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REVIEW ARTICLE

Half-Time Strategies to Enhance Second-Half Performance in Team-Sports Players: A Review and Recommendations

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Abstract A number of intermittent team sports require that two consecutive periods of play (lasting for ~30–45 min) are separated by a 10–20 min half-time break. The half-time practices employed by team-sports players generally include returning to the changing rooms, temporarily relaxing from the cognitive and physical demands of the first half, rehydration and re-fuelling strategies, addressing injury or equipment concerns, and receiving tactical instruction and coach feedback. However, the typically passive nature of these actions has been associated with physiological changes that impair performance during the second half. Both physical and cognitive performances have been found to decline in the initial stages of subsequent exercise that follows half-time. An increased risk of injury has also been observed during this period. Therefore, half-time provides sports scientists and strength and conditioning coaches with an opportunity to optimise second-half performance. An overview of strategies thought to benefit team-sports athletes is presented; specifically, the efficacy of heat maintenance strategies (including passive and active methods), post-activation potentiation, hormonal priming, and modified hydro-nutritional practices are discussed. A theoretical model of applying these strategies in a manner that compliments current practice is also offered.

Key Points

- Passive half-time practices impair performance in the initial stages of the second half of team-sports competition.
- The efficacy of heat maintenance strategies, post-activation potentiation, hormonal priming, and modified hydro-nutritional practices have been shown in isolated studies.

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1 Introduction

A number of intermittent team sports, such as Association football (soccer), rugby league and union, Gaelic sports (e.g. Gaelic football and hurling), team handball, field hockey and Australian rules football are played over consecutive periods (normally 30–45 min durations) that are separated by a temporary pause in play at the mid-way point; a period known as half-time which is 10–20 min long. While the regulations of the various sports dictate the practices that can be performed during half-time, empirical observations highlight that players primarily aim to relax mentally from the cognitive and physical demands of the first half of match-play, rehydrate and re-fuel, attend to injury or equipment concerns, engage in personal reflection, and receive tactical instruction and coach feedback in preparation for the second half. Indeed, Towlson et al. [1] reported that soccer players primarily return to the dressing room to engage in tactical discussion, receive medical treatment and consume nutritional ergogenic aids during the half-time break.

However, during the initial stages of the second half, numerous authors have reported that reductions in key aspects of team-sport performance occur. For example, Mohr et al. [2] showed that as many as 20 % of elite soccer players have their least intense 15-min period in a match during the initial part of the second half. Weston et al. [3] also highlighted that selected physical performance markers of soccer players and referees decreased between 45 and 60 min when compared with the first 15 min of soccer match-play. In respect to cognitive performance, as very often success in team sports is determined by the proficiency of skilled actions, the increase in response accuracy observed during the first 30 min of intermittent exercise was attenuated upon restarting exercise after half-time [4]. It therefore appears that half-time practices influence subsequent performance during the initial stages of the second half, a statement supported by intervention studies that have demonstrated that attenuated losses in body temperature lead to favourable responses in isolated performance tests and game-related activities [5, 6].

A significant increase in injury risk has also been reported in the first 20 min of the second half [7]. Analysis of ten Premier League soccer matches has highlighted that of the injuries occurring in the second half, the greatest number of actions causing injury were elicited in the first 15 min of this period [8]. Additionally, Ekstrand et al. [9] have reported that the incidence of soccer-match injuries show an increasing tendency over time in both the first and second halves. Interestingly, the perception of increased injury risk immediately after the half-time break is also shared by practitioners involved in the delivery of half-time activities for soccer players [1].

Factors contributing to increased injury risk are likely multifaceted; however, Greig [10] reported that while the concentric strength of both the knee extensors and flexors was maintained throughout 90 min of intermittent treadmill running, a speed-dependent fatigue effect observed in indices of eccentric hamstring strength did not normalise during a passive half-time period. Specifically, when using isokinetic dynamometry, eccentric peak torque measurements taken after half-time were reduced when compared with the start of the recovery period, a finding that was statistically significant at higher movement speeds. As a result, the authors postulated that susceptibility to muscular strain injury is likely to increase during explosive ballistic actions, such as those requiring high levels of acceleration and deceleration. Notably, the number of deceleration efforts performed in the first 15 min of the second half of soccer match-play is lower than that observed during the opening phase of a match [11].

Evidence from studies that have employed passive half-time practices further highlight the subsequent impairments of performance capacities observed throughout the second half [3, 5, 6, 12–14]. Consequently, the physiological changes relating to muscle (T_m) and core (T_{core}) temperature [6, 13–16], acid-base balance [17] and glycaemic response [18–20] which arise from passive periods comparable in length to those observed during half-time (i.e. ~15 min) may therefore contribute to a reduction in play performance in the first part of the second half. Notably, Krustrup et al. [21] observed a ~1.3 °C reduction in quadriceps T_m during half-time in assistant soccer referees. Although a desire to enforce tactical superiority [22] and residual ergogenic effects resulting from the warm-up [23] have been cited to artificially elevate the pace of play in the initial stages of a match and thus influence subsequent comparisons to observations made during this interval [12], transient reductions in performance during the initial stages of the second half have been confirmed using a more robust statistical approach (i.e. when variables are expressed in relative and thus comparable terms: m·min^{-1}) [12]. It is therefore clear that half-time provides an additional opportunity on the day of competition to optimise performance during the second half.

However, as time pressures, cooperation of the coach/manager and concerns over impairing a player's psychological preparations have been cited as barriers to the use of specific ergogenic strategies during the half-time period [1], it is clear that any modification to half-time protocols must complement current practice. The time-course of activities performed during a typical half-time period is outlined in Fig. 1. Although likely to vary between different sports and according to individual team practices, Towlson et al. [1] reported that ~2 min of the soccer half-time period consists of player's making their way back to the changing rooms. Thereafter, although tactical debriefing and medical and nutritional practices occupy the most time (~5 min), personal preparation, addressing playing kit/equipment concerns, receiving video feedback and engaging in player/coach interactions also occur during this break in play. Additionally, a ~3-min period of re-warm-up activities that are performed either on the pitch or within the stadia may precede the second half of soccer match-play [1].

In summary, although often considered crucial for primarily tactical reasons, physiologically, half-time can be viewed as a recovery period following the previous bout of match-play, a preparatory period preceding subsequent competition, or a period of transition between the two

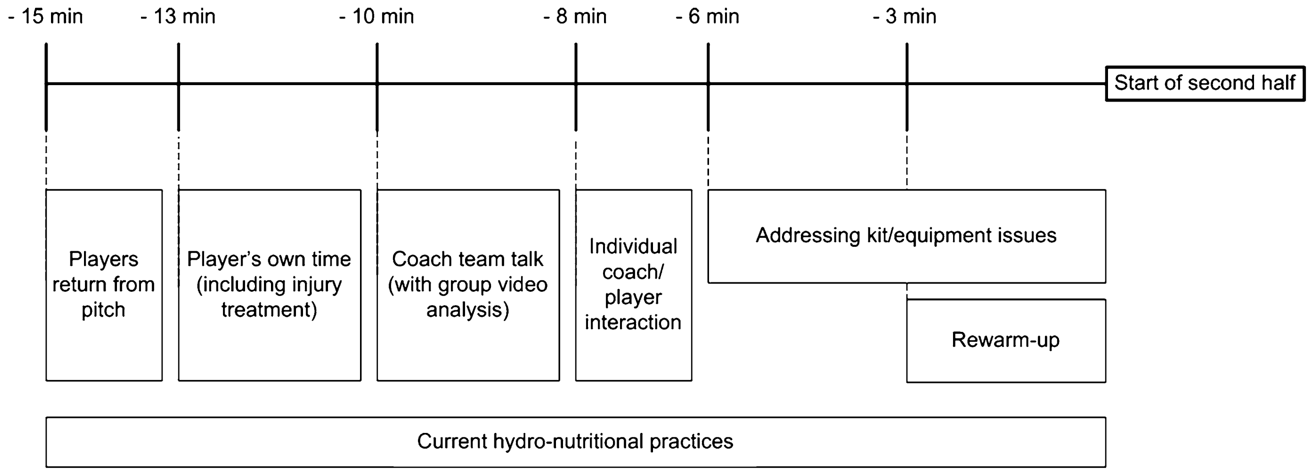

Fig. 1 Current model of strategies employed during a typical 15-min half-time period

halves [24]. Given the transient changes in physical and cognitive performance that have been found to occur following the half-time break [2–4, 6, 12, 14], and the evidence which suggests that the perception [1], and incidence [7, 8], of injury risk is elevated in the initial stages of the second half, half-time provides an additional opportunity on the day of a match to influence subsequent competitive performance. Therefore, the purpose of this review was twofold: (1) to present an overview of the literature examining practices that may have application to the half-time strategies of players involved in team sports; and (2) to provide a theoretical model of application of such strategies in the context of current practice. Computerised literature searches were performed in the PubMed, Google Scholar and SPORTDiscus databases between May 2014 and November 2014. The following keywords were used in different combinations: 'half time', 'recovery', 'soccer', 'football', 'rugby', 'handball', 'Gaelic', 'hockey', 'potentiation', 'performance', 'hydration', 'carbohydrate', 'caffeine', 'priming', 'heat maintenance', 're-warm up', 'warm up', 'testosterone'. All titles were scanned and relevant articles were retrieved for review. In addition, the reference lists from both original and review articles retrieved were also reviewed and relevant publications known to the authors were also obtained.

2 Half-Time Strategies to Enhance Second-Half Performance in Team-Sports Players

2.1 Heat Maintenance Strategies

Nearly every athletic competition is preceded by a warm-up. Typically, varying intensities of exercise, dynamic stretching and technical practice are performed so that preparedness for subsequent activity is optimised. While the ergogenic effects of the warm-up have been proposed to relate to non-temperature-related mechanisms (e.g. elevated baseline oxygen consumption, post-activation potentiation [PAP], increased mental preparedness, etc. [25, 26]), previous research also highlights the role of T_m on performance.

Notably, Mohr et al. [6] observed initial elevations of both T_m and T_{core} during the first half of a soccer match; however, during a passive half-time period both T_m and T_{core} dropped in excess of 1 °C. Sargeant [27] highlighted the importance of changes in T_m on subsequent performance by demonstrating that every 1 °C reduction in T_m corresponded to a 3 % reduction in lower-body power output. Moreover, findings from studies reporting attenuated losses of T_m and concomitant protection of physical performance in team-sports players following an active re-warm-up [5, 6, 13] further substantiate the importance of attenuating body temperature losses during half-time.

However, despite an acknowledgement that attenuating losses in body temperature impact positively on subsequent exercise performance, intermittent sports players do not frequently use active re-warm up strategies in the applied setting [1]. Indeed, despite periods of warm-up preceding the first half of competition, only 58 % of practitioners questioned have reported performing re-warm-up activities before the second half, a finding that may be attributed to the limited time (~3 min) available for such activities [1]. Furthermore, a lack of co-operation from the coach/manager and a perceived negative impact upon the psychological preparations of players have also been proposed as barriers to explain the inconsistent use of an active re-warm-up during the half-time period. Additionally, in sports such as rugby where the number of collisions is high, considerable time may also be required for provision of medical attention at half-time. Therefore, half-time practices that are easily administered and which attenuate temperature loss and thus protect the temperature-related mechanisms that aid subsequent performance warrant further investigation.

2.1.1 Passive Heat Maintenance Strategies

The use of specific methods (e.g. heated clothing, outdoor survival jackets, and heating pads) which seek to attenuate body temperature loss is known as passive heat maintenance [28]. Such strategies are easily applied to the desired muscle groups to maintain T_m, and thus the temperature-mediated pathways that aid performance [15]. For example, repeated sprint performance and lower-body peak power outputs were greater than observed in a control trial when professional rugby union players wore a survival garment during the post-warm-up recovery period [15]. Furthermore, the decline in lower-body peak power output observed post-warm-up was significantly associated ($r = 0.71$) with the decline in T_{core} [15].

In professional rugby union players who wore a survival jacket during a simulated half-time period, muted losses of T_{core} (-0.74 ± 0.08 % vs. -1.54 ± 0.06 %) throughout the 15-min period were observed versus a passive condition [16]. The drop in T_{core} over the simulated half-time was significantly associated with reduced peak power output at the start of subsequent exercise ($r = 0.63$). In support of previous authors [28, 29], we proposed that the preservation of temperature-mediated pathways contributed to the improved physical performances observed after the half-time break.

Maintenance of T_m during the half-time period is therefore likely to attenuate decrements in subsequent performance, especially during the initial stages of successive exercise. Passive heat maintenance offers an effective and practical method for preserving body temperature, which helps to combat the decrements in performance that may occur through the loss of T_m. However, further research into strategies that seek to attenuate losses in body temperature and that have application to team-sports players is warranted. Although encouraging players to wear specific garments is recommended and has proven beneficial [15, 16, 29], some players (e.g. those receiving injury treatments) may find this strategy restrictive when such clothing is worn during half-time. Other methods of maintaining body temperature during the half-time break should therefore be considered; speculatively, the effects of increased changing-room temperatures (within tolerable limits) may confer performance advantages during subsequent exercise. However, it is likely that modified hydration strategies are required if such protocols are administered so that the potential ergolytic effects resulting from impaired hydration status are minimised.

2.1.2 Active Heat Maintenance Strategies (Half-Time Re-Warm-Up)

Moderate-intensity running commencing after 7 min of a half-time recovery period has been found to attenuate a 1.5 °C reduction in T_m and protect the 2.4 % decrements in mean sprint performance observed under passive control conditions [6]. Moreover, the half-time decrease in T_m was correlated to the reduction in sprint performance observed over half-time ($r = 0.60$). Edholm et al. [5] reported similar magnitudes of sprint performance maintenance and attenuated losses in jump performance following a low-intensity half-time re-warm-up. Additionally, intermittent agility exercise, whole-body vibration, small-sided games and lower-body resistance exercises performed during half-time have been found to be beneficial [13, 30].

Active re-warm-ups may also benefit skilled, as well as physical, performances executed in the second half. For example, 7 min of low-/moderate-intensity activity and light calisthenics performed towards the end of half-time improved performance during an actual match as less defensive high-intensity running and more ball possession was observed in the second half [5]. In support of the findings of Edholm et al. [5], skilled performance during an isolated technical assessment has also been reported to be maintained when small-sided games incorporating skilled actions are performed during a simulated half-time break [30]. However, while active re-warm-ups appear beneficial, consideration must be given to the duration of the activities performed in the context of applied practice.

2.2 Post-Activation Potentiation

The ability of a muscle group to produce force can be influenced by the previous contractive history of the same muscle group [31]. The mechanisms of this transient improvement in physical performance are suggested to relate to enhanced motor neuron recruitment, a more favourable central input to the motor neuron and/or an enhanced Ca^{2+} sensitivity of actin–myosin myofilaments [32]. Despite a large body of evidence supporting the ergogenic effects of a preload stimulus [33], not all studies have demonstrated performance improvements as a number of factors modulate the PAP response (e.g. the strength of the participant, volume and type of the preload stimulus, and the duration of recovery between the preload stimulus and subsequent activity) [32]. When considering the potential application of PAP during the half-time period of team sports, the type of activities performed and the timing of the preload stimulus are likely to be of primary interest.

2.2.1 Timing between the Preload Stimulus and Subsequent Activity

Improved physical performance attributable to PAP following a preload stimulus is a function of both muscle fatigue and potentiation that simultaneously co-exist. Optimised recovery between the preload stimulus and the subsequent exercise therefore favours an acute enhancement of subsequent performance as the effects of potentiation persist for longer than the effects of fatigue [34]. Additionally, the time demands associated with established half-time practices (Fig. 1) are likely to influence the decision of whether to recommend performing a preload stimulus to team-sports players.

Between 0 and 24 min has previously been reported to separate the conditioning exercise and the subsequent explosive activity. Power output, peak rate of force development and countermovement jump height were significantly elevated above baseline values at 8 min of recovery for the majority (i.e. 70 %) of professional rugby players who performed repeated assessments (i.e. baseline, ~15 s and every 4 min) of explosive activity in the 24 min following a preload stimulus (i.e. three sets of three repetitions at 87 % 1-repetition maximum [1RM] squat) [31], a finding that has since been confirmed [33]. From a practical perspective, the transient nature of the PAP response means that the benefit to performance may be limited to the initial stages of a player's involvement in subsequent competition. However, this is the period whereby decrements in performance attributable to passive practices have been shown to be at their greatest [16].

From studies where heavy-resistance exercise has been used to induce PAP, explosive lower-body power production is consistently compromised immediately after the preload stimulus [33]. Therefore, should practitioners consider the use of PAP during half-time, the preload stimulus should be timed relative to the start of match-play in order to minimise the effects that a transient reduction in performance may have upon subsequent competition.

2.2.2 Type of Preload Stimulus Performed

Heavy (i.e. 75–95 % 1RM) resistance exercise has been used as the preload stimulus in the majority of studies examining the PAP phenomenon [33]. However, at half-time this approach may not be feasible as issues relating to access to facilities at away venues has previously been reported [1]. Methods of stimulating PAP that have less equipment demands and/or may be better tolerated by players and coaches on the day of competition provide attractive alternatives. Notably, ballistic activities such as weighted jumps are associated with the preferential recruitment of type 2 motor units [35], and may therefore be utilised as a PAP stimulus. Furthermore, plyometric exercise has also been found to potentiate sprint performance [36].

Using jumps performed against a resistance of 2 % body mass (via a weighted vest) that were incorporated into a dynamic warm-up, improved jumping performance has subsequently been observed in the following 2 min [37]. Similarly, Chen et al. [38] reported improvements in countermovement jump height following multiple sets of depth jumps. Turner et al. [36] recently reported that ~75 s of alternate-leg bounding performed with (+10 % body mass) and without (body mass only) a weighted vest, potentiated subsequent sprint performance when compared with a control trial. Notably, a greater enhancement of sprint performance was observed in the body mass plus 10 % trial when compared with the body mass only trial, and this increase was related to the baseline speed of participants.

Practitioners may therefore wish to recommend plyometric activities during the final stages of half-time to enhance subsequent performance. Notably, the shorter durations of PAP-inducing exercise are likely to be better tolerated when compared with those typically used in active re-warm-up studies (~7 min). However, consideration should also be given to the fact that a transient reduction in performance is commonly observed in the immediate period (i.e. <3 min) following the preload stimulus [33] and that the effects of PAP as a specific half-time strategy have not been directly examined.

2.3 Hormonal Priming

High-intensity exercise can promote rapid changes in the hormonal milieu postulated to benefit subsequent exercise performance [39, 40]. Indeed, in a workout performed 2 min after a short-duration (~40 s) maximal exercise bout that elevated salivary testosterone concentrations, improved strength performance was observed in professional rugby players [40]. Acute modification of the hormonal environment induced by the bout of sprint-cycle exercise was reported to have contributed to the improvement of subsequent exercise performance [40]. In support of this finding, previous authors have observed improved upper-body strength profiles following the systemic elevation of endogenous hormones via prior lower-body resistance exercise [41].

Interestingly, a number of authors have also reported that the content of videos watched prior to exercise can influence hormonal responses and subsequent physical performance. For example, in professional rugby players, Cook and Crewther [42] observed improvements in squat strength 15 min after watching short (4 min) video clips that included aggressive, training, erotic or humorous content. Notably, the aggressive video caused significant increases in salivary testosterone that exceeded all other video types and improved squat performance more so than either the erotic or humorous clips. Moreover, viewing footage 75 min before a match that showed successful skill executions performed by an athlete, which was reinforced with positive coach feedback, promoted the highest pre-game testosterone concentrations and best subsequent performance ratings [43]. Conversely, presenting footage of successful skill executions of opposing players while providing cautionary coach feedback, induced an enhanced stress response [43].

While the direct effect of specific hormonal priming strategies administered during the half-time break have not yet been examined, and assuming that the relationships between pre-match testosterone concentrations and match performance [44] remain true, it is plausible that strategies which elevate free testosterone employed during the half-time break may improve subsequent match performance. As shown in Fig. 1, half-time often includes a period of tactical instruction, be it either individual or team-based, which may utilise video playback [1]. Therefore, modification of the footage and feedback presented to the players may offer a simple strategy to improve subsequent performance. Furthermore, high-intensity exercise, perhaps used as part of a half-time re-warm-up, may also optimise the hormonal milieu that contributes to improved exercise performance thereafter.

2.4 Carbohydrate Consumption

When soccer has been used as the modality of exercise, numerous authors have reported that muscle glycogen concentrations reduce throughout both simulated and actual match-play [45, 46]. Consequently, team-sports players are often encouraged to acutely consume carbohydrates on the day of competition. Such recommendations usually include guidance to ingest carbohydrates in the hours before exercise, throughout competition and during breaks in play, such as at half-time [47]. The proposed mechanisms of ingesting carbohydrates relate to an effort to spare muscle glycogen and to maintain blood glucose concentrations for the duration of a match [48–50]. However, the physiological response to carbohydrates consumed during exercise, such as a match, differs to that observed when carbohydrates are consumed in the non-exercising state [51], similar to half-time.

Under normal physiological conditions, ingesting carbohydrates that increase blood glucose concentrations in a passive state elicits an increase in insulin synthesis and secretion from the β cells of the islets of Langerhans. Insulin, in an attempt to normalize blood glucose concentrations, subsequently decreases lipolysis and increases glucose uptake in liver, skeletal muscle and fat cells [51]. Conversely, hyperglycaemic responses are observed during high-intensity exercise by the actions of counter-regulatory hormones, including catecholamines, cortisol and growth hormone [51]. Given the pattern of competitive match-play in team-sports competition, it is surprising that the influence of carbohydrate supplementation on the glycaemic response to a bout of exercise that is completed after a period of recovery from a previous bout of exercise has received little attention.

Ingestion of a 6 % sucrose-electrolyte beverage before (i.e. within 2 h of commencing exercise and within 5 min of starting each half) and during (i.e. every 15 min of exercise) simulated soccer-specific exercise attenuated a reduction in post-exercise shooting performance (assessed during an isolated soccer skills test) [19]. However, in support of data reported by Bangsbo et al. [52], exogenous carbohydrate provision before and during soccer-specific exercise reduced blood glucose concentrations during the initial stages of the second half by ~30 %, a finding that has since been confirmed in both simulated and actual soccer match-play [18, 20]. Most likely, this exercise-induced rebound glycaemic response is explained by the previously active muscles increasing glucose uptake, lowered catecholamine concentrations, and reduced stimulation of liver glycogenolysis at the start of the second half [52].

It appears that cerebral glucose availability is impaired when blood glucose concentrations fall below 3.6 mmol·L^{-1} [53], and cognitive performance decrements occur when blood glucose concentrations fall below 3.4 mmol·L^{-1} [54–63], concentrations that represent those previously reported in soccer players [20, 64]. As the quality of cognitive and physical performances executed during and after soccer-specific exercise appear to be influenced by changes in blood glucose concentrations, strategies that maintain glycaemia for the full duration of match-play represent an opportunity to achieve maximum soccer performance. A number of factors, including the glycaemic index of the carbohydrate consumed, timing of consumption and the dose consumed, are likely to modulate the efficacy of carbohydrates consumed on the day of competition [65]. In this review we present an overview of studies that have application to these factors in the context of the half-time break.

2.4.1 Glycaemic Index

Commercially-available sports drinks generally tend to consist of between 6 and 10 % concentrations of high-glycaemic index carbohydrates (e.g. maltodextrin). Ingesting high-glycaemic index carbohydrates while in a non-exercising state, such as that observed during the initial phases of half-time, results in rapid increases in postprandial blood glucose concentrations. However, consumption of high-glycaemic index carbohydrates in the hour before exercise has also been reported to lower blood glucose concentrations 15–30 min after starting subsequent activity [55, 66], a response attributed to free fatty acid inhibition which increases carbohydrate usage throughout isolated exercise bouts performed soon after carbohydrate ingestion [55].

As highlighted in Sect. 2.4, we have consistently reported that consuming sucrose-electrolyte beverages before, and throughout, simulated soccer match-play caused transient reductions in blood glucose concentrations in the initial stages of the second half of soccer-specific exercise [19, 20, 67]. However, low glycaemic index carbohydrates prolong the delivery of glucose to the systemic circulation. Indeed, mean and peak oxidation rates of isomaltulose have been reported to be 50 and 42 % lower than the oxidation rates of sucrose, respectively, when ingested at the same rate (1.1 g·min^{-1}) [68]. Although the effects of different glycaemic index carbohydrates consumed during the half-time period remain to be examined, it is plausible that a reduced rate of digestion and absorption of low-glycaemic index carbohydrates prolongs blood glucose concentrations that have typically been found to decline in the second half of intermittent activity.

2.4.2 *Timing of Ingestion*

Consistent evidence provided from studies requiring that carbohydrates are consumed before a single bout of exercise demonstrate that the timing of pre-exercise carbohydrate ingestion can influence subsequent metabolic responses. For example, Moseley et al. [69] investigated the metabolic response to 75 g of glucose ingested 15, 45 or 75 min before exercise. Plasma glucose and insulin concentrations were significantly elevated immediately before exercise in the 15-min feeding group, whereas the lowest insulin concentrations were observed when carbohydrate was ingested 75 min before exercise. Similarly, ingestion of a 20 % fructose solution 15 min before the second half of an intermittent cycling protocol resulted in reductions in blood glucose concentrations compared with pre half-time values for 40 min of the second half [24]. Consequently, the timing of carbohydrate ingestion during the half-time period has the potential to influence responses; however, no studies have systematically examined the influence of modifying the timing of carbohydrates provided during half-time in soccer players.

2.4.3 *Dose Consumed*

In studies that have employed continuous exercise protocols and have focused on water absorption as a priority, the detrimental effects observed on gastric emptying and intestinal absorption have led to recommendations that beverages containing between 5 and 8 % carbohydrates are consumed during exercise [68, 70, 71]. However, when intermittent exercise is performed, limited data currently exist about the effects of providing additional carbohydrates (9 % solutions). Notably, ingestion of a 20 % glucose solution has been reported to enhance sprint capacity after 90 min of intermittent cycling [24], and a dose-dependent relationship exists between the amount of carbohydrate consumed and indices of cognitive function in non-exercising participants [72].

In recreational soccer players, greater blood glucose concentrations have been observed from 75 min onwards relative to a fluid–electrolyte placebo when a 9.6 % carbohydrate–electrolyte beverage was consumed before and during (including at half-time) a simulated soccer match [18]. Interestingly, differences in glycaemic responses were observed despite similarities in blood glucose concentrations between conditions at the 60 min time point (~4.0 mmol·L^{-1}). As the pre-exercise carbohydrate dosage appears to elicit similar glycaemic responses [68, 73], and that the rebound hypoglycaemic response appears to decay within the initial stages of exercise when high-glycaemic index carbohydrates are consumed [24, 69], it is plausible that provision of additional carbohydrates at half-time may afford ergogenic effects in the latter stages of a match; however, this remains to be confirmed.

2.4.4 *Interactions between Carbohydrate Ingestion and a Half-Time Re-Warm-Up*

It is well established that high-intensity exercise can elicit a hyperglycaemic response in both clinical and non-clinical populations. An exercise-induced catecholamine release inhibits pancreatic β-cell activity [74]; therefore, elevated blood glucose concentrations result from exogenous carbohydrate provision during exercise. It is therefore plausible that a combination of high-intensity exercise performed during the half-time period, as well as simultaneous carbohydrate ingestion, could feasibly maintain blood glucose concentrations thereafter. In support of this, Achten et al. [68] observed that ingestion of 600 ml of a concentrated maltodextrin drink consumed during a 25-min cycle warm-up that included isolated sprint bouts, increased catecholamine concentrations, blunted the insulin response and actually increased blood glucose concentrations at the onset of exercise. Although reductions in blood glucose concentrations were observed after 20 min of subsequent continuous exercise, these differences were non-significant. Consequently, a half-time re-warm-up that includes a high-intensity component, combined with the ingestion of carbohydrates, may prove beneficial for team-sports players who experience an exercise-induced rebound glycaemic response. However, this is yet to be determined when carbohydrates are provided during recovery from previous activity and when the exercise performed is intermittent in nature.

2.4.5 *Carbohydrate Mouth Rinsing*

Mouth-rinsing carbohydrate solutions can positively influence the perception of effort during subsequent exercise and facilitate peak power output during the initial stages of repeated sprint tests [75, 76]. The mechanisms proposed relate to the excitation of reward and motor control centres in the brain [77] and an enhanced corticomotor pathway excitability [78] induced by oral receptor stimulation. Whether the presence of carbohydrate in the mouth can facilitate improvements in subsequent performance when used as a half-time strategy remains to be investigated; however, the benefits of mouth swilling observed during exercise provide a rationale for using this strategy at half-time.

2.5 Caffeine Consumption

The ergogenic effects of caffeine (a central nervous system stimulant) in team-sport athletes have been proposed to relate to the attenuation of fatigue-related decrements in skilled performances, concentration or cognitive function as opposed to enhanced endurance capacity [79]. With respect to soccer skill performance, the efficacy of caffeine is unclear [65] despite the mean sprinting performances of recreational players being improved when doses of $6\ mg{\cdot}kg^{-1}$ body mass were co-ingested with $142 \pm 3\ g{\cdot}h^{-1}$ of carbohydrate [18]. Additionally, the mean performance of rugby passes made during an isolated technical test over the duration of a simulated match was improved when caffeine was ingested [80]. Therefore, caffeine consumed during half-time may be efficacious for subsequent performance.

When considering whether to recommend caffeine use during half-time, the time-course of peak systemic concentrations of caffeine and/or its metabolites following acute ingestion is likely to be of interest to practitioners. Whether caffeine is consumed in either the fed or fasted state appears to influence the rate of subsequent appearance in the circulation [71]. Nevertheless, when the mechanisms of action are reliant upon absorption via the lower gastrointestinal tract, peak concentrations of caffeine and/or its metabolites are generally realised within 1 and 3 h of ingestion. However, the efficacy of drug administration has been proposed to be related to its speed of absorption [81] and the ergogenic 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 [82].

In the last decade, caffeinated chewing gums have become commercially available and have been associated with significantly faster absorption times when compared with a traditional pill-based administration modality [83]. For example, Ryan et al. [81] have recently observed improved cycling performance when caffeinated gum containing 300 mg of caffeine was provided 5 min before exercise. Interestingly, providing the same dose of caffeinated gum 60 and 120 min prior to the start of exercise negated the ergogenic effects observed. Despite very few studies having investigated the effects of this novel method of caffeine delivery, early evidence suggests that caffeinated gum may benefit the performance of intermittent team-sports players. Furthermore, the time-course of effects of action of caffeinated gums mean that they could plausibly be consumed during half-time.

3 Model of Theoretical Application

As reviewed, the transition from a period of exercise to rest and back to exercise replicates the general demands of a number of team sports. This pattern of activity induces a number of physiological effects that appear to influence performance during subsequent exercise. Notably, impaired performance has been observed during the initial stages of the second half. Therefore, when seeking to optimise performance throughout the full duration of competition, half-time is an opportunity to employ specific strategies that seek to maintain performance throughout the second half.

However, the match-day practices of professional teams are often very structured and rigid in nature. It is therefore important that any proposed modification to the half-time period seeks to complement, rather than replace, existing protocols. Therefore, practical recommendations concerning the implementation of such strategies may be beneficial for the sports scientist and/or strength and conditioning coach. In this review we present a theoretical model of organising a 15-min half-time period to incorporate both the practices currently employed and the strategies that we have proposed to acutely enhance performance (Fig. 2). While this proposed theoretical model may appear quite complex, applied practitioners are encouraged to interpret our recommendations within the context of the requirements of their specific sports. Speculatively, these recommendations may also have application outside of the context of the half-time break as some sports (e.g. rugby league) allow rolling interchanges and therefore players may experience extended breaks in play between consecutive match involvements.

In order to attenuate the losses in body temperature observed during the half-time break, strategies that seek to maintain temperature-mediated pathways [15] should be considered. Heated clothing, outdoor survival jackets and heating pads can be applied with relatively little inconvenience to athletes, and have proved beneficial when seeking to attenuate reductions in performance attributable to T_m loss [15, 16, 29]. Furthermore, an increased changing-room temperature may also prove worthwhile; however, this remains to be explored.

At some point throughout half-time, individualised footage of successful player skill executions supported by affirmative positive cues from a coach may also benefit a player's subsequent performance [43]. However, it should be noted that if such videos focus upon the successful skill executions of opposing players while cautionary coach feedback is provided, an enhanced stress response can be observed [43]. Furthermore, acute bouts of high-intensity exercise may prove beneficial in terms of priming the systemic hormonal environment for subsequent exercise [40].

Active re-warm-ups administered in the final stages of half-time improve subsequent physical and technical performance by attenuation of the reductions in body temperature seen when passive half-time practices are performed [5, 6, 13, 14]. As PAP has been observed following short-duration plyometric activities [36], such exercises, when used as part of a re-warm-up strategy, may serve as a time-efficient method of improving subsequent performance.

Due to the mechanisms of action, the presence of caffeine and carbohydrate in the mouth has been found to facilitate motor output and improve subsequent exercise [76, 81]. However, based upon literature examining the efficacy of caffeine, if the duration between ingestion and subsequent exercise is prolonged, the ergogenic effects of these substances can be lost [81]. Therefore, within the final stages preceding the restart of competition, the provision of caffeinated gum (with subsequent expectoration before competition recommences) and carbohydrate solutions (for the purposes of mouth swilling) should be considered (Fig. 2).

Finally, when seeking to minimise perturbations in blood glucose concentrations that have consistently been observed when recommencing the second half of exercise, it is plausible that half-time strategies relating to the consumption of exogenous energy (i.e. carbohydrates) could be optimised by modifying the glycaemic index of the beverage consumed, the timing of ingestion, the amount of carbohydrate consumed and/or by combining ingestion with a half-time re-warm-up. Therefore, consideration of these factors should be given, especially in players deemed to be susceptible to reduced blood glucose concentrations upon restarting exercise.

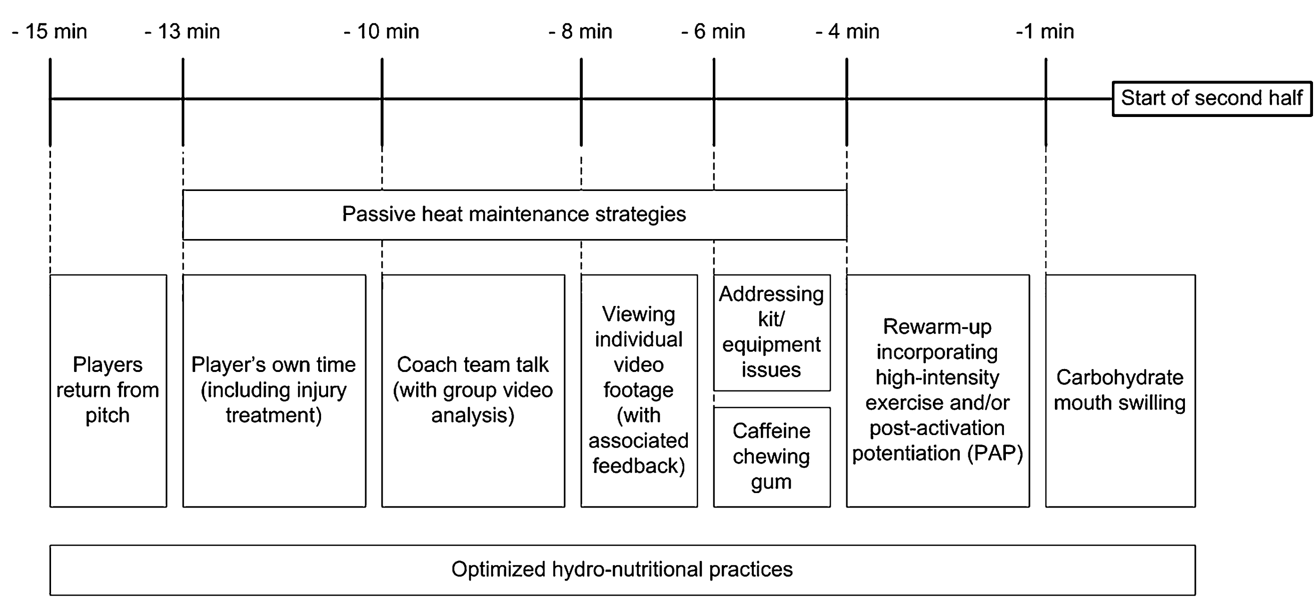

Fig. 2 Theoretical model of strategies suggested during a 15-min half-time period

4 Conclusion

Periods of reduced activity between successive exercise bouts have been found to influence an array of physiological responses. Furthermore, reduced physical and cognitive performance, as well as increased risk of injury, have been identified in the initial stages of the second half of team-sport competition. Therefore, the support of previous authors for the use of heat maintenance strategies, half-time re-warm-ups (including actions to induce PAP), hormonal priming, and caffeine and carbohydrate consumption means that a method which combines a number of these strategies for use on the day of competition may be of interest to sports scientists and strength and conditioning coaches involved with team sports. In addition to appraising the evidence of these isolated strategies, we have presented a practical model that allows combination of a number of interventions that could theoretically elicit additive effects over the use of such strategies in isolation. However, given the differences that exist between sports in half-time regulations (e.g. duration of break, access to pitch, etc.), and players' normal practices, we recommend that the model is interpreted with considerable flexibility, and we acknowledge that some adjustment is likely dependent upon the players involved.

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