions.

Thirteen studies have examined the efficacy of nutritional interventions for maintenance of skilled performance in soccer (Tables 1, 2, 3). Considerable variation existed in the specific soccer skills assessed (e.g., passing, shooting, dribbling, tackling, controlling and heading) and the method of assessment (e.g., subjective evaluations, criterion-based measures according to the use of targets, and/or outcomes which were continuous in nature). For example, Zeederberg et al. [44] subjectively assessed skills performed throughout actual match-play in order to examine the efficacy of carbohydrate ingestion. A detailed discussion of the suitability of specific methods of skilled performance assessment in soccer is beyond the scope of this paper (interested readers are directed to Russell and Kingsley [45]); however, methods which maintain experimental control and provide outcomes which are easily interpreted by coaches have previously been recommended [45]. Nevertheless, other variables commonly associated with the modulation of physiological responses (e.g., duration of exercise performed, aerobic fitness of players, gender, environmental conditions, etc.) were relatively comparable between studies. Although a single study examined the skilled response to nutritional interventions in female players [46], male players who were highly trained (reported maximal aerobic capacity range: 50–59 ml·kg^{-1}·min^{-1}; Tables 1, 2, 3) completed prolonged durations (minimum duration was 75 min [47]) of soccer-specific exercise in temperate environments (reported temperature range 13–25 °C; Tables 1, 2, 3). The highest mean trial temperature reported was 25 °C [48]. Although such methodological factors have previously been implicated in the technical response to soccer match-play (e.g., differences in aerobic fitness [49–51]), the degree of homogeneity in such characteristics between the studies reviewed here mean that the influence of these factors remains unclear. Consequently, research opportunities exist to examine the influence of exercise duration, aerobic fitness, gender, and environmental conditions on skills performed during soccer-specific exercise.

4.1 Carbohydrates

The acute supplementation of carbohydrate is recommended for improvement of physical performance markers, particularly those relating to exercise endurance (e.g., time to exhaustion [52, 53]). More recent evidence suggests that carbohydrate supplementation is also beneficial for the maintenance of skilled performance throughout exercise (Table 1). For example, consumption of a 6 % carbohydrate–electrolyte solution before and during a simulated soccer match attenuated the 10 % reduction in shot speed observed in players who consumed a fluid-electrolyte placebo beverage [34]. Furthermore, an 8 % glucose polymer solution ingested before and during 90 min of intermittent exercise attenuated the incidence of hypoglycaemia and also negated the drop in shooting and passing accuracy observed in the last 15 min of a placebo trial [40]. Similarly, a 7.5 % maltodextrin beverage ingested before and during soccer-specific exercise has been reported to improve overall dribbling and shooting performance [54].

Although mechanisms remain unclear, it is plausible that decision-making processes and the performance of the skills executed during a soccer match are influenced by blood glucose concentrations [34] as the brain is primarily dependent on blood glucose for maintenance of optimal functioning [55]. The influence of acute carbohydrate supplementation strategies on glycaemic responses and technical performances in soccer players have been reviewed previously [45, 56]; however, limited consideration has been given to factors which modulate the efficacy of this specific type of ergogenic aid when technical as opposed to physical indices of performance are examined. Here we examine the role of the dose consumed, transient changes in blood glucose concentrations and the mode of administration in modulating the efficacy of carbohydrates consumed during exercise for the purpose of maintaining skilled performance.

4.1.1 The Dose of Carbohydrate Consumed

In agreement with recommendations about fluid consumption during exercise [52, 57, 58], the studies examined in this review utilised beverages with a carbohydrate content of between 6 and 8 %. Such recommendations have primarily been based on the findings from studies that have employed continuous exercise protocols and that have focused on water absorption as a priority. Notwithstanding the potential ergolytic effects attributable to gastric distress resulting from higher doses of carbohydrate consumed during intermittent exercise (for a review see Coyle [53]), the dose–response relationship that has previously been observed in the non-exercise setting between carbohydrate provision and cognitive function [59] suggests that it remains to be determined whether the current carbohydrate intake recommendations are optimal for preservation of technical performances in soccer players that require cognitive input.

Based upon the recommendations of previous authors [32, 40], it has been proposed that to improve motor skill performance, exogenous carbohydrate supply must exceed a rate of 50 $g{\cdot}h^{-1}$ [35]. However, ingestion of 52 $g{\cdot}h^{-1}$ of carbohydrates yielded no benefit to Loughborough Soccer Passing Test (LSPT) performance in fasted and previously glycogen-depleted participants [35]. It seems that the efficacy of carbohydrate provision during soccer-specific exercise can be influenced by the type of skill being performed. For example, when passing was assessed before and after exercise and carbohydrates were supplied at a rate of 30 $g{\cdot}h^{-1}$, ergogenic effects were absent for passing performances despite the same dose of carbohydrate enhancing the mean points scored in a post-exercise criterion-based shooting assessment compared with a non-electrolyte placebo beverage [36].

Similarly, 59 $g{\cdot}h^{-1}$ of carbohydrate has shown differential effects upon the post-exercise performances of shooting, passing and dribbling skills when ingested before and during soccer-specific exercise [34]. Given the array of skilled actions performed during soccer match-play and the varied response to carbohydrate supplementation relating to passing, shooting and dribbling skills [45], it remains to be determined whether the doses of carbohydrate examined previously were optimal when seeking to maintain the quality of all skills performed under conditions of soccer-specific fatigue.

Limited data currently exists about the effects of providing additional carbohydrates (>8 % solutions) when intermittent, as opposed to continuous, exercise is performed. This is somewhat surprising given that ingestion of a 20 % glucose solution has been reported to enhance sprint capacity after 90 min of intermittent cycling [60]. Notably, despite higher ratings of gastric discomfort and increases in plasma osmolality occurring post-exercise, elevated blood glucose concentrations have been observed from 75 min onwards when a 9.6 % carbohydrate–electrolyte drink was consumed before and during (including at half-time) soccer-specific exercise [30]. Moreover, differences in the glycaemic response in the final 15 min of exercise were apparent despite blood glucose concentrations at 60 min ($\sim$4.0 $mmol{\cdot}l^{-1}$) being similar to a placebo [30]. It is, therefore, plausible that the efficacy of exogenous carbohydrate ingestion is transient in nature and interactions with other physiological changes occurring during soccer-specific exercise may modulate the efficacy of this intervention.

4.1.2 Transient Changes in Blood Glucose Concentrations Throughout Exercise

It has generally been suggested that blood glucose concentrations are better maintained in the latter stages of exercise when carbohydrates are consumed [23, 53, 61]. Consequently, soccer players are often encouraged to ingest carbohydrates throughout exercise in an effort to spare muscle glycogen and maintain blood glucose concentrations. However, consistent observations from our research group have indicated that the elevated blood glucose concentrations observed during the first half of soccer-specific exercise are negated in the early stages of the subsequent exercise period when studies have employed a regular fluid ingestion strategy and passive half-time practices [4, 30, 34, 62]. Although we attributed the identification of this response to the regularity of blood samples taken [4], such data supports the preliminary findings of Bangsbo et al. [63]. Notably, it has been observed that reductions in physical performance markers occur throughout the initial stages of the second half of soccer match-play when compared with the opening phase of a game [16, 17]. Although studies examining half-time practices have primarily focused on temperature-related interventions [64–66], it is plausible that altered glycaemic status might influence both physical and technical responses at the start of the second half.

While acknowledging the individual nature of blood glucose responses to carbohydrates ingested during exercise [67], blood glucose concentrations of <3.0 mmol·l^{-1} have been reported in soccer players [62]. As reviewed by Warren and Frier [68], almost immediate reductions in cognitive performance have been observed in healthy non-exercising participants when plasma glucose concentrations were 3.0 mmol·l^{-1} or less. Moreover, given the complex nature of the skilled performances associated with soccer match-play [3] and the increased susceptibility of complex versus simple tasks to hypoglycaemia [68], it is plausible that transient reductions in blood glucose concentrations could negate the ergogenic effects associated with carbohydrate ingestion that have previously been observed in soccer skill performances [34, 36]. That said, the quality of passing performance remained unchanged when assessed at the onset of the second half when blood glucose concentrations were reduced to $\sim$30 % of values observed at half-time [34]. Although the average blood glucose concentrations of this group of players remained above 3.5 mmol·l^{-1}, a threshold which has been used to define rebound hypoglycaemia [69], the effect of rapidly reducing blood glucose concentrations is unclear as there is currently no evidence of skill impairment with hypoglycaemia.

The effects on performance that might be associated with transient reductions in blood glucose concentrations during soccer match-play remain unclear, as the influence of rebound hypoglycaemia has primarily been investigated from a physical perspective (e.g., time-trial performance [67, 70]). As the glycaemic response to a subsequent bout of exercise appears to be independent of carbohydrate dose [71, 72], and the rebound hypoglycaemic response appears to decay within the initial stages of exercise when high glycaemic index carbohydrates are consumed [60, 67], the provision of additional carbohydrates may afford ergogenic effects for technical actions performed in the latter stages of a match. However, as mentioned previously, the efficacy of carbohydrate ingestion might differ according to the skill being performed.

4.1.3 The Mode of Administration of Carbohydrate

All studies that focused on carbohydrate provision evaluated in this review provided the treatment intervention in beverage form before and during exercise. However, absorption of carbohydrate by the lower gastrointestinal tract is not always required to elicit ergogenic effects as carbohydrate mouth swilling, without subsequent ingestion, has been found to improve moderate- to high-intensity exercise performance [73]. For example, in a time trial lasting approximately 1 hour, Carter et al. [74] observed improved performance when a 6.4 % carbohydrate solution was swilled around the mouth compared with a water placebo. Similarly, a 6 % glucose solution swilled around the mouth prior to exercise facilitated peak power output during the initial stages of a repeated sprint test [75]. Therefore, given the individual nature of tolerance to drinking during exercise, carbohydrate mouth swilling may offer an alternative strategy to those players who are reluctant to drink due to concerns surrounding gastrointestinal distress.

Ergogenic responses to carbohydrate mouth swilling have been attributed to the excitation of reward and motor control centres in the brain [76] and an increased excitability of the corticomotor pathways [77] via oral receptors. Similarly, the presence of carbohydrate in the mouth can positively influence the perception of effort during exercise (for a review see references [73, 78]); however, specific factors, including the duration of pre-exercise fasting, mouth-rinse protocol employed, type of exercise performed, and concentrations of muscle and liver glycogen before exercise have been proposed to modulate this response [73]. Although mouth swilling was not reported before subsequent ingestion in any of the studies analysed in this review, the similarities in beverage composition reported in mouth swilling research (i.e., 6–8 % carbohydrate content), suggests that the presence of carbohydrate in the mouth may facilitate ergogenic effects in soccer players over the course of a match. However, specific research examining the skilled response to such interventions is currently lacking.

It also appears that the ergogenic potential of carbohydrates is not solely limited to studies where carbohydrates have been provided immediately before (i.e., <3 h) the start of exercise. Very few studies have examined the effects of a more prolonged period of increased carbohydrate intake before subsequent skill performance assessment. However, where players consumed water before and throughout match-play, Souglis et al. [79] have recently observed more favourable score lines when soccer players were fed a high carbohydrate (8 $g{\cdot}kg^{-1}$ BM) diet for 3.5 days before a match when compared with a low carbohydrate (3 $g{\cdot}kg^{-1}$ BM) diet. These findings, which do not support those of Abt et al. [80] who observed no benefit of a high carbohydrate diet (8 $g{\cdot}kg^{-1}$ BM for 48 h) on shooting and dribbling performance, should be interpreted with caution due to inherent variability in the external factors that influence match-play. Nevertheless, the improved score line observed by Souglis et al. [79] was supported by more distance being covered at varying thresholds of intensity following the high carbohydrate diet. Given the discrepancy between estimated energy intake and expenditure observed in soccer players during the competitive season [81], increasing dietary carbohydrate in the days before a match may also prove beneficial for energy balance as well as skilled performances.

4.2 Caffeine

Caffeine, a substance which is not prohibited for use in sport (according to the World Anti-Doping Agency at the time of publication), is a central nervous system stimulant that has consistently been reported to moderate concentration, cognitive function, decision making and reaction time during non-sports-related tasks [82–84]. Given the importance of mental processes in soccer, it has also been proposed that the beneficial effects of caffeine for team-sport athletes might relate to the attenuation of fatigue-related decrements in skilled performances, concentration or cognitive function as opposed to enhanced endurance capacity [37]. Despite the volume of literature that has examined the efficacy of this central nervous system stimulant upon non-sports-related tasks (for a review see Glade [85]), fewer studies have implemented performance assessments which demonstrate greater specificity to the athletic population, especially in soccer. Our search identified two studies, with inconsistent results, which have investigated the ergogenic effects of caffeine on soccer skill performance. The lack of agreement in these studies might reflect methodological differences relating to the dose of caffeine consumed, the mode of administration and/or individual responsiveness to caffeine administration.

4.2.1 The Dose of Caffeine Consumed

Ingesting 6 $mg{\cdot}kg^{-1}$ BM of caffeine in capsule form 60 min prior to exercise has been reported to reduce the penalty time accrued during the LSPT in male soccer players; a finding attributed to an increase in passing accuracy [37]. Although it is important to acknowledge the limitations of some soccer skills tests used in research (e.g., use of criterion-based outcomes; for a review see Russell and Kingsley [45]), this study is one of the very few that has attempted to establish the efficacy of caffeine upon soccer skills using methods which are more applicable to athletic performance compared with those that have implemented non-sports-specific tasks. These data support previous observations that 6 $mg{\cdot}kg^{-1}$ BM dose of caffeine, administered in capsule form, improved the mean performance of rugby passes made over the duration of a simulated match when performed in both fatigued and non-fatigued states [86]. Overall, caffeine enhanced pass success rates from 83 % in the placebo trial to 90 % in the caffeine condition.

Conversely, when a lower dose of caffeine (3.7 $mg{\cdot}kg^{-1}$ BM) was consumed in solution with carbohydrate (1.8 $g{\cdot}kg^{-1}$ BM), the ergogenic effects on the quality of passes performed by soccer players during high-intensity exercise were absent [38]. Although the lack of a placebo trial that was void of both carbohydrate and caffeine precludes comparison to a stimulant and energy-free beverage, it is possible that the dose of caffeine was insufficient to produce an additional ergogenic effect when compared with the acute ingestion of carbohydrate alone [36].

4.2.2 The Mode of Caffeine Administration

It has been proposed that the efficacy of drug administration is related to its speed of absorption [87]. While acknowledging the influence of the fed or fasted state on caffeine absorption rate [88], peak systemic concentrations of caffeine and/or its metabolites are generally realised within 1–3 hours of ingestion when the mechanisms of action are reliant upon absorption via the lower gastrointestinal tract. Notably, the effects associated with the chewing of caffeinated gums have included significantly faster absorption times when compared with traditional pill-based administration [89] and the effects of caffeine have also been attributed to the antagonism of receptors in the upper gastrointestinal tract facilitating a central modulation of motor unit activity and adenosine receptor stimulation [90].

When ergogenic effects of caffeine have been attributed to mechanisms in the upper gastrointestinal tract, enhanced mood and memory have been observed in non-sports-related tasks [91] and improved indices of physical performance also occur [75, 92]. For example, the addition of caffeine to a carbohydrate solution has been reported to increase the mean power of the first and fifth sprints of a six-sprint repeated cycling protocol when compared with the swilling of a carbohydrate-only solution [75]. However, to date, no study has investigated the effects of these novel methods of caffeine administration upon the performance of soccer skills. Therefore, it appears that the ergogenic effects of caffeine can occur despite the lack of absorption in the gut and although promising, the performance effects of such strategies remain to be established when technical as opposed to physical actions are performed by soccer players.

4.2.3 *Individual Responsiveness to Caffeine*

Considerable inter-individual variation has been reported in the performance responses elicited following caffeine ingestion [93–95]. As such, categorising participants as either being 'responders' or 'non-responders' when studying the effects of caffeine that has been absorbed by the lower gastrointestinal tract is not uncommon [96]. Although the mechanisms of caffeine are likely to be multifaceted in origin, it has been proposed that individuality in the response to caffeine might be attributable to pharmacokinetic, pharmacodynamic, demographic and/or environmental factors [97]. More recently, genetics have been proposed to play a role in determining the individual responsiveness to caffeine ingestion [98].

The main effects of caffeine are due to competitive inhibition of adenosine receptors, mainly A1 and A2A receptors [99]. Variation of the adenosine A2A receptor gene (*ADORA2A*) has been reported to modulate habitual caffeine consumption and psychomotor vigilance in rested and sleep-deprived states [98]. Given such findings, and also the cognitive component of soccer skill performance, it is plausible that the individualised nature of the caffeine response attributable to genetic variation can also influence the efficacy of this central nervous system stimulant on the performance of soccer skills. However, the genetic influence of caffeine responsiveness on exercise and skilled performance remains to be elucidated and thus presents future research opportunities.

4.3 Fluid Provision

Despite acknowledging the difficulties of separating the effects of elevated core temperature and reductions in hydration status, a number of studies have consistently identified that a reduction in hydration status impairs performance when actions requiring strength, power and anaerobic endurance are executed [100]. However, when considering the quality of performance of soccer skills, the evidence is less clear. For example, despite a lack of change in plasma volume, Ali et al. [36] observed reductions in post-exercise shooting performance when participants who started exercise in a fasted and energy-depleted state drank a beverage that did not replace fuel or electrolytes during a continuous 90-min exercise test. Similarly, soccer dribbling performance has been observed to decline by 5 % when players abstained from fluid ingestion during 90 min of exercise [39], but the same duration of intermittent exercise, which induced modest dehydration effects, had a limited and inconsistent influence on soccer skills performed in temperate environments [101].

Although the application of these findings are limited by the unrealistic nature of pre-exercise practices of the participants (i.e., fasted and previously glycogen depleted), and the fluid-intake regimens used during exercise (i.e., current recommendations advocate consumption of 150–300 ml of a carbohydrate–electrolyte beverage every 15 min during exercise lasting longer than 60 min when weight loss is not desired [102]), such studies do provide an important insight into the effects of dehydration upon technical performances in soccer players.

5 Conclusions

Despite the majority of ergogenic strategies employed by soccer players focusing primarily upon improving the physical components of match-play (i.e., high-intensity exercise performance and endurance capacity), the administration of selected nutritional interventions such as carbohydrates, caffeine and fluid can offset fatigue-induced declines in soccer skill performance.

The weight of evidence supports the use of beverages containing between 6 and 8 % carbohydrates (from a variety of sources including glucose, sucrose and maltodextrin) ingested before and during intermittent exercise at rates of 30–60 $g \cdot h^{-1}$. The utilization of mouth rinsing prior to carbohydrate consumption, and modification of dietary carbohydrate intake should also be considered. Although future research should seek to provide further evidence, the consumption of caffeine (6 $mg \cdot kg^{-1}$ BM) may also elicit ergogenic effects. Evidence from studies investigating the effects of fluid abstinence on soccer skill performance also suggests that prescribing fluid intake might be warranted.

Additionally, this review highlights that the efficacy of nutritional interventions might be modulated by specific factors, including the skill being performed, the dose of the substance consumed, the mode of administration, the effect of other physiological changes occurring during soccer-specific exercise and individual responsiveness to the intervention. Consequently, such factors should be considered by practitioners and researchers when seeking to influence the performance of soccer skills throughout exercise. Specific evidence should be sought to determine if factors known to modulate physiological responses in other domains of sports science research (e.g., duration of exercise performed, gender, aerobic fitness of participants, environmental factors, etc.) might influence the effects of nutritional interventions on soccer skills performed throughout exercise.

This review has several limitations. Firstly, the included studies used a variety of methods and outcome measures to assess performance relating to a range of soccer skills; consequently, it was not possible to calculate pooled statistics associated with a quantitative meta-analysis. Additionally, given the differential response of soccer skills to selected nutritional interventions [36], it is plausible that our recommendations apply only to the specific skills examined. Nevertheless, this systematic review is the first to examine the efficacy of nutritional interventions on soccer skill performance and thus provides a benchmark for future studies.

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