The Performance and Physiological Responses of Soccer Substitutes on Match-day

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I, the candidate, confirm that the work submitted is my own, except where work which has formed part of jointly authored publications has been included. The contribution of myself and the other authors to this work has been explicitly indicated below. I, the candidate, confirm that appropriate credit has been given within the thesis where reference has been made to the work of others.

Parts of chapters two, three, four, six, and seven have already been published in the following citations:

Chapter two

Hills SP, Barwood MJ, Radcliffe JN, Cooke CB, Kilduff LP, Cook CJ, Russell M. 2018. Profiling the Responses of Soccer Substitutes: A Review of Current Literature. Sports Medicine. 48(10): 2255-2269.

Chapter three

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Chapter four

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Chapter five

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Chapter six

Hills SP, Barrett S, Busby M, Kilduff LP, Barwood MJ, Radcliffe JN, Cooke CB, Russell M. 2020. Profiling the post-match top-up conditioning practices of professional soccer substitutes: An analysis of contextual influences. Journal of Strength and Conditioning Research. 34(10): 2805:2814.

Chapter seven

Hills SP, Barrett S, Hobbs M, Barwood MJ, Radcliffe JN, Cooke CB, Russell M. 2020. Modifying the pre-pitch entry practices of professional soccer substitutes may contribute towards improved movement-related performance indicators on match-day: A case study. PLoS One. 15(5): e0232611.

For all chapters that include published material, I, the candidate, helped in the planning of the projects (including ethical applications where relevant), collected and analysed the data (including reviewing and screening the literature in chapter two), before writing the relevant manuscript. Professor Russell, Dr Barwood, Professor Cooke, and Dr Radcliffe were involved in supervising the projects from inception to completion as well as drafting and revising the manuscripts for publication. Professor Kilduff (chapters two, four, five, and six), Dr Cook (chapters two and four), and Dr Arent (chapters three and five) were consulted during the final stages of writing and revision of certain published manuscripts due to their expertise in the field. Dr Barrett (chapters four, six, and seven) and Mr Busby (chapter six) assisted by providing access to professional soccer players from whom I was able to collect data, and also provided feedback during the final stages of manuscript preparation. Dr Feltbower (chapter four) and Dr Hobbs (chapter seven) provided guidance relating to the appropriate statistical approach to answer the research questions adopted in chapters four and seven, whilst Mr Aben and Mr Starr assisted with aspects of the practical data collection for chapter five. The information included within the thesis represents my own work.

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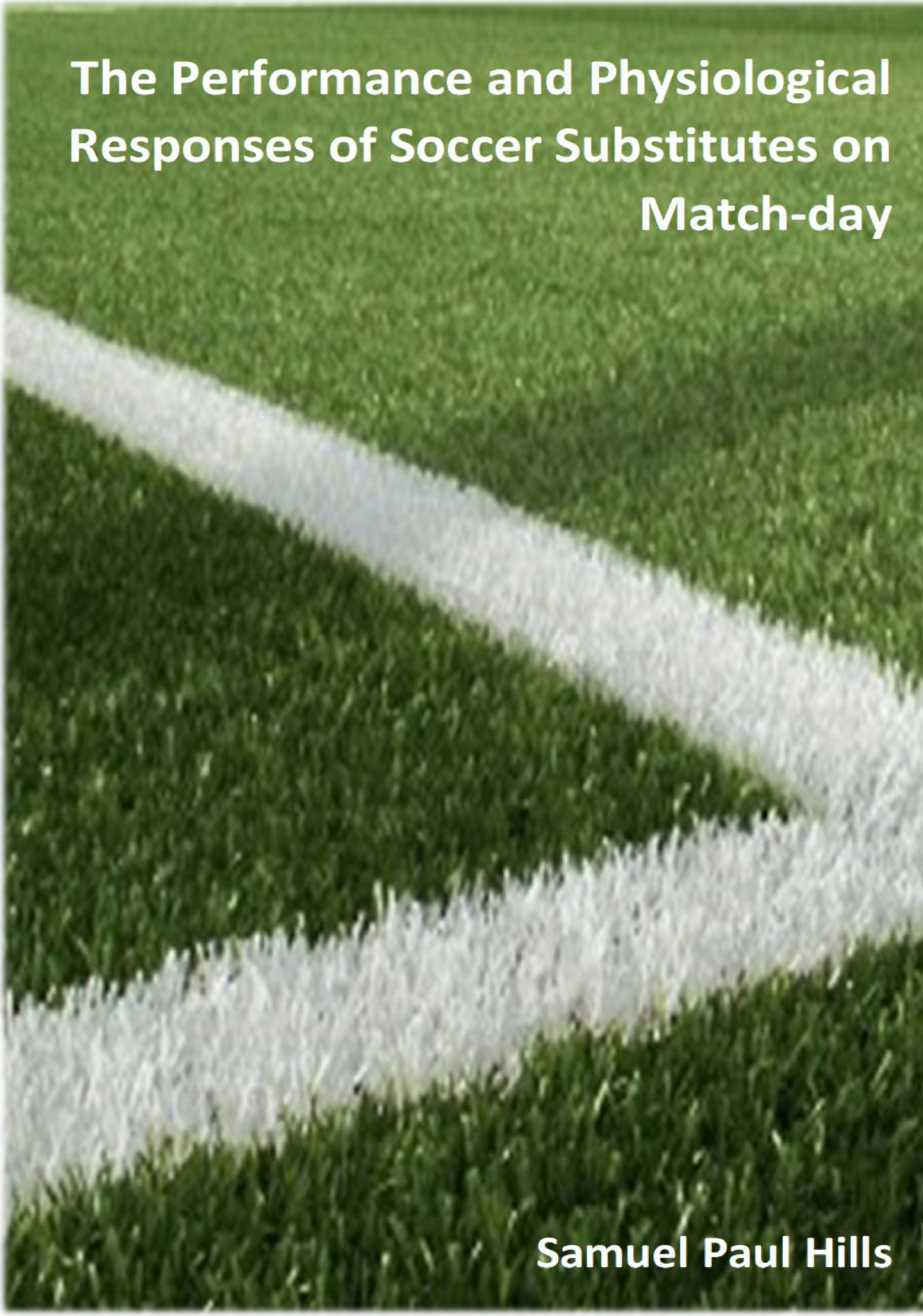

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Abstract

This thesis aimed to elucidate current practices and practitioner perceptions regarding the match-day activities of soccer substitutes, assess physiological and performance responses to current practices, and implement a substitute-specific match-day intervention in an applied scenario. Survey findings (chapter three) and empirical observations indicated that substitutions are typically made at half-time or later, often to increase the pace of play and/or change team tactics. Practitioners highlighted the importance of pre-pitch-entry preparations for allowing substitutes to positively influence matches, noting preparatory strategies as a crucial research area (chapter three). Perhaps due to regulatory and practical constraints, and despite delays of ~75-120 min following cessation of the pre-match warm-up before pitch-entry, chapter four showed that professional substitutes typically perform minimal activity (~3 rewarm-up bouts$\cdot$player$^{-1}\cdot$match^{-1}) prior to match-introduction. When replicated in controlled conditions (chapter five), such practices failed to maintain body temperature (~1.6% decrease) and physical performance capacity (~3.9-9.4% decrease) from an initial warm-up until simulated second-half pitch-entry. Transient changes in physical outputs were recorded after actual match-introduction, but evidence of performance limiting fatigue was absent during ~30 min of simulated match-play. Although substitutes often perform post-match 'top-up' conditioning sessions to help maintain favourable physical loads, contextual factors influenced session demands (chapter six). Crucially, chapter seven showed that modified practices that included substitutes 1) performing a new pre-match warm-up alongside members of the starting team, 2) participating in a staff-led half-time rewarm-up, and 3) receiving education emphasising the value of substitutes and the efficacy of (re)warm-up activities, increased the activity completed pre-pitch-entry whilst appearing to benefit post-pitch-entry physical performance responses and potentially match scoreline differentials. Practitioners and policy-makers should therefore consider assessing current preparatory strategies for substitutes and, where necessary, modifying existing practice. Given the barriers existing on match-day, ensuring appropriate exposure to additional high-speed activities throughout a training week may also be important.

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List of abbreviations

CMJ: Countermovement jump

CV%: Coefficient of variation

FIFA: Fédération Internationale de Football Association

GPS: Global Positioning Systems

HR: Heart rate

HSR: High-speed running distance

LSR: Low-speed running distance

MEMS: Microelectromechanical Systems

MSR: Moderate-speed running distance

NCAA: National Collegiate Athletic Association

PAP: Postactivation potentiation

PL: PlayerLoad™

RHIE: Repeated high-intensity effort

RPE: Rating of perceived exertion

SMS: Soccer match simulation

SPR: Sprinting distance

T_{core}: Core body temperature

TD: Total distance

T_m: Muscle temperature

$\dot{V}O_2$: Oxygen uptake

$\dot{V}O_{2max}$: Maximal oxygen uptake

Chapter 1.0 Introduction

Soccer is one of the world's most popular team sports, typically contested between two teams of 11 players (i.e., 10 outfield players and one goalkeeper per team) over 45 min halves that are separated by a ~15 min half-time interval. For each team, the ultimate objective is to score more goals than the opposition within the allotted time in order to win the match. The popularity of soccer as a research topic is illustrated by the fact that as of June 2020, a PubMed search for the term "soccer" returns over 11000 results. Although this figure includes articles that relate to all aspects of the sport, a substantial body of literature has investigated the physiological and performance responses to soccer match-play and/or training. However, researchers investigating such concepts have largely focussed their attentions on those players who start a match on the pitch.

In most competitions worldwide, soccer coaches and managers can introduce substitute players into a game after the match has already begun. Fédération Internationale de Football Association (FIFA) rules first included reference to substitutions in 1958 and currently permit a maximum of three starting players (up to six in some competitions) to be irreversibly replaced from a 'bench' of typically six or seven (up to 12 in some competitions) nominated substitutes (FIFA, 2019/20). Whilst FIFA govern the majority of competitions worldwide, it should be noted that National Collegiate Athletic Association (NCAA) competitions in addition to some youth or lower-level fixtures allow the use of 'rolling' interchanges, whereby players may re-enter the pitch having previously been replaced in the match (FIFA, 2019/20).

Substitutes in team sports have generated much media attention in recent years, with the head coach of England's rugby union team, Eddie Jones, now publicly referring to his replacements as 'finishers' on account of their highly specialised role. Although soccer players do not typically specialise as whole-match or partial-match players, substitutes may often represent an important means by which management staff can attempt to influence the outcome of a match. Empirical observations suggest that managers value highly the role of substitute players, and published research has observed that an increase (i.e., relative to less successful seasons) in the number of matches won directly via a goal scored by a substitute was a characteristic of a championship winning season in French Ligue 1 soccer (Carling et al., 2015).

In contrast to the abundance of literature that exists in relation to whole-match soccer players, a relatively limited number of studies have specifically considered the responses of substitutes. Indeed, narrowing a PubMed search from "soccer", to "(soccer) AND (substitute*)" returns fewer than 100 results (of which many studies do not relate to substitute players, but instead reflect other uses of the word substitute). The research that does exist is characterised by substantial methodological variation and has typically focussed on three main themes, namely reporting the patterns of match-play introduction for substitutes, assessing substitutes' match-play performances, and the psychology of substitute players. Although the findings of these preliminary investigations are valuable for highlighting the unique role occupied by substitutes compared with players who start a match on the pitch, a substitute's performance and physiological responses remain somewhat poorly understood. Accordingly, given their potential importance for influencing the outcome of a match and/or season (Carling et al., 2015), additional research is warranted to help better understand and thus potentially improve the strategies employed in relation to this bespoke population of soccer players.

Chapter 2.0 Literature review

Chapter Summary

- Although empirical observations suggest that substitutes can often be an important factor influencing team success, limited research has considered substitute responses.
- Research that does exist has typically focused on the patterns of match-play introduction for substitutes, the match-play movement responses of substitutes following pitch-entry, and the psychology of players selected as substitutes.
- Unless first-half replacements are enforced due to player injury, substitutions in professional soccer are typically made at half-time or later during a match. Exposure to limited match-play has the potential to negatively influence a substitute's adaptive responses if important indices of physical loading are reduced over time.
- Members of the starting team experience progressive declines in physical and technical performance during match-play, and substitutes can typically exceed the second-half relative running responses of players who started the match.
- An inability to exceed typical first-half movement responses and potential increases in substitutes' physical outputs as the second-half progresses, alongside findings that substitutes mostly experience negative emotions, appear to suggest the importance of pre-pitch-entry preparations for optimising the match-play performance of substitutes.
- Substantial delays (i.e., typically ~75-120 min) between pre-match warm-up cessation and entry onto the pitch have the potential to elicit physiological responses (e.g., decreases in body temperature) that could negatively influence a substitute's physical performance capacity and potentially increase injury-risk upon match-introduction.

Parts of this chapter have been published in the following citation:

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2.1 Typical team microcycle structure and a substitute's match-day routine

Acknowledging that different organisations adopt different weekly and daily training structures (i.e., based upon the availability of resources, the preferences of specific players and staff members, travel commitments, etc.), Figure 2.1 provides an illustrative example of how professional soccer teams may structure a seven day in-season training microcycle. This example is based upon empirical observations alongside published literature from English professional soccer (Anderson et al., 2016b; Kelly et al., 2020; Malone et al., 2015), and reflects the fact that fatigue-management and technical/tactical development typically represent primary objectives during the competitive season as teams seek to maximise 'readiness' for each match. In the proposed model, 'match-day plus one' (i.e., the day after a match) represents a rest day for all squad members, whilst 'match-day minus one' (i.e., the day before a match) involves mostly technical and tactical drills (i.e., focusing on team shape and cohesion) alongside potential 'priming' resistance exercises that have been designed to elicit minimal physical fatigue. Depending on factors including fixture scheduling, travel commitments, and a player's previous physical loading patterns, other training opportunities during the week (i.e., those furthest away from match-day) typically encompass longer and more physically demanding drills such as small- and large-sided games. These sessions can be used by team staff to develop technical and tactical aspects of player performance whilst achieving specific physical loading targets by manipulating the constraints of any given drill.

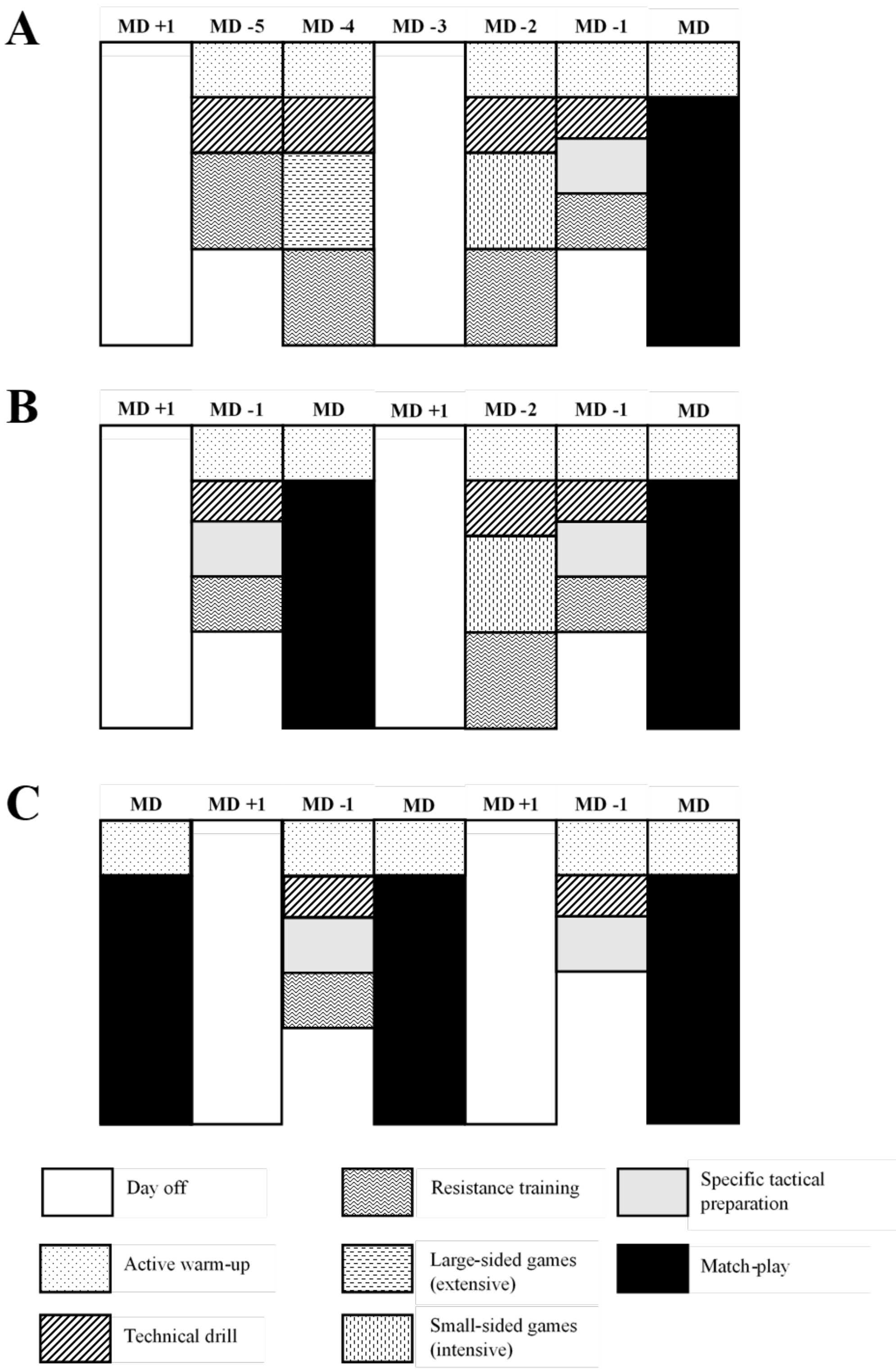

Figure 2.1: Example in-season microcycle structure for a professional soccer team during weeks in which one (panel A), two (panel B), or three (panel C) matches are played. Structure based upon empirical observations and published research from English professional soccer (Anderson et al., 2016b; Kelly et al., 2020; Malone et al., 2015). MD: Match-day.

As this thesis is concerned with the performance and physiological responses of soccer substitutes on match-day, the specific responses elicited on other days within the training week fall largely outside the scope of the current literature review. Acknowledging that practices may vary, Figure 2.2 draws upon empirical observations from professional soccer players to outline an example of a current match-day structure for a substitute who enters the pitch after ~75 min of match-play (i.e., ~90 min following the match kick-off). Match-day observations suggest that although they may perform lower-intensity activities, substitutes typically warm-up at the same time as members of the starting team prior to kick-off. As the expectation is that (failing injury) replacements will enter the pitch at half-time or later in the match, substitutes often face substantial delays (i.e., typically ~75-120 min) between the match kick-off and their entry onto the pitch. That time is mostly spent seated pitch-side, although sporadic individual player-led rewarm-up activity will typically be performed along the touchline between the halfway line and the corner flag whilst play is underway (empirical observations). Additional rewarm-ups may also take place on the pitch at half-time. Following pitch-entry, participation in typically ≤45 min of match-play is likely to result in bespoke (i.e., lower) absolute match-day demands compared with whole-match players and substitutes often therefore perform 'top-up' training sessions on the pitch immediately after the match conclusion. Given the unique position occupied by substitute soccer players, this chapter aimed to review the currently available literature that relates directly and indirectly to the performance and physiological responses of substitutes on match-day.

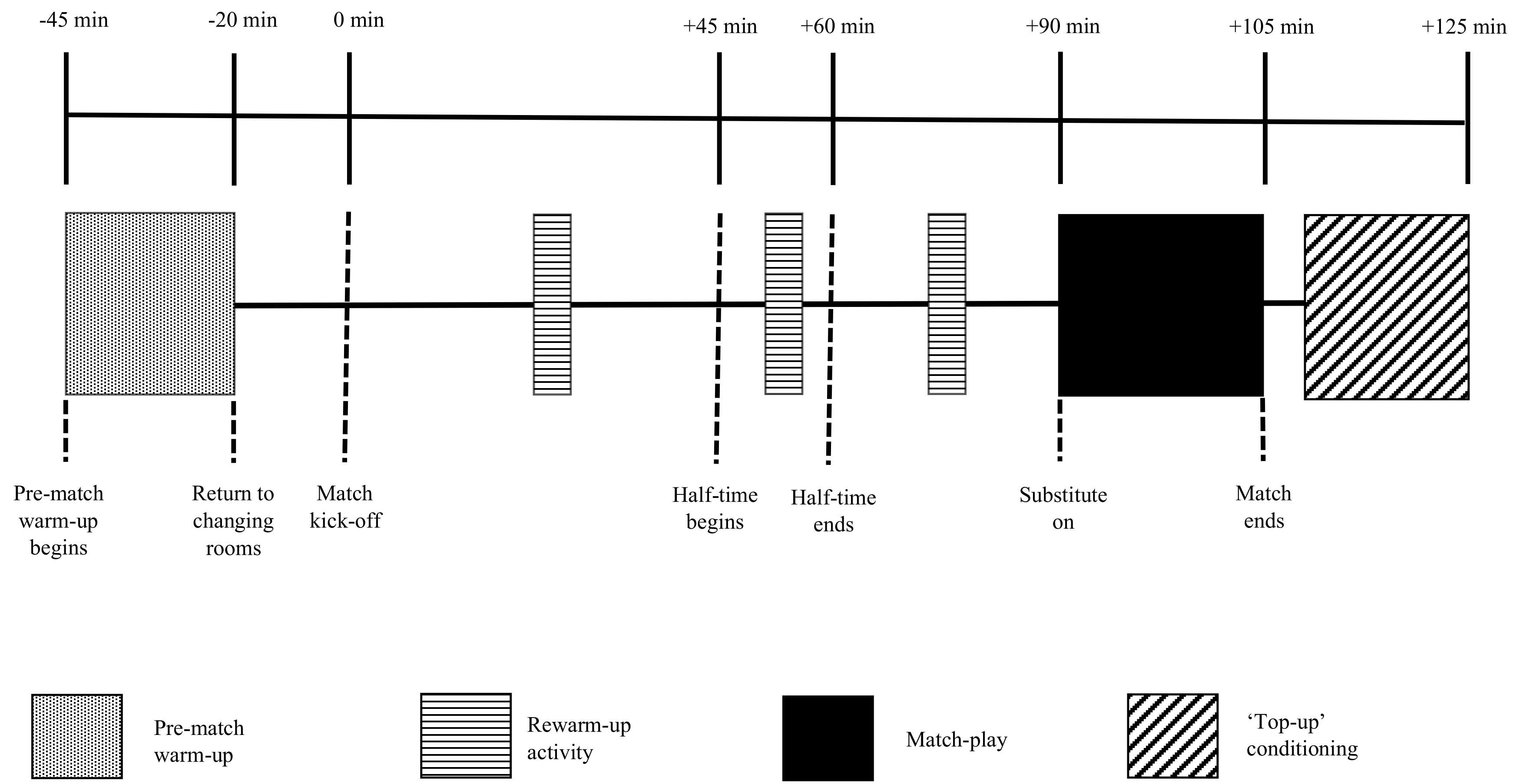

Figure 2.2: Exemplar model constructed from empirical observations of substitute practises on match-day with a player introduced after 75 min (i.e. ~90 min post-kick-off)

2.2 Patterns of match-play introduction for soccer substitutes

Empirical observations suggest that unless first-half replacements are enforced due to an injury sustained by a member of the starting team, substitutes are rarely introduced prior to half-time in a match. However, the length of an individual's match playing time is likely to represent an important factor influencing a substitute's match-play demands and/or the extent to which a player entering the pitch can substantially influence the outcome of a match. Table 2.1 therefore shows the findings from studies that have reported the patterns of match-play introduction for soccer substitutes. Pooling data from the English Premier League, Italian Serie A, and Spanish La Liga highlighted that the mean time of introduction for first, second, and third substitutions was at ~57 min, ~71 min, and ~81 min, respectively (Myers, 2012). However, the mean data for the first substitution were likely influenced by the occasional need for first-half replacements (mostly related to player injury). A team's first replacement of the match was most often introduced at half-time, whereas the greatest frequencies of second and third substitutions were at ~70 min and 90+ min (i.e., during second-half stoppage-time), respectively (Myers, 2012). The specific European leagues in question appeared to influence the timing of the first, but not second or third replacements, with English Premier League managers making their first substitution later (i.e., 58th min) than those in the Italian Serie A League (i.e., 52nd min).

Table 2.1: Studies examining the patterns of substitutes' match-play introduction

Study	Players	Data collection	Variables measured	Key results
Del Corral et al. (2008)	Spanish Division 1 players. 2108 subs made in 380 matches (including 676 1st subs).	Referees' official post-match reports.	Time of substitution, position of replacement, and factors influencing timing.	Number of subs ↑ from 46-70 min, then ↓ from 70-90 min. MF-MF subs most common (825 observations). Offensive subs more common, defensive subs ↑over time. Scoreline (losing teams: 1st sub earlier) and match location (home teams: 1st sub earlier) influence timing.
Carling et al. (2010)	French Division 1 MF and CF (n=25 subs), observed over 18 matches.	Multiple-camera tracking system.	Time on field.	MF subs played 22.5±8.1 min and CF subs played 24.8±7.4 min (only subs playing >10 min included).
Myers (2012)	485 observations from English Premier League (155), Italian Serie A (172), and La Liga in Spain (158).	Data provided by ESPN Soccernet.	Time of substitution, factors influencing timing, scoreline differential.	Mean subs introduction times were 57 (1st subs), 71 (2nd subs), and 81 (3rd subs) min. Scoreline (losing teams: 1st subs earlier), and league (Serie A 1st subs: 52 min, Premier league 1st subs: 58 min) influence timing. Best outcomes: when team is behind, make 1st subs <58th min, 2nd subs <73rd min, 3rd subs <79th min.
Bradley et al. (2014)	English Premier League players (n=286 subs).	Multiple-camera tracking system.	Time of substitution and position of replacement.	Most subs made at half time or 60-85 min. More offensive vs defensive subs between 60-90 min.
Vescovi and Favero (2014)	NCAA Division 1 women's players (n=113), 1 observation per player.[a]	Wearable MEMS; 5 Hz.	Time on field.	1st half: replaced players had ↑ time on field vs subs: F (30.0±1.5 vs. 19.0±2.0 min), MF (31.0±1.5 vs. 18.0±1.8 min), DF (32.0±1.2 vs. 12.0±1.9 min). 2nd half: replaced F had ↑ time on field vs subs (30.0±2.0 vs. 20.0±1.5 min), but ↔ for MF (25.0±3.2 vs. 22.0±2.1 min) and DF (21.0±4.4 vs. 29.0±3.1 min).
Silva and Swartz (2016)	Same data as Myers (2012), plus additional 3 seasons from English Premier League, 4226 observations.	Data provided by ESPN Soccernet.	Time of substitution, and scoreline differential.	No discernible time period where there is a clear benefit to making a substitution.

Hz: Hertz, MEMS: Microelectromechanical Systems, NCAA: National Collegiate Athletic Association (USA), Subs: Substitutes, ↑: Higher than/increased, ↓: Lower than/decreased, ↔: No difference. [a:] unlimited interchanges permitted. CF: Centre-forward player, DF: Defender, F: Forward player, MF: Midfield player .

Whilst observed discrepancies in substitution timing between leagues have been attributed to differences in managerial styles (Myers, 2012), physical demands may also vary between leagues and thus potentially influence the timing of those substitutions that are made with the objective of offsetting the physical performance declines experienced by outfield players who start a match on the pitch. Although the activity profiles of players in most positions appear broadly similar across competitions, and acknowledging the continual evolution and between-match variation in match-play demands (Barnes et al., 2014; Bush et al., 2015; Gregson et al., 2010), attackers in the English Premier League may cover less distance at a speed >14.1-14.4 $km \cdot h^{-1}$ (a threshold often used to denote 'high-intensity running') than those in the Spanish top division (Bradley et al., 2009; Di Salvo et al., 2007). Speculatively, if conditioning levels are similar between leagues, lower physical demands for English Premier League attackers could delay the accumulation of within-match fatigue amongst starting players and thus temporarily defer the need to replace them (i..e, if offsetting the effects of fatigue is a primary substitution aim) when compared with their European counterparts.

Bradley et al. (2014) observed that the majority of English Premier League replacements were made at half-time or between 60-85 min of a match, with substitutions becoming more 'offensive' (i.e., involving attackers and midfielders) as the second-half progressed. This finding conflicts with a study in the Spanish first division in which the number of replacements increased from 46-70 min, with a greater probability of a substitution being 'defensive' as the match went on (Del Corral et al., 2008). Although it should be considered that even an 'offensive' substitution (i.e., from a player position perspective) can be made with defensive intent (e.g., to use up time), such observations further demonstrate inter-competition differences in relation to substitution strategies (Bradley et al., 2014; Del Corral et al., 2008; Myers, 2012).

In line with observations from European top-tier competitions, French Ligue 1 substitute midfielders and attackers were reported to typically spend ~23 min and ~25 min on the pitch, respectively, suggesting that they were introduced midway through the second-half of a 90 min match (Carling et al., 2010). When unlimited 'rolling' substitutions were permitted during NCAA women's competition, forwards were the only position for whom players being substituted into the match had significantly lower second-half playing time (i.e., ~20 min vs. ~30 min) than those players who were substituted out (Vescovi & Favero, 2014). Observations that ~12 interchanges were made per match and only four players routinely completed 90 min (Vescovi & Favero, 2014) suggests a vastly different scenario from FIFA competitions, which may have implications for the physical responses of players in the respective competitions.

Teams that are losing in a match (i.e., in terms of the match scoreline) typically make their first substitution sooner than when ahead (Del Corral et al., 2008; Myers, 2012), a trend that may exist for all three replacements in FIFA-regulated 90 min matches (Myers, 2012). It therefore appears that managers whose team is behind have a greater inclination to make tactical changes in an attempt to alter the direction of a match. Indeed, it seems likely that players who are on the pitch when the team is losing at the time of a substitution are more likely to be deemed underperforming than when members of the starting team have been able to generate a lead (Myers, 2012). Accordingly, match scoreline is an important factor influencing substitution timing as managers seem to attribute a higher value to awaiting substitutes when the team is losing compared with when ahead in the match.

The effect of match location on the timing of substitutions is unclear. A higher probability of making a first replacement at half-time has been suggested when a team is playing at home relative to away (Del Corral et al., 2008), yet observations across three European leagues reported no effect of match location except for the third substitution being made later during home matches compared with away fixtures (Myers, 2012). The limited data currently available means that such findings are difficult to reconcile. Potentially, as home managers are more likely to face crowd pressure from their own team's supporters, it is possible that they may favour making changes at half-time when seeking to avoid negative scrutiny (Del Corral et al., 2008). Conversely, because home advantage means that teams are more likely to be leading in the match, the likelihood of the final substitute being delayed is increased (Myers, 2012). Further research is required to enable firm conclusions to be made.

Drawing statistics from three major European leagues, Myers (2012) used decision trees to propose and test a ‘rule’ for optimising the timing of substitutions. The analysis indicated that when a team was behind in a match, the probability of improving their scoreline differential (i.e., the number of goals scored minus the number of goals conceded) was increased if the first substitution was made before the 58^{th} min, the second before the 73^{rd} min, and the final substitution before the 79^{th} min. Although the proposed ‘rule’ was only followed in ~34% of scenarios for potential application in the matches that were observed, losing teams improved their scoreline differential following a substitution in ~38-47% of cases when the rule was followed, compared with improvements in ~17-24% of matches otherwise (Myers, 2012). However, Silva and Swartz (2016) criticised this approach as too simplistic, and considered a Bayesian logistic regression based upon a prior distribution in which team strength was related to the probability of the trailing team scoring the next goal. Using the same data as Myers (2012), they found no discernible time-period in which there was a clear benefit to making a substitution.

Although empirical observations suggest that substitutes typically receive match-specific tactical information from team officials immediately prior to pitch-entry (e.g., whilst removing outer clothing etc.), no study has directly examined the exact reasons that managers typically make substitutions. However, the data currently available make clear that the majority of teams across the top professional competitions (~82%) use all three substitutions permitted and that substitutes are usually introduced at half-time or later during a match (Bradley et al., 2014; Del Corral et al., 2008; Myers, 2012). As such, unless a first-half replacement is enforced because of an injury sustained by a member of the starting team and/or a match progresses to extra-time, substitutes typically experience <45 min of match-play (and often far less than this value) on any given occasion.

2.3 Demands of soccer match-play

2.3.1 Match-play responses of whole-match players

Professional soccer players who occupy outfield positions typically cover a total distance (TD) of ~10-13 km during a 90 min match (Akenhead et al., 2013; Bangsbo et al., 2007; Bangsbo et al., 2006; Barnes et al., 2014; Bradley et al., 2009; Di Salvo et al., 2009; Krustrup et al., 2006; Mohr et al., 2003; Russell et al., 2011b; Russell et al., 2016; Stølen et al., 2005), of which high-speed running (HSR; typically defined as distance covered at a speed >5.5 $m \cdot s^{-1}$) and sprinting (SPR; >7.0 $m \cdot s^{-1}$) may account for ~0.8-1.0 km and ~0.2-0.3 km, respectively (Anderson et al., 2016b; Bradley et al., 2009; Di Salvo et al., 2010; Di Salvo et al., 2009; Rampinini et al., 2007). Although low-intensity activities predominate (Bangsbo et al., 2007; Bangsbo et al., 2006; Krustrup et al., 2006), many of the most decisive moments of match-play often involve explosive high-speed movements such as jumps, changes of direction, HSR, and/or SPR (Di Salvo et al., 2010; Faude et al., 2012; Reilly, 1997; Stølen et al., 2005). Indeed, video analysis of 360 goals scored in German professional soccer highlighted that ~83% of goals were preceded by at least one subjectively determined 'powerful action' performed by a player who either scored or provided an assist, with ~51% involving a sprint by the scoring player (Faude et al., 2012). Acknowledging that increasing match running responses may not necessarily contribute to improved chances of overall match success (Bradley et al., 2013; Di Salvo et al., 2009; Rampinini et al., 2009), empirical observations suggest that within-player or within-team assessments of match-play HSR and SPR outputs are often considered to represent important indicators of physical performance in soccer.

Alongside the physical demands outlined above, whole-match soccer players typically perform >100 technical actions during a 90 min match (Bloomfield et al., 2007), with short passing representing the most frequent involvement with the ball (Rampinini et al., 2009). The importance of technical skill to the outcome of soccer matches is highlighted by observations that successful teams in the FIFA World Cup scored a greater proportion of goals per possession following longer passing sequences than shorter (Hughes & Franks, 2005), and that winning teams in Spanish professional soccer have outperformed losing teams in their ability to retain ball possession whilst also completing more shots and crosses per match (Lago-Penas et al., 2010). Improvements in technical performance indicators such as the number of involvements with the ball, total passes, short passes, crosses, tackles, dribbles, and shots taken were also recorded amongst the most successful compared with the least successful teams (i.e., teams differentiated according to final league position) in the Italian Serie A League (Rampinini et al., 2009).

2.3.1.1 Transient changes in match-play performance for players who start a match

Progressive declines in several indices of physical (e.g., TD, HSR, SPR, acceleration and declaration outputs, etc.) and skilled (e.g., the number of possessions achieved, alongside markers of shooting and passing performance such as speed, accuracy, success, etc.) performance are observed throughout 90 min of actual or simulated soccer match-play (Akenhead et al., 2013; Bradley et al., 2010; Bradley & Noakes, 2013; Bradley et al., 2009; Di Salvo et al., 2009; Harper et al., 2014; Mohr et al., 2003; Rampinini et al., 2011; Rampinini et al., 2009; Russell et al., 2011a; Russell et al., 2013; Russell et al., 2016; Stevenson et al., 2017), with the potential for further decreases during matches that progress to extra-time (Harper et al., 2016a; Russell et al., 2015b; Stevenson et al., 2017). Acknowledging the likely influence of factors including self-pacing strategies, changes in team tactics, and/or the relative amount of time for which the ball is in play (Lago-Peñas et al., 2012; Paul et al., 2015; Waldron & Highton, 2014), the development of acute physical fatigue appears largely to explain such responses amongst members of the starting team (Reilly et al., 2008). In support, greater between-half decrements in distance covered at a speed ≥14.4 $km \cdot h^{-1}$ were observed amongst English Premier League players who recorded a 'high' (i.e., defined as players ≥70th percentile for TD), compared with 'moderate' (i.e., 35–65th percentile) or 'low' (i.e., ≤30^{th} percentile), level of first-half activity (Bradley & Noakes, 2013). Moreover, an apparent link between declines in physical and technical outputs is suggested by reports that decreases in the number of possessions achieved alongside reductions in the number of short passes and successful short passes performed during Italian Serie A League matches were limited to those players who also experienced the largest between-half decrements (i.e., >8.9%) in distance covered at a speed >14.4km·h^{-1} (Rampinini et al., 2009)

The notion that performance-limiting fatigue develops throughout 90 min of soccer-specific exercise is further supported by observations from soccer simulation protocols designed to negate the influence of match-specific confounding variables. In these scenarios, participants have typically recorded slower sprint speeds and reduced indices of skilled performance (e.g., passing and shooting skills) during the latter stages of simulated match-play compared with during the first 15 min of exercise (Russell et al., 2012; Russell et al., 2011b; Stevenson et al., 2017). Moreover, isolated performance tests have highlighted reductions in physical performance capacity (e.g., sprint speed, change of direction ability, markers of muscle function and strength, jumping performance, and/or endurance capacity) when assessed after 90 min of actual or simulated match-play compared with pre-exercise measurements (Harper et al., 2017; Krustrup et al., 2006; Mohr et al., 2004; Rampinini et al., 2011; Silva et al., 2017). A variety of physiological fatigue-mechanisms, both central and peripheral in origin, have been proposed to explain the changes in performance capacity that are typically observed throughout a whole soccer match, although such responses are likely to be multifactorial in origin (Bangsbo, 2014; Bangsbo et al., 2007; Mohr et al., 2005; Reilly, 1997; Reilly et al., 2008). As physical fatigue may therefore limit a starting player's ability to perform many of the explosive high-speed actions and/or technical skills that may be important during decisive periods of a match, the use of substitutions has been proposed as a means by which management staff can attempt to offset the negative effects of fatigue across a team (Bradley et al., 2014; Reilly et al., 2008). Indeed, empirical observations suggest that alongside other factors such as a desire to change team tactics or replace players deemed to be underperforming/injured, offsetting the accumulation of physical fatigue amongst starting players often represents an important factor motivating the introduction of substitutes during the latter stages of a soccer match.

2.3.2 Match-play responses of soccer substitutes

A handful of studies have investigated the match-play responses of soccer substitutes after their introduction onto the pitch (Table 2.2), with a number of between- and within-player comparisons having been made over various timeframes (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Coelho et al., 2012; Mohr et al., 2003; Vescovi & Favero, 2014). Because their reduced playing time (i.e., typically ≤45 min) is likely to result in substantially lower absolute match-play demands for substitutes compared with members of the starting team, studies seeking to make comparisons between groups of players who may typically spend different lengths of time on the pitch (e.g., substitutes vs. players who started the match on the pitch) have typically corrected match performance variables to represent indices relative to playing time (i.e., variable$\cdot$min^{-1}). However, perhaps partly due to methodological differences between studies and the inherent variability in soccer match-play demands (Gregson et al., 2010; Rampinini et al., 2007; Russell et al., 2015a), existing literature has reported somewhat inconsistent findings. Bradley et al. (2014) suggested that for a substitution to be deemed effective from a physical performance perspective, players being introduced onto the pitch must be immediately able to produce equivalent or higher relative running responses than those being replaced and/or other players remaining on the pitch. The focus on making an immediate impact emphasises the importance of a substitute's preparation strategies implemented directly prior to pitch-entry. If preparation is sub-optimal, substitutes may require the initial period of match involvement to elicit the physiological responses that are typically desired from a pre-performance warm-up, rather than being able to immediately perform at the level expected of them. Notably, preliminary investigations have indicated an inability for players introduced as substitutes to exceed the relative running performance that they typically adopt during the first-half of matches that they start (Bradley et al., 2014; Carling et al., 2010).

Table 2.2: Studies examining the match-play performance of substitutes following pitch-entry

Study	Players	Data-collection	Variables measured	Key results
Mohr et al. (2003)	Elite European team (n=13 2nd half subs), 1-4 observations per player.	Video time-motion analysis.	Distances covered across various speed thresholds.	Subs covered 25% ↑ HSR (>15 km·h^{-1}; 0.40±0.03 vs. 0.32±0.03 km), and 63% ↑ SPR (>30 km·h^{-1}; 0.13±0.01 vs. 0.07±0.00 km) distances at 75-90 min vs. whole-match players.
Carling et al. (2010)	French Ligue 1 MF and CF (subs: n=25), observed over 18 matches.	Multiple-camera tracking system.	Distances covered (·min^{-1}) over various speed thresholds, and recovery time between high-speed actions.	MF subs covered ↑ 2nd half TD (136.6±9.1 vs 129.3±3.6 m·min^{-1}) vs. players replaced. MF subs covered ↑ TD (136.6±9.1 m·min^{-1}), HSR (19.1-23 km·h^{-1}; 9.8±3.6 m·min^{-1}), and ↓ recovery-times between HSR efforts (95.1±38.5 s) vs. whole-match MF. F covered ↓ TD during initial 10 min as a sub vs. their initial 10 min when starting.
Coelho et al. (2012)	Brazilian Division 1 (subs: n=15) players, observed over 29 matches.	HR monitor.	% HR_{max} and time in various HR zones.	↑ 2nd half HR (84±3 vs 81±4% HR_{max}) when subs included vs whole-match players alone, HR remained ↓ vs. 1st half HR for full-match players (86±3% HR_{max}).
Bradley and Noakes (2013)	English Premier League players (n=65), observed completing full matches and when introduced as subs.	Multiple-camera tracking system.	Distances covered (·min^{-1}) over various speed thresholds.	Subs covered ↑ TD (117.2±1.7 vs. 109.2±1.7 m·min^{-1}) and HSR (≥14.4 km·h^{-1}; 32.5±1.2 vs. 28.3 ± 1.0 m·min^{-1}, +15%) vs. equivalent period when playing a full match. CD and FB ↑ SPR (>25.1 km·h^{-1}) as subs vs. equivalent time playing full match (1.85±0.39 vs. 1.11±0.34 and 3.85±0.59 vs. 2.86±0.49 m·min^{-1}, respectively). Subs covered ↑ TD and HSR than the mean of all on-field players.
Bradley et al. (2014)	English Premier League players, whole-match (n=810), subs (n=286), players replaced (n=286).	Multiple-camera tracking system.	Distances covered (·min^{-1}) over various speed thresholds, and pass completion rates.	Subs covered ↑ TD (120.1±14.5 m·min^{-1}) and HSR (≥ 19.8 km·h^{-1}; 12.4±5.3 m·min^{-1}) vs. whole-match (TD: 112.3±10.3, HSR: 9.8±3.2 m·min^{-1}), and replaced players (TD: 116.2±10.6, HSR: 11.3±3.2 m·min^{-1}). Subs covered ↑ TD (118.1±13.6 vs. 105.9±16.2 m·min^{-1}), and HSR (12.2±4.7 vs. 10.1±4.1 m·min^{-1}) as subs vs. their habitual 2nd half performances when playing full match. ↔ for pass-completion rates. Trend for ↑ TD and HSR over successive 5 min blocks for subs.
Vescovi and Favero (2014)	NCAA Division 1 women's players (n=113), 1 observation per player[a].	Wearable MEMS; 5 Hz.	Distances covered (absolute and ·min^{-1}) across various speed thresholds.	↑ HSR (15.6–20.0 km·h^{-1}) between 78-90 min for players re-introduced vs. whole-match players (9.0 ± 0.6 vs. 6.0 ± 0.4 m·min^{-1}). 1st half: MF subs covered ↓ moderate-speed (12.1–15.5 km·h^{-1}) distance·min^{-1} vs. those replaced (15.0±1.8 vs. 19.0±0.9 m·min^{-1}). DF playing whole 1st half covered ↓ HSR (6±1 m·min^{-1}) vs. players introduced (16.0±2.8 m·min^{-1}) or replaced (11.0±1.0 m·min^{-1}). DF subs covered ↑ 1st half HSR vs. those replaced.
Carling et al. (2015)	French Ligue 1 team over 5 seasons (190 matches).	Multiple-camera tracking system.	TD, HSR distance (≥19.1 km·h^{-1}), and technical KPIs.	↑ matches won by goals from subs (+5), matches won between 75-90 min (+7) during successful vs other seasons. ↑ goals scored, ↓ goals conceded during 2nd half injury time.

HR: Heart rate, HR_{max}: Maximum heart rate, HSR: High-speed running, Hz: Hertz, KPI: Key performance indicator, MEMS: Microelectromechanical Systems, NCAA: National Collegiate Athletic Association (USA), SPR: Sprinting, Subs: Substitutes, TD: Total distance, ↑: Higher than/increased, ↓: Lower than/decreased, ↔: No difference. CD: Central defender, CF: Centre-forward player, DF: Defender, F: Forward player, FB: Fullback, MF: Midfield player. [a]: unlimited interchanges permitted.

2.3.2.1 Substitute responses relative to whole-match players remaining on the pitch

Seminal work employing time-motion analysis identified that elite substitutes who had been introduced during the second-half of a match covered 25% more distance at a speed >15 $km \cdot h^{-1}$ and 63% greater distance at a speed >30 $km \cdot h^{-1}$ during the final 15 min of play (i.e., 75-90 min), when compared with the responses of whole-match players over the same period (Mohr et al., 2003). Subsequent research has reported similar physical response patterns between substitutes and whole-match players (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010), including for female players utilising unlimited interchanges (Vescovi & Favero, 2014). A study of French Ligue 1 midfielders also observed reductions in mean recovery time between efforts performed at >19.1 $km \cdot h^{-1}$ for second-half substitutes compared with members of the starting team who remained on the pitch after the substitution (Carling et al., 2010). Similarly, although limitations exist with using heart rate (HR) as a proxy for exercise intensity (Bangsbo et al., 2007), mean second-half HR was significantly higher (~84% vs. ~81% of maximum HR) when half-time substitutes were included within the analysis compared with when only those players completing 90 min were considered (Coelho et al., 2012).

A wealth of literature has documented differential whole-match demands between soccer players who occupy different outfield positions (Bradley et al., 2009; Di Salvo et al., 2007; Di Salvo et al., 2009; Miñano-Espin et al., 2017; Mohr et al., 2003; Reilly & Thomas, 1976). Notably, an investigation in the English Premier League highlighted that whilst substitutes across their playing period performed ~27% more HSR (~12.4 $m \cdot min^{-1}$) than whole-match players (~9.8 $m \cdot min^{-1}$), this was modulated by playing position and was not the case for fullbacks (Bradley et al., 2014). Conversely, with regard to SPR, substitute fullbacks and central midfielders covered more ground than their whole-match counterparts (Bradley et al., 2014). Substitute midfielders therefore covered greater relative SPR and HSR distances than whole-match players (Bradley et al., 2014), and Carling et al. (2010) considered only midfielders for their corresponding comparison in the French Ligue 1. These findings are potentially of relevance, as professional midfielders typically cover the greatest match distances of any playing position (Di Salvo et al., 2007; Di Salvo et al., 2009; Miñano-Espin et al., 2017; Mohr et al., 2003) and consequently suffer the largest between-half decrements in their physical performance responses (Bradley & Noakes, 2013; Di Salvo et al., 2009). Whilst no study has considered the actual match effectiveness of a substitute's relatively heightened movement responses, and acknowledging that different positions have different tactical roles, central midfielders were the only position for whom substitutes covered more relative HSR (~4.7 $m \cdot min^{-1}$ vs. ~3.8 $m \cdot min^{-1}$) whilst in possession of the ball (i.e., as opposed to relative HSR responses irrespective of possession status) than whole-match players (Bradley et al., 2014).

Taken together, the foregoing findings appear to suggest a potential role for the introduction of substitutes to increase match running responses relative to those around them. However, caution must be exercised when drawing conclusions based purely upon movement data. Even if substitutes can cover more ground than players remaining on the pitch, their effectiveness may rely upon the ability of other team members to respond. Moreover, technical and tactical performances are key components of soccer success alongside physical responses (Di Salvo et al., 2009; Hughes & Franks, 2005; Lago-Penas et al., 2010; Rampinini et al., 2009). Although pass-completion rates were similar between substitutes and whole-match players in the English Premier League (Bradley et al., 2014), further work is necessary to determine a substitute's technical/tactical performance and their overall impact on team success following match-introduction. It should also be noted that applied practitioners often use a player's movement data to inform the design of 'top-up' conditioning sessions for players who play <90 min (empirical observations). Therefore, when considered with reference to the goals of the overall periodised training programme, comparisons of match-play activity between substitutes and whole-match players may be important when determining the degree of 'topping-up' required.

2.3.2.2 Substitute responses relative to the same player's own habitual performance when completing a full match

English Premier League players covered greater TD and recorded 21% more HSR when they had been introduced as substitutes compared with the responses that the same individuals typically produced during the equivalent period of the second-half, but not the first-half, of matches in which they started (Bradley et al., 2014). These data support previous observations in which substitutes covered greater TD and 15% more distance at a speed ≥14.4 $km \cdot h^{-1}$ than during the equivalent period when completing 90 min (Bradley & Noakes, 2013). Unlike in the comparisons with whole-match players above, neither study observed differences in SPR responses. To determine the effect of substitution timing, players entering the pitch have been further categorised as either early (i.e., 45-65 min) or late (i.e., 65-90 min) substitutions (Bradley & Noakes, 2013). However, relative increases in TD and distance covered at a speed ≥14.4 $km \cdot h^{-1}$ compared with the equivalent period when completing a full match (~7-8% and ~14-16% increases, respectively) were similar for both the early and late groups (Bradley & Noakes, 2013).

With regard to the influence of playing position, findings have been inconsistent. Bradley et al. (2014) reported that although TD was greater for substitute central defenders, attackers, and central and wide midfielders, only attackers covered more HSR as substitutes compared with during the equivalent second-half period when completing a whole-match (~11.6 $m \cdot min^{-1}$ vs. ~9.3 $m \cdot min^{-1}$). In contrast, an earlier study had observed that central midfielders were the only position for whom distance covered at a speed ≥14.4 $km \cdot h^{-1}$ was significantly greater as a substitute compared with the same time period when completing 90 min, whilst substitute central defenders and fullbacks performed more SPR (Bradley & Noakes, 2013). Such inconsistencies notwithstanding, position-specific factors therefore seem to modulate a substitute's match running responses.

Carling et al. (2010) assessed players' activity profiles over their initial 10 min following introduction as substitutes with reference to their habitual responses during the opening 10 min when starting matches. The opening phase of play typically encompasses the most intense period of matches (Carling et al., 2008) and, although no differences were observed for midfielders, forwards covered significantly less TD during their first 10 min of competition when introduced as a substitute compared with the opening 10 min when the same players started a match. Unfortunately, no information was provided to indicate the adequacy of substitute forwards' pre-entry preparation (e.g., rewarm-ups), but the authors suggested that the discrepancy between positions may be related to differences in their respective tactical roles that may have resulted in difficulties for substitute forwards to 'get into the game' (Carling et al., 2010). Such inter-position variation highlights the potential importance of management staff making substitutions based upon situational and positional considerations such as a player's tactical role, amount of activity already performed in the match, and level of physical conditioning.

2.3.2.3 Substitute responses relative to the players being replaced

Given that an attempt to offset the effects of fatigue appears often to be a major motivation for managers in making substitutions (Bradley et al., 2014), it may be important to consider the ability of substitutes to produce higher relative running responses compared with the player that they directly replace (i.e., assuming that a substantial tactical change does not occur simultaneously). However, such analyses have rarely been conducted and existing findings are difficult to reconcile. A preliminary investigation using French Ligue 1 players observed no significant differences in running performance for substitute forwards following pitch-entry, when compared with the responses that had been produced during the preceding period of the second-half by those players being replaced (Carling et al., 2010). Although in midfielders TD was greater (~136.6 $m \cdot min^{-1}$ vs. ~129.3 $m \cdot min^{-1}$) for substitutes (Carling et al., 2010), their frequent involvement in many of the most decisive passages of play (Faude et al., 2012; Stølen et al., 2005) means that HSR and SPR rather than TD are often considered more important indicators of physical performance in soccer (Mohr et al., 2003).

When the relative responses of English Premier League starters and their direct replacements were compared across their respective playing times, substitutes covered greater TD and 10% more HSR, with fullbacks being the only position for whom substitutes' relative HSR did not exceed that of the players being replaced (Bradley et al., 2014). However, no differences were observed for pass-completion rates, and players being replaced alongside whole-match players both attained faster maximal running speeds than substitutes. The latter finding may be due to an increased playing duration providing greater opportunities for members of the starting team to sprint, but could also reflect differences in physical performance capacity (e.g., measures of linear speed, lower-body strength, and power) between players categorised as 'starters' and 'non-starters' (Manson et al., 2014; Risso et al., 2017; Silvestre et al., 2006). Moreover, the authors acknowledged the limitations of this independent-measures analysis (Bradley et al., 2014). Indeed, despite correcting for the amount of time spent on the pitch (i.e., variable$\cdot$min^{-1}), discrepancies in the length of the playing period between starters and substitutes (e.g., 75 min vs. 15 min) may have influenced how indices of running performance were represented due to differences in overall tempo or pacing strategies over different portions of a match (Bradley et al., 2014; Bradley & Noakes, 2013; Weston et al., 2011).

Research to date has therefore provided inconclusive evidence, but highlights the potential benefits of introducing substitute players during the second-half of FIFA-governed matches for increasing relative running outputs compared with players who started a match on the pitch (Bradley et al., 2014; Carling et al., 2010). However, whilst the perceived ability of substitutes to produce such responses appears to underlie a high proportion of substitutions that are made, indices of physical activity alone do not represent a player's overall performance or match impact. The objective of soccer is to outscore the opposition, and a replacement may still be considered a successful substitution if they make a substantial contribution to a match, irrespective of the fact that they may display 'worse' running performance than their exchanged counterpart (Bradley et al., 2014; Carling et al., 2010). Notably, an increased number of goals from substitutes was a factor discriminating a championship-winning season from four less successful years for a team competing in French Ligue 1 soccer (Carling et al., 2015).

A manager making a substitution may do so to facilitate alterations in team formation or strategy. Unfortunately, no study has investigated the effect of substitutions on inter-personal coordination or movement synchronisation, factors which may provide some indication of a team's tactical performance (Folgado et al., 2015). Notwithstanding, the fact that pass-completion rates remained similar for substitutes compared to either the player being replaced or those remaining on the pitch for the full 90 min (Bradley et al., 2014) is potentially an important observation. Whilst starting players may set a lower benchmark for comparison due to the deleterious effects of soccer-specific exercise on their ability to execute crucial technical skills (Harper et al., 2017; Harper et al., 2014; Russell et al., 2011a, 2012; Stevenson et al., 2017), these reports appear to suggest that despite regulations often preventing the performance of ball-skills during their pre-pitch-entry rewarm-ups performed whilst the match is underway, substitutes are able to meet the technical demands of the matches that they enter. However, pass-completion is not the only skill that is important to soccer match-play, and it is possible that other technical responses may deteriorate to a greater extent amongst players who start a match (Harper et al., 2014; Rampinini et al., 2009; Russell et al., 2011a; Russell et al., 2013). Alongside more in-depth profiling of physical match-play responses, further information regarding a substitute's technical and/or tactical performance following pitch-entry would be a valuable addition to the literature.

2.3.2.4 Within-match transient changes in substitute responses

The only study to have investigated transient changes in substitutes' match running responses following pitch-entry found no significant differences in physical outputs between successive five min match epochs (Bradley et al., 2014). However, there was a tendency for both TD and HSR to increase as the second-half progressed (Bradley et al., 2014). Whilst findings from small-sided games have demonstrated that knowledge of task-duration influences how soccer players regulate their physical outputs (Ferraz et al., 2018), this observation appears to conflict with the suggestion that substitutes likely respond to a shortened overall playing period by adopting unsustainably high initial running intensities upon entering the pitch (Waldron & Highton, 2014). Indeed, the performance profile observed in relation to soccer substitutes (Bradley et al., 2014) appears more akin to that reported during a player's second interchange bout as a substitute in rugby league, whereby certainty over the task end-point (i.e., full-time) means that a lower-intensity is initially adopted to allow for a possible 'end-spurt' of heightened activity (Waldron & Highton, 2014; Waldron et al., 2013). Nevertheless, this is only a single study in which match epochs were defined relative to the match kick-off. It is therefore possible that the reported data were influenced by the fact that substitutes are unlikely to be introduced neatly at the boundary of a pre-defined epoch (e.g., a substitution made after 67 min would occur in the middle of the 65-70 min match epoch). Research that defines epochs on an individual player basis according to the precise time of pitch-entry would allow assessment of transient changes in a substitute's match-play responses from the exact moment of introduction (e.g., 0-5 min post-pitch-entry, 5-10 min post-pitch-entry, etc.), irrespective of when in the match pitch-entry occurs. Moreover, given the logistical constraints associated with the role (i.e., restrictions on warm-ups etc.) and players' own concerns over inadequate opportunities for preparation when selected as substitutes (Holt & Hogg, 2002; Woods & Thatcher, 2009), it must be considered whether soccer substitutes are physically and mentally 'primed' to perform immediately upon pitch-entry. To support or refute the suggestion that current pre-entry activities may not optimally prepare substitutes to immediately perform to their capacity, further work should asses the physiological, psychological, and performance responses to current practices and seek to address any observed deficiencies.

2.4 Transitioning from rest to exercise

Undertaking an a period of prior physical activity before a main exercise bout is almost universally accepted as beneficial for improving physical performance capacity and potentially decreasing the risk of injury when subsequent activity commences (Bishop, 2003; Fradkin et al., 2010; McGowan et al., 2015; Silva et al., 2018; Towlson et al., 2013; Woods et al., 2007; Zois et al., 2011). Acknowledging that prior exercise may elicit physiological responses other than changes in indices of body temperature alone (Bailey et al., 2009; Burnley et al., 2001; Gerbino et al., 1996; Jones et al., 2003; Kilduff et al., 2007; MacDonald et al., 1997; Till & Cooke, 2009; Turner et al., 2015; West et al., 2013a; Wilson et al., 2013), this practice is typically referred to as ‘warming-up’. Notably, a meta-analysis that included 92 combinations of preparatory exercise (i.e., ‘warm-up’) and physical performance measures identified that an active warm-up improved performance in 79% of cases (Fradkin et al., 2010). More recently, the importance of an active warm-up for enhancing outcomes during team sports-specific explosive tasks (i.e., jumps, sprints, and changes of direction) has been reviewed (Silva et al., 2018). Whilst substantial methodological variation was observed with regard to factors such as the type of preparatory exercise performed, post-warm-up transition times, and physical performance outcome measures, 87.5% of the 19 eligible studies demonstrated significant improvements in jumping performance following an active warm-up (Silva et al., 2018). Similarly, 83% of studies observed improved change of direction ability when a warm-up had been performed, whilst isolated sprinting performance was enhanced in 69% of cases (Silva et al., 2018).

2.4.1 Pre-match warm-ups in soccer

Prior to the match kick-off, professional soccer teams typically complete an active warm-up that commonly lasts ≥25 min and at times up to ~45 min (Mohr et al., 2004; Towlson et al., 2013; Williams et al., 2019). Acknowledging that pre-match preparations vary between teams, warm-ups for outfield players often begin with low-intensity activities including dynamic stretching and activation movements, before progressing in intensity with the inclusion of sport-specific movement patterns and technical/tactical drills (Hammami et al., 2016; Williams et al., 2019; Zois et al., 2011). Despite such practices having traditionally been accepted as the norm (Hammami et al., 2016; Towlson et al., 2013), current evidence appears to suggest that as long as warm-up intensity is sufficient, comparable or favourable subsequent physical performance outcomes could be achieved with a substantial reduction in warm-up duration (Hammami et al., 2016; Pringle et al., 2013; Silva et al., 2018; Zois et al., 2011). For example, whereas no improvements were observed after a typical soccer warm-up that lasted for ~23 min, Zois et al. (2011) reported increases relative to baseline in reactive agility performance and countermovement jump (CMJ) height following completion of either a ~12 min small-sided game (i.e., three repetitions of two min, with two min rest between repetitions) or five repetition maximum leg press protocol. Acknowledging that the four min post-warm-up transition period adopted in that study may limit the ecological validity of these findings in relation to soccer players who start a match (Towlson et al., 2013), it is notable that sprint performance had declined following the longer traditional warm-up compared with a baseline measure (Zois et al., 2011). Whilst other non-physiological factors such as the ability to undertake psychological and tactical preparations must also be considered when designing any soccer preparation strategy, applied practitioners have ranked these effects amongst the least important potential benefits to flow from an active pre-match warm-up (Towlson et al., 2013). Indeed, when practitioners working in professional soccer were surveyed on the topic, elevating body temperature and increasing blood flow to muscles were stated as the primary reasons for undertaking a warm-up prior to the match kick-off (Towlson et al., 2013).

2.4.2 Physiological responses to preparatory exercise

Proposed mechanisms underlying the ergogenic effects of an active pre-match warm-up that reaches a sufficient intensity include increases in muscle metabolism (Edwards et al., 1972; Febbraio et al., 1996; Gray et al., 2006; Gray et al., 2008; Gray et al., 2011; McGowan et al., 2015), faster muscle fibre and/or nerve conduction rates (De Ruiter et al., 1999; Farina et al., 2005; Girard et al., 2009; Gray et al., 2006; Pearce et al., 2012), decreased resistance of muscles and joints (Bishop, 2003), increased blood flow to muscles (Bishop, 2003), a speeding of oxygen uptake ($\dot{V}O_2$) kinetics (Bailey et al., 2009; Burnley et al., 2001; Gerbino et al., 1996; Jones et al., 2003; MacDonald et al., 1997), postactivation potentiation (PAP) (Kilduff et al., 2007; Till & Cooke, 2009; Turner et al., 2015; West et al., 2013a; Wilson et al., 2013), and psychological benefits (Bishop, 2003; McGowan et al., 2015; Taylor et al., 2008; Tod et al., 2005). Acknowledging that many of the responses to an active warm-up are inherently interrelated, these mechanisms can be broadly categorised into a) those that are primarily induced by increases in indices of body temperature, and b) non-temperature-related mechanisms.

2.4.2.1 Elevated body temperature

During moderate- or high-intensity muscular activity (i.e., ≥~80% of an individual's lactate threshold) in ambient conditions of ~10-30 ºC, muscle temperature (T_m) rises rapidly from a baseline of ~33-37 ºC, before typically stabilising after ~10-20 min of exercise (Bishop, 2003; McGowan et al., 2015; Mohr et al., 2004; Saltin et al., 1968). Moreover, because T_m may increase or decrease as a consequence of surrounding environmental temperatures (Ferguson et al., 2006; Gray et al., 2006; Gray et al., 2008; Gray et al., 2011), a number of studies have employed passive methods (e.g., via the use of insulated garments, clothing containing electrical heating elements, warm water immersion, etc.) by which to elevate T_m without concomitant depletion of fuel substrates (Ferguson et al., 2006; Gray et al., 2006; Gray et al., 2008; Gray et al., 2011). Although team sports players are unlikely to engage in pre-match preparations that lack any active exercise component (Hammami et al., 2016; Silva et al., 2018; Towlson et al., 2013), passively manipulating T_m allows researchers to directly assess the specific responses flowing from temperature fluctuations by decoupling them from other physiological changes that may also be induced by an active warm-up.

Perhaps due to increases in the activity of key enzymes such as myosin ATPase, creatine kinase, phosphofructokinase, and lactate dehydrogenase, T_m elevations promote greater rates of phosphocreatine hydrolysis and glycolysis that accelerate adenosine triphosphate turnover and cross-bridge cycling during high-intensity exercise (Edwards et al., 1972; Febbraio et al., 1996; Gray et al., 2006; Gray et al., 2008; McGowan et al., 2015). Increases in T_m may also augment physical performance via increases in muscle fibre conduction velocity and rate of force development (De Ruiter et al., 1999; Farina et al., 2005; Girard et al., 2009; Gray et al., 2006; Pearce et al., 2012). A ~1 ºC elevation in T_m (i.e., measured at a depth of 1-4 cm) typically promotes improvements in muscular power output of up to ~2-10% (Faulkner et al., 2013; Sargeant, 1987), with performance during high-velocity muscle actions being particularly sensitive to temperature changes (Sargeant, 1987). Acknowledging that deep body or core temperature (T_{core}) values that exceed a critical level (~40 ºC) could be detrimental to muscular power output (Nybo & Nielsen, 2001), it has been proposed that an increase in body temperature typically represents the primary mechanism underlying the ergogenic effects of an active warm-up for soccer players (McGowan et al., 2015),

2.4.2.1.1 Assessing body temperature changes during soccer-specific exercise

Direct assessment of T_m during team sports-specific exercise is often precluded by the invasive nature of the measurement techniques required, particularly for research that is conducted in youth or elite player populations. However, acknowledging that discrepancies may exist with regard to the absolute magnitude and/or exact time-course of change (Mohr et al., 2004), T_{core} and T_m appear to follow very similar response patterns during a soccer match (Mohr et al., 2004). In situations where ethical or other reasons render T_m measurement impractical, quantifying T_{core} responses may therefore offer valuable insight into body temperature changes that have the potential to influence physical performance capacity. Indeed, several studies have observed a positive relationship between increases in T_{core} and improvements in physical performance outcomes within team sports players during high-intensity intermittent exercise (Kilduff et al., 2013b; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015d; West et al., 2016).

2.4.2.2 Non-temperature related warm-up responses

2.4.2.2.1 A speeding of oxygen uptake ($\dot{V}O_2$) kinetics

Alongside the ergogenic effects of raising T_m, other metabolic benefits may be realised when a main exercise bout is preceded by high-intensity activity (Bailey et al., 2009; Burnley et al., 2001; Gerbino et al., 1996; Jones et al., 2003; MacDonald et al., 1997). Possibly due to increases in oxidative enzyme capacity and/or motor unit recruitment (McGowan et al., 2015), performing prior activity at or above an individual's lactate threshold could promote a speeding of $\dot{V}O_2$ kinetics before and/or during subsequent exercise (Bailey et al., 2009; Burnley et al., 2001; Gerbino et al., 1996; Jones et al., 2003; MacDonald et al., 1997). Concomitant with such responses, ~15-30% improvements in the ability to maintain exercise performance have been reported during fixed-intensity tasks that were preceded by exercise of a sufficient intensity (Bailey et al., 2009; Jones et al., 2003). Acknowledging that studies using time to exhaustion as an outcome variable may have limited direct applicability to soccer players, it is plausible that increasing the contribution from oxidative metabolism during the early stages of a match could help to spare anaerobic pathways and thus limit the extent of intramuscular disturbance that a player experiences during intense periods of match-play (Bailey et al., 2009; Jones et al., 2003).

2.4.2.2.2 Postactivation potentiation (PAP)

The term PAP is used to refer to the phenomenon whereby prior high-intensity muscular contractions can facilitate transient improvements in neuromuscular performance, the magnitude of which exceeds the benefits of 'warming-up' *per se* (Turner et al., 2015). Immediately following exposure to a contraction stimulus of sufficient intensity, fatigue and potentiation may coexist within the muscle (Kilduff et al., 2013a; Rassier & MacIntosh, 2000; Tillin & Bishop, 2009). If an appropriate recovery period is subsequently provided, fatigue may dissipate to a greater extent than potentiation and muscular performance could be acutely enhanced (Kilduff et al., 2013a; McGowan et al., 2015; Tillin & Bishop, 2009; Turner et al., 2015; Wilson et al., 2013). Heavy resistance exercise has traditionally been used as a conditioning stimulus to induce PAP (Tillin & Bishop, 2009; Wilson et al., 2013), but performing plyometric exercises can also elicit PAP within sport-specific movement patterns due to their preferential recruitment of type II muscle fibres (Hamada et al., 2000; Tillin & Bishop, 2009; Turner et al., 2015). Whilst PAP responses may be influenced by factors such as the intensity of a conditioning contraction, the nature and intensity of subsequent exercise, and subject-specific considerations including an individual's strength levels, training experience, and muscle fibre composition (Chiu et al., 2003; de Alcantara Borba et al., 2017; Hamada et al., 2000; Tillin & Bishop, 2009; Turner et al., 2015; Wilson et al., 2013), the optimal recovery time between a moderate or high-intensity contraction stimulus and subsequent exercise performance appears typically to be ~7-10 min for trained individuals (Bevan et al., 2009; Kilduff et al., 2007; Turner et al., 2015; Wilson et al., 2013). Although the length of the transition period (i.e., typically >12 min) between cessation of the pre-match warm-up and the match-kick-off may often limit a starting player's ability to harness any substantial PAP effects from their pre-match warm-up (de Alcantara Borba et al., 2017; Kilduff et al., 2007; Towlson et al., 2013; Wilson et al., 2013), substitutes awaiting pitch-entry can usually complete further preparations whilst the match is underway. Therefore, it may be possible that substitutes could derive PAP benefits in addition to potential body temperature increases through the use of well-timed, well-designed, and well-executed active rewarm-ups performed shortly prior to pitch-entry.

2.4.2.2.3 Psychological responses

Engaging in a structured pre-exercise warm-up routine may provide an important opportunity for athletes to narrow their focus onto the task in hand (Bishop, 2003; Holt & Hogg, 2002; McGowan et al., 2015), and thus potentially enhance aspects of subsequent physical or technical performance via psychological as well as physiological mechanisms (Bishop, 2003; McGowan et al., 2015). Routinely undertaking specific pre-performance mental preparations is a characteristic of successful Olympians (Taylor et al., 2008), whilst 'psyching up' improved bench press force production by ~8% relative to a control condition and by ~12% compared with when a distraction technique had been implemented prior to performance (Tod et al., 2005). Acknowledging that psychological responses could plausibly differ depending on the precise circumstances surrounding an individual's selection (e.g., the potential for different responses between a player who has been 'dropped' from the starting team vs. a youth player or player returning from injury, for whom being named in the match-day squad as a substitute may provide a valuable opportunity for match-play exposure), players who have been named as substitutes (i.e., as opposed to being named within the starting team) may suffer several negative emotions such as self-presentation concerns and a lack of motivation to prepare (Woods & Thatcher, 2009). As the ability to complete a routine warm-up has been identified as a valuable coping mechanism to help maintain task-focus amongst international women's soccer players (Holt & Hogg, 2002), it is possible that substitutes may derive important psychological benefits from engaging in structured pre-pitch-entry preparatory activities, irrespective of the physiological responses elicited.

2.5 Physiological and performance responses to inactivity following exercise

2.5.1 Declines in body temperature and physical performance capacity

Despite its potential importance for helping members of the starting team to transition from a state of rest to a state of exercise (Bishop, 2003; Fradkin et al., 2010; McGowan et al., 2015; Silva et al., 2018; Towlson et al., 2013; Woods et al., 2007; Zois et al., 2011), many of the primary ergogenic benefits of a pre-match active warm-up may begin to dissipate shortly after warm-up completion (Kilduff et al., 2013b; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c). In support, half-time and post-warm-up transition time studies have typically observed significant declines in T_m and T_{core} alongside reductions in physical performance capacity after just ~10-15 min of inactivity following an initial exercise bout (Kilduff et al., 2013b; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c).

Vastus lateralis T_m may decrease by up to ~2 °C during a passive 15 min half-time (Lovell et al., 2013; Mohr et al., 2004), responses that demonstrate significant correlations ($r = 0.60$; ~1-4% reduction in sprint performance for every 1°C decrease in T_m) with reductions in sprint performance over the same period (Lovell et al., 2013; Mohr et al., 2004). Similar relationships ($r = 0.63\text{-}0.71$) have been observed between ~0.5-0.6 ºC losses of T_{core} and decrements in CMJ peak power output following ~15 min of inactivity (Kilduff et al., 2013b; Russell et al., 2017; Russell et al., 2015d). Notably, Mohr et al. (2004) reported that at least five min of subsequent match-play was required to restore T_m to first-half values after a passive half-time (Mohr et al., 2004). Acknowledging the likely influence of factors such as changes in team tactics and self-pacing strategies (Edwards & Noakes, 2009; Waldron & Highton, 2014), such responses may at least partly explain the transient reductions in physical outputs that are typically observed during the initial stages of the second-half compared with the first-half of a soccer match (Bradley et al., 2009; Mohr et al., 2003; Weston et al., 2011). Increases in known injury-risk factors such as declines in dynamic eccentric hamstring strength have also been reported to accompany a ~1.5 ºC reduction in T_m following a passive half-time (Lovell et al., 2013), whilst the frequency of injury treatments during the 1994 FIFA World Cup was greater during the initial period of the second-half compared with any other match quarter (Hawkins & Fuller, 1996).

Kilduff et al. (2013b) reported that ~72% of the T_{core} increase that was induced by an initial warm-up had dissipated when professional rugby league players subsequently rested for ~15 min in ~20 °C ambient conditions, whilst longer periods (i.e., beyond ~15 min) of post-warm-up inactivity typically facilitate even greater temperature and performance declines (Galazoulas et al., 2012; West et al., 2013b; Zochowski et al., 2007). Linear decreases in body temperature (i.e., assessed via the ear) and indices of explosive physical performance (i.e., CMJ height, 10 m and 20 m sprint speed) were reported when 14 elite basketball players remained rested for 10 min, 20 min, 30 min, or 40 min following cessation of a ~27 min warm-up (Galazoulas et al., 2012). Moreover, more pronounced T_{core} decreases (~0.7 °C vs. ~0.3 °C) were observed alongside ~1.5% inferior 200 m freestyle time trial performance when international swimmers remained inactive for 45 min after a standardised active warm-up compared with when just 20 min had elapsed following warm-up completion (West et al., 2013b). These findings expand upon previous reports in national standard swimmers, for whom ~1.4% inferior 200 m time trial performance was reported following a 45 min versus 10 min post-warm-up transition period (Zochowski et al., 2007). In the aforementioned study of international swimmers, it is notable that whilst ~40% of the T_{core} increases that were induced by the initial warm-up had been lost after 20 min of subsequent inactivity, T_{core} remained elevated above pre-warm-up values (West et al., 2013b). In contrast, T_{core} in the 45 min condition had returned to baseline (i.e., pre-warm-up) levels before the time trial commenced (West et al., 2013b). Such observations highlight that 45 min of subsequent inactivity negated the temperature benefits of performing the initial warm-up.

Substitute soccer players often face a substantial delay between cessation of the pre-match warm-up and their eventual entry onto the pitch. When one considers the ~15 min half-time period, the potential for first-half stoppage time, and the fact that >10 min typically elapses between the end of the pre-match warm-up and the match kick-off (FA, 2019/2020; Towlson et al., 2013), it is likely that pitch-entry would occur upwards of ~75 min following cessation of the initial warm-up even for a substitute who is introduced at half-time (i.e., the earliest point at which non-enforced changes are typically made). If effective preventative measures are not taken, there exists the clear potential for the restoration of thermal homeostasis to negatively influence physical performance capacity and possibly increase the risk of injury upon a substitute's introduction into a match (Galazoulas et al., 2012; Kilduff et al., 2013b; West et al., 2013b).

2.5.2 Strategies to offset body temperature and physical performance declines

2.5.2.1 Active rewarm-up strategies

Given the potential for body temperature (i.e., T_m and T_{core}) and physical performance capacity to decline during periods of inactivity that separate exercise bouts (Kilduff et al., 2013b; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c), identifying interventions that effectively maintain an optimised physical state following the warm-up completion may be of substantial importance to researchers and applied practitioners seeking to improve a player's subsequent performance. Primarily conducted in relation to the half-time interval, a body of research has developed that highlights how performing appropriately designed rewarm-up activities during otherwise inactive periods that last >10 min may benefit T_m, T_{core}, and subsequent physical performance responses compared with passive rest (Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c). For example, completing seven min of low- to moderate-intensity aerobic activity (i.e., running and other exercises at ~70% of maximum HR) during a 15 min half-time was effective at attenuating the declines in body temperature and sprint performance that were otherwise observed when players remained passive throughout this period (Mohr et al., 2004). The rewarm-up maintained T_m and T_{core} from the end of the first-half until the start of the second-half, producing T_m and T_{core} values at the end of half-time that were ~1.5 °C and ~0.9 °C higher, respectively, compared with the passive control condition (Mohr et al., 2004). Moreover, in contrast to the ~2.4% declines that were observed following a passive half-time, completing the active rewarm-up meant that sprint performance immediately after half-time had not decreased from pre-half-time or pre-match assessments (Mohr et al., 2004). Beneficial body temperature and/or physical performance responses (i.e., compared with a passive half-time) have been observed when rewarm-ups consisting of field-based agility exercise, heavy resistance exercise, low- to moderate-intensity jogging and calisthenics, or whole body vibration training have been performed during a ~15 min half-time period (Edholm et al., 2015; Lovell et al., 2013; Zois et al., 2013). However, observations from a ~12 min post-warm-up transition period appear to suggest that rewarm-up activities that emphasise eccentric muscle actions (i.e., four sets of three repetitions of the Nordic hamstring exercise) may impair explosive performance in subsequent tasks (i.e., CMJs and sprints) that require substantial stretch-shortening cycle contributions (Abade et al., 2017).

In addition to promoting improved physical performance during explosive tasks such as jumps and sprints, it is possible that undertaking appropriate rewarm-up activities could help to offset the potential increases in injury-risk that players may experience following a period of inactivity (Lovell et al., 2013). Possessing adequate eccentric hamstring strength represents an important factor in minimising the risk of hamstring strain injury for team sports players (Buckthorpe et al., 2019; McGrath et al., 2019; Timmins et al., 2016). As such, it is notable that dynamic eccentric knee flexion peak torque was maintained when soccer players performed five min of intermittent agility exercise or were exposed to whole-body vibration during a 15 min simulated half-time, whereas a ~6% decrease was observed during the equivalent period of inactivity (Lovell et al., 2013). Moreover, although the available data do not allow a firm causal link to be drawn, the frequency of strains and sprains during the third quarter of a match was reduced when team sports players performed a half-time rewarm-up compared with when such half-time activity was omitted (Bixler & Jones, 1992).

Potentially due to a priming of appropriate cognitive processing pathways alongside other physiological benefits such as increases in body temperature, incorporating soccer-specific technical actions during an active rewarm-up could augment subsequent skill execution (Russell et al., 2015c; Zois et al., 2013). In support, a half-time rewarm-up that included a three min small-sided game facilitated ~14% greater subsequent Loughborough Soccer Passing Test performance compared with a passive half-time condition, and produced ~6.4% improvements from pre- to post-rewarm-up (Zois et al., 2013). Furthermore, observations of reductions in defensive running at a speed >15 $km \cdot h^{-1}$ and increases in ball possession during the first 15 min of the second-half could potentially suggest an overall team advantage following an active half-time rewarm-up compared with a passive half-time (Edholm et al., 2015).

Based upon the foregoing information, and acknowledging the absence of data concerning physiological and performance responses during post-warm-up transition times that better reflect a substitute's typical match-day experiences (i.e., often ≥75-120 min), it seems likely that the activities completed by awaiting soccer substitutes between the match kick-off and pitch-entry may directly influence physical performance capacity and potentially affect injury-risk upon introduction into the match. Notwithstanding, several practical and regulatory barriers often exist that may limit the rewarm-up activity that can be performed between warm-up cessation and a substitute's entry onto the pitch. In addition to the limited space that is often available within many modern stadia, regulations in several competitions require members of team coaching staff to remain within a small 'technical area' whilst the match is underway (EFL, 2019). Unless an established pre-prepared routine exists within any specific team, the content of any rewarm-up activity in these circumstances must therefore be determined ultimately by the awaiting substitutes themselves. This may be an important consideration given that a lack of motivation to prepare has been identified amongst players who are selected as substitutes (Woods & Thatcher, 2009) and that athletes may demonstrate an inclination to perform the preparatory activities that they prefer, rather than necessarily those that best promote subsequent performance (Cook et al., 2013). Empirical observations suggest that when substitutes are left to determine their own pre-pitch-entry preparations, events unfolding on the pitch (e.g., controversial incidents occurring and/or the proximity of play to the awaiting substitutes) may profoundly influence the type and intensity of activities performed prior to pitch-entry.

2.5.2.2 Passive heat maintenance strategies

In situations where it may not be possible or desirable to perform active rewarm-ups, implementing passive heat maintenance techniques such as wearing insulated or head garments may also help to preserve body temperature and thus contribute towards physical performance maintenance when periods of inactivity follow an initial exercise bout (Beaven et al., 2018; Bishop, 2003; Faulkner et al., 2013; McGowan et al., 2016; Russell et al., 2017; Russell et al., 2015d; West et al., 2016). When a 30 s maximal cycling test was commenced 30 min after cessation of an active warm-up, improvements in absolute power output (~9.6%) and power output expressed relative to body mass (~9.1%) were observed when heated tracksuit pants had been worn during the post warm-up period compared with wearing a conventional tracksuit (Faulkner et al., 2013). Whilst vastus lateralis T_m declined during the 30 min transition period in all conditions, these performance improvements after wearing the heated pants were attributed to the fact that T_m at the start of exercise was maintained at a significantly higher level compared with when either an insulated garment or a normal tracksuit had been worn (Faulkner et al., 2013).

With regard to team sports players performing team sports-specific tasks, wearing a custom made survival garment during a passive half-time attenuated declines in T_{core} (~0.7% vs. ~1.5% decline) amongst professional rugby union players compared with when normal training attire had been worn (Russell et al., 2015d). Such responses were accompanied by ~3.2% improvements in post-half-time CMJ peak power output and up to ~1.4% greater second-half sprint performance in the passive heat maintenance (i.e., survival garment) condition (Russell et al., 2015d). Similar temperature and physical performance benefits have been reported when professional rugby league players wore a survival garment during a 15 min post-warm-up transition period (Kilduff et al., 2013b). Given the positive relationship ($r = 0.67$-0.71) that was observed between changes in T_{core} and CMJ peak power output during 15 min of inactivity, it is notable that ~72% and ~24% of the T_{core} increases that had been elicited by the initial warm-up were lost in the control and intervention conditions, respectively (Kilduff et al., 2013b). Although not all studies have demonstrated a physical performance benefit to applying passive heat maintenance techniques (Marshall et al., 2015), when the foregoing observations are considered alongside other similar reports (Russell et al., 2017; West et al., 2016), it appears likely that implementing passive heat maintenance via the use of insulated or heated garments may at least partially attenuate declines in body temperature and thus help to maintain explosive physical performance during periods of inactivity that last ≥15 min.

2.5.2.3 Combining active and passive strategies

Although active rewarm-ups and passive heat maintenance techniques may each independently help to attenuate the negative body temperature and/or physical performance responses that are typically associated with periods of inactivity prior to exercise (Faulkner et al., 2013; Kilduff et al., 2013b; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c), it is possible in cold or thermoneutral environments that the greatest benefits may be derived from implementing both strategies in combination (McGowan et al., 2016; Russell et al., 2017; West et al., 2016). During a simulated half-time amongst professional rugby union players, preceding a seven min active rewarm-up (i.e., consisting of low- to moderate-intensity jogging and ball skills) with eight min of passive heat maintenance (i.e., via the use of a survival jacket) better maintained T_{core}, CMJ peak power output, and repeated sprint performance compared with both a control condition and relative to when either technique was used in isolation (Russell et al., 2017). Moreover, when another sample of professional rugby union players wore normal training attire during a 20 min post-warm-up transition period, ~85-88% of the T_{core} elevations that were induced by the initial warm-up had subsided in conditions in which they either remained inactive throughout or punctuated the ~20 min transition with three sets of five CMJs (with an additional load equivalent to 20% of body mass) performed after 12 min (West et al., 2016). Although wearing a survival garment attenuated T_{core} declines (i.e., a ~29-30% loss of warm-up-induced T_{core} increases) irrespective of whether used in isolation or in conjunction with the CMJ rewarm-up protocol (West et al., 2016), the combination of passive heat maintenance and the CMJ rewarm-up better maintained subsequent physical performance compared with passive rest and compared with either intervention in isolation (West et al., 2016). Whilst improved temperature preservation is likely to largely explain the increased physical performance when the survival garment had been worn relative to normal training attire, it is possible that the combined condition enabled players to simultaneously access a PAP effect alongside the benefits of T_{core} maintenance (West et al., 2016).

2.6 Considerations for substitutes receiving limited match-play exposure

Potentially heightened relative physical responses notwithstanding (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010), their reduced playing time (i.e., typically ≤45 min) is likely to result in substitutes experiencing substantially lower absolute match-play demands compared with outfield players who started a match on the pitch. This may be an important consideration when one contemplates that professional soccer teams often design in-season preparatory programmes with the primary objectives of maximising recovery and minimising fatigue across a whole squad prior to the next match or series of matches (Anderson et al., 2016b; Kelly et al., 2020; Malone et al., 2015). As such aims may typically be realised through a reduction in training volume and/or intensity compared with the pre-season period (Jeong et al., 2011; Malone et al., 2015), the activities performed during match-play itself could represent a substantial contributor to a player's overall physical loading and may thus provide an important stimulus for several sport-specific physical adaptations (Morgans et al., 2018; Silva et al., 2011). In support, a player's overall match playing time during periods of a professional soccer season was positively associated ($r = 0.58$-0.79) with improvements in 5 m sprint performance and markers of lower-limb strength (Silva et al., 2011), whilst HSR outputs during English Premier League matches may have acutely benefited CMJ performance when assessed three days following the match completion (Morgans et al., 2018). If a substitute's limited playing time restricts their overall physical loading (e.g., absolute HSR loads) on an acute or ongoing basis, and these deficits are not adequately addressed through additional training, they may receive a reduced stimulus for important physical adaptations such as improvements in speed and strength (Morgans et al., 2018; Silva et al., 2011).

Substantial fluctuations in physical loading may be associated with an increase in injury-risk amongst team sports players (Duhig et al., 2016; Malone et al., 2017a; Malone et al., 2017b). Acknowledging that unused squad members or partial-match players often perform some 'top-up' training in an effort to maintain appropriate loading patterns, their exposure to typically limited match-day demands has the potential to elevate a player's subsequent injury-risk if absolute loads are allowed to decline over time (Buchheit, 2019). Notably, when combined match-play and training loads were quantified across an entire English Premier League season, habitual 'non-starters' (i.e., defined as individuals who were selected in the starting team for <30% of matches) accumulated significantly lower HSR (~19 km vs. ~35 km), and SPR (~3 km vs. ~11 km) distances compared with players who started in ≥60% of matches (Anderson et al., 2016a). If a reduction in physical load is not desired as part of the broader training programme, these observations may highlight potential disadvantageous loading patterns for non-starters compared with players who are regularly selected within the starting team (Bowen et al., 2017; Buckthorpe et al., 2019; Colby et al., 2018; Morgans et al., 2018; Silva et al., 2011).

Despite observations that increasing the number of matches scheduled per week led to greater overall weekly physical loads (i.e., combined training and match-play loads) across a squad (Anderson et al., 2016b), factors such as likely heightened travel demands and limited access to training facilities mean that an increase in fixture density may serve to reduce the number of team training sessions that can be completed within a given timeframe (Anderson et al., 2016b). Moreover, compared with when only one match is scheduled to be played, a team that must fulfil two or three fixtures per week is likely to require more days of reduced training volume or intensity alongside modification of nutritional practices to promote physical and psychological recovery ahead of each match (Anderson et al., 2016b; Ranchordas et al., 2017). In support, English Premier League players trained on four out of six non-match-days when only one fixture was played in a week, covering between ~1.9 $km \cdot player^{-1} \cdot day^{-1}$ and ~2.5 $km \cdot player^{-1} \cdot day^{-1}$ (Anderson et al., 2016b). In contrast, the same squad completed training sessions on just two days during a three-match week, with TD remaining <1.6 $km \cdot player^{-1} \cdot day^{-1}$ (Anderson et al., 2016b). Match-play loads aside, these data indicate that increases in the density of fixture scheduling may serve to reduce the physical loads that are elicited during team training (Anderson et al., 2016b). Such observations could be important considerations in relation to squad members who receive limited match-play exposure, for whom training activities are likely to provide a proportionately greater contribution to their overall physical loading compared with players who regularly feature within the starting team (Anderson et al., 2016a). For these individuals, it may be necessary to perform additional training activities during periods of high fixture density to help maintain appropriate physical loading patterns that could promote or maintain positive physical adaptations and thus potentially reduce injury-risk (Bowen et al., 2017; Buckthorpe et al., 2019; Colby et al., 2018; Morgans et al., 2018; Silva et al., 2011).

The notion that substitutes typically experience reduced weekly loads compared with regular whole-match players is reinforced by empirical observations that the use of substitutions may at times reflect an effort to limit the accumulation of fatigue for a given individual or across a whole squad by ensuring that physical loads remain within tolerable limits (i.e., by managing the amount of match-play exposure that a player receives). Indeed, it has been suggested that the effective implementation of this 'squad rotation' strategy may at least partly explain reports that professional soccer teams have typically been able to maintain match running responses during congested fixture periods (Carling et al., 2012; Dellal et al., 2015). When a professional team completed eight matches within a 26 day period, only six players participated in every match as either a starter or a substitute and just a single outfield player spent the full duration of all eight matches on the pitch (Carling et al., 2012). Similarly, only four outfield players from a French Ligue 1 club completed ≥75 min of every match across three separate periods of fixture congestion (i.e., six matches in 18 days) (Dellal et al., 2015). Acknowledging that other reasons may also contribute to these findings (e.g., injury, illness, player suspensions, etc.), such observations appear to indicate the use of squad rotation to minimise the exposure of any individual players to a potentially performance-limiting volume of match-play.

2.7 Psychological responses of soccer substitutes

Three studies to date (Table 2.3) have considered the position of soccer substitutes from a psychological standpoint, either as a primary aim (Woods & Thatcher, 2009), or as part of wider research documenting players' mental states (Gilbourne & Richardson, 2006; Holt & Hogg, 2002). Woods and Thatcher (2009) individually interviewed 15 semi-professional and five professional soccer players, both male and female, to explore their emotional responses to being selected as substitutes. During both the 'pre-game' and 'performance' periods, players selected as substitutes reported mainly negative experiences which were broadly categorised into 'person' and 'organisational' factors. Person factors included dissatisfaction with status, self-presentation worries, a lack of control over their own performance and coaches' decisions, reduced motivation to prepare, and increased anxiety. Organisational factors centred on restriction of a substitute's ability to prepare for match-play, a lack of communication/explanation from coaches, and segregation from other team members. Being named 'on the bench' has previously been identified as a source of stress for players, who take dissatisfaction at the lack of control associated with this role and may view the position as one of diminished status relative to members of the starting team (Holt & Hogg, 2002; Ryall, 2008). Indeed, it has been suggested that even when players experience success as a substitute, this may foster fears of becoming typecast in this perceived 'lesser' role (Woods & Thatcher, 2009).

Self-presentation concerns and anxiety surrounding their perception by others (Holt & Hogg, 2002; Woods & Thatcher, 2009), may see substitutes align themselves with social goals (i.e., to prove their worth) that detract from their match-focus (Woods & Thatcher, 2009). As a player's mental-state has the potential to influence hormonal and performance responses (Cook & Crewther, 2012a, 2012b), team coaches and psychologists must be aware of a substitute's possible negative emotions and devise methods by which players may better cope with their role and ensure that they pursue task-orientated goals (Gilbourne & Richardson, 2006; Holt & Hogg, 2002; Reilly & Gilbourne, 2003; Woods & Thatcher, 2009). Notably, the ability to complete a routine warm-up has been identified as an effective coping mechanism to help maintain task-focus in international women's soccer players (Holt & Hogg, 2002).

The substitute populations considered to date appear to have associated the position with overwhelmingly negative experiences. However, although no respondents were happy with their status as substitutes, more positive sentiments were expressed by those individuals who managed to accept the role and retain confidence in their ability to perform well (Holt & Hogg, 2002; Woods & Thatcher, 2009). Whilst a strikingly negative reaction from a professional player was recalled by Gilbourne and Richardson (2006), it remains to be seen whether the emotional responses of substitutes at the highest level of soccer, who are often well remunerated, or in leagues with different substitution rules (e.g., NCAA competitions), mirror those reported to date. Moreover, it would appear logical to posit that experiences may contrast between substitutes who have been or are likely to be introduced during a match, and those who remain unutilised. Existing investigations appear to assume that all players expect to be selected in the starting eleven, whereas it is plausible that a more positive outlook may be had by a player who has been named as a substitute after a lengthy injury layoff, a designated 'impact substitute', or a youth player making their first-team debut. In addition, the influence of selection frequency on players' attitudes has not yet been examined.

Table 2.3: Studies examining the emotions or experiences of soccer substitutes

Study	Players	Data collection	Negative experiences	Positive experiences	Coping strategies
Holt and Hogg (2002)	International women's players (n=7).	Face-to-face interviews.	Stress, pressure, fear, anxiety, lack of preparation, self-presentation concerns, lack of confidence, lack of certainty/communication of role.	Having a good start.	Task-focus (e.g. routine warm-up). Supportive behaviour from teammates, parents, and significant others.
Gilbourne and Richardson (2006)	Professional player (n=1).	Psychologist's observations and reflections.	Anger, upset, frustration, lack of belonging, rejection, loneliness, embarrassment.	Psychologist can help with role acceptance.	Caring environment is essential (psychologist can aid this).
Woods and Thatcher (2009)	Semi-professional (n=15; 12 male, 3 female), and professional (n=5) players.	Face-to-face training ground interviews.	Person factors: dissatisfaction, self-presentation concerns, reduced control, reduced motivation, anxiety, pressure. Organisational factors: short notice, segregation, poor communication/explanation, restricted preparation.	Some role acceptance, task-focus, and confidence.	Coaches should provide communication and be aware of how to help subs cope with the role.

Subs: Substitutes.

2.8 The role of descriptive research and conceptual approach to the thesis

Despite pursuing broadly similar objectives (i.e., to improve aspects of athletic performance, reduce the risk of injury, etc.), the effective transfer of knowledge from academic researchers to applied practitioners is often made difficult by the diverging contextual frameworks within which these two groups operate (Coutts, 2016; Jones et al., 2017; Malone et al., 2018). University-based researchers may be able to dedicate a substantial amount of time and resources to solving complex theoretical problems, whereas practitioners working 'in the field' are required to quickly and effectively provide athletes with practical answers to daily questions (Coutts, 2016; Jones et al., 2017). Although having simultaneous access to 'fast' working practitioners and 'slow' working researchers may be beneficial for enhancing real world sporting practice, it is not always possible to position both of these groups within an applied environment (Coutts, 2016; Harper & McCunn, 2017). As such, developing effective ways in which to 'bridge the gap' between research knowledge generation and research knowledge application represents a crucial endeavour for the success of applied research in sport.

Particularly with regard to professional sport, maximising the transferability of science into practice requires researchers to understand the contextual backdrop against which their findings may be applied (Bishop, 2008; Drust & Green, 2013; Jones et al., 2017; Malone et al., 2018). Beyond delineating a specific set of problems to be addressed, it is necessary to identify the broader traditions and potential barriers existing within applied practice, so that relevant research questions may be tackled using methods which carry the greatest possible ecological validity (Drust & Green, 2013). Such information may be gleaned by conducting descriptive research, which can help to identify a specific set of real world problems and also provides contextual information to inform the appropriate design of subsequent studies (Drust & Green, 2013).

Technological advances in recent decades have provided the opportunity for researchers and practitioners from around the world to freely and quickly communicate. One method of descriptive study that has gained traction within professional soccer seeks to involve practitioners from multiple organisations during the early stages of the research process by soliciting (e.g., through distribution of short surveys) their perceptions, opinions, or current approaches in relation to a topic (Akenhead & Nassis, 2016; Harper et al., 2016c; Harper & McCunn, 2017; McCall et al., 2014; McCall et al., 2015; Towlson et al., 2013). By giving practitioners a stake (albeit indirect) throughout the research process, it is hoped that pertinent problems may be identified and receptiveness to the uptake of research findings may be more forthcoming (Harper & McCunn, 2017). Indeed, if prior descriptive studies lead to appropriate framing of research questions and greater ecological validity in study design, the potential for research to enhance practice could be greatly improved (Harper & McCunn, 2017).

Where an area of research is in its infancy, survey-based studies have been combined with other observational methods to glean an understanding of problems that need to be addressed and to identify areas in which practitioners may be most amenable to research intervention. For example, alongside observational work documenting physical and technical performance responses (Harper et al., 2014; Russell et al., 2015b), Harper et al. (2016c) surveyed 46 practitioners working within professional soccer to establish their perceptions and practices with regard to the soccer extra-time period. Besides highlighting a desire for specific regulatory changes such as allowing a fourth substitution to be made during matches that require extra-time, practitioners identified nutritional interventions and fatigue responses as important areas requiring research attention (Harper et al., 2016c); findings that were reflected in the design of future extra-time studies (Goodall et al., 2017; Harper et al., 2016b). Owing to the limited knowledge currently existing in relation to soccer substitutes, the body of research contained within this thesis will broadly align with the conceptual framework that was advanced by Bishop (2008) and subsequently modified by Drust and Green (2013) with specific reference to applied research in soccer. This model emphasises the importance of conducting descriptive research to identify a specific set of problems and provide context to inform the design of subsequent studies on the same or similar topics (Drust & Green, 2013). Moreover, the value of 'effectiveness' research is championed, in which researchers assess the impact and feasibility of interventions within a real world (i.e., as opposed to highly-controlled laboratory conditions) context (Drust & Green, 2013).

2.9 Thesis aims

The foregoing information highlights the need for additional research relating to the bespoke practices and responses of soccer substitutes. Using an "assess then address" approach to applied soccer research, this thesis aimed to investigate the performance and physiological responses of substitute soccer players on match-day. Such information would add to the currently limited literature relating to substitutes and allow recommendations to be made for players, practitioners, researchers, and policy makers seeking to improve the match-day and non-match day practices of this bespoke and highly valued population of soccer players. The primary objectives of this work were thus:

- To examine practitioner perceptions regarding the practices of substitutes, whilst identifying potential barriers to the uptake of future research findings ('assess').
- To quantify the match-day responses of professional soccer substitutes before and after pitch-entry, including during post-match conditioning sessions ('assess').
- To explore the efficacy of modified practices associated with improving match-day preparations for substitutes ('address').

A series of studies were therefore designed to achieve these objectives (Figure 2.3). The specific aims of each study were: were as follows:

Study one (chapter three): As limited research was available in relation to the practices of soccer substitutes, the aim of this study was to use both qualitative and quantitative methods to examine the perceptions of applied practitioners regarding the practices of substitutes in professional soccer.

- It was anticipated that practitioners and coaches would value the role of substitute players and employ specific preparatory strategies unique to this population.

However, specific logistical considerations would exist to limit what is possible and preparatory practices would be based largely upon players' individual preferences.

Study two (chapter four): Uniquely, substitutes typically face lengthy delays (often ≥75 min) between cessation of the initial warm-up (i.e., preparatory activities performed prior to kick-off) and their entry onto the pitch for usually <45 min of match-play. To provide a starting point on which to base future research, the dual objectives of this study were to investigate substitutes' pre-pitch-entry activities and assess transient changes in their physical responses following introduction into a match.

- H_{0a}: Substitutes' pre-pitch-entry activity profiles will be similar during rewarm-ups performed whilst the match is underway compared with the pre-match warm-up.
- H_{0b}: Substitutes' physical performance responses will not differ from 0-5 min post-pitch-entry during any subsequent five min epoch following match-introduction.
- H_{1a}: Substitutes' activity profiles will differ during rewarm-ups compared with the pre-match warm-up.
- H_{1b}: Substitutes will demonstrate transient changes in physical performance responses across five min epochs following pitch-entry.

Study three (chapter five): By replicating current practices within a controlled environment, this study aimed to profile the physiological and performance effects of typical pre-pitch-entry preparations for substitutes while also assessing responses during simulated partial match-play.

- H_0: No changes in physiological or performance responses during the pre-pitch-entry or post-pitch-entry periods will be observed when replicating substitutes' current match-day preparatory strategies.
- H_1: Physiological and performance responses will change transiently during the pre-pitch-entry and post-pitch-entry periods of a simulated match-day for substitutes.

Study four (chapter six): Post-match 'top-up' conditioning sessions may be important for helping to maintain an appropriate degree of physical loading for substitutes who experience little or no match-play exposure. However, data were lacking with regard to profiling the acute responses to such practices. The aim of this study was to quantify the external loads elicited during post-match top-up sessions for players who were selected in the match-day squad as substitutes, whilst investigating contextual influences.

- H_0: Contextual factors will not influence the physical demands of post-match top-up sessions.
- H_1: Contextual factors will influence the physical demands of post-match top-up sessions.

Study five (chapter seven): Modifying a player's pre-pitch-entry preparatory strategies has the potential to influence their responses following match-introduction. Therefore, taking an applied case-study approach similar to that in study two in chapter four, this study aimed to profile the pre- and post-pitch-entry movement responses of professional soccer substitutes following modification of their pre-pitch-entry routine.

- H_{0a}: Substitutes' pre-pitch-entry activity profiles will be similar during rewarm-ups performed whilst the match is underway compared with the pre-match warm-up.
- H_{0b}: Substitutes' physical performance responses will not differ from 0-5 min post-pitch-entry during any subsequent five min epoch following match-introduction.
- H_{1a}: Substitutes' activity profiles will differ during rewarm-ups compared with the pre-match warm-up.
- H_{1b}: Substitutes will demonstrate transient changes in physical performance responses across five min epochs following pitch-entry.

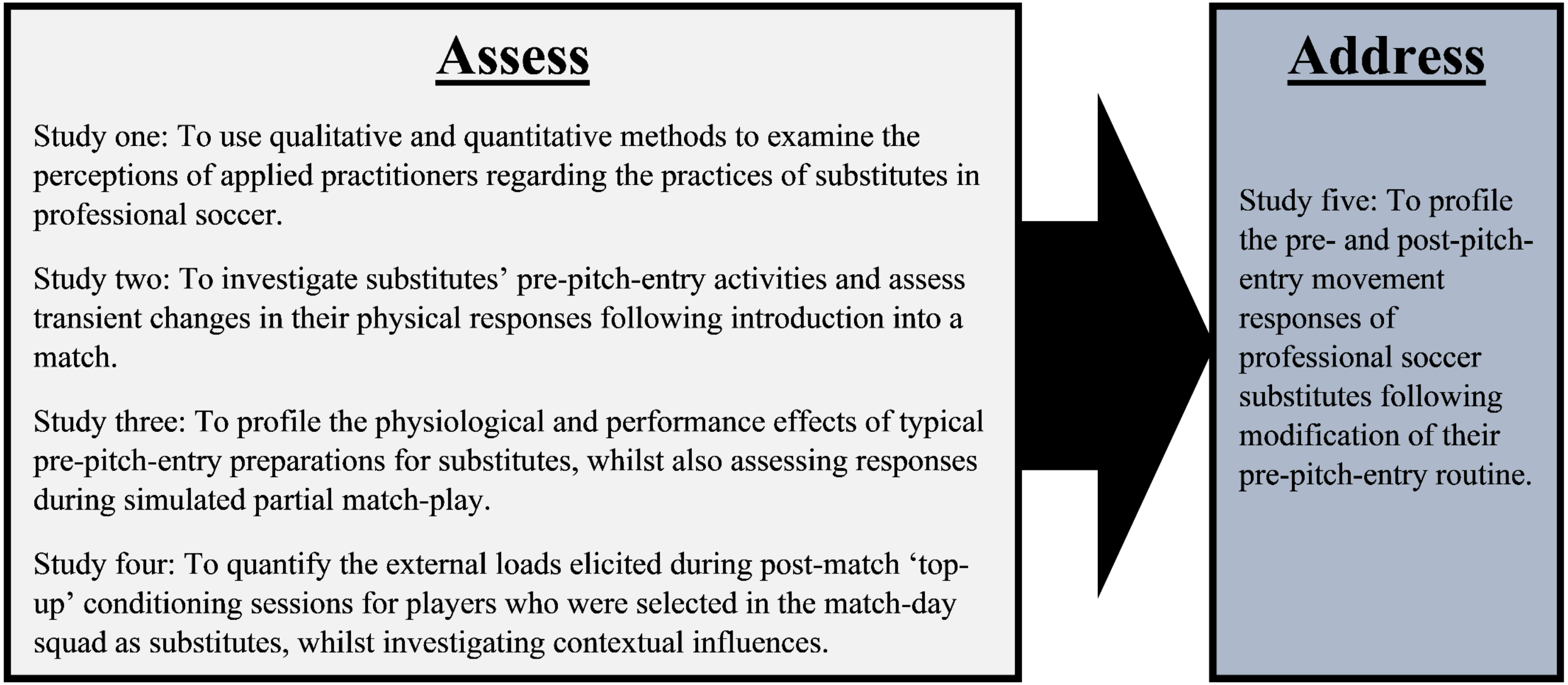

Figure 2.3: Outline of specific study aims

Chapter 3.0 Practitioner perceptions regarding the practices of soccer substitutes

Chapter summary

- Thirty-three practitioners working in professional soccer completed one of two surveys, depending upon whether their primary role related mostly to tactical (n = 7) or physical (n = 26) aspects of player/team management.
- Eighty-five percent of practitioners believed that substitutes are important in determining team success during match-play, with the primary justification being the perceived ability of such players to provide a physical and/or tactical impact on a match.
- Contextual factors such as substitutes undergoing adequate pre-pitch-entry preparation may be important for realising substitution aims, but uncertainty exists as to the efficacy of current pre-pitch-entry practices. Practitioners (100%) highlighted 'preparatory strategies' as at least a 'moderately important' direction for future research.
- Although many practitioners believed that there was a need for substitutes to engage in bespoke non-match-day preparations and recovery strategies that differ from starting players, logistical considerations such as scarcity of resources, often limit their scope.
- Notwithstanding, 96% of respondents indicated that substitutes frequently perform extra conditioning sessions to account for deficits in physical loads compared with players exposed to a longer period of match-play.
- This study presents novel insights and highlights areas that are considered to be future research priorities amongst those working in the field.

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3.1 Introduction

Depending on the specific competition regulations, soccer teams are permitted to replace between three and an unlimited number of starting players during a match, on either a permanent or 'rolling' basis. Rules imposed by FIFA currently permit a maximum of three starting players (up to six in some competitions) to be irreversibly replaced from a 'bench' of typically six or seven (up to 12 in some competitions) substitutes (FIFA, 2019/20). Notably, regulations governing the use and practices of substitutes vary markedly between competitions (i.e., often due to the jurisdiction of different national governing bodies), and certain rules appear to be in a state of flux. For example, the English Football League requires team staff to remain within a 'technical area' whilst the match is underway (EFL, 2019). Conversely, where stadium design allowed, legislation governing the 2018 FIFA World Cup permitted up to two officials to accompany up to six players at any one time in a designated rewarm-up area behind the goals (FIFA, 2018). Moreover, in a change endorsed by applied practitioners (Harper et al., 2016c), some competitions (including the 2018 FIFA World Cup) have incorporated a rule permitting a fourth substitution (i.e., in addition to the three allowed during 'normal time') to be made when tournament matches progress to extra-time (FIFA, 2018; Harper et al., 2016c). As contextual and regulatory factors may thus modulate the practices of substitutes and their support staff, a deeper understanding of the potential impact of such provisions would be beneficial for researchers and practitioners seeking to optimise the preparations of substitute players.

Although the physical demands of soccer are primarily aerobic in nature (Bangsbo et al., 2007; Bangsbo et al., 2006; Krustrup et al., 2006; Mohr et al., 2005), the most decisive passages of match-play often involve higher-intensity actions such as HSR, SPR, changes of direction, and/or the execution of technical skills (Di Salvo et al., 2010; Faude et al., 2012; Reilly, 1997; Stølen et al., 2005). For players who start a match, progressive declines in indices of physical (e.g., HSR, number of accelerations and decelerations, etc.) and technical performance (e.g., shooting and passing skills, etc.) are experienced throughout 90 min of soccer-specific exercise (Di Salvo et al., 2009; Mohr et al., 2003; Rampinini et al., 2011; Rampinini et al., 2009; Russell et al., 2011a, 2012), with further deteriorations observed during matches that progress to extra-time (Harper et al., 2016a; Harper et al., 2014; Russell et al., 2015b; Stevenson et al., 2017). Given the likely importance of such actions in determining the outcome of a match (Di Salvo et al., 2010; Faude et al., 2012; Rampinini et al., 2009; Reilly, 1997; Stølen et al., 2005), researchers and practitioners share an interest in elucidating means by which team performance may be maintained throughout the duration of match-play.

Soccer substitutes are typically introduced at half-time or during the second-half of a match (Bradley et al., 2014; Del Corral et al., 2008; Gomez et al., 2016; Myers, 2012; Padrón-Cabo et al., 2018; Rey et al., 2015), ostensibly with the primary objectives of offsetting the effects of fatigue, changing team tactics, or replacing players deemed to be injured or underperforming. However, it is acknowledged that the timing and rationale for the introduction of substitutes may be context-specific, and other motivations (e.g., providing match-exposure to inexperienced players or those returning from injury) may also play a role. The limited research published to date suggests that players entering the pitch at half-time or later may perform relatively more TD and/or HSR compared with during the equivalent second-half period when the same individuals complete a full-match (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010). However, they appear unable to exceed the relative locomotor responses that they would typically cover during the first-half of matches that they start (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010). As substitutes are presumed to be free from substantial physical fatigue at the time of pitch-entry, questions may thus remain as to whether the acute pre-pitch-entry preparations undertaken by this population facilitate optimal performance thereafter. Notably, given the length of time typically elapsing between cessation of the pre-match warm-up and a substitute's entry onto the pitch (i.e., often ≥75-120 min), there exists the potential for processes such as acute losses in T_m and T_{core} to negatively influence a player's ability to execute important sport-specific actions upon pitch-entry compared with if they had started a match (Crowther et al., 2017; Galazoulas et al., 2012; Lovell et al., 2013; Russell et al., 2017; Russell et al., 2015d; Silva et al., 2018; West et al., 2013b).

Surveying applied practitioners allows researchers to better understand the context within which this population operates and may thus help to improve the transfer of science to practice (Harper et al., 2016c; Harper & McCunn, 2017). Indeed, when taking an "assess then address" approach to applied research, knowledge gleaned through descriptive studies can provide the context necessary to formulate apposite research questions, whilst identifying potential barriers to uptake may better inform study designs that are greater in ecological validity (Bishop, 2008; Drust & Green, 2013; Harper & McCunn, 2017). In professional soccer research, surveys have been used to report the perceptions and practices of practitioners in relation to topics such as player monitoring and injury prevention (Akenhead & Nassis, 2016; McCall et al., 2014; McCall et al., 2015), warm-up and rewarm-up strategies (Towlson et al., 2013), and the extra-time period (Harper et al., 2016c). Notably, including qualitative components within such surveys (e.g., via the use of open-ended questions) allows further valuable insight into the intricacies and idiosyncrasies of applied practice. Given the scarcity of research presently available in relation to the practices of soccer substitutes, the aim of this study was to use both qualitative and quantitative methods to examine the perceptions and approaches of applied practitioners regarding substitutes in professional soccer. Such novel information may help to contextualise the currently limited literature pertaining to soccer substitutes, in addition to highlighting important directions and considerations for future research in this area.

3.2 Methods

3.2.1 Participants

Following ethical approval from the School of Social and Health Sciences Research Ethics Committee at Leeds Trinity University (Appendix 1), an online poster and web link were advertised via social media. Inclusion criteria for participation required that individuals were at least 18 years of age and currently practiced as a coach, manager, or member of support staff for a professional soccer team. A total of 33 participants were recruited. This sample size broadly reflects previously published work using online surveys amongst professional soccer practitioners (McCall et al., 2015; Towlson et al., 2013).

Eligible participants were invited to complete one of two surveys (depending upon their specific occupational role) on a single occasion, which were specifically created and accessed via an online resource (Jisc Online Surveys; Bristol, UK). All responses were anonymous, whereby the only personal information that participants were asked to disclose was the highest level of professional soccer team that they worked with at the time (Table 3.1). The survey remained 'live' for 150 days following initial dissemination of the access web link, and all participants were required to confirm their informed consent to progress to the survey questions. The surveys were piloted in advance within the PhD supervisory team and each had a completion time of approximately 10-15 min.

Online surveys were chosen as the appropriate mode of data-collection for this study because such instruments can reach a wide range of potential participants and allow participant anonymity to be guaranteed (Harper et al., 2016c; Harper & McCunn, 2017; Towlson et al., 2013). Given that empirical observations and low response-rates in previous practitioner research suggest a culture of relative secrecy and suspicion within professional soccer (McCall et al., 2015; Towlson et al., 2013), anonymity was deemed important for encouraging practitioners to engage. In addition, online survey-based research may help to minimise the burden (e.g., in terms of time) on practitioners who choose to volunteer, whilst allowing a valuable mix of quantitative (e.g., via Likert scale questions) and supporting qualitative (e.g., via the use of open-ended questions) data to be collected. After also applying for and receiving ethical approval, the lead researcher was responsible for designing and administering the surveys before coordinating data organisation and analyses in accordance with the aims of this study. Members of the PhD supervisory team had input at each of these stages (e.g., helping in the piloting of the surveys, acting as "critical friends" during analyses, etc.).

Table 3.1: Highest level of professional soccer at which respondents were employed at the time of survey completion (n = 33)

Highest level of current employment	Number of respondents
Top division domestic (senior)	10
Second highest division domestic (senior)	6
Third highest division domestic (senior)	3
Below third highest division domestic (senior)	4
International (junior)	1
Top division domestic (academy)	5
Academy (other)	3
Other	1

3.2.2 Survey content

To ensure that practitioners answered questions on topics falling within their specific area of expertise, participants were asked to indicate whether they considered their *primary* role to concern mostly the tactical/strategic decisions relating to the team with which they were employed (e.g., managers, technical coaches, etc.; 'tactical practitioners') or whether their main role related mostly to players' physical preparation/recovery (e.g., sports scientists, strength and conditioning coaches, etc.; 'physical practitioners'). This question was used to automatically direct participants to the appropriate set of survey questions (i.e., either physically focused or tactically focused). The tactically focused survey contained 12 main questions and four sub-questions, each taking either a multiple-choice, scaled, or rank format. Practitioners were also asked to elaborate on their responses to nine of these questions (Appendix 2). The physically focused survey comprised 16 main questions and eight sub-questions, with participants being asked to elaborate in 12 instances (Appendix 3). Both surveys contained questions relating to the match impact or value of substitutes, the number of substitutions permitted, and areas for future research. The remainder of the tactically focused survey asked practitioners about the objectives underlying their use of substitutions, as well as questions surrounding the level of advanced planning involved and the process of communication with players. Conversely, physical practitioners were asked about substitutes' match-day and non-match-day preparation strategies, recovery practices, and training load monitoring. Quantitative responses were primarily provided on five-point Likert scales to determine perceived importance (i.e., 'not at all important'; 'slightly important'; 'moderately important'; 'very important'; 'extremely important'), extent of agreement (i.e., 'strongly disagree'; 'disagree'; 'neither agree nor disagree'; 'agree'; 'strongly agree'), or frequency of implementation (i.e., 'never'; 'rarely'; 'sometimes'; 'often'; 'all of the time'). In addition to several multiple-choice questions (i.e., requiring either single or multi-response answers), other questions asked participants to rank importance from 'most important' to 'least important' or to indicate the most and least important options from a list of available responses. Where elaboration was desired (i.e., qualitative data), this was ensured through activation of an open-ended field requiring participants to 'justify' their responses. Of the 33 practitioners recruited, 26 and seven respondents completed the physically focused and tactically focused surveys, respectively.

3.2.3 Data analyses

This observational study followed a descriptive, cross-sectional design, therefore quantitative data presentation is mostly descriptive in nature. Where participants were invited to indicate their response on a Likert scale, frequency analysis was conducted to determine the percentage of practitioners who provided any given response. For questions incorporating unipolar Likert scales (i.e., where participants were presented with a topic/suggestion and asked to rate the degree of presence of an attribute in relation to this topic) relating to importance, responses were coded incrementally from a minimum of '1' ('not at all important') to a maximum of '5' ('extremely important'). Points for each response were then summed to facilitate ranking of topics from highest to lowest in importance based on the total number of points achieved (Harper et al., 2016c; McCall et al., 2014). For open-ended questions (e.g., where participants were invited to 'justify' their answers), responses were read multiple times prior to analysis to gain familiarity with the depth and breadth of their content (Braun & Clarke, 2006; Tracy, 2010). Thematic analysis was then conducted, whereby themes and sub-themes were established inductively (i.e., analysis was conducted in the absence of any pre-determined framework (Braun & Clarke, 2006)) using open coding. To ensure the credibility of the identified themes, independent validation was then employed (Creswell & Miller, 2000; Harper & McCunn, 2017), before analysis concluded with data being re-considered with reference to the identified thematic framework (Harper et al., 2016c; Tracy, 2010).

3.3 Results

Across the two surveys, data were broadly categorised into the five general dimensions presented below, of which four represent higher-order themes identified through thematic analysis (Figures 3.1, 3.2, 3.3, and 3.4).

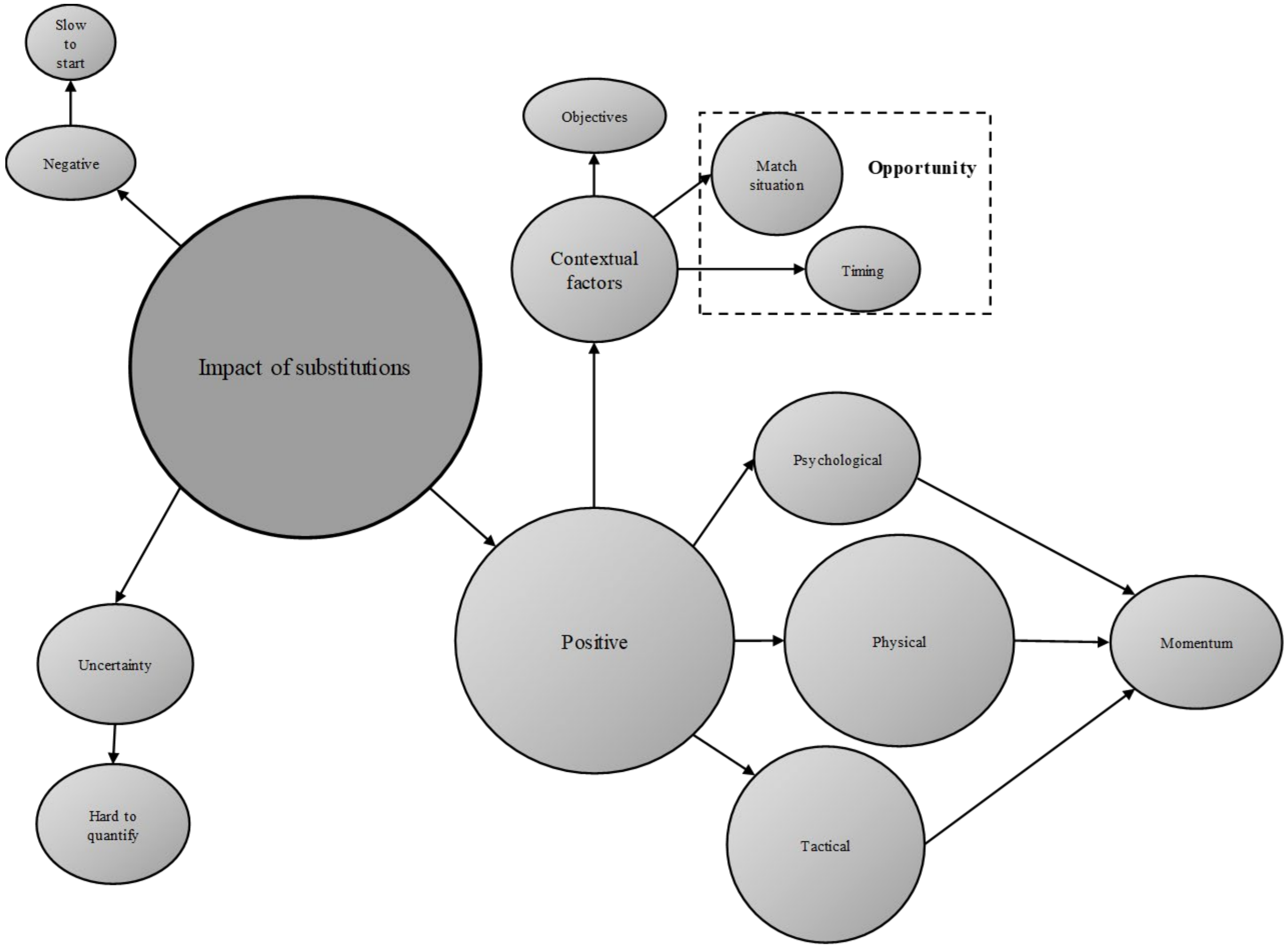

Figure 3.1: Thematic map of practitioner responses concerning the impact of substitutions (n = 33). Prevalence is indicated by size and arrows represent links between themes.

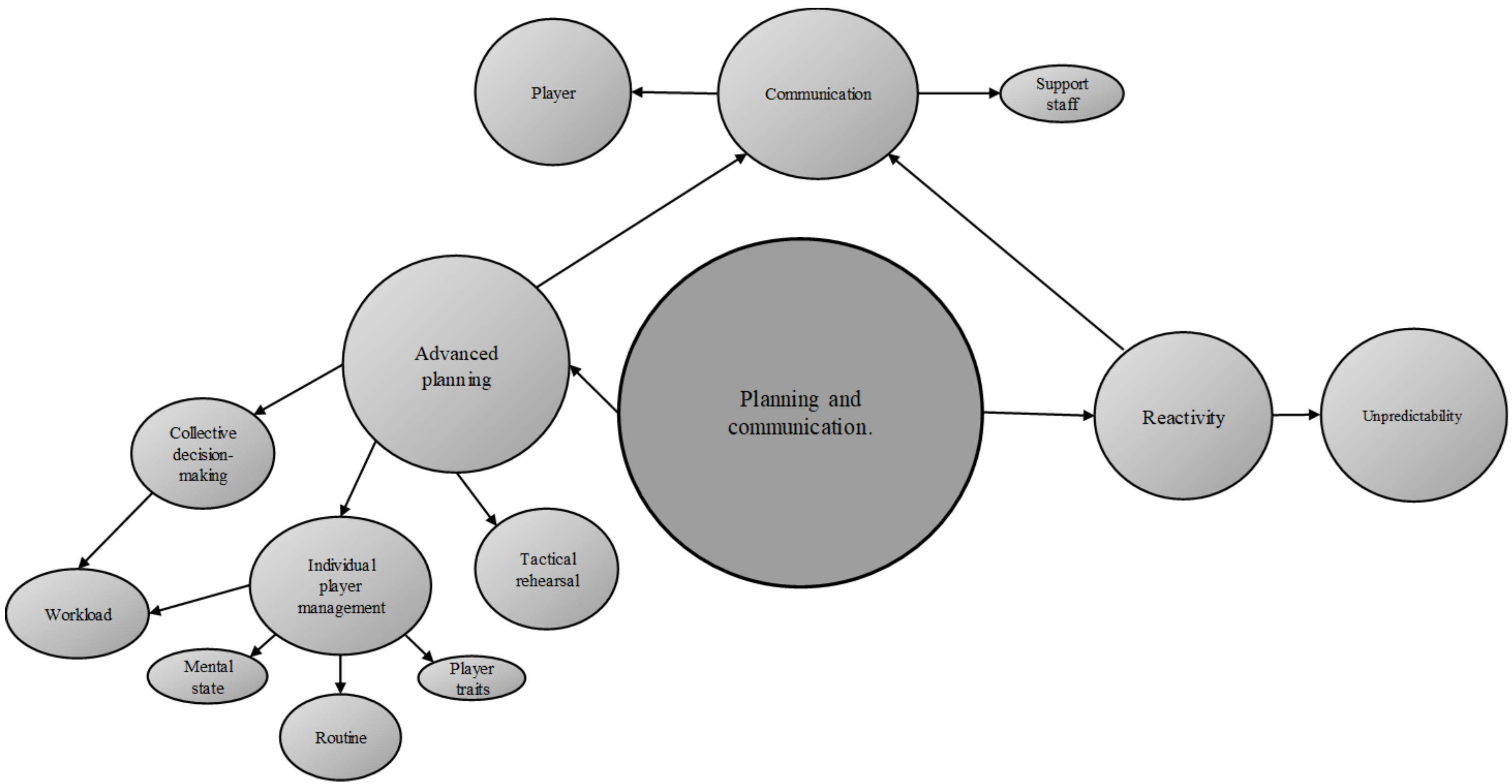

Figure 3.2: Thematic map of tactical practitioner responses concerning planning and communication (n = 7). Prevalence is indicated by size and arrows represent links between themes.

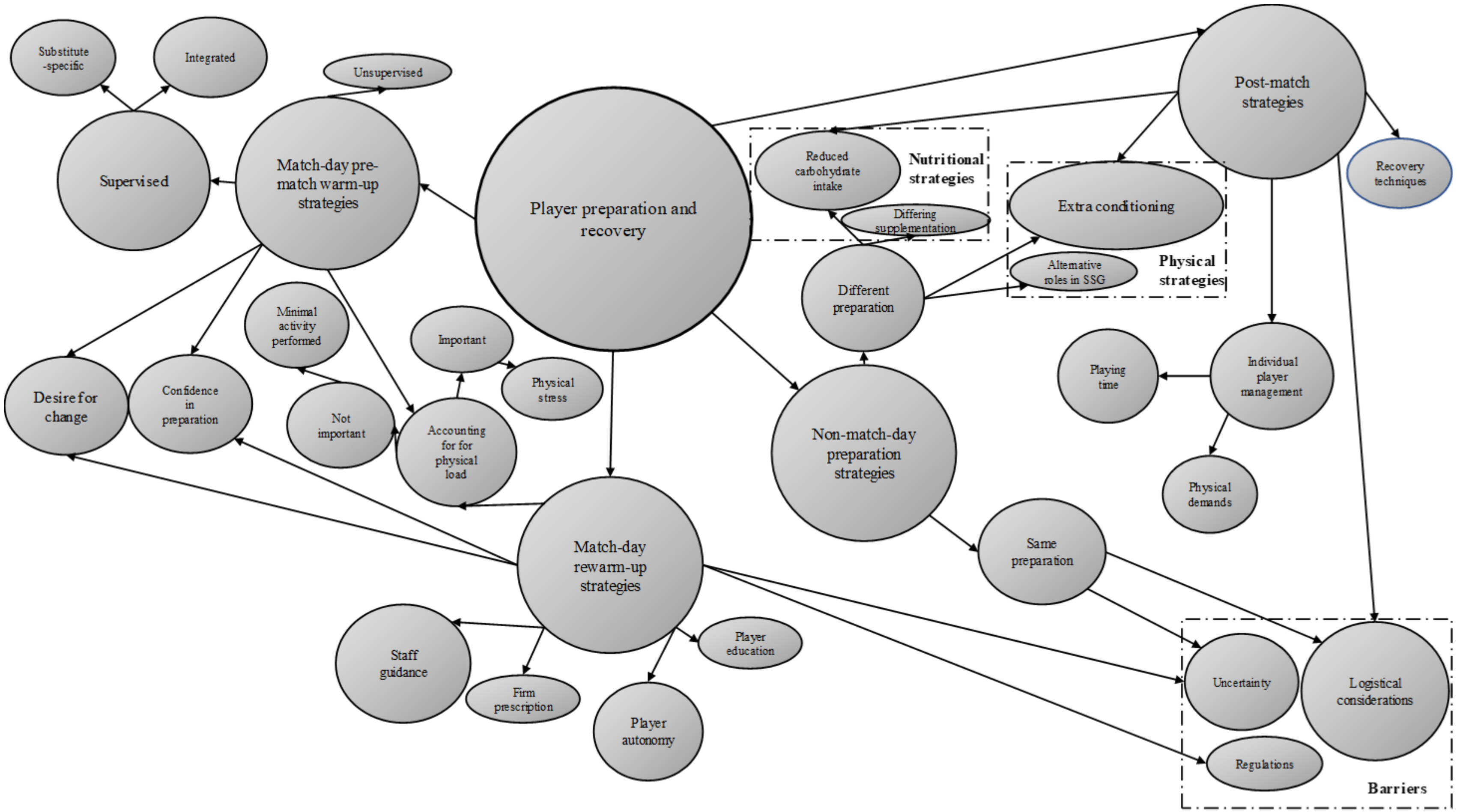

Figure 3.3: Thematic map of physical practitioner responses concerning player preparation and recovery (n = 26). Prevalence is indicated by size and arrows represent links between themes.

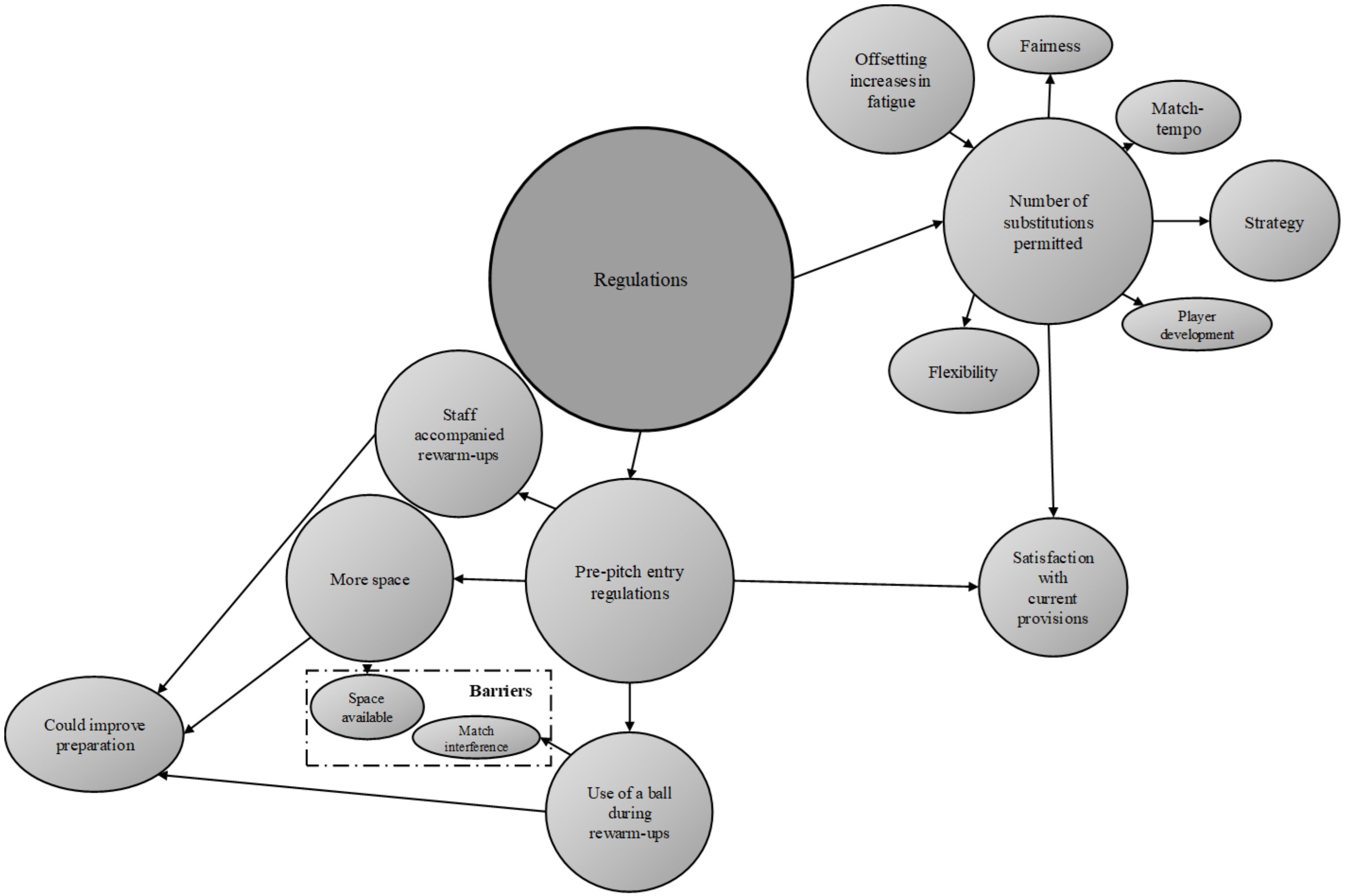

Figure 3.4: Thematic map of practitioner responses concerning current regulations (n = 33). Prevalence is indicated by size and arrows represent links between themes.

3.3.1 Impact of substitutions

'Changing team tactics (e.g., formation)', *'increasing the pace of play relative to other players'*, *'replacing underperforming/fatigued players'*, and *'replacing injured players'* were each selected by six out of seven (86%) respondents to the tactically focused survey as reasons motivating their use of substitutions. Four tactical practitioners (57%) highlighted '*squad rotation/reduce accumulated fatigue across a squad'*, and two (29%) suggested that substitutes may be introduced with the aim of '*providing playing time to youth/returning players'*. When asked to indicate the two most important reasons, '*changing team tactics (e.g., formation)'* and '*increasing the pace of play relative to other players'* were each selected by four tactical practitioners (57%), whilst three respondents (43%) rated each of '*replacing underperforming/tired players'* and *'replacing injured players'* amongst their two most important uses for substitutions.

Six tactical practitioners (86%) 'agreed' and only one (14%) 'disagreed' with the statement that "*substitutes are an important factor in determining success in soccer match-play*". From the physically focused survey, 85% of respondents either 'strongly agreed' (n = *9*; 35%) or 'agreed' (n = 13; 50%), whilst the remaining four physical practitioners responded negatively. Over half of tactical practitioners (n = 4; 57%) believed that the introduction of substitutes 'often' "*substantially influences the outcome of a match*", whereas a further three (43%) indicated that this is 'sometimes' the case. 'Sometimes' (n = 18; 69%) and 'often' (n = 7; 27%) also represented the most prevalent responses amongst physical practitioners.

Four second-order themes were identified from qualitative responses concerning the impact of substitutions. Amongst both groups of practitioners, sub-themes in favour of substitutes having a 'positive impact' reflected their 'physical' (e.g., "fresh legs", "other players get fatigued"), 'tactical' (e.g., "tactical adjustment", "easier to give them tactical information"), and 'psychological' (e.g., "intimidate the opposition", "psychological lift to the players currently playing") influence on a match. Physical practitioners also highlighted 'momentum' (e.g., "change the flow") as an important positive sub-theme, which may encompass physical, tactical, and psychological elements. 'Contextual factors' represented a prevalent second-order theme amongst both sets of practitioners, whereby the impact of substitutions may be “dependant on several factors”. Of these contextual factors, ‘timing’ (e.g., “often minimal time left”), ‘objectives’ (e.g., “[making an impact] may not be the aim”), and ‘match-situation’ (e.g., “depends on the state of play”) were prominent sub-themes. Physical practitioners also identified ‘uncertainty’ and the potential for substitutes to have a ‘negative impact’ on a match as second-order themes, with ‘difficulties in quantification’ (e.g., “hard to determine”) and ‘slowness to start’ (e.g., “may not be up to speed”, “potentially negatively due to preparation”), respectively, representing sub-themes in support.

3.3.2 Strategic planning and communication

Amongst tactical practitioners, 72% either ‘strongly agreed’ (n = 3; 43%) or ‘agreed’ (n = 2; 29%) that “*the role of substitutes is an important consideration during pre-match planning,”* and Table 3.2 indicates responses relating to specific aspects of substitution planning. For players not informed prior to the match, practitioners indicated that substitutes are typically notified of the likely timing of their introduction between *‘<04:00 min’* (n = 3; 43%) and *‘12:00-15:59 min’* (n = 2; 29%) prior to pitch-entry.

Table 3.2: Tactical practitioner responses relating to substitution planning (n = 7)

	All of the time	**Often**	**Sometimes**	**Rarely**	**Never**
The identity of players who are likely to be introduced/replaced is planned in advance of the match.	14%	0%	43%	43%	0%
If planned, the identity of players who are likely to be introduced/replaced is communicated to players.	0%	0%	86%	14%	0%
The likely timing of a substitute's introduction is planned in advance of the match.	14%	0%	29%	57%	0%
If planed, the likely timing of a substitute's introduction is communicated to players	0%	29%	43%	29%	0%

Qualitative sub-themes in support of advanced planning and communication amongst support staff reflected 'individual player-management' (e.g., "specific roles suit specific players", "injured players coming back may need a certain number of minutes"), 'tactical rehearsal' (e.g., "planning for all eventualities", "play out situations in advance"), and 'collective decision-making' (e.g., "get a consensus"). 'Unpredictability of match-play' (e.g., "don't know how the game is going to go") was identified as the most prominent sub-theme relating to 'reactivity' (i.e., not planning and/or communicating in advance). With regard to how far in advance of pitch-entry players are notified of their likely introduction, tactical practitioners highlighted 'individual player management' (e.g., "to give time to prepare") and 'reactivity' (e.g., "last minute", "on the spot") in support of the communication timeframes provided.

3.3.3 Physical preparation and recovery

When physical practitioners were asked how frequently *"the design of non-match-day training and preparation strategies differ for substitute players when compared with the starting team"*, the most prevalent responses were 'often' (n = 10; 39%) and 'rarely' (n = 8; 31%), followed by 'never' (n = 4; 15%). 'Sometimes' and 'all of the time' each received two responses (8%). Practitioners reported implementing bespoke 'physical' (e.g., "training will often be adjusted", "extra conditioning during the week", "on the opposite team to starters during small-sided games") and 'nutritional' (e.g., "reduce their carbohydrate intake", "supplementation differs") strategies, whereas explanations for substitutes following the same non-match-day preparations as starting players reflected 'uncertainty' (e.g., "don't know how long they will play") and 'logistical considerations' (e.g., "structure of training sessions does not allow it", "squad not announced [soon enough]").

With regard to the frequency with which "*on match-day, substitutes are accompanied by at least one member of team staff during the pre-match warm-up"*, 92% of physical practitioners responded with either 'all of the time' (n = 17; 65%) or 'often' (n = 7; 27%). Qualitative responses relating to 'supervised warm-ups' indicated that some teams employ 'integrated warm-ups' (e.g., "include substitutes within the starters warm-up", "substitutes support through attack versus defence drills"), whilst others promote 'substitute-specific warm-ups' (e.g., "have their own warm-up", "brief, general warm-up").

Figure 3.5 indicates that from the options provided, *'active rewarm-up strategies'* and *'tactical preparations (e.g., receive tactical advice)'* were considered by physical practitioners to be the most important preparatory practices implemented between kick-off and a substitute's introduction into a match. Two respondents also noted '*psychological preparation'* (e.g., "attune to the game") as an additional factor, which they considered to be an 'extremely important' strategy. More than half of physical practitioners reported implementing '*energy provision'*, '*tactical preparations'*, '*active rewarm-ups'*, and '*hydration strategies'* 'all of the time', but '*passive heat maintenance techniques'* appear to be used less frequently (Figure 3.6).

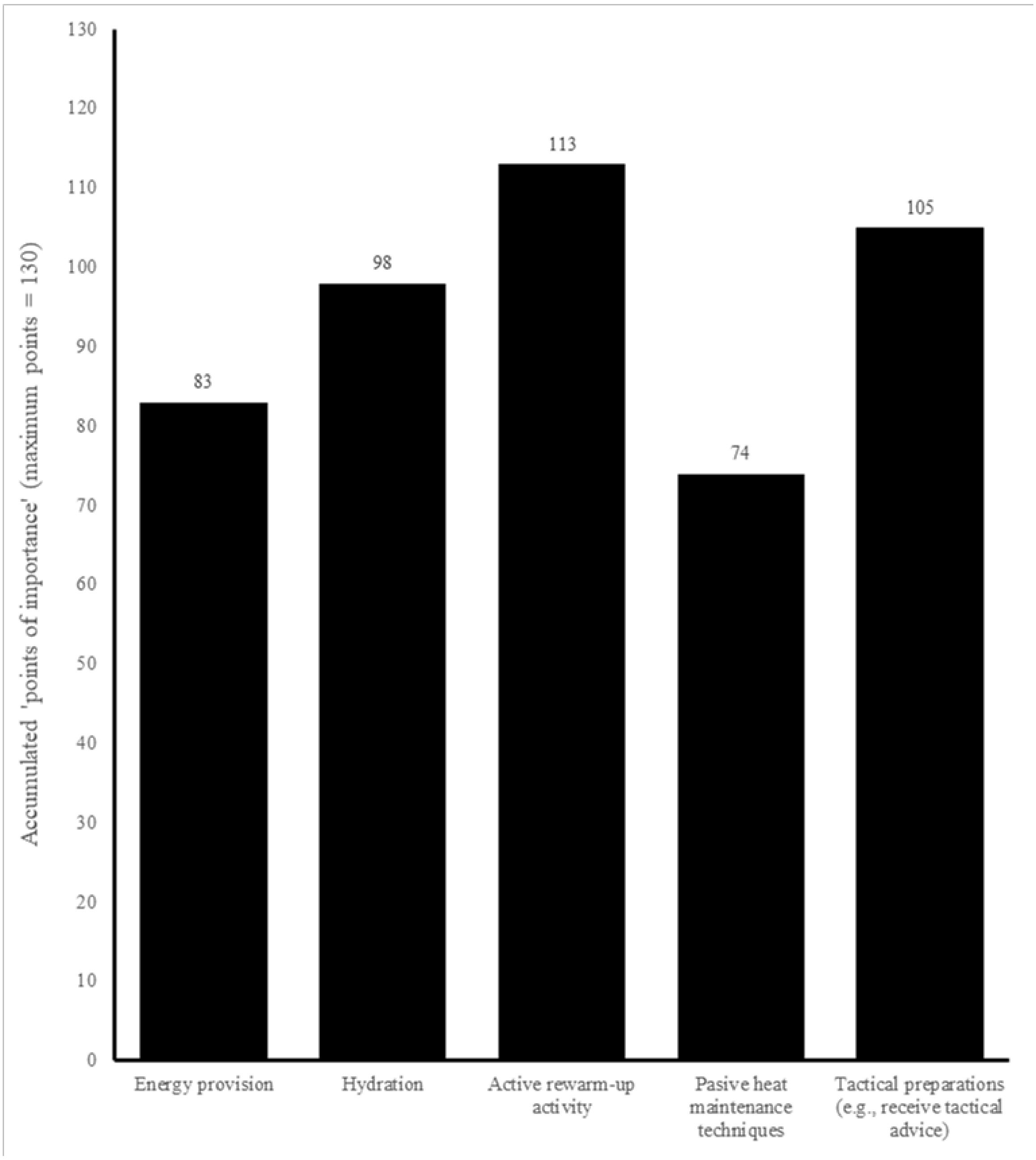

Figure 3.5: Physical practitioners' perceived importance of preparatory strategies implemented between kick-off and pitch-entry (n = 26)

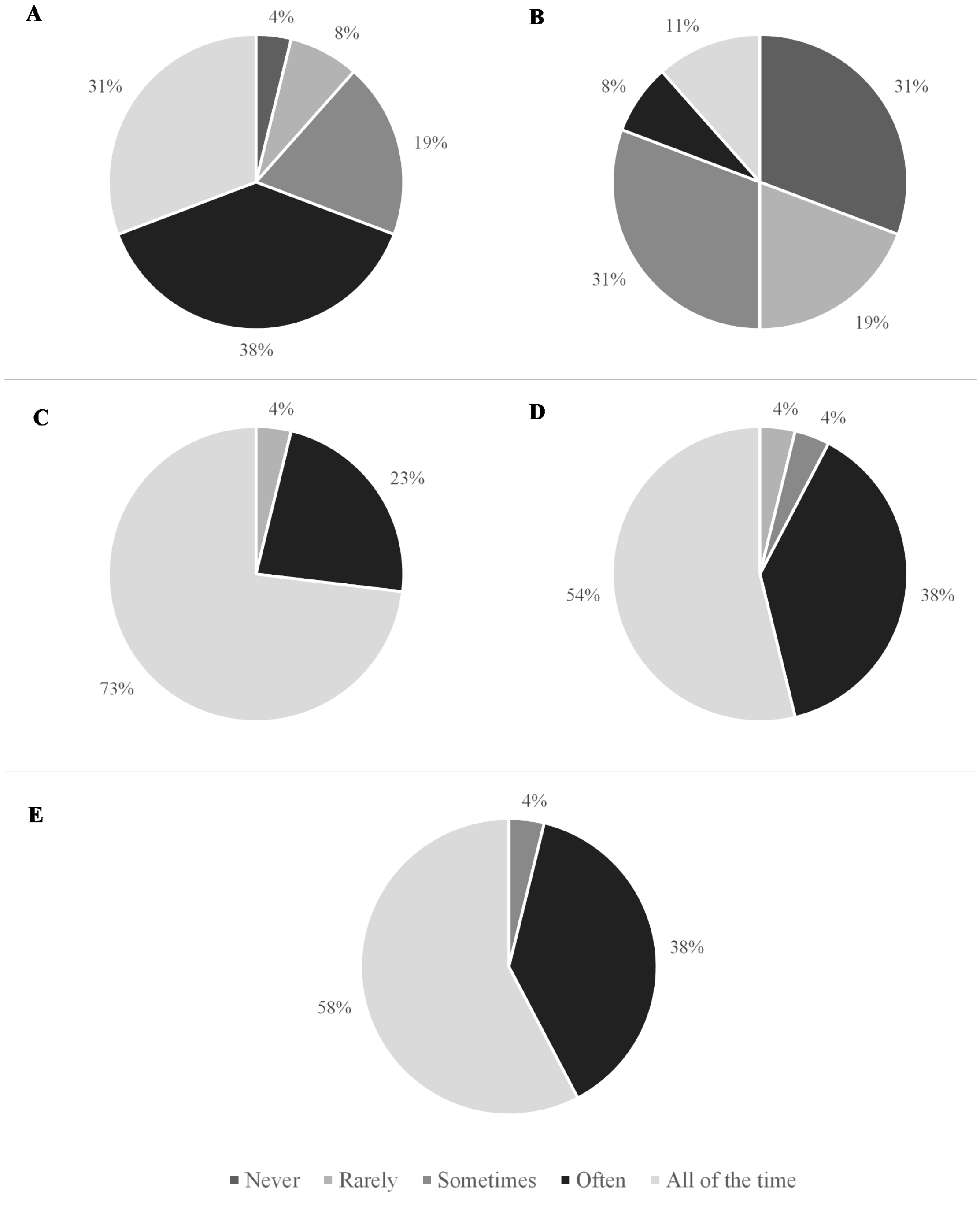

Figure 3.6: Frequency with which physical practitioners (n = 26) implement energy provision (panel A), passive heat maintenance (panel B), tactical preparations (panel C), active rewarm-up strategies (panel D), and hydration strategies (panel E) between the match kick-off and a substitute's entry onto the pitch

When physical practitioners were asked how frequently *"substitutes are provided with input from team staff in relation to any rewarm-up activity performed between kick-off and pitch-entry"*, 'all of the time' (n = 11; 42%) and 'often' (n = 7; 27%) represented the most prevalent responses. Three practitioners (12%) chose 'sometimes', and the remaining five participants selected either 'rarely' (n = 3; 12%) or 'never' (n = 2; 8%). Sub-themes reflecting these varying levels of input were: 'player education' (e.g., "every few months we reiterate the type of exercises players need to be doing"), 'staff guidance' (e.g., "specified times to warm-up"), and 'firm prescription' (e.g., "instructed on the content, frequency, and duration"), whilst 'player autonomy' (e.g., "left to their own devices", "give ownership to the players") represented the prominent explanation amongst practitioners providing little or no input. 'Regulation' was also highlighted as a sub-theme, with competition legislation influencing the amount of direct input that can be provided by staff during the pre-pitch-entry period. Responses suggested that clothing recommendations are typically provided less frequently than information relating to active rewarm-up strategies (Figure 3.7).

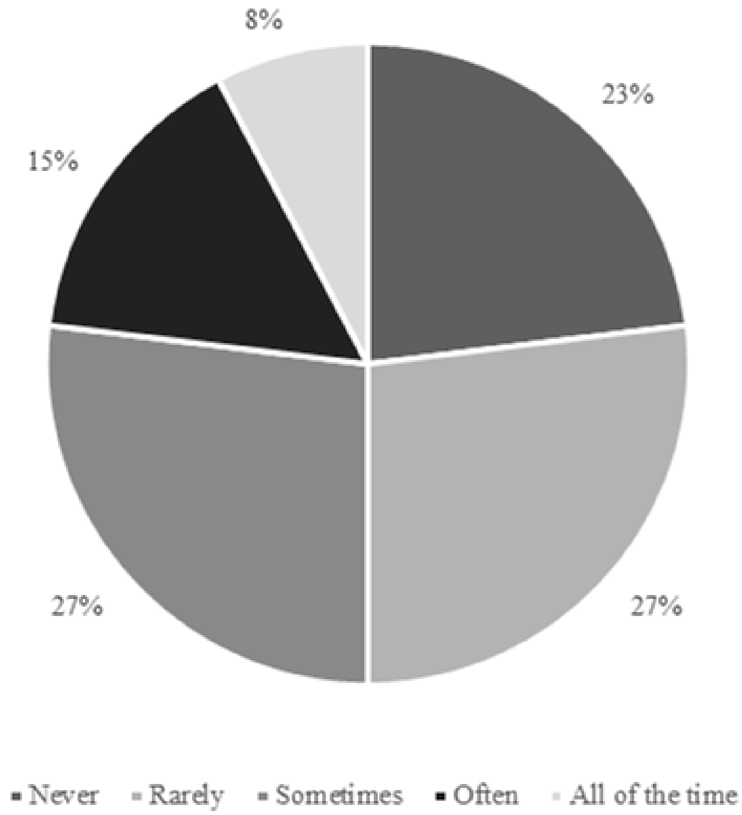

Figure 3.7: Frequency with which physical practitioners provide clothing recommendations to substitutes during the period between kick-off and pitch-entry (n = 26)

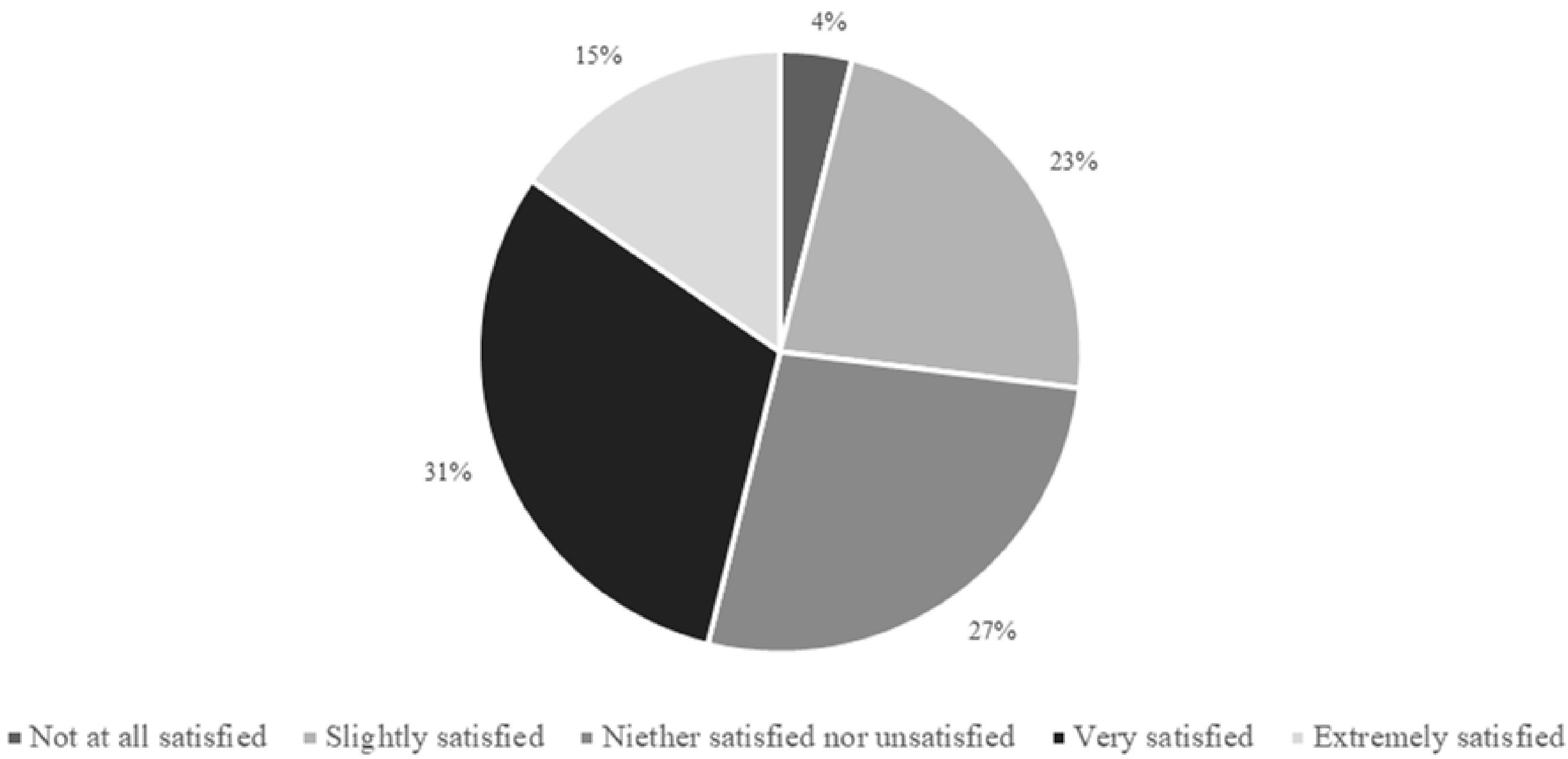

Figure 3.8: Physical practitioners' level of satisfaction that the match-day pre-pitch-entry activities undertaken by substitutes are sufficient to prepare for subsequent match performance (n = 26)

Responses ranging from 'very' to 'not at all' were recorded when physical practitioners were asked how satisfied they were that *"the match-day pre-pitch-entry activities undertaken by substitutes are sufficient to prepare for subsequent match performance"* (Figure 3.8). The equally prevalent supporting sub-themes identified were: 'confidence in preparation' (e.g., "high work-rate on entering the field of play", "no injuries", "the warm-ups are robust"), 'uncertainty' (e.g., "would need [more information] to confirm", "strategies can vary significantly"), and 'desire for change' (e.g., "would like a higher intensity", "heated trousers would be beneficial", "strategies more optimised towards substitutes", "often put on with insufficient warm-up").

Only two physical practitioners (8%) believed that *"accounting for any activity performed by substitutes prior to pitch-entry when considering the overall physical load that players are exposed to"* was 'extremely important', although seven respondents (27%) indicated that doing so was 'very important'. 'Moderately important' (23%), 'slightly important' (27%), and 'not at all important' (15%) received six, seven, and four responses, respectively. Figure 3.9 indicates the frequency with which these pre-pitch-entry loads are accounted for in practice, with 'sometimes' representing the most prevalent outcome. Arguments provided for and against accounting for pre-pitch-entry activity within assessments of overall loading were 'physical stress' (e.g., "[pre-pitch-entry activity is a] stress to the body") and 'insufficient activity performed' (e.g., "the amount of work is often negligible"), respectively. Even amongst those physical practitioners who did not consider it important to do so, some nonetheless account for pre-pitch-entry activity as their substitutes typically wear Microelectromechanical Systems (MEMS) throughout match-day. Other respondents indicated that they deliberately exclude these data from their assessment of match-day loading.

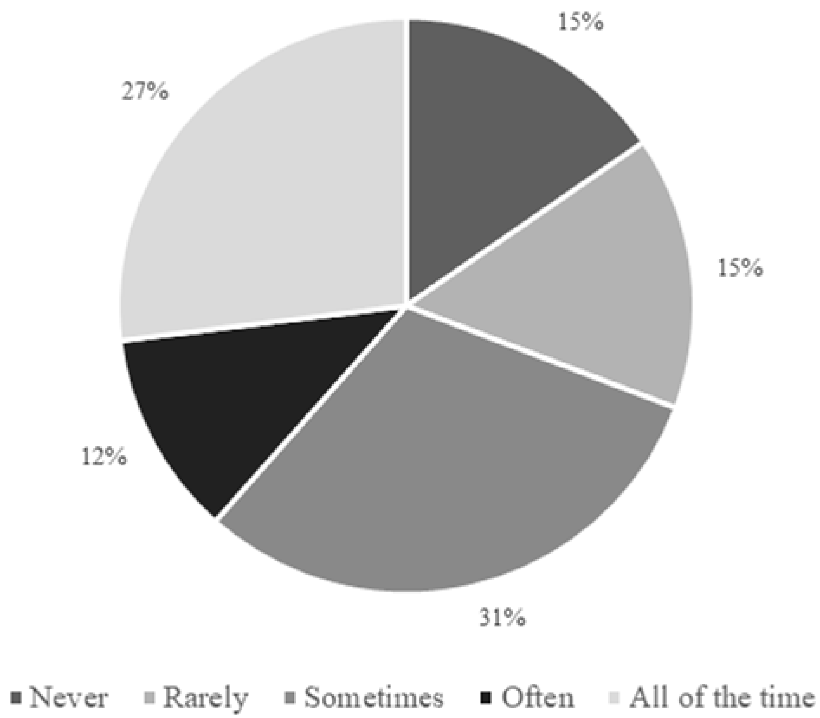

Figure 3.9: Frequency with which physical practitioners account for any activity performed by substitutes prior to pitch-entry when considering the overall physical load that players are exposed to (n = 26)

Although 89% of physical respondents believed that *"there is a need for different post-match recovery practices between substitutes and starting players"*, 38% reported that bespoke recovery strategies were 'never' (n = 5; 19%) or 'rarely' (n = 5; 19%) applied. A further 54% indicated that different strategies were adopted either 'often' (n = 7; 27%) or 'all of the time' (n = 7; 27%), and the remaining two respondents (8%) selected 'sometimes'. Amongst practitioners advocating different post-match recovery practices for substitutes compared with starting players, bespoke 'nutritional' (e.g., "do not have a high carbohydrate recovery drink"), 'physical' (e.g., "different cool-downs"), and 'specialised recovery' (e.g., "will not take part in ice baths") strategies were reported. 'Logistical considerations' (e.g., "due to resources players are often given the same recovery", "hard to tailor logistically") and 'individual player management' (e.g., "depending on how long they have played") represented sub-themes influencing whether or not different recovery strategies were employed for substitutes compared with starting players.

Ninety-six percent of physical practitioners indicated that substitutes perform extra 'top-up' conditioning sessions to account for their only partial-match exposure. Again, 'logistical considerations' (e.g., "depends on travel…and facilities available") and 'individual player management' were identified as sub-themes influencing whether or not substitutes performed additional conditioning. Specifically, a player's 'physical demands' (e.g., "depending on their loading for the week") and 'playing time' (e.g., "if they play less than [values ranged from 20-45 min] minutes") represented the most prevalent determinants mentioned within the 'individual player management' sub-theme. Several training modalities were reported, with HSR representing the primary stimulus desired from these top-up sessions.

3.3.4 Regulations

Tactical practitioners believed that 'three' (n = 3; 43%) or 'four' (n = 4; 57%) substitutions should be permitted during a competitive 90 min match, and physical practitioners mostly (n = 17; 65%) indicated that 'three' was the appropriate number. From the tactically focused survey, ‘strategy’ (e.g., “take the risk or don’t”) and ‘satisfaction’ (e.g., “works well”) represented sub-themes in support of limiting the number of replacements to a maximum of three, whereas tactical practitioners in favour of four substitutions highlighted the potential for increased ‘flexibility’ (e.g., “additional one for unforeseen circumstances”). Most physical respondents were happy with current regulations regarding the number of substitutions permitted, with ‘fairness’ (e.g., “keeps the game on a level playing field”) and ‘satisfaction’ representing supporting sub-themes. Some physical practitioners also warned that increasing the number of replacements may adversely affect ‘match-tempo’ (e.g., “would slow the game down”), whereas others highlighted ‘player development’ (e.g., “need for match exposure”) as a justification for permitting more substitutions in youth soccer compared with the number allowed during senior matches. In contrast to tactical practitioners, physical respondents noted ‘strategy’ (e.g., “would add an interesting tactical dimension”) as an argument in favour of *increasing* the number of substitutes permitted, whilst ‘offsetting increases in fatigue’ (e.g., “may protect players from injury with increasingly congested calendars”) and ‘flexibility’ were also identified as sub-themes in support of this idea.

With regard to matches progressing to extra-time, 43% (n = 3) of tactical respondents and 54% (n = 14) of physical practitioners believed that ‘one’ additional substitution (i.e., beyond those permitted during the initial 90 min) should be permitted, although ‘none’, ‘two’, ‘three’, ‘four’, ‘five’, and ‘11+’ each received selections. ‘Offsetting increases in fatigue’ (e.g., “it is an additional physical load”, “increased risk to players”) and ‘strategy’ (e.g., “don’t have to worry during normal time”) represented sub-themes in support of permitting additional substitutions during extra-time compared with the number allowed during the initial 90 min. Physical practitioners also highlighted ‘player development’ (e.g., “gives an opportunity”) as an argument for permitting additional substitutions during extra-time, whilst ‘match-tempo’ (e.g., “fatigue enhances scoring opportunities”) and ‘fairness’ (e.g., “teams who cannot afford or do not have strength in depth”) were identified as sub-themes in favour of strictly limiting the number of replacements permitted.

The physically focused survey also presented practitioners with three statements regarding regulations governing the rewarm-up activity performed between match kick-off and entry onto the pitch (Table 3.3). From qualitative analysis, ‘potentially improved preparation’ (e.g., “would prepare muscles/tendons/ligaments”, “would allow more varied activities”, “better structure”, “currently inadequate”) represented the prominent sub-theme amongst those practitioners who supported changing current pre-pitch-entry regulations or provisions, although ‘limited space’ (e.g., “difficult in a stadium environment”) and ‘potential match-interference’ (e.g., “could be used to disrupt play”) were highlighted as likely barriers. Conversely, ‘satisfaction’ with current provisions (e.g., “not needed for an adequate warm-up”) was identified amongst a small number of practitioners.

Table 3.3: Physical practitioner responses to statements regarding regulations governing rewarm-up activity performed whilst the match is underway (n = 26)

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Team staff should be permitted to accompany substitutes during rewarm-up activity	42%	15%	31%	8%	4%
More space should be provided for rewarm-up activity	39%	35%	23%	4%	0%
Use of a ball should be permitted during rewarm-up activity	39%	23%	19%	15%	4%

3.3.5 Future research directions

Both surveys asked about the importance of future research into several areas relating to substitutes, with *'tactical impact'* and *'preparatory strategies'* rated as the most important areas amongst tactical and physical practitioners, respectively (Figures 3.10 and 3.11). When given the opportunity to indicate any areas other than those listed, one physical respondent highlighted that of 'moderate importance' was future research into the *'psychology'* of substitutes at the time of entering the pitch (i.e., "often they can be in a negative mind state").

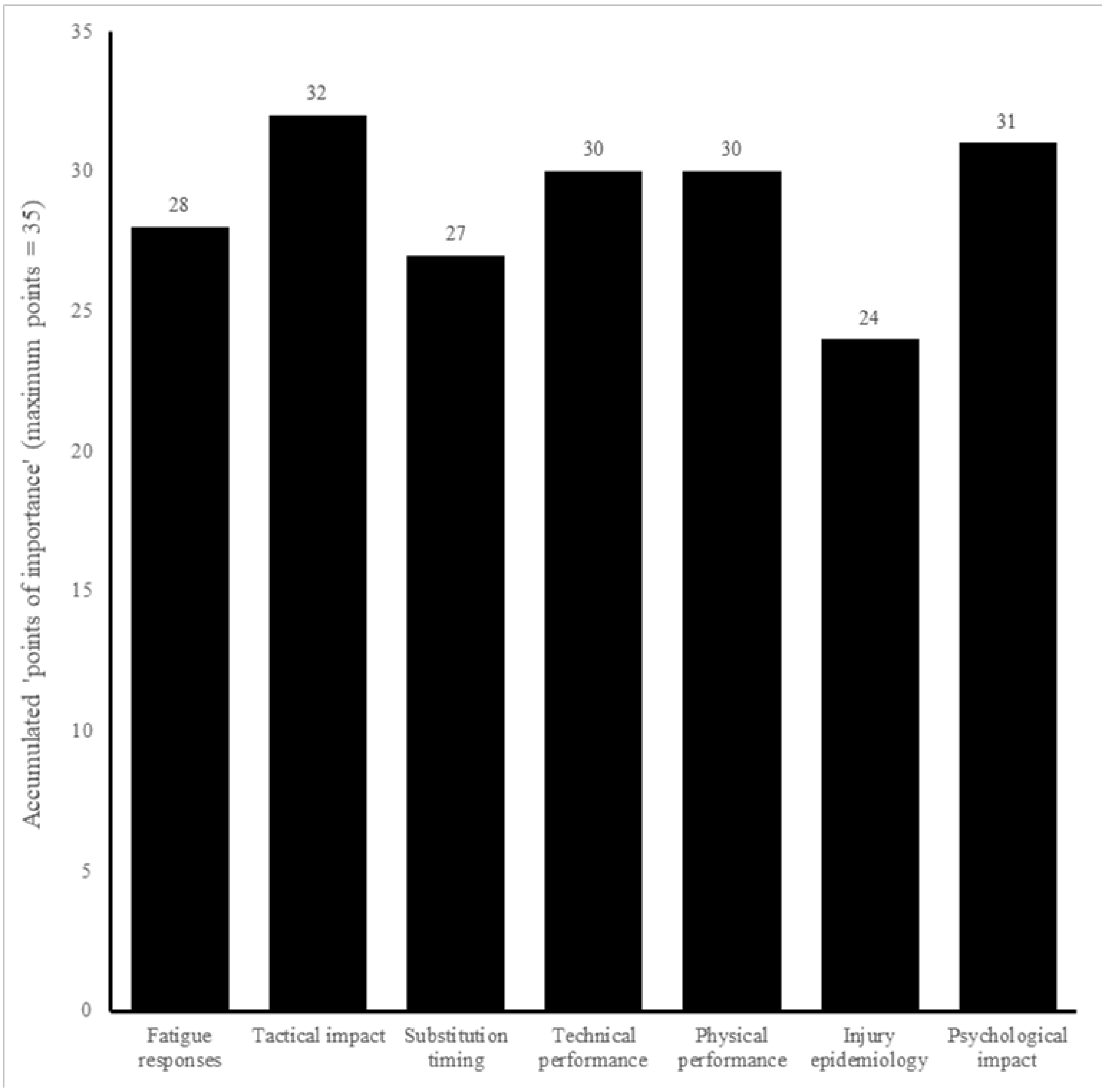

Figure 3.10: Tactical practitioners' perceived importance of areas for future research (n = 7)

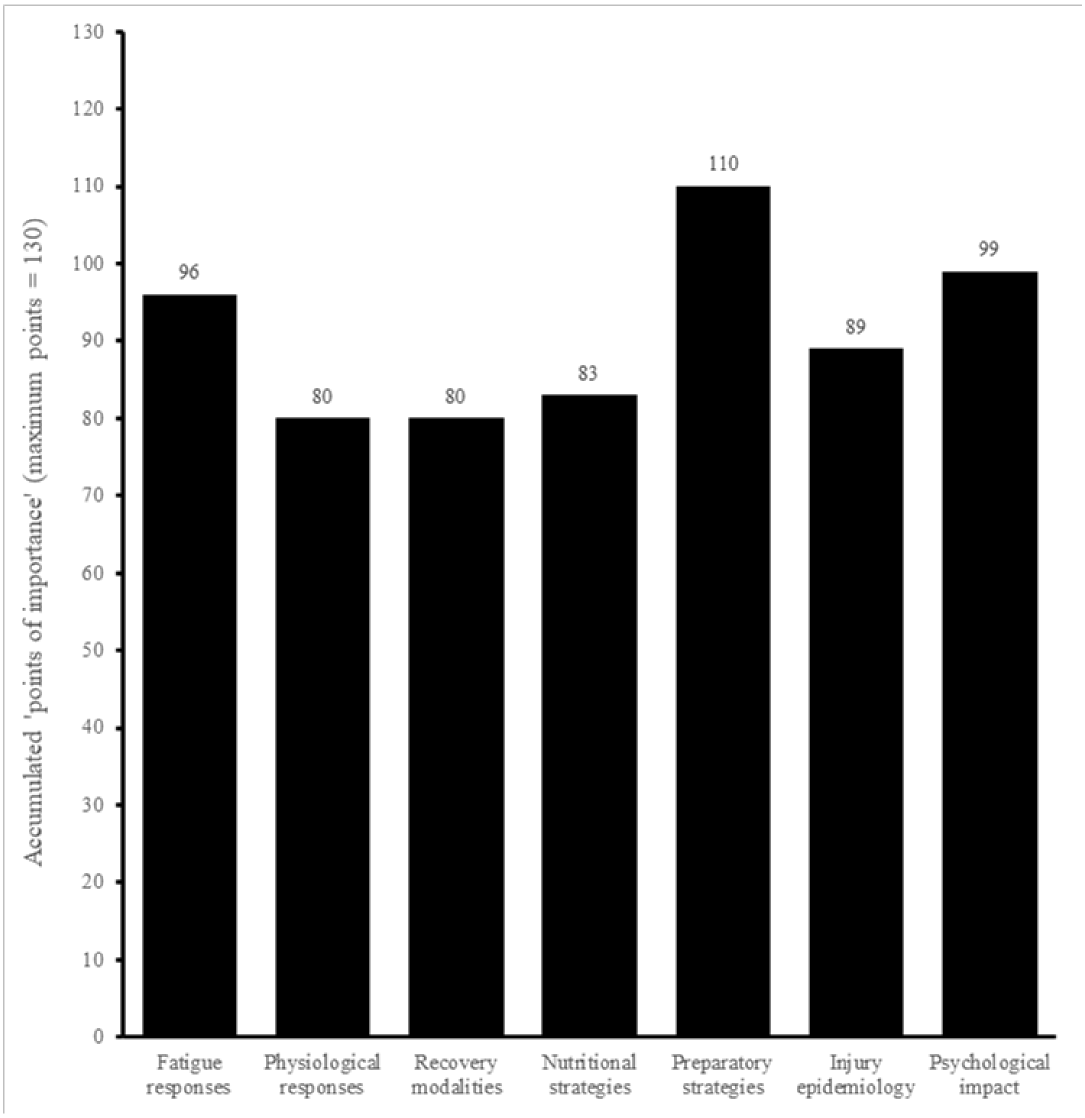

Figure 3.11: Physical practitioners' perceived importance of areas for future research (n = 26)

3.4 Discussion

This study assessed the practices and perceptions of applied practitioners working within professional soccer in relation to various aspects pertaining to substitutes. Practitioners provided opinions on 'the impact of substitutions', 'strategic planning and communication', 'physical preparation and recovery', 'regulations', and 'future research directions', with topics reflecting each respondent's area of expertise (i.e., whether 'tactical' or 'physical' practitioners). Novel insights are presented, which provide context for existing and forthcoming studies concerning the practices of soccer substitutes and highlight important considerations for future research.

The majority (≥85%) of respondents to each survey believed that substitutions represent an important factor in determining team success. Amongst both groups of practitioners, the potential for replacement players to provide physical impetus (e.g., offset the progressive fatigue experienced by starting players) and/or facilitate changes in team tactics represented the most prevalent justifications for this stance, although other explanations (e.g., psychological influences on their teammates and opposition players) were also provided. Unsurprisingly, these sub-themes broadly reflect the objectives highlighted by tactical practitioners, who identified *'changing team tactics'* and *'increasing the pace of play relative to other players'* as primary motivations underlying their decisions to use substitutions.

Existing research profiling the match-play responses of soccer substitutes has typically reported higher relative running distances for individuals introduced at half-time or during the second-half of matches, when compared with players being replaced and those other non-substituted players remaining on the pitch (Bradley et al., 2014; Gai et al., 2019; Liu et al., 2019; Mohr et al., 2003; Padrón-Cabo et al., 2018). These observations support the findings of the current study, whereby practitioners view the introduction of substitutes as an opportunity to provide a physical impact on a match. However, whilst it is acknowledged that the ability to perform high-intensity activity may represent an important component of soccer match-play (Faude et al., 2012; Mohr et al., 2003), it remains unclear whether the heightened physical output observed amongst substitutes (i.e., compared with whole-match players and those being replaced) actually reflects a positive contribution to team success. Nonetheless, it appears that the ability to introduce 'fresh' players is highly valued by practitioners, and several survey respondents forwarded anecdotal evidence of substitutes substantially changing the course of a match (e.g., by scoring goals, making decisive plays, etc.).

Although the tactical impact of making a substitution may be clear on occasions in which a change in team formation occurs simultaneously, the influence on team tactics might often be more subtle. Indeed, despite one tactical practitioner postulating that introducing a new player into a dynamic system must necessarily have "some impact", quantifying 'tactical performance' within this fluid framework remains inherently difficult (Bradley & Ade, 2018). Notwithstanding, given that tactical objectives often represent a major motivation for the introduction of substitutes, it is unsurprising that the importance of future research in this area was emphasised by survey respondents. It should be noted that in keeping with the characteristically stochastic nature of soccer match-play, practitioners highlighted several contextual variables which may at times moderate a substitute's potential value to their team. Indeed, in addition to the importance of the match situation providing an opportunity to contribute, players being introduced with sufficient time remaining in the match (tactical practitioners) and having undergone appropriate pre-pitch-entry preparations (physical practitioners), were deemed to be important factors in allowing substitutes to have a positive impact and avoid negatively influencing team performance by not being 'up to speed'.

Given their engagement in only partial match-play, substitutes may face vastly different match-day demands compared with players who start a match (Bradley et al., 2014; Mohr et al., 2003). Therefore, as many team sport preparatory activities may be determined based upon the specific demands that a player is expected to face (Reilly et al., 2009), it is plausible that partial-match players may benefit from bespoke practices during the days prior to and following a match. Physical practitioners provided a range of responses when asked to indicate the frequency with which non-match-day preparation strategies differ between substitutes and the starting eleven; with the substantial variation being highlighted by the fact that 'often' (39%) and 'rarely' (31%) represented the two most common selections. Notably, although many practitioners advocated the adoption of different physical (e.g., modified training) and nutritional (e.g., reduced carbohydrate/energy intake) strategies for substitutes, several barriers frequently prevented these approaches in practice. For example, fixture congestion and structural rigidity within team training were identified as potential logistical limitations, and some practitioners also indicated that team selection may not occur soon enough to allow for the provision of tailored preparation during the days leading up to a match (e.g., the team being announced on the day before a match). In addition, substantial uncertainty exists with regard to the likely match-day demands faced by substitutes. Although strategic substitutions are typically made at half-time or later (Bradley et al., 2014; Del Corral et al., 2008; Myers, 2012), substitutes may be required to enter the pitch during the very early stages of match (e.g., in the case of injury) or potentially to complete 90+ min if a starting player suffers injury/illness prior to kick-off. In these scenarios, their rarity notwithstanding, it is important for players to have prepared suitably for the physical, tactical, and psychological demands associated with their extended playing period.

Performing an appropriate warm-up may improve physical performance and reduce the risk of injury during subsequent exercise that is performed shortly thereafter (Bishop, 2003; Fradkin et al., 2006; McGowan et al., 2015; Safran et al., 1989; Woods et al., 2007). Notably, compared with during the first-half of a match, concerns have previously been expressed by practitioners that starting players may be less prepared to avoid injury at the start of the second-half due to the likely absence of exercise during the half-time break (Towlson et al., 2013). Indeed, half-time rewarm-up activity has benefitted indices of physical performance and potentially reduced injury-risk following half-time during actual or simulated team sports match-play (Bixler & Jones, 1992; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Towlson et al., 2013). Inferring from half-time research that prolonged periods of inactivity may not represent optimal preparation for subsequent exercise performance, the length of time typically elapsing between the end of the pre-match-warm-up and a substitute's entry onto the pitch means that activities performed during this period may be of utmost importance for maximising performance and/or minimising injury-risk upon introduction into a match. However, practitioners in the current study remained largely uncertain as to the efficacy of current pre-pitch-entry practices and often deemed the amount of activity performed between kick-off and pitch-entry too negligible to warrant inclusion within assessments of a substitute's overall match-day loading.

Although substitutes are typically accompanied by members of team staff during an active pre-match warm-up (albeit that this may be conducted either alongside or separately from members of the starting line-up), the level of input provided to substitutes in relation to any strategies adopted between kick-off and pitch-entry appears to vary considerably. Indeed, whilst some practitioners advocated player autonomy to take ownership of their own performance or to prepare based upon 'feel', survey responses suggested that others prefer to dictate the timing and/or content of rewarm-up activity and make firm recommendations regarding the clothing worn by substitutes during this period. Several competitions worldwide impose regulations that require members of team staff to remain within a 'technical area' whilst the match is underway (FIFA, 2019/20). In these scenarios, unless there exists an established pre-prepared routine, the precise characteristics (e.g., intensity) of any rewarm-up activity must ultimately be determined by the players themselves. This may be an important consideration when one contemplates that a lack of opportunity and reduced motivation to prepare has been identified amongst players named 'on the bench' (Woods & Thatcher, 2009), and that anecdotal evidence highlights how events unfolding on the pitch appear to influence the rewarm-up activities performed by awaiting substitutes .

Given that improved outcomes have been reported from coach-supervised versus unsupervised training (Mazzetti et al., 2000), it is unsurprising that 57% of physical practitioners either 'agreed' or 'strongly agreed' with the proposition that regulations should permit members of support staff to accompany substitutes during their pre-pitch-entry rewarm-ups. Whilst certain competitions (e.g., the 2018 FIFA World Cup) have allowed this practice (FIFA, 2018), it remains unclear whether the presence of additional personnel can positively influence the quality of any rewarm-up activity performed during a match, and thus confer benefits in terms of improving on-pitch performance and potentially reducing injury-risk following a player's introduction. In addition, although it was acknowledged that stadium design may often preclude it, 74% of practitioners believed that the provision of additional space for rewarm-up activity may allow substitutes to undergo more thorough pre-pitch-entry preparations than are currently completed. Many respondents (62%) also suggested that, provided that enough space was available to avoid potential interference with the match, permitting the use of a ball during rewarm-up activity could be beneficial. However, little information currently exists in relation to the preparatory strategies utilised by substitute players. Given the potential role for rewarm-up activity in terms of improving physical performance and reducing injury-risk (Bixler & Jones, 1992; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Silva et al., 2018; Towlson et al., 2013), the importance of future research into the match-day preparations of soccer substitutes was highlighted by practitioners.

Several physical practitioners noted the potential for substitutes to negatively influence a match, with the possibility of players having undergone inadequate pre-pitch-entry preparations representing the primary justification for this proposition. It should be considered that substitutes may receive a very short amount of time (i.e., survey responses suggest often <4 min) between notification of their impending introduction, and physically entering onto the pitch. Although some tactical practitioners may seek to provide enough notice to allow players to properly prepare, it is possible that a lack of time may limit a substitute's ability to undergo extensive physical preparations in addition to their tactical (e.g., receiving instructions from technical coaches) and practical (e.g., removing outer clothing) obligations immediately prior to introduction.

Although research into the physiological responses of partial-match soccer players is lacking, it seems logical to suggest that substitutes typically experience less post-match fatigue compared with individuals exposed to a more prolonged period of match-play. Practitioners appear to adopt this stance, with 89% believing that there exists a need for different post-match recovery strategies for substitutes compared with starting players. However, as was observed in relation to non-match-day preparations, a disparity seemed to exist between this perceived need and the 38% of physical practitioners who indicated that bespoke strategies were 'never' or 'rarely' applied in practice. Again, whilst several respondents reported that substitutes engaged in tailored physical, nutritional, and 'specialised recovery' (e.g., not engaging in cold-water immersion) strategies, typically determined based upon the length of an individual's match exposure, it was highlighted that logistical considerations such as access to limited resources often make this difficult to apply.

Overwhelmingly, physical practitioners recognised that a substitute's often limited playing time may have negative implications for their adaptive responses over the course of a training cycle. Exposure to high-intensity activity represents an important factor in developing and maintaining aspects of soccer-specific fitness (Morgans et al., 2018; Silva et al., 2011), and match-play may provide an important stimulus for adaptation during the competitive season. Indeed, in English Premier League players, the amount of HSR performed during a match has demonstrated a positive relationship with CMJ performance when assessed three days post-match (Morgans et al., 2018), whilst improvements in lower-body strength and sprint performance during a professional soccer season may be linked to a player's overall playing time (Silva et al., 2011). Moreover, if individuals are repeatedly selected as partial- rather than whole-match players, they may experience increases in subsequent injury-risk as a result of ongoing reductions in certain indices of physical loading (Buckthorpe et al., 2019; Colby et al., 2018; Duhig et al., 2016). For these reasons, 96% of practitioners reported that substitutes perform extra 'top-up' conditioning sessions (i.e., typically immediately post-match and/or on the following day) to account for their participation in only partial match-play. When determining whether an individual should perform extra conditioning in any given instance; the number of minutes played, physical demands experienced (i.e., during the match and/or on a longer-term basis), and various logistical restrictions (e.g., match location, the facilities available, etc.) were the primary considerations identified. Practitioners reported implementing a range of different training modalities (e.g., straight-line and/or multi-directional running, small-sided games, resistance exercise, etc.) and, although specific session prescription may potentially be influenced by factors such as fixture scheduling, time of day, match location, and the resources available at the time, providing a HSR stimulus appeared to represent the main objective within these 'top-up' sessions.

Several competitions now allow teams to use an additional substitution (i.e., above those permitted during the initial 90 min) when tournament matches progress to extra-time (FIFA, 2018). Although a range of opinions existed in relation to the number of substitutions that should be permitted during a normal 90 min match, practitioners in the current study were largely in favour of allowing at least one additional substitution during extra-time. This stance reflects previous observations from professional soccer practitioners (Harper et al., 2016c), with the potential for an additional substitute to help offset increases in physical fatigue and perceived concomitant elevations in injury-risk representing the most prevalent justification for such opinions. Notably, in keeping with the numerous objectives potentially motivating the introduction of substitutes, the opportunity to provide a greater number of players with developmental playing time was forwarded as an argument for permitting more substitutions to be made during youth or academy matches, compared with first team soccer.

Although important observations are presented, this study carries several potential limitations which should be borne in mind. Alternative methods such as semi-structured interviews or practitioner focus groups could have provided a greater depth of qualitative information. However, online surveys were chosen as the appropriate method in order to minimise the burden on potential participants and to maintain practitioner anonymity. Both of these factors were believed to be important for participant recruitment, based on the low response rates observed in previous studies of professional soccer practitioners (McCall et al., 2015; Towlson et al., 2013). The surveys also enabled a mixture of quantitative and qualitative data to be collected, whereby practitioners provided answers to open-ended follow-up questions to justify or contextualise their quantitative responses.

As practitioners were made aware of the topic (i.e., substitutes) prior to commencing the survey, there exists the potential that the sample was biased towards individuals with an existing interest in this area. Moreover, a descriptive cross-sectional design was adopted, whereby practitioners were asked to respond based upon their perceptions and practices at the time of survey completion. To ensure complete anonymity of participants, respondents were not asked to provide personal information such as their level of experience or professional qualification/accreditation. Therefore, it was not possible to determine the precise demographic that chose to participate. Finally, although reflective of previous research to have conducted online surveys of professional soccer practitioners (McCall et al., 2015; Towlson et al., 2013), the sample size in the current study was limited by difficulties in accessing practitioners and a potential reluctance to divulge their practices. As such, whilst inductive thematic analysis was performed in relation to qualitative survey responses, it was believed that attempting inferential statistics would not be appropriate (Harper et al., 2016c). It is possible that responses may have differed between practitioners working at different levels of soccer, for whom likely discrepancies in the availability of resources could influence strategies that can be adopted by substitutes. Nonetheless, these novel qualitative and quantitative data provide context for existing research, highlight clear priorities for future investigation as identified by those working in the field, and may enable practitioners to critically reflect upon their own practices.

3.5 Conclusion

This chapter has presented novel insights from applied practitioners regarding current perceptions and practices in relation to substitutes in professional soccer. Substitutes may be introduced into a match for different reasons, although the perceived ability of this playing group to provide physical and/or tactical impetus is often the primary motivation. Whilst practitioners generally believe that substitutes can have a positive impact upon a match, contextual factors such as the timing of their introduction, match scenario, and the adequacy of players' pre-pitch-entry preparations may be influential in facilitating the desired outcome. Indeed, the unpredictability of match-play and the reactive nature of substitutions were frequently highlighted by practitioners, factors which may contribute to uncertainty amongst players and staff alike. Approaches vary substantially with regard to substitutes' physical preparation and recovery, and practitioners emphasised the importance of future research in this area. The design of such research may be informed by findings from the current study, which highlight the presence of logistical barriers and the importance of communication between stakeholders (i.e., sub-sets of practitioners and players themselves) to help optimise the treatment of this bespoke population of soccer players.

Chapter 4.0 A match-day analysis of the movement profiles of substitutes from a professional soccer club before and after pitch-entry

Chapter summary

- Whilst the movement demands of players completing a whole soccer match have been well-documented, comparable information relating to substitutes is sparse.
- Focusing separately on the pre- and post-pitch-entry periods, 17 English Championship soccer players were monitored using 10 Hz MEMS during 13 matches in which they participated as substitutes (35 observations).
- Substitutes performed a pre-match warm-up separately from the starting team, before ~3 individual player-led rewarm-up bouts·player^{-1}·match^{-1}. The warm-up and rewarm-ups consisted primarily of low-speed movements, with little HSR and no SPR performed prior to pitch-entry.
- For 10 out of 20 physical variables measured after a player's introduction into the match, values reduced from 0-5 min post-pitch-entry thereafter, with substitutes covering more TD and HSR during their first five min of match-play versus all subsequent five min epochs.
- These findings provide novel insights into the match-day demands faced by substitute soccer players. Future research opportunities exist to better understand the match-day practices of this population.

PLOS | ONE

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4.1 Introduction

English Football League rules currently permit up to three substitutions from a maximum of seven nominated players (EFL, 2019). Chapter three highlighted that substitutes are typically introduced to provide a physical impact on a match by offsetting the effects of fatigue amongst starting players and/or to change team tactics, although other motivations may also exist (e.g., allowing playing time for youth players or those returning from injury). Whilst situational variables (i.e., league-type, match scoreline, etc.) may also influence substitute timing, substitutions typically occur after at least 45 min of match-play (Bradley et al., 2014; Del Corral et al., 2008; Myers, 2012), with midfielders being the most common replacement (Del Corral et al., 2008).

Soccer-specific exercise compromises indices of physical and technical performance throughout 90 min (Di Salvo et al., 2009; Mohr et al., 2003; Rampinini et al., 2011; Rampinini et al., 2009; Russell et al., 2011a, 2012), responses which appear exacerbated during extra-time (Harper et al., 2016a; Harper et al., 2014; Stevenson et al., 2017). As strategic substitutions often represent a means by which coaches/managers seek to attenuate fatigue-induced deteriorations in physical performance (chapter three, Bradley et al., 2014), the efficacy of this strategy remains to be confirmed. Indeed, although other motivations may underpin the decision to make a replacement (e.g., technical/tactical considerations), it has been proposed that for a substitution to be deemed effective from a 'work-rate' perspective, substitutes entering the field of play need to achieve or surpass the running responses of players being replaced and/or remaining on the pitch (Bradley et al., 2014).

English Premier League substitutes have demonstrated a trend towards increasing TD and HSR over successive five min periods following introduction (Bradley et al., 2014), thus possibly suggesting either conservative self-pacing strategies or questioning the efficacy of pre-pitch-entry preparations. However, as the match epochs used for analysis were determined relative to kick-off (e.g., data from a player introduced at 57 min may not register until the next five min epoch; 60-65 min), such responses could have been influenced by the potential omission of the moments immediately following players' introduction. Conversely, professional substitutes entering the pitch at half-time or during the second-half appear able to exceed the relative (i.e., $m \cdot min^{-1}$) TD and HSR performed by players who started a match on the pitch (Bradley et al., 2014; Carling et al., 2010; Mohr et al., 2003). Whilst substitutes may perform more HSR than is recorded during the equivalent second-half period when the same players complete a full-match, they appear unable to exceed the HSR performed during the first-half of matches that they start (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010). These observations come despite it being assumed that substitutes enter the pitch in a state free from substantially accumulated acute fatigue. Acknowledging the likely influence of match-specific contextual variables (e.g., scoreline, opposition quality, potential differences in playing formation, etc.) on the movement profiles observed, such findings may call into question whether the pre-pitch-entry strategies employed by soccer substitutes facilitate optimal performance following match-introduction, especially given coaches' desire for substitutes to make an immediate and sustained impact on the match (chapter three).

As substitutes typically face lengthy delays (often ≥75-120 min) between cessation of the initial warm-up (i.e., preparatory activities performed prior to kick-off) and their entry onto the pitch (Bradley et al., 2014; Del Corral et al., 2008; Myers, 2012), their actions during this period are of particular interest if preparedness for match-introduction is to be optimised (chapter three). However, despite the direct relevance for subsequent match performance, no existing study appeared to have profiled the specific match-day preparatory activities undertaken by soccer substitutes. Therefore, the dual objectives of this chapter were to investigate substitutes' pre-pitch-entry activities, and their physical performance responses following introduction into the match.

4.2 Methods

4.2.1 Participants

Following specific project approval from the School of Social and Health Sciences sub-committee of the Leeds Trinity University ethics board (Appendix 4), professional male players (n = 17; age: 25 ± 8 years; stature: 1.80 ± 0.09 m; body mass: 85.2 ± 8.6 kg) from an English Championship soccer club (representing the second tier of professional soccer in England and Wales) were monitored throughout 13 home league matches in which they participated as substitutes during the latter half of the 2017/18 competitive season. Data were included from players who were introduced at half-time or during the second-half of a match (i.e., not from unused substitutes, or enforced injury replacements made during the first-half) and the sample included three defenders, seven midfielders, and seven attackers. Given the observational nature of the study, no attempt was made to influence players' responses, and part of the activity monitoring was routinely required as part of their employment. Written informed consent was achieved and a total of 35 performance observations (16, 14, and 5 observations from midfielders, attackers, and defenders, respectively; 2 ± 2 matches·player^{-1}; range: 1-6 matches·player^{-1}) were included.

4.2.2 Activity monitoring

Players' movements were captured by 10 Hz MEMS (S5, Optimeye; Catapult Innovations, Melbourne, Australia) units that were worn underneath the playing jersey between the scapulae in a vest specifically designed to minimise movement artefacts. A combination of Global Positioning Systems (GPS)- and accelerometer-derived variables were profiled. Sampling at 10 Hz has demonstrated acceptable reliability (coefficient of variation; CV% = 2.0-5.3%) for measuring instantaneous velocity (Varley et al., 2012b), and the specific units used demonstrated small-to-moderate typical error of the estimate (1.87-1.95%) versus a radar gun when assessing sprinting speed (Roe et al., 2017). Similarly, no significant differences between criterion values and MEMS-derived measures of TD were observed during a team sport-specific circuit (Johnston et al., 2014), whilst very large or near-perfect correlations (r = 0.89-0.91) were reported for peak speed (Johnston et al., 2014). At all speeds examined (1-8 $m \cdot s^{-1}$), CV% less than or similar to the smallest worthwhile change in performance (i.e., defined as: 0.2 multiplied by the between-participant standard deviation (Batterham & Hopkins, 2006)) have been observed for measuring instantaneous velocity during the constant velocity, acceleration, and deceleration phases of straight line running (Varley et al., 2012b). The accelerometers within the devices have also demonstrated good intra (CV% = 0.9-1.1%) and inter-unit (CV% = 1.0-1.1) reliability in both laboratory and field test environments (Boyd et al., 2011). Players wore the same units in each match to avoid inter-unit variation.

In accordance with manufacturer's guidelines, the MEMS units were activated outdoors and ~30 min prior to the initial warm-up, whilst raw data were exported post-match (Sprint 5.1.7, Catapult Innovations, Melbourne, Australia). Table 4.1 defines the MEMS-derived variables profiled. Data were organised on an individual player basis and were classified into periods according to each bout of warm-up activity performed (pre-pitch-entry) and into five min epochs from the moment a player entered the pitch (post-pitch-entry). To support the MEMS-derived movement data, substitutes were filmed (50 Hz; GX1; JVC; Yokohama; Japan) between the start of the initial pre-match warm-up and their entry onto the pitch. A tripod-mounted camera was focused on the initial pre-match warm-up prior to kick-off, whilst separate cameras were concentrated on the team dugout area and pitch-side rewarm-up area whilst the match was underway. The footage obtained was subjectively analysed to determine the types of activities that were performed prior to match-introduction and thereby support the objective movement data. For each substitution, contextual information relating to match scoreline, playing position, and the timing of introduction was also recorded.

The lead researcher was responsible for securing ethical approval and contacting the professional soccer club who provided the data for chapters four, six, and seven. The lead researcher attended matches and conducted all filming of substitutes' pre-pitch-entry practices, before analysing the captured footage to ascertain the types of activities that were performed prior to match-introduction. The MEMS data were collected as part of routine monitoring practices at the club but were not typically analysed for substitutes. Based on the specific established aims of the study, the lead researcher was responsible for clipping and exporting all raw MEMS files for each individual player observation to allow for subsequent statistics analysis, which they also conducted. Members of the PhD supervisory team provided input at all stages of study design and senior sports science staff at the club provided access to the raw MEMS data, whilst an experienced statistician was consulted prior to and throughout the formal statistical analysis.

Table 4.1: Operational definition for Microelectromechanical Systems (MEMS)-derived outcome variables

Measurement	Variable	Definition
Distance covered	TD (m)	Total amount of distance covered by any means
	Relative TD ($m \cdot min^{-1}$)	Total amount of distance covered per min
	LSR (m)	Distance covered at a speed of ≤4 $m \cdot s^{-1}$
	Relative LSR ($m \cdot min^{-1}$)	Distance covered per min at a speed of ≤4 $m \cdot s^{-1}$
	MSR (m)	Distance covered at a speed of >4 to ≤5.5 $m \cdot s^{-1}$
	Relative MSR ($m \cdot min^{-1}$)	Distance covered per min at a speed of >4 to ≤5.5 $m \cdot s^{-1}$
	HSR (m)	Distance covered at a speed of >5.5 to ≤7 $m \cdot s^{-1}$
	Relative HSR ($m \cdot min^{-1}$)	Distance covered per min at a speed of >5.5 to ≤7 $m \cdot s^{-1}$
	SPR (m)	Distance covered at a speed of >7 $m \cdot s^{-1}$
	Relative SPR ($m \cdot min^{-1}$)	Distance covered per min at a speed >7 $m \cdot s^{-1}$
PL	Absolute (AU)	Quantification of external workload: Square root of the summed rates of change in instantaneous velocity in each of the three (forwards, sideways, upwards) vectors, divided by a scaling factor of 100
	Relative ($AU \cdot min^{-1}$)	Player load accumulated over X number of min, divided by X number of min
Acceleration/deceleration count	High-intensity accelerations (#)	Count of the number of accelerations >3 $m \cdot s^{-2}$ for a period of ≥0.4 s
	High-speed decelerations (#)	Count of the number of decelerations <−3 $m \cdot s^{-2}$ for a period of ≥0.4 s
	Moderate-speed accelerations (#)	Count of the number of accelerations >2 to ≤3 $m \cdot s^{-2}$ for a period of ≥0.4 s
	Moderate-speed decelerations (#)	Count of the number of decelerations <−2 to ≥−3 $m \cdot s^{-2}$ for a period of ≥0.4 s
Acceleration/deceleration distance	High-speed acceleration (m)	Distance covered whilst accelerating at >3 $m \cdot s^{-2}$
	High-speed deceleration (m)	Distance covered whilst decelerating at <−3 $m \cdot s^{-2}$
	Moderate-speed acceleration (m)	Distance covered whilst accelerating at >2 to ≤3 $m \cdot s^{-2}$
	Moderate-speed deceleration (m)	Distance covered whilst decelerating at <−2 to ≥−3 $m \cdot s^{-2}$
Time	Duration (min)	Length of time for any given period

AU: Arbitrary units, #: Count, HSR: High-speed running, LSR: Low-speed running, MEMS: Microelectromechanical Systems, MSR: Moderate-speed running, PL: PlayerLoad™, SPR: Sprinting, TD: Total distance.

4.2.3 Data analyses

To account for the interdependence of data arising through repeated observations across multiple matches, linear mixed modelling was conducted to differentiate outcome variables as a function of time. Separate models were constructed for each dependent variable both pre- and post-pitch-entry. 'Match' and 'player' were entered as random effects, whilst playing position and match scoreline at the time of introduction were specified as categorical fixed effects. Time (i.e., 'epoch' or 'bout') was modelled first as a continuous, and then categorical (fixed) effect to allow comparisons with a baseline reference, for which the first time-period (i.e., initial warm-up or 0-5 min for pre- and post-pitch-entry data, respectively) was used. For the fixed effect of position, midfielders were used as baseline, whilst the team being ahead in a match was specified as the reference category for the scoreline variable. For each outcome measure, a variance components model with no predictors was established before sequentially allowing intercepts and then slopes to vary. A combination of random slopes and intercepts were employed based upon Bayesian information criterion assessments of model fit. For 'count' data, responses were analysed via mixed-effects Poisson regression. Analyses were conducted using StataCorp; 2017, Stata Statistical Software Release 15, College Station, TX: StataCorp LLC. Data are presented as mean ± standard deviation, whilst magnitude of change is demonstrated by effect estimates (or incidence rate ratios; IRR for 'count' variables), with associated 95% confidence intervals (CI).

4.3 Results

All three replacements were utilised in 12 out of 13 matches and the mean timing of the first, second and third substitutions were 59 ± 9 min, 71 ± 10 min, and 77 ± 10 min, respectively. Video footage indicated that substitutes' initial (i.e., pre-match) warm-ups were conducted separately from the starting players and began with dynamic stretching (~10 min) followed by possession games (~10 min) and passing sequences (~6 min) before returning to the changing rooms ~15 min before kick-off. The pre-match warm-up remained consistent across all matches profiled. Following kick-off, substitutes mostly remained seated; occasionally standing to perform rewarm-up activity (3 ± 1 rewarm-up bouts·player^{-1}·match^{-1}). The captured footage suggested that these rewarm-ups were performed pitch-side between the halfway line and the corner flag. Whilst specific activities varied substantially and were often difficult to classify, rewarm-ups performed whilst the match was underway consisted primarily of static and dynamic stretching with occasional periods of jogging and side-stepping for distances of ~5-30 m along the touchline. Substitutes often appeared to become distracted by events unfolding on the pitch, causing them to pause their activities. During any self-selected half-time rewarm-ups, awaiting substitutes performed close-quarter passing and possession games amongst themselves.

The team won four, drew three, and lost six of the 13 matches, scoring and conceding a total of 16 and 13 goals, respectively. In 13 of the 35 substitutions observed, a player entered the pitch when the team was leading (in terms of match scoreline) in the match. In a further 13 instances a substitution was made when the team was behind, whilst the remaining nine substitutes were introduced when the scores were level. The mean scoreline was 1 ± 1 goal scored and 1 ± 1 goal conceded at the time of pitch-entry for each of the first, second, and third substitutions, respectively. There were nine occasions when the team goal differential (i.e., goals scored minus goals conceded) improved during the time between a substitution being made and the end of the match. The goal differential became less favourable following seven of the substitutions, and 19 instances were observed in which the goal difference between the two teams was the same after 90 min when compared with the time of pitch-entry.

4.3.1 Pre-pitch-entry responses

Tables 4.2 and 4.3 detail MEMS outputs from the pre-pitch-entry activities performed. Each rewarm-up was shorter than the initial warm-up (all $p \leq 0.001$), whilst absolute TD, PlayerLoad™ (PL), low-speed running distance (LSR), and the number of moderate-speed accelerations were also lower for rewarm-ups (all $p \leq 0.001$). However, relative TD, PL, and LSR during each rewarm-up exceeded initial warm-up values (all $p \leq 0.001$). Relative HSR responses during the first ($p = 0.345$) and half-time ($p = 0.194$) rewarm-up bouts were similar to the initial warm-up, but relative HSR was significantly higher for second-half rewarm-ups compared with the initial warm-up (all $p \leq 0.05$). When time was modelled as a continuous variable, effect estimates indicated significant decreases in duration, absolute TD, absolute LSR, and absolute PL for each successive bout of pre-pitch-entry activity performed (all $p \leq 0.001$). However, increases were observed for absolute and relative moderate-speed running distance (MSR) and HSR, relative TD, relative LSR, and relative PL, as well as distance covered whilst decelerating at high- and moderate-speeds (all $p \leq 0.001$). In addition, increases in the number of high- and moderate-speed accelerations and declarations were observed as proximity to pitch-entry neared (all $p \leq 0.05$). Scoreline at the time of pitch-entry influenced the amount HSR performed during rewarm-up activity, with players covering an additional 3.17 m of HSR per rewarm-up bout ($p = 0.047$, CI: 0.04 to 6.31 m) when the team was losing at the time of introduction, compared with when the team was ahead. Scoreline did not influence any other variable prior to pitch-entry.

Table 4.2: Descriptive statistics for physical performance variables for substitutes prior to pitch-entry

Variable		**Initial warm-up (*n=35*)**	**RWU1 (*n=34 first-half, n=1 second-half*)**	**Half-time warm-up (*n=27*)**	**RWU2 (*n=6 first-half, n=22 second-half*)**	**RWU3 (*n=1 first-half, n=7 second-half*)**	**RWU4 (*n=2 second-half,*)**
Duration (min)		26.25 ± 2.43	6.51 ± 2.39[b]	5.51 ± 2.31[b]	5.96 ± 3.74[b]	3.14 ± 1.68[b]	3.23 ± 0.39[b]
TD	Absolute (m)	992 ± 218	386 ± 143[b]	423 ± 170[b]	428 ± 286[b]	229 ± 93[b]	321 ± 44[b]
	Relative ($m \cdot min^{-1}$)	37.9 ± 7.8	64.3 ± 23.5[b]	83.0 ± 30.3[b]	80.2 ± 28.9[b]	89.3 ± 40.2[b]	99.5 ± 1.6[b]
LSR	Absolute (m)	963 ± 210	369 ± 131[b]	394 ± 159[b]	378 ± 259[b]	198 ± 100[b]	280 ± 45[b]
	Relative ($m \cdot min^{-1}$)	36.8 ± 7.5	61.1 ± 19.8[b]	76.1 ± 22.9[b]	70.7 ± 25.6[b]	72.3 ± 28.1[b]	86.5 ± 3.4[b]
MSR	Absolute (m)	15 ± 31	15 ± 22	18 ± 28	42 ± 39[b]	27 ± 26	37 ± 6
	Relative ($m \cdot min^{-1}$)	0.6 ± 1.2	2.9 ± 5.5	4.5 ± 8.7[a]	8.6 ± 9.3[b]	14.7 ± 18.0[b]	11.3 ± 0.6[b]
HSR	Absolute (m)	1 ± 4	2 ± 6	3 ± 6	6 ± 10[a]	3 ± 5	5 ± 7
	Relative ($m \cdot min^{-1}$)	0.0 ± 0.1	0.3 ± 1.0	0.5 ± 1.3	0.8 ± 1.2[a]	1.9 ± 3.9[b]	1.7 ± 2.4[a]
SPR	Absolute (m)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	Relative ($m \cdot min^{-1}$)	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
PL	Absolute (AU)	127.64 ± 24.10	38.54 ± 12.56[b]	40.19 ± 19.29[b]	42.50 ± 27.31[b]	20.54 ± 9.26[b]	30.27 ± 1.87[b]
	Relative ($AU \cdot min^{-1}$)	4.88 ± 0.90	6.58 ± 2.79 [b]	7.54 ± 2.05[b]	7.90 ± 2.77[b]	7.82 ± 3.72[b]	9.42 ± 0.55[b]
$_{ACC}$dist	High (m)	2 ± 2	1 ± 1[a]	2 ± 3	1 ± 4	1 ± 1	1 ± 0
	Moderate (m)	7 ± 4	3 ± 3[b]	5 ± 4	6 ± 7	2 ± 1	7 ± 1
$_{DEC}$dist	High (m)	0 ± 0	0 ± 1	0 ± 1	1 ± 1[b]	0 ± 0	0 ± 0
	Moderate (m)	1 ± 2	1 ± 2	2 ± 2	4 ± 4[b]	1 ± 1	2 ± 1
#$_{ACC}$	High (#)	2 ± 2	1 ± 1[b]	2 ± 2	1 ± 2[b]	0 ± 1[a]	0 ± 0
	Moderate (#)	11 ± 6	3 ± 2[b]	6 ± 4[b]	4 ± 4[b]	1 ± 1[b]	3 ± 1[b]
#$_{DEC}$	High (#)	0 ± 1	0 ± 1	1 ± 1	1 ± 1[b]	0 ± 1	1 ± 1
	Moderate (#)	3 ± 2	1 ± 2[a]	2 ± 2	3 ± 3	1 ± 1[a]	4 ± 2

$_{ACC}$dist: Acceleration distance, AU: Arbitrary units, $_{DEC}$dist: Deceleration distance, HSR: High-speed running, LSR: Low-speed running, MSR: Moderate-speed running, PL: Player Load, RWU: Rewarm-up, SPR: Sprinting, TD: Total Distance, #$_{ACC}$: Number of accelerations, #$_{DEC}$: Number of decelerations, [a] different from initial warm-up at $p \leq 0.05$ level, [b] different from initial warm-up at $p \leq 0.001$ level. Data are presented as mean ± standard deviation.

Table 4.3: Magnitude of change in physical performance variables for substitutes prior to pitch-entry

Variable		**Initial warm-up (*n=35*)**	**RWU1 (*n=34 first-half, n=1 second-half*)**	**Half-time warm-up (*n=27*)**	**RWU2 (*n=6 first-half, n=22 second-half*)**	**RWU3 (*n=1 first-half, n=7 second-half*)**	**RWU4 (*n=2 second-half,*)**	**Time effects**
Duration	(min)	REF	-19.74 (-20.92 to -18.55)^{b}	-20.79 (-22.06 to -19.51)^{b}	-20.30 (-21.56 to -19.04)^{b}	-22.88 (-24.86 to -20.90)^{b}	-22.86 (-26.56 to -19.15)^{b}	-5.30 (-6.12 to -4.47)**
TD	Absolute (m)	REF	-606.46 (-692.96 to -519.95)^{b}	-572.23 (-665.70 to -478.76)^{b}	-565.32 (-657.26 to -473.38)^{b}	-740.62 (-884.96 to -596.28)^{b}	-642.28 (-914.96 to -369.60)^{b}	-152.12 (-186.51 to -117.73)**
	Relative ($m \cdot min^{-1}$)	REF	26.44 (15.94 to 36.94)^{b}	46.30 (34.97 to 57.63)^{b}	42.69 (31.53 to 53.84)^{b}	52.41 (34.95 to 69.88)^{b}	68.88 (35.95 to 101.80)^{b}	13.43 (10.31 to 6.55)**
LSR	Absolute (m)	REF	-594.51 (-674.55 to -514.48)^{b}	-575.86 (-662.39 to -489.34)^{b}	-586.62 (-671.70 to -501.53)^{b}	-745.66 (-879.37 to -611.96)^{b}	-669.70 (-922.48 to -416.92)^{b}	-157.85 (-190.36 to -125.39)**
	Relative ($m \cdot min^{-1}$)	REF	24.33 (15.92 to 32.73)^{b}	40.03 (30.75 to 49.32)^{b}	33.86 (24.30 to 43.42)^{b}	32.71 (16.79 to 48.63)^{b}	55.87 (25.26 to 86.49)^{b}	10.18 (7.34 to 13.02)**
MSR	Absolute (m)	REF	0.17 (-12.05 to 12.39)	5.69 (-7.53 to 18.92)	27.92 (14.91 to 40.92)^{b}	16.89 (-3.61 to 37.40)	31.94 (-6.81 to 70.69)	7.59 (4.10 to 11.09)**
	Relative ($m \cdot min^{-1}$)	REF	2.36 (-0.57 to 5.29)	4.27 (0.87 to 7.66)^{a}	8.02 (4.28 to 11.75)^{b}	16.12 (9.79 to 22.45)^{b}	20.48 (8.77 to 32.18)^{b}	3.04 (1.93 to 4.14)**
HSR	Absolute (m)	REF	0.83 (-1.71 to 3.37)	1.67 (-1.40 to 4.74)	4.62 (1.06 to 8.18)^{a}	5.76 (-0.18 to 11.71)	9.10 (-1.45 to 19.66)	1.44 (0.40 to 2.49)*
	Relative ($m \cdot min^{-1}$)	REF	0.24 (-0.26 to 0.74)	0.39 (-0.20 to 0.98)	0.78 (0.12 to 1.44)^{a}	2.38 (1.26 to 3.49)^{b}	3.00 (0.96 to 5.03)^{a}	0.35 (0.16 to 0.54)**
SPR	Absolute (m)	REF	n/a	n/a	n/a	n/a	n/a	n/a
	Relative ($m \cdot min^{-1}$)	REF	n/a	n/a	n/a	n/a	n/a	n/a
PL	Absolute (AU)	REF	-89.10 (-97.81 to -80.39)^{b}	-87.09 (-96.5 to -77.67)^{b}	-84.89 (-94.14 to -75.63)^{b}	-103.72 (-118.25 to -89.8)^{b}	-94.20 (-121.66 to -66.73)^{b}	-22.26 (-26.53 to -17.99)**
	Relative ($AU \cdot min^{-1}$)	REF	1.70 (0.74 to 2.66)^{b}	2.89 (1.85 to 3.92)^{b}	3.08 (2.06 to 4.10)^{b}	3.23 (1.62 to 4.83)^{b}	5.42 (2.39 to 8.44)^{b}	0.95 (0.67 to 1.22)**
$_{ACC}$**dist**	High (m)	REF	-1.49 (-2.50 to -0.47)^{a}	0.13 (-1.08 to 1.34)	-0.70 (-2.06 to 0.67)	-0.33 (-2.63 to 1.97)	-0.21 (-4.38 to 3.97)	None
	Moderate (m)	REF	-4.46 (-6.13 to -2.79)^{b}	-1.78 (-3.83 to 0.27)	-1.16 (-3.57 to 1.26)	-2.65 (-6.65 to 1.35)	1.82 (-5.21 to 8.84)	None
$_{DEC}$**dist**	High (m)	REF	0.17 (-0.18 to 0.52)	0.25 (-0.16 to 0.65)	0.85 (0.41 to 1.30)^{b}	0.50 (-0.26 to 1.25)	0.39 (-1.01 to 1.78)	0.21 (0.08 to 0.35)*
	Moderate (m)	REF	0.03 (-0.96 to 1.02)	0.50 (-0.66 to 1.65)	2.23 (0.95 to 3.52)^{b}	0.15 (-2.02 to 2.33)	0.87 (-3.12 to 4.86)	0.51 (0.12 to 0.91)*
#$_{ACC}$	High (IRR)	REF	0.32 (0.20 to 0.50)^{b}	0.73 (0.50 to 1.06)	0.32 (0.19 to 0.52)^{b}	0.18 (0.06 to 0.58)^{a}	n/a	1.61 (1.54 to 1.69)**
	Moderate (IRR)	REF	0.24 (0.19 to 0.31)^{b}	0.53 (0.43 to 0.65)^{b}	0.41 (0.33 to 0.52)^{b}	0.15 (0.08 to 0.26)^{b}	0.21 (0.09 to 0.53)^{b}	1.50 (1.42 to 1.58)**
#$_{DEC}$	High (IRR)	REF	1.1 (0.47 to 2.59)	1.91 (0.85 to 4.32)	3.46 (1.69 to 7.16)^{b}	1.23 (0.34 to 4.51)	1.92 (0.24 to 15.30)	2.30 (2.15 to 2.47)**
	Moderate (IRR)	REF	0.58 (0.41 to 0.82)^{a}	0.86 (0.62 to 1.20)	1.09 (0.80 to 1.48)	0.27 (0.12 to 0.62)^{a}	1.53 (0.69 to 3.41)	1.69 (1.62 to 1.77**

$_{ACC}$dist:: Acceleration distance, AU: Arbitrary units, $_{DEC}$dist: Deceleration distance, HSR: High-speed running, LSR: Low-speed running, MSR: Moderate-speed running, PL: Player Load, REF: Reference category for comparison, RWU: Rewarm-up, SPR: Sprinting, TD: Total Distance, #$_{ACC}$: Number of accelerations, #$_{DEC}$: Number of decelerations, ^{a} different from initial warm-up at $p \leq 0.05$ level when 'bout' modelled as categorical, ^{b} different from initial warm-up at $p \leq 0.001$ level when ‘bout’ modelled as categorical,*: Significant effect at p ≤0.05 level, **: Significant effect at p ≤0.001 level. Data are reported as effect estimates (95% CI), except for $\#_{ACC}$ and $\#_{DEC}$ which are incidence risk ratios (IRR).

4.3.2 Post-pitch-entry responses

Tables 4.4 and 4.5 present activity profile data following a substitute's introduction into a match. Effect estimates indicated significant declines in absolute and relative values for TD, MSR, HSR, and PL, as well as decreases in distance covered at high- and moderate-speeds from 0-5 min onwards as a function of time. Notably, 38.6% reductions in relative HSR, and 12.2% declines in both relative TD and relative PL were observed from 0-5 min to 5-10 min (all $p \leq 0.001$). Moreover, 31.1% and 20.0% decrements occurred for relative MSR and moderate-speed acceleration distance, respectively (both $p \leq 0.001$).

Compared with midfielders, attackers and defenders covered less TD (-41.22, CI: -63.68 to -18.77 m, and -41.15, CI: -74.48 to -7.82 m), MSR (-14.57, CI: -26.49 to -2.64 m, and -28.36, CI: -45.21 to -11.51 m), and performed fewer high-speed decelerations (IRR: 0.77, CI: 0.64 to 0.93, and 0.70, CI: 0.52 to 0.95) per five min epoch (all $p \leq 0.05$). Moreover, defenders covered less HSR (-19.95, CI: -33.21 to -6.70 m), moderate-speed acceleration distance (-3.20, CI: -5.46 to -0.93 m), high-speed deceleration distance (-1.88, CI: -3.02 to -0.75 m), and moderate-speed deceleration distance (-3.62, CI: -5.48 to -1.76 m), whilst attackers executed more high-speed accelerations (IRR: 1.25, CI: 1.04 to 1.50), compared with midfielders (all $p \leq 0.05$).

When the team was drawing or losing at the time of pitch-entry, players covered less TD (-26.64, CI: -52.45 to -0.83 m, and -48.71, CI: -75.40 to -22.02 m), high-speed acceleration distance (-1.89, CI: -3.08 to -0.69 m, and -2.44, CI: -3.74 to -1.14 m), and moderate-speed deceleration distance (-1.48, CI: -2.75 to -0.20 m, and -3.48, CI: -4.85 to -2.10 m), in addition to performing fewer high-speed accelerations (IRR: 0.79, CI: 0.64 to 0.97, and 0.80, CI: 0.65 to 0.99) and moderate-speed decelerations (IRR: 0.82, CI: 0.67 to 0.99, and 0.69, CI: 0.56 to 0.84) per five min epoch, compared with when the team was winning (all $p \leq 0.05$). Moreover, substitutes introduced when the scores were level accumulated less LSR (-26.00, CI: -49.75 to -2.25 m), whilst players entering the pitch when the reference team was losing performed less moderate-speed acceleration distance (-2.03, CI: -3.70 to -0.36 m), high-speed deceleration distance (-1.83, CI: -2.74 to -0.93 m), and fewer high-speed decelerations (IRR: 0.76, CI: 0.61 to 0.94) per five min epoch, alongside returning lower PL values (-5.10, CI: -8.53 to -1.68 AU), relative to when the team was winning at the time of introduction (all $p \leq 0.05$).

Table 4.4: Descriptive statistics for physical performance variables for substitutes from timing of pitch-entry to the end of match-play

Variable		**0-5 min (*n=33*)**	**5-10 min (*n=32*)**	**10-15 min (*n=30*)**	**15-20 min (*n=26*)**	**20-25 min (*n=19*)**	**25-30 min (*n=11*)**	**30-35 min (*n=7*)**	**35-40 min (*n=4*)**
TD	Absolute (m)	599 ± 75	527 ± 66[b]	527 ± 81[b]	531 ± 59[b]	527 ± 60[b]	508 ± 72[b]	507 ± 110[b]	521 ± 56[a]
	Relative (m·min^{-1})	120.0 ± 14.8	105.3 ± 13.3[b]	105.6 ± 16.5[b]	106.0 ± 11.5[b]	105.2 ± 11.8[b]	101.7 ± 14.5[b]	101.4 ± 22.1[b]	104.2 ± 11.2[a]
LSR	Absolute (m)	438 ± 55	414 ± 49	414 ± 66	413 ± 7	402 ± 48 [a]	405 ± 51	425 ± 80	431 ± 58
	Relative (m·min^{-1})	87.6 ± 11.0	82.9 ± 9.8	82.8 ± 13.2	82.5 ± 9.3	80.5 ± 9.5 [a]	81.1 ± 10.3	84.9 ± 16.0	86.1 ± 11.5
MSR	Absolute (m)	105 ± 34	72 ± 27[b]	78 ± 38[b]	78 ± 29[b]	84 ± 36[a]	68 ± 33[b]	58 ± 28[b]	72 ± 29[a]
	Relative (m·min^{-1})	20.9 ± 6.8	14.3 ± 5.4[b]	15.5 ± 7.5[b]	15.7 ± 5.8[b]	16.8 ± 7.1[a]	13.6 ± 6.6[b]	11.5 ± 5.5[b]	14.3 ± 5.8[a]
HSR	Absolute (m)	51 ± 29	31 ± 22[b]	28 ± 19[b]	30 ± 20[b]	36 ± 22[a]	24 ± 18[b]	20 ± 19[b]	18 ± 14[b]
	Relative (m·min^{-1})	10.1 ± 5.9	6.2 ± 4.5[b]	5.7 ± 3.9[b]	6.1 ± 4.0[b]	7.1 ± 4.4[a]	4.9 ± 3.6[b]	3.9 ± 3.7[b]	3.7 ± 2.8[b]
SPR	Absolute (m)	6 ± 10	10 ± 15	7 ± 11	10 ± 12	5 ± 10	11 ± 14	5 ± 9	1 ± 2
	Relative (m·min^{-1})	1.3 ± 1.9	2.1 ± 3.1	1.4 ± 2.1	2.0 ± 2.5	1.1 ± 2.0	2.2 ± 2.8	1.1 ± 1.8	0.2 ± 0.3
PL	Absolute (AU)	61.21 ± 8.43	53.94 ± 6.80[b]	52.78 ± 9.65[b]	53.04 ± 8.17[b]	52.90 ± 7.07[b]	49.67 ± 6.28[b]	46.31 ± 10.35[b]	45.76 ± 10.38 [b]
	Relative (AU·min^{-1})	12.25 ± 1.67	10.77 ± 1.39[b]	10.59 ± 1.94[b]	10.59 ± 1.61[b]	10.55 ± 1.41[b]	9.93 ± 1.25[b]	9.26 ± 2.07[b]	9.15 ± 2.08[b]
ACCdist	High (m)	8 ± 3	6 ± 3[a]	5 ± 3[b]	5 ± 3[b]	7 ± 4	6 ± 2	3 ± 3[b]	6 ± 4
	Moderate (m)	16 ± 5	13 ± 5[b]	13 ± 4[b]	13 ± 4[b]	14 ± 5[a]	13 ± 4[a]	10 ± 2[b]	11 ± 2[a]
DECdist	High (m)	5 ± 2	4 ± 3 [a]	3 ± 1 [a]	4 ± 3	5 ± 3	4 ± 1[a]	3 ± 2[a]	3 ± 3 [a]
	Moderate (m)	10 ± 4	8 ± 5	8 ± 3 [a]	8 ± 3	8 ± 4	8 ± 3	7 ± 4	7 ± 4
#ACC	High (#)	3 ± 2	3 ± 2	3 ± 2	2 ± 1 [a]	3 ± 2	2 ± 1	2 ± 1	3 ± 2
	Moderate (#)	10 ± 4	9 ± 4	9 ± 4	9 ± 4	9 ± 3	8 ± 5	9 ± 3	9 ± 2
#DEC	High (#)	4 ± 2	3 ± 2 [a]	3 ± 2 [a]	2 ± 2 [a]	3 ± 2	3 ± 1	2 ± 3 [a]	2 ± 2
	Moderate (#)	5 ± 2	5 ± 3	5 ± 3	5 ± 2	4 ± 2	5 ± 3	4 ± 2	4 ± 2

ACCdist: Acceleration distance, AU: Arbitrary units, DECdist: Deceleration distance, HSR: High-speed running, LSR: Low-speed running, MSR: Moderate-speed running, PL: Player Load, TD: SPR: Sprinting, Total Distance, $\#_{ACC}$: Number of accelerations, $\#_{DEC}$: Number of decelerations, [a] different from 0-5 min at $p \leq 0.05$ level, [b] different from 0-5 min at $p \leq 0.001$ level. Data are presented as mean ± standard deviation.

Table 4.5: Magnitude of change in physical performance variables for substitutes from timing of pitch-entry to the end of match-play

Variable		**0-5 min (*n=33*)**	**5-10 min (*n=32*)**	**10-15 min (*n=30*)**	**15-20 min (*n=26*)**	**20-25 min (*n=19*)**	**25-30 min (*n=11*)**	**30-35 min (*n=7*)**	**35-40 min (*n=4*)**	**Time effects**	**Position effects**	**Scoreline effects**
TD	Absolute (m)	REF	-71.76 (-102.23 to -41.31)[b]	-73.29 (-104.32 to -42.27)[b]	-66.61 (-98.96 to -34.26)[b]	-71.39 (-107.16 to -35.61)[b]	-91.22 (-134.72 to -47.70)[b]	-92.98 (-145.39 to -40.57)[b]	-84.91 (-151.78 to -18.04)[a]	-11.30 (-16.97 to -5.63)**	MID>ATT** MID>DEF*	WI>DR* WI>LO**
	Relative ($m \cdot min^{-1}$)	REF	-14.58 (-20.70 to -8.46)[b]	-14.40 (-20.64 to -8.17)[b]	-13.62 (-20.12 to -7.12)[b]	-14.46 (-21.65 to -7.28)[b]	-18.26 (-27.01 to -9.51)[b]	-18.64 (-29.17 to -8.11)[b]	-16.45 (-29.90 to -3.00)[a]	-2.28 (-3.14 to -1.14)**	MID>ATT** MID>DEF*	WI>DR* WI>LO**
LSR	Absolute (m)	REF	-23.31 (-47.66 to 1.04)	-23.20 (-48.02 to 1.62)	-23.14 (-49.05 to 3.10)	-35.58 (-64.25 to -6.93)[a]	-31.80 (-66.70 to 3.10)	-16.07 (-58.11 to 25.97)	-16.07 (-69.20 to 38.04)	None	MID>ATT*	WI>DR*
	Relative ($m \cdot min^{-1}$)	REF	-4.59 (-9.36 to 0.16)	-4.63 (-9.48 to 0.21)	-4.75 (-9.81 to 0.30)	-7.05 (-12.65 to -1.46)[a]	-6.14 (-12.95 to 0.67)	-3.06 (-11.26 to 5.14)	-2.44 (-12.92 to 8.04)	None	MID>ATT*	WI>DR*
MSR	Absolute (m)	REF	-32.61 (-47.06 to -18.16)[b]	-27.30 (-41.99 to -12.59)[b]	-26.31 (-41.60 to -11.03)[b]	-21.05 (-37.87 to -4.21)[a]	-38.47 (-58.82 to -18.12)[b]	-49.65 (-74.12 to -25.18)[b]	-34.21 (-65.41 to -3.01)[a]	-4.37 (-7.01 to -1.74)**	MID>ATT* MID>DEF*	None
	Relative ($m \cdot min^{-1}$)	REF	-6.52 (-9.41 to -3.63)[b]	-5.45 (-8.40 to -2.52)[b]	-5.26 (-8.32 to -2.21)[b]	-4.21 (-7.58 to -0.84)[a]	-7.69 (-11.76 to -3.62) [b]	-9.93 (-14.82 to -5.04)[b]	-6.84 (-13.08 to -0.60)[a]	-4.37 (-7.01 to -1.74)**	MID>ATT* MID>DEF**	None
HSR	Absolute (m)	REF	-19.70 (-28.85 to -10.56)[b]	-23.23 (-32.55 to -13.91)[b]	-21.03 (-30.75 to -11.30)[b]	-14.30 (-25.06 to -3.55)[a]	-25.50 (-38.59 to -12.41)[b]	-29.20 (-44.97 to -13.42)[b]	-33.23 (-53.33 to -13.12)[b]	-3.38 (-5.10 to -1.65)**	MID>DEF*	None
	Relative ($m \cdot min^{-1}$)	REF	-3.94 (-5.77 to -2.11)[b]	-4.65 (-6.51 to -2.78)[b]	-4.21 (-6.15 to -2.26)[b]	-2.86 (-5.01 to -0.71)[a]	-5.10 (-7.72 to -2.48)[b]	-5.84 (-8.99 to -2.68)[b]	-6.65 (-10.66 to -2.62)[b]	-0.68 (-1.02 to -0.33)**	MID>DEF*	None
SPR	Absolute (m)	REF	3.83 (-1.38 to 9.04)	0.30 (-5.01 to 5.61)	3.63 (-1.91 to 9.17)	-1.04 (-7.17 to 5.08)	3.96 (-3.51 to 11.43)	-0.19 (-9.18 to 8.80)	-4.15 (-15.64 to 7.33)	None	None	None
	Relative ($m \cdot min^{-1}$)	REF	0.77 (-0.28 to 1.81)	0.06 (-1.00 to 1.81)	0.73 (-0.38 to 1.83)	-0.21 (-1.43 to 1.02)	0.79 (-0.70 to 2.29)	-0.04 (-1.84 to 1.76)	-0.83 (-3.13 to 1.47)	None	None	None
PL	Absolute (AU)	REF	-7.38 (-10.65 to -4.12)[b]	-8.49 (-11.83 to -5.16)[b]	-7.97 (-11.45 to -4.49)[b]	-7.60 (-11.45 to -3.74)[b]	-10.61 (-15.31 to -5.91)[b]	-12.56 (-18.23 to -6.89)[b]	-13.46 (-20.68 to -6.23)[b]	-1.67 (-2.29 to -1.06)**	None	WI>LO*

	Relative ($AU \cdot min^{-1}$)	REF	-1.50 (-2.16 to -0.85)[b]	-1.68 (-2.35 to 1.01)[b]	-1.62 (-2.32 to -0.92)[b]	-1.55 (-2.33 to -0.78)[b]	-2.13 (-3.08 to -1.19)[b]	-2.53 (-3.66 to -1.39)[b]	-2.70 (-4.15 to -1.25)[b]	-0.34 (-0.46 to -0.21)**	None	WI>LO*
ACC**dist**	High (m)	REF	-1.33 (-2.68 to 0.00)[a]	-2.48 (-3.85 to -1.11)[b]	-3.05 (-4.47 to -1.62)[b]	-0.61 (-2.19 to 0.96)	-1.54 (-3.46 to 0.37)	-4.03 (-6.34 to -1.73)[b]	-1.60 (-4.53 to 1.33)	-0.27 (-0.53 to -0.02)*	None	WI>DR* WI>LO**
	Moderate (m)	REF	-3.22 (-5.03 to -1.41)[b]	-3.62 (-5.47 to -1.77)[b]	-3.59 (-5.52 to -1.67)[b]	-2.54 (-4.67 to -0.42)[a]	-3.80 (-6.37 to -1.22)[a]	-5.57 (-8.67 to -2.47)[b]	-4.74 (-8.69 to -0.80)[a]	-0.55 (-0.88 to -0.22)**	MID>DEF*	WI>LO*
DEC**dist**	High (m)	REF	-1.24 (-2.29 to -0.18)[a]	-1.84 (-2.91 to -0.76)[a]	-0.93 (-2.05 to 0.19)	-0.30 (-1.54 to 0.94)	-1.75 (-3.26 to -0.24)[a]	-2.17 (-3.98 to -0.35)[a]	-2.40 (-4.72 to -0.08)[a]	None	MID>DEF**	WI>LO**
	Moderate (m)	REF	-1.39 (-2.89 to 0.11)	-1.56 (-3.09 to -0.03)[a]	-0.93 (-2.53 to 0.66)	-0.53 (-2.30 to 1.24)	-1.40 (-3.57 to 0.76)	-2.47 (-5.35 to 0.14)	-2.02 (-5.35 to 1.31)	None	MID>DEF**	WI>DR* WI>LO**
$\#_{ACC}$	High (IRR)	REF	0.98 (0.74 to 1.29)	0.87 (0.65 to 1.16)	0.66 (0.47 to 0.92)[a]	1.11 (0.81 to 1.52)	0.74 (0.48 to 1.15)	1.01 (0.54 to 1.89)	0.76 (0.56 to 1.02)	None	MID<ATT*	WI>DR* WI>LO*
	Moderate (IRR)	REF	0.94 (0.80 to 1.10)	0.88 (0.74 to 1.04)	0.88 (0.74 to 1.05)	0.88 (0.73 to 1.06)	0.83 (0.66 to 1.06)	0.98 (0.74 to 1.30)	0.96 (0.67 to 1.39)	None	None	None
$\#_{DEC}$	High (IRR)	REF	0.70 (0.53 to 0.92)[a]	0.69 (0.52 to 0.92)[a]	0.66 (0.49 to 0.89)[a]	0.90 (0.67 to 1.22)	0.68 (0.45 to 1.03)	0.54 (0.31 to 0.93)[a]	0.57 (0.29 to 1.13)	None	MID>ATT* MID>DEF*	WI>LO*
	Moderate (IRR)	REF	0.95 (0.75 to 1.19)	1.05 (0.84 to 1.31)	1.01 (0.80 to 1.29)	0.91 (0.69 to 1.19)	1.06 (0.78 to 1.45)	0.75 (0.48 to 1.15)	0.78 (0.46 to 1.36)	None	None	WI>DR* WI>LO**

ACCdist: Acceleration distance, ATT = Attacker, AU: Arbitrary units, DECdist: Deceleration distance, DEF = Defender, DR: Scores level at the time of pitch-entry, HSR: High-speed running, LO: Team losing at the time of pitch-entry, LSR: Low-speed running, MID: Midfielder, MSR: Moderate-speed running, PL: Player Load, REF: Reference category for comparison, SPR: Sprinting, TD: Total Distance, WI: Team winning at the time of pitch-entry, $\#_{ACC}$: Number of accelerations, $\#_{DEC}$: Number of decelerations, [a] different from 0-5 min at p ≤0.05 level when 'epoch' modelled as categorical, [b] different from 0-5 min at p ≤0.001 level when 'epoch' modelled as categorical,*: Significant effect at p ≤0.05 level, **: Significant effect at p ≤0.001 level. Data are reported as effect estimates (95% CI) except for $\#_{ACC}$ and $\#_{DEC,}$ which are incidence risk ratios (IRR).

4.4 Discussion

The aim of this study was to investigate the match-day physical demands experienced by English Championship soccer substitutes before and after pitch-entry. Prior to introduction into a match and after an initial pre-match warm-up, substitutes performed 3 ± 1 rewarm-up bouts·player^{-1}·match^{-1}, with rewarm-ups consisting largely of static and dynamic stretching but generally becoming shorter and more intense (i.e., increasing relative TD, LSR, MSR, and HSR ·bout^{-1}) as pitch-entry approached. Following introduction, time negatively influenced absolute and relative TD, MSR, HSR, and PL, as well as distance covered whilst accelerating at high- and moderate-speeds. Playing position and match scoreline also influenced the movement profiles observed, with the greatest match-distances per epoch being covered by midfielders (i.e., compared with attackers and defenders), and on occasions when the team was winning at the time of introduction (i.e., compared with when drawing or losing). Such data provide novel insights into transient changes in the match-day movement demands experienced by substitutes from a professional soccer club and highlight important future research opportunities, findings of which have the potential to positively influence practitioners seeking to optimise the match-day strategies for this bespoke population of soccer players.

Substitutes covered ~37.9 m·min^{-1} during their initial pre-match warm-up, of which 97% was LSR, before performing ~3 subsequent rewarm-ups between the match kick-off and pitch-entry. This study provides potentially important observations regarding the frequency and/or intensity of pre-pitch-entry activities in professional soccer players. For example, acknowledging that other actions such as dynamic stretching may also have occurred, awaiting substitutes performed <2 m·min^{-1} of HSR during each warm-up or rewarm-up bout and performed no SPR at any time prior to match-introduction. Whilst the absence of a comparator trial precludes definitive comment on the suitability of this pattern of activity for subsequent match-play, increasing the intensity of warm-up exercise from 300 m of striding (six repetitions of 50 m) to an equidistant bout of combined striding (100 m) and race-pace running (200 m) has been shown to enhance subsequent 800 m running performance by ~1% (Ingham et al., 2013). Moreover, a positive relationship exists between body temperature increases and performance in tasks requiring high-velocity muscle actions, with improvements of ~2-10% being reported for every 1°C increase in T_m (McGowan et al., 2015). Declines in T_{core} and T_m alongside concomitant reductions in physical performance occur following the cessation of exercise, with significant reductions typically observed within just ~10-15 min (Edholm et al., 2015; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c; Zois et al., 2013). Indeed, better maintenance of body temperature and improved physical performance capacity has been demonstrated when rewarm-up activity is performed during a ~15 min half-time interval, compared with the responses observed following the equivalent period of passive rest (Edholm et al., 2015; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c; Zois et al., 2013).

Consistent with observations that increasing warm-up intensity may be beneficial for subsequent high-intensity exercise performance (Ingham et al., 2013), where ≥15 min separates an initial warm-up and entry into a match, active rewarm-ups consisting of brief high-intensity efforts (~2 min at ~90% HR_{max}) may better maintain subsequent performance in explosive tasks relative to passive rest (Silva et al., 2018). Substitutes in the current study covered ~29.1 $m \cdot min^{-1}$ (including ~0.4 $m \cdot min^{-1}$ of HSR) during the 15 min prior to pitch-entry, but it may be notable that no SPR occurred in either the initial warm-up or subsequent rewarm-ups. Whilst the efficacy of this pre-pitch-entry strategy as a means of preparing for subsequent performance remains to be determined, modifying rewarm-up strategies alongside potentially incorporating passive heat maintenance techniques (e.g., wearing specialist heat-retaining garments) between initial warm-up cessation and match-introduction could further assist in body temperature preservation and thereby improve physical performance capacity thereafter (Russell et al., 2017; Russell et al., 2015c; Russell et al., 2015d; Silva et al., 2018).

Given the timeframes involved and the desire to maintain energy stores, it may be suggested that optimising rewarm-up strategies is of equal or greater importance to substitutes than is the initial pre-match warm-up. Team officials in English Soccer are not permitted to leave the 'technical area' whilst a match is underway, therefore the content and intensity of rewarm-ups is likely determined primarily by the players themselves in the absence of a practiced routine. As superior outcomes have been reported as a result of coach-supervised versus unsupervised training

(Mazzetti et al., 2000), it is possible that such regulations may negatively impact upon the quality of preparatory activity undertaken. Notably, video footage highlighted that events unfolding on the pitch such as the proximity of match-play to the rewarm-up area appeared to directly influence the activities being performed by substitutes. Although the match scoreline at the point of pitch-entry does not necessarily reflect the scoreline at the time of any given pre-pitch-entry rewarm-up, and that the magnitude of the observed differences may not necessarily be practically meaningful, awaiting substitutes performed more HSR per rewarm-up bout (+3.17 m) when the team was losing at the time of introduction compared with when the team was ahead. Whilst the adequacy of current pre-pitch-entry practices remains to be determined, practitioners in chapter three postulated that the presence of additional personnel (e.g., team coaching staff), and/or the provision of larger rewarm-up spaces (that may facilitate sprinting) and/or equipment may enable the completion of more structured rewarm-up protocols that improve the preparatory actions undertaken before pitch-entry, thus affecting match-play performance thereafter. Notably, in addition to allowing a fourth substitution to be made in matches progressing to extra-time, regulations at the 2018 FIFA World Cup finals permitted up to six substitutes at a time to be accompanied by two coaches while completing their preparations in a designated rewarm-up area behind the goalposts (FIFA, 2018).

Observations of decreases in relative running distances following a substitute's initial five min of match-play appear to contradict previous reports of a trend towards increasing TD and HSR for English Premier League substitutes as the second-half progressed (Bradley et al., 2014). Indeed, the current findings better align with suggestions that whilst starting players may adopt a 'slow-positive' pacing profile in which they conserve energy in an effort to minimise the magnitude of performance decrements over the course of 90 min (Edwards & Noakes, 2009; Waldron & Highton, 2014), their shorter playing duration and desire to make an impact on the match means that substitutes may favour an 'all-out' pacing strategy (Waldron & Highton, 2014). Whilst discrepancies may appear to exist, the previous study of English Premier League substitutes (Bradley et al., 2014) analysed data according to five min match-epochs which were fixed relative to the time of the match kick-off. When compared with defining epochs relative to the precise moment of a substitute's pitch-entry as was the case in the current study, the former approach may have underestimated the initial demands via omission of data collected in the stages of match-play immediately following match-introduction. It is also possible that differences in playing style between teams and/or leagues could have influenced match running responses (Bradley et al., 2013).

Relative TD (~12.2%) and HSR (~38.6%) declined substantially between 0-5 min and 5-10 min post-pitch-entry, but values for the next four epochs (i.e., 5-25 min post-pitch-entry) remained within 1 $m \cdot min^{-1}$ of each other. Speculatively, this relatively stable physical performance profile after the initial five min of match-play may indicate that mechanisms other than either progressive or transient fatigue explain the observed responses. For players who start a match on the pitch, the initial ~15 min of play typically elicits the greatest movement demands of any match-period (Akenhead et al., 2013; Bradley et al., 2010; Bradley et al., 2014; Bradley & Noakes, 2013; Bradley et al., 2009; Carling & Dupont, 2011; Mohr et al., 2003; Russell et al., 2016). Such responses may be attributable largely to players' desire to assert their dominance (Carling, 2013), and the current data suggest that these initially heightened locomotor outputs may be specific to the timing of match-introduction for any given individual as opposed to the proximity to kick-off per se. Alternatively, players' own concerns surrounding the lack of opportunity and/or motivation to prepare for match-play when selected as substitutes (Woods & Thatcher, 2009), highlight that the higher exercise intensity adopted during the first five min following a substitute's introduction into a match could partially represent a conscious or subconscious effort to account for perceived inadequacies in pre-pitch-entry preparation by 'warming-up' (i.e., eliciting the physiological responses desired from a pre-performance warm-up) having already entered the field of play. Unfortunately, it cannot be determined whether the movement responses observed in this study reflected positive match-contributions and it will be important for future research to assess the extent to which making a substitution can influence overall team success. Moreover, as discrete five min epochs were employed in this study, albeit normalised on an individual basis to pitch-entry rather than kick-off, it was not possible to determine the exact time-course of this transiently elevated running intensity following pitch-entry.

As is typically the case for whole-match players, replacement midfielders covered greater distances per epoch compared with players in other positions (Di Salvo et al., 2007; Di Salvo et al., 2009; Mohr et al., 2003). Moreover, the ~101-120 $m \cdot min^{-1}$ of TD and ~4-10 $m \cdot min^{-1}$ of HSR covered following a substitute's introduction broadly parallels values (~120 $m \cdot min^{-1}$ and ~9 $m \cdot min^{-1}$, respectively) that have been reported for substitutes in English Premier League soccer (Bradley et al., 2014). However, the mean running demands reported by Bradley et al. (2014) correspond approximately to the values observed for 0-5 min in the current study, with current values for subsequent epochs (TD: 101–106 $m \cdot min^{-1}$, HSR: 4–7 $m \cdot min^{-1}$) being markedly lower in comparison. These apparent discrepancies may be attributable to differences in match-play demands between playing standards (Mohr et al., 2003), inconsistent methodologies between studies, varying degrees of pre-match preparation, and/or the influence of situational factors such as the playing 'style' of the reference team and/or opposition (Bradley & Noakes, 2013). Indeed, the potential influence of contextual factors is highlighted in the current study by differences in movement demands according to the match scoreline at the time of pitch-entry. Such responses may reflect changes in the 'momentum' of a match, tactical or strategic objectives (e.g., playing 'style'), and/or the relative quality of the reference team and their opponents (Bradley & Noakes, 2013).

Acknowledging that the present data are derived from one team during one season, and that MEMS may be incapable of detecting every aspect of a substitute's individualised pre-pitch-entry preparation (e.g., less dynamic activities such as stretching, etc.), the movement profiles and video footage captured in this study highlight a number of avenues for further exploration. As well as the need for controlled studies to further assess the physiological and performance responses to current pre-pitch-entry practices, research into the effectiveness of pre-pitch-entry interventions for substitutes (e.g., modifying active rewarm-up practices and/or employing passive heat maintenance techniques) is warranted. Indeed, preparatory strategies were deemed by practitioners in chapter three to be a particularly important area for future research. The pre-performance period has also been identified as an opportunity to enhance hormonal and psychological responses (Cook & Crewther, 2012b; McGowan et al., 2015). Self-motivation may enhance subsequent performance (McGowan et al., 2015), and watching video footage of players' own previous success has been associated with elevated free testosterone concentrations and improved measures of overall match-performance thereafter (Cook & Crewther, 2012b). In addition to the likely value of interventions targeting body temperature maintenance, such observations highlight a potential role for strategies which may positively contribute to manipulating the environment in which substitutes await pitch-entry.

The execution of technical and/or tactical skills is an important component of soccer performance (Folgado et al., 2015; Harper et al., 2014), and tactical motivations may underpin a substantial proportion of substitutions that are made (chapter three). In addition to the lack of technical/tactical information, a limitation of this study is that MEMS indices alone cannot quantify a substitute's overall contribution to a match. Alongside research evaluating key physiological measurements such as body temperature and isolated performance test responses in controlled conditions, studies combining MEMS data with analysis of the match-consequences of any periods of heightened activity may allow further commentary on the potential reasons underlying the movement patterns observed following pitch-entry. Moreover, future research should analyse a substitute's match-play performance with reference to their tactical impact (e.g., changing team formation or 'style') whilst noting the precise reasons for their introduction. All substitutes in the current study were introduced to play in their preferred tactical position. However, given the differences in match demands experienced by different playing positions, it is plausible that the responses may differ in instances where a player is required to adopt an unfamiliar tactical or positional role. Finally, given that soccer teams may adopt a 'rotation policy' in which the use of substitutes represents an attempt to minimise the accumulation of fatigue across a competition period (chapter three, Carling et al., 2016), investigating the magnitude of the post-match fatigue response for partial-match players may be useful when tailoring training and/or recovery strategies based upon their unique match-play demands.

4.5 Conclusion

Acknowledging that these observations are based upon one team, and that other soccer clubs may adopt different pre-pitch-entry practices, substitutes in the current study performed an initial warm-up and an average of ~3 bouts of rewarm-up activity prior to entering the pitch, with increases in relative TD and PL, but decreasing rewarm-up duration as pitch-entry approached. Considering existing recommendations for the structure of warm-ups and rewarm-ups in team sports (Silva et al., 2018), alongside the known time-course of body temperature changes (McGowan et al., 2015; Russell et al., 2017; Russell et al., 2015d), further research is required to examine whether the observed strategies are adequate to prepare players for optimal performance upon pitch-entry. Such investigations may be conducted through the use of soccer match-play simulation protocols, which allow assessment of physiological and performance responses without the confounding influence of the situational variables inherent in soccer match-play (Russell et al., 2011b). Although substitutes produced substantially greater physical outputs during the first five min following introduction compared with 5-10 min post-pitch-entry and thereafter, the underlying reasons and match-consequences of the observed responses remain unclear.

Chapter 5.0 Profiling the performance and physiological responses to soccer substitute-specific match-day practices

Chapter summary

- Practitioners in chapter three highlighted the importance of research into preparatory practices for substitutes, whilst chapter four observed that minimal pre-pitch-entry activity was typically performed by this playing group.
- To profile performance and physiological responses, observed patterns of match-day activity for second-half soccer substitutes (chapter four) were replicated in controlled conditions.
- At the point of simulated second-half pitch-entry, body temperature and physical performance responses were not maintained from warm-up cessation despite typical substitute-specific match-day practices being employed in ~16°C ambient temperatures.
- Evidence of performance-limiting fatigue was absent during ~30 min of simulated match-play as sprint times were maintained throughout and CMJ peak power output improved from pre- to post-exercise.
- These data further question the efficacy of practices typically implemented by substitutes before pitch-entry.

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5.1 Introduction

The introduction of substitutes represents one means by which soccer coaches or managers can attempt to positively influence match outcomes. Whilst other motivations exist, the findings of chapter three suggested that strategic substitutions (i.e., replacements that are not enforced due to injury) are often made with the primary aims of increasing the pace of play relative to players who started the match and/or changing team tactics, typically at half-time or later. In addition to appropriate pre-exercise strategies potentially helping to reduce injury-risk (Safran et al., 1989), such objectives mean that substitutes should preferably enter the pitch having prepared in a way that facilitates optimised high-intensity physical performance immediately upon match-introduction (chapter three).

An active pre-match warm-up can help members of the starting team smooth the transition from rest to exercise, thus improving physical performance capacity and potentially reducing injury-risk during the opening stages of match-play (Bishop, 2003; Fradkin et al., 2010; McGowan et al., 2015; Silva et al., 2018; Towlson et al., 2013; Woods et al., 2007; Zois et al., 2011). For team sports players, acknowledging the role of other metabolic (e.g., a speeding of $\dot{V}O_2$ kinetics), neural (e.g., PAP), and psychological (e.g., establishing task-focus) mechanisms (Bishop, 2003; Kilduff et al., 2013b; McGowan et al., 2015), the prominent ergogenic effects of warming-up may be derived primarily from elevated T_m and T_{core} (Bishop, 2003; McGowan et al., 2015; Silva et al., 2018). Increased body temperature demonstrates a positive relationship with improved high-intensity exercise performance, with a 1°C change in T_m augmenting muscular power output by ~2-10% (Faulkner et al., 2013; Sargeant, 1987).

Substitutes typically perform active warm-ups prior to the match kick-off, either independently or alongside members of the starting team (chapters three and four). However, unless additional ergogenic strategies are employed, the length of time that typically separates the end of the pre-match warm-up and a substitute's entry onto the pitch (i.e., often ≥75-120 min) may elicit physiological responses (e.g., restoration of thermal homeostasis) that negatively affect physical performance capacity and elevate injury-risk immediately upon match-introduction (Galazoulas et al., 2012; Kilduff et al., 2013b; Lovell et al., 2013; Russell et al., 2017; Russell et al., 2015d; West et al., 2013b). Partly due to the presence of practical and regulatory restrictions, the findings of chapters three and four suggested that awaiting substitutes often perform minimal activity between the match kick-off and pitch-entry. Despite practitioners acknowledging the importance of appropriate pre-pitch-entry preparations for allowing substitutes to positively influence a match (chapter three), the efficacy of current practices remains unknown. Moreover, whilst substitutes have demonstrated transient post-pitch-entry changes in physical performance indicators such as TD and/or HSR (chapter four, Bradley et al., 2014), the acute physiological responses following second-half match-introduction are unclear. Therefore, this study profiled the physiological and performance responses to typical substitute-specific pre-pitch-entry preparations, while assessing the effects of simulated partial match-play.

5.2 Methods

5.2.1 Participants

Following receipt of ethical approval (Appendix 5), 13 male university and recreational standard team sports athletes (age: 24 ± 7 years, mass: 79.5 ± 10.3 kg, stature: 1.80 ± 0.04 m) volunteered to participate. All participants provided written consent before data collection, whilst preliminary visits allowed familiarisation with all exercise and testing procedures. Retrospective power calculations (G*Power v3.1.9.2; Universität Düsseldorf, Germany) highlighted that >90% statistical power existed for differences in physiological and performance variables.

5.2.2 Testing procedures

Figure 5.1 outlines testing procedures. Players attended an indoor sports hall (temperature: 16.1 ± 1.9 °C, humidity: 55 ± 4%) following an overnight fast and having refrained from caffeine, alcohol, and strenuous exercise during the preceding 24 h. Mid-flow urine samples were taken before participants consumed a standardised breakfast (Rice Krispies; Kellogg's, UK, and semi skimmed milk: 1067 KJ, 44 g carbohydrates, 10 g protein, 4 g fat) with 500 ml of water

(Highland Spring; Highland Spring Group, UK). Body mass was then measured before ~45 min of rest preceded a standardised warm-up (~20 min) consisting of dynamic stretches and movements progressing from low to moderate intensity, concluding with sprints at near-maximal speeds. Five min of passive rest followed, during which water (500 ml) was consumed.

Isolated performance testing was conducted post-warm-up (within five min), before an ~85 min transition period. This time was mostly spent seated, whilst wearing normal training attire and viewing standardised footage of soccer match-play on a mobile tablet device (iPad, Apple, USA), but was punctuated at ~25 min (RWU1), ~50 min (half-time RWU), and ~70 min (RWU2), by ~5.3 min bouts of rewarm-up activity. Rewarm-ups were performed within a narrow space that was representative of a typical pitch side-line area and were designed to closely reflect the observations derived from video footage and MEMS data in chapter four. Rewarm-up activities therefore consisted primarily of static and dynamic stretching interspersed with low-intensity jogging and sidestepping movements. As the sample recruited for this study were not professional soccer players, participants were guided through the rewarm-ups via verbal instruction and visual demonstration. Further performance testing (i.e., pre-SMS) took place ~10 min after RWU2 (i.e., ~85 min after post-warm-up assessments), before ~30 min of the soccer match simulation (SMS (Russell et al., 2011b)). For this study, the lead researcher was primarily responsible for study design and obtaining ethical approval as well as participant recruitment, familiarisation, and leading data collection. The lead researcher then analysed the raw physiological and performance test data that had been collected, before performing formal statistical analyses. Members of the PhD supervisory team provided input at all stages of study design, whilst data collection was assisted by other students for whom the lead researcher provided the necessary training.

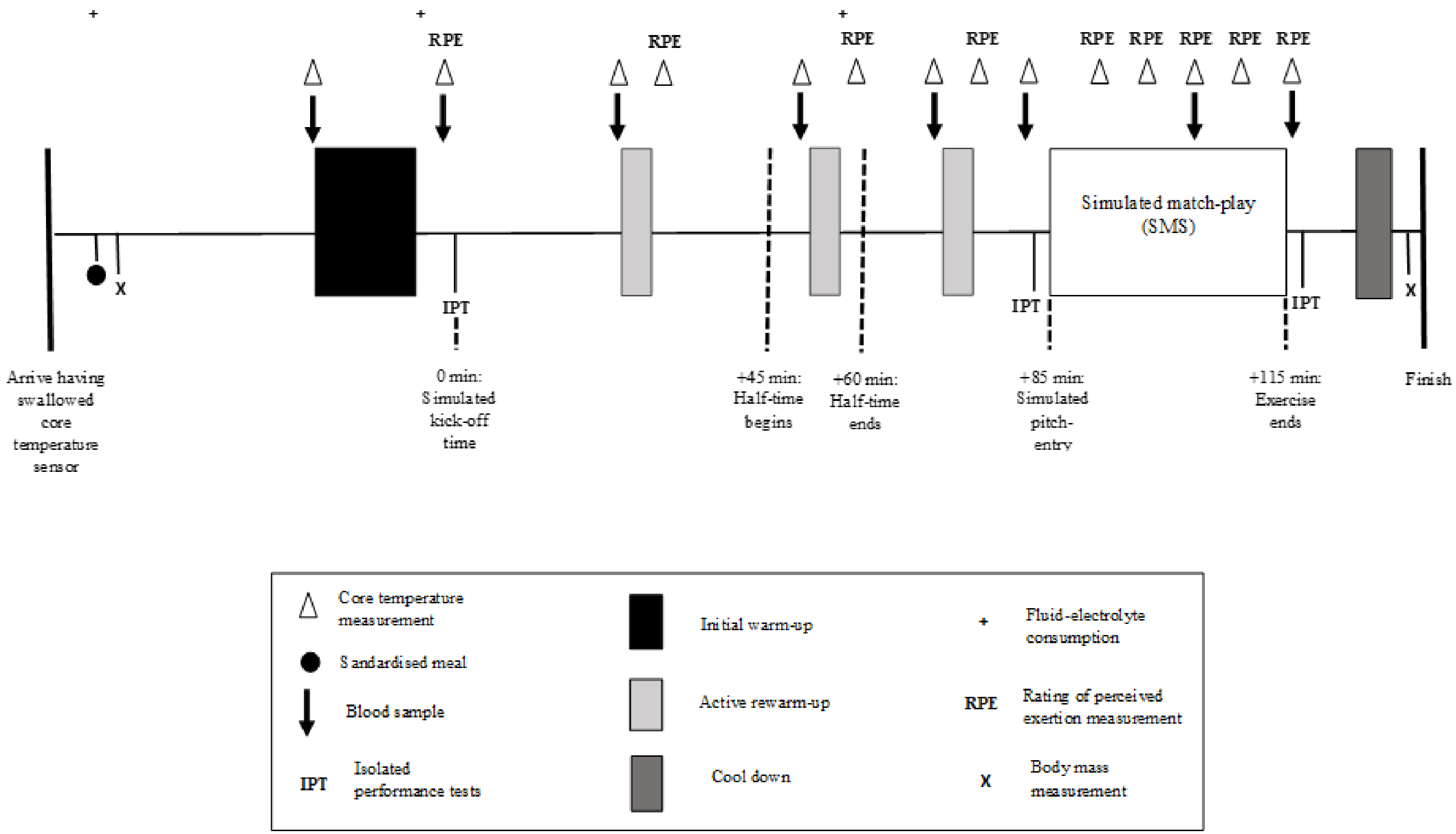

Figure 5.1: Outline of testing procedures

5.2.3 Soccer Match Simulation (SMS)

The SMS was outlined by Russell et al. (2011b) and includes movements reflecting the demands of actual soccer match-play whereby participants alternate between movements in response to an audio signal. Similar physical and physiological responses are elicited by the SMS compared with actual soccer match-play, whilst the researcher retains a greater degree of experimental control (Russell et al., 2011a; Russell et al., 2011b). The full SMS consists of two ~45 min halves separated by a ~15 min half-time interval. Each half is made up of seven standardised ~4.5 min blocks that include three repeated cycles of three 20 m walks, one walk to the side, an alternating timed maximal 15 m sprint or a 20 m dribble, a 4 s passive recovery period, five 20 m jogs at a speed corresponding to ~40% maximal oxygen uptake ($\dot{V}O_{2max}$), one 20 m backwards jog at ~40% $\dot{V}O_{2max}$, and two 20 m strides at ~85% $\dot{V}O_{2max}$. In the current study, the original SMS was shortened (~30 min in duration) to reflect the demands of partial match-play and was further modified to exclude tests of passing and shooting skill. Participants were therefore required to perform five ~4.5 min 'blocks' of exercise (i.e., block one to block five) separated by two min passive rest.

5.2.4 Physical performance measurements

Sprint time (15 m) was repeatedly assessed during each block of exercise as part of the SMS, whereas isolated 15 m sprint times and CMJ performances were tested post-warm-up, immediately pre-SMS, and post-SMS. Each CMJ commenced in a standing position, from which participants performed a preparatory 'dip' before explosively jumping to attain maximum height. Hands remained on hips throughout and participants were instructed to 'jump as high and fast as possible'. A portable force platform (FP4060-05-PT; 1000 Hz, Bertec Corporation, USA) provided vertical force-time data, from which peak power output and jump height were calculated (Moir, 2008; Owen et al., 2014). A jump was deemed to have been initiated at the point at which vertical force was reduced by a threshold of five standard deviations of bodyweight when assessed during ~1 s of quiet standing (McMahon et al., 2018; Moir, 2008; Owen et al., 2014). Measuring the standard deviation of vertical force values recorded during a

300 ms period of the flight phase of the jump allowed the moments of take-off and landing to be identified as the points at which force deviated by five times this value (McMahon et al., 2018). Instantaneous vertical velocity of the participant's centre of mass was derived from vertical force data and instantaneous power output (W) was calculated as the centre of mass velocity multiplied by the vertical ground reaction force at the corresponding timepoint (Owen et al., 2014). Peak power output represented the highest instantaneous power value produced, whilst jump height was calculated from the vertical velocity at the identified point of take-off (Moir, 2008). For isolated sprint assessments, participants sprinted in a straight line as fast as possible from a static start through markers placed 20 m away, with timing gates (Brower TC-System; Brower Timing Systems, USA) at 0 m and 15 m. Two sprint repetitions and three CMJ repetitions were performed at each relevant timepoint, with the fastest sprint and the CMJ that produced the greatest peak power output being retained for further analysis.

5.2.5 Physiological measurements

An ingestible sensor (CorTemp™; HQ Inc, USA) which transmitted a signal to an external device allowed T_{core} to be assessed pre- and post-warm-up, before and after each rewarm-up, pre-SMS, and after every ~4.5 min block of the SMS. This method is safe, valid, and reliable (Byrne & Lim, 2007) and, as per the manufacturer's guidelines, sensors were consumed at least three hours before the first measurement was taken. Capillary blood samples, analysed for glucose and lactate concentrations (YSI 2300 STAT PLUS; Yellow Springs Instruments, USA), were taken pre- and post-warm-up, before each rewarm-up, pre-SMS, and after ~15 min and ~30 min of simulated match-play. Participants indicated subjective ratings of perceived exertion (RPE) on a 6-20 scale (Borg, 1982) immediately after the warm-up, each rewarm-up, and every block of the SMS, whilst HR was continuously recorded during exercise (Polar T31; Polar Electro, Finland). Pre- to post-trial changes in urine osmolality (Osmocheck; Vitech Scientific, UK) and fluid-corrected body mass were also determined.

5.2.6 Data analyses

Statistical analyses were conducted using SPSS software (Version 21.0; SPSS Inc., USA), with significance established when $p \leq 0.05$. One-way repeated measures analyses of variance were used to assess whether 'time' influenced physiological and performance responses. Mauchly's test was consulted, and the Greenhouse-Geisser correction was applied if the assumption of sphericity was violated. Significant time effects were investigated via post-hoc Bonferroni-adjusted pairwise comparisons, whilst changes in body mass and urine osmolality were assessed using paired t-tests. Cohen's d effect sizes (ES) with 90% CIs were calculated for post-hoc comparisons where $p \leq 0.05$, and were interpreted as: 0.00-0.19, *trivial*; 0.20-0.59, *small*; 0.60-1.20, *moderate*; 1.21–2.0, *large*; and >2.01, *very large* effects (Hopkins et al., 2009). Where necessary, mean data from the corresponding time-point was imputed for any missing values (Harper et al., 2017).

5.3 Results

5.3.1 Body temperature responses

Time influenced T_{core} ($F_{(4,43)} = 153.022$, $p \leq 0.001$, partial-eta$^2 = 0.927$), which was elevated by the warm-up ($p \leq 0.001$, ES: 2.27 [1.45-3.10], *very large*) and maintained at pre-RWU1 and post-RWU1. Relative to post-warm-up, T_{core} had declined by pre-half-time RWU ($p = 0.005$, ES: 1.71 [0.96-2.46], *large*) and thereafter (all $p \leq 0.05$, ES: 1.37-2.40, *large* to *very large*), being similar to pre-warm-up levels at pre-RWU2, post-RWU2, and pre-SMS (Figure 5.2). All rewarm-ups were ineffective at elevating T_{core} from pre- to post-rewarm-up, whilst two blocks of simulated match-play were necessary to restore T_{core} to at least post-warm-up values. Elevated T_{core} was observed after block one of simulated match-play compared with pre-SMS ($p = 0.002$, ES: 0.86 [0.19-1.53], *moderate*), before further stepwise increases between each subsequent SMS block (all $p \leq 0.05$, ES: 0.64-1.72, *moderate* to *large*). From block three onwards, T_{core} exceeded all pre-exercise time-points (all $p \leq 0.05$, ES: 1.55-7.06, *large* to *very large*).

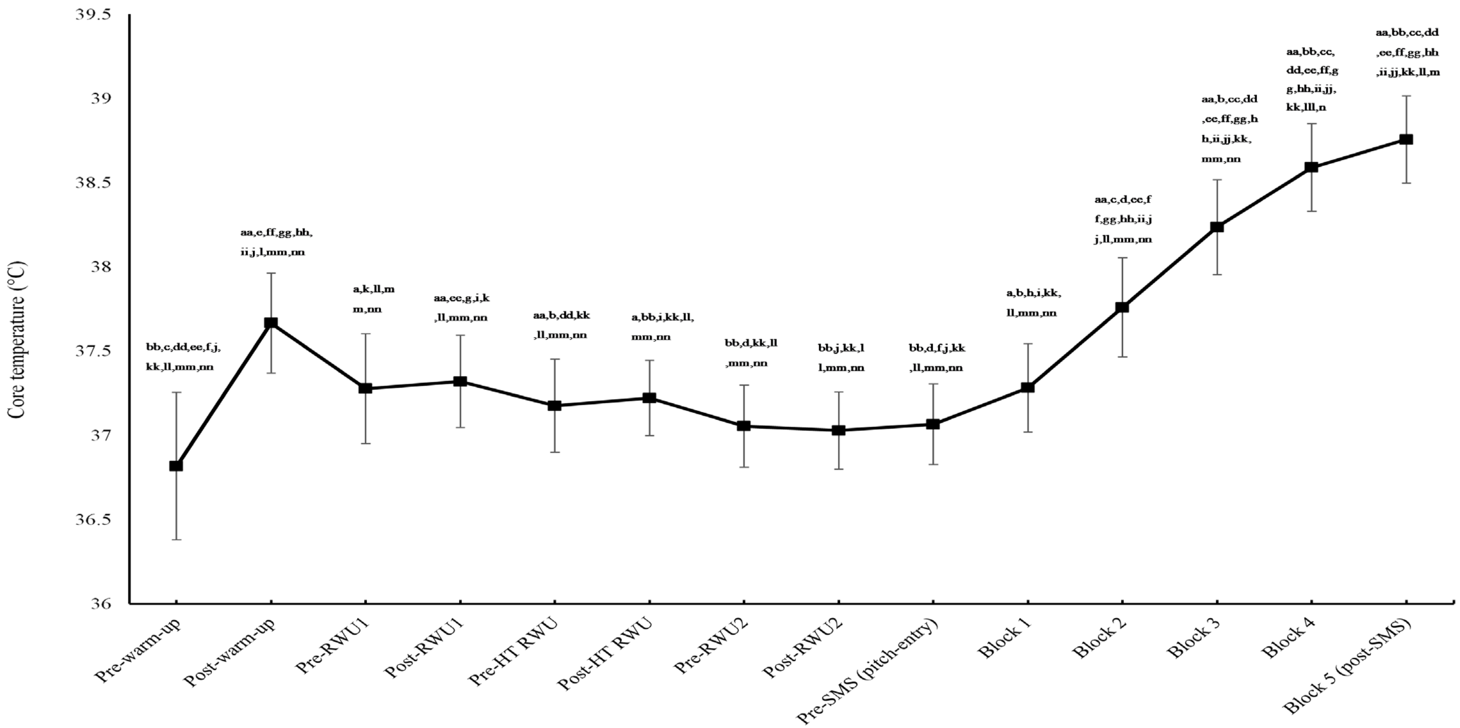

Figure 5.2: Time-course of changes in core temperature during a simulated match-day for substitutes (n = 13)

RWU: Rewarm-up, SMS: Soccer match simulation, [a]; Different from pre-warm-up, [b]: Different from post-warm-up, [c]: Different from pre-RWU1, [d]: Different from post-RWU1, [e]: Different from pre-half-time RWU, [f]: Different from post-half-time RWU, [g]: Different from pre-RWU2, [h]: Different from post-RWU2, [i]: Different from pre-SMS, [j]: Different from block 1, [k]: Different from block 2, [l]: Different from block 3, [m]: Different from block 4, [n]: Different from block 5. A single letter denotes differences at the p ≤0.05 level, whilst p ≤0.001 is represented by two of the same letter. Data are presented as mean ± standard deviation.

5.3.2 Physical performance responses

Time also influenced isolated 15 m sprint times ($F_{(2,24)}$ = 6.275, p = 0.006, partial-eta^2 = 0.343), alongside CMJ peak power output ($F_{(2,24)}$ = 14.389, p ≤0.001, partial-eta^2 = 0.545) and jump height ($F_{(2,24)}$ = 5.92, p = 0.008, partial-eta^2 = 0.33). Sprints performed pre-SMS (2.54 ± 0.12 s, p = 0.003, ES: 0.77 [0.11-1.44], *moderate*) were slower than post-warm-up (2.44 ± 0.13 s), whereas post-SMS sprint times (2.51 ± 0.10 s) remained unchanged from pre-SMS. Post-warm-up CMJ responses (peak power output: 4088 ± 884 W, jump height: 32.7 ± 5.7 cm) exceeded pre-SMS values (peak power output: 3792 ± 873 W, jump height: 29.6 ± 4.8 cm) for peak power output (p ≤0.001, ES: 0.34 [-0.31-0.98], *small*) and jump height (p = 0.017, ES: 0.58 [-0.07-1.24], *small*). Increased peak power output (p = 0.006, ES: 0.33[-0.32-0.98], *small*) occurred from pre-SMS to post-SMS (4086 ± 913 W), whereas sprint performances remained unchanged throughout exercise (Table 5.1).

Table 5.1: Physiological and performance responses during a simulated match-day for substitutes (n = 13)

Variable	Warm-up	RWU1	Half-time RWU	RWU2	SMS block 1	SMS block 2	SMS block 3	SMS block 4	SMS block 5
RPE (AU)	11 ± 2 ^{bb,cc,dd,e,ff,gg,hh,ii}	7 ± 1 ^{aa,ee,ff,gg,hh,ii}	7 ± 1 ^{aa,ee,ff,gg,hh,ii}	7 ± 1 ^{aa,ee,ff,gg,hh,ii}	14 ± 2 ^{a,bb,cc,dd,g,hh,ii}	15 ± 2 ^{aa,bb,cc,dd,gg,hh,ii}	16 ± 2 ^{aa,bb,cc,dd,e,ff,h,i}	17 ± 2 ^{aa,bb,cc,dd,ee,ff,gg}	18 ± 1 ^{aa,bb,cc,dd,ee,ff,g}
Mean HR (beats·min^{-1})	139 ± 10 ^{bb,cc,dd,ee,ff,gg,hh,ii}	113 ± 8 ^{aa,dd,ee,ff,gg,hh,ii}	111 ± 10 ^{aa,ee,ff,gg,hh,ii}	108 ± 8 ^{aa,bb,ee,ff,gg,hh,ii}	161 ± 5 ^{aa,bb,cc,dd,ff,gg,hh,ii}	171 ± 6 ^{aa,bb,cc,dd,ee,gg,h,i}	175 ± 5 ^{aa,bb,cc,dd,ee,ff}	175 ± 5 ^{aa,bb,cc,dd,ee,f}	176 ± 5 ^{aa,bb,cc,dd,ee,f}
Peak HR (beats·min^{-1})	188 ± 9 ^{bb,cc,dd}	140 ± 9 ^{aa,ee,ff,gg,hh,ii}	138 ± 9 ^{aa,ee,ff,gg,hh,ii}	138 ± 10 ^{aa,ee,ff,gg,hh,ii}	189 ± 10 ^{bb,cc,dd,g}	192 ± 6 ^{bb,cc,dd,g}	196 ± 6 ^{bb,cc,dd,gg,f}	192 ± 4 ^{bb,cc,dd}	191 ± 3 ^{bb,cc,dd}
Mean HR (%$_{max}$)	69 ± 6 ^{bb,cc,dd,ee,ff,gg,hh,ii}	57 ± 4 ^{aa,dd,ee,ff,gg,hh,ii}	55 ± 5 ^{aa,ee,ff,gg,hh,ii}	54 ± 4 ^{aa,bb,ee,ff,gg,hh,ii}	81 ± 3 ^{aa,bb,cc,dd,ff,gg,hh,ii}	85 ± 4 ^{aa,bb,cc,dd,ee,gg,h,i}	88 ± 4 ^{aa,bb,cc,dd,ee,ff}	88 ± 5 ^{aa,bb,cc,dd,ee,f}	88 ± 5 ^{aa,bb,cc,dd,ee,f}
Peak HR (%$_{max}$)	94 ± 6 ^{bb,cc,dd}	70 ± 5 ^{aa,ee,ff,gg,hh,ii}	69 ± 4 ^{aa,ee,ff,gg,hh,ii}	69 ± 5 ^{aa,ee,ff,gg,hh,ii}	95 ± 5 ^{bb,cc,dd,g}	97 ± 4 ^{bb,cc,dd,g}	98 ± 4 ^{bb,cc,dd,gg,f}	96 ± 3 ^{bb,cc,dd}	96 ± 3 ^{bb,cc,dd}
15 m SMS sprint time (s)	Not applicable	Not applicable	Not applicable	Not applicable	2.76 ± 0.16	2.80 ± 0.22	2.84 ± 0.23	2.95 ± 0.30	2.84 ± 0.31

AU: Arbitrary units, HR: Heart rate, RPE: Rating of perceived exertion, RWU: Rewarm-up, SMS: Soccer match simulation, ^{a}: different from the warm-up, ^{b}: different from RWU1, ^{c}: Different from half-time RWU, ^{d}: Different from RWU2, ^{e}: Different from SMS block 1, ^{f}: Different from SMS block 2, ^{g}: Different from SMS block 3, ^{h}: Different from SMS block 4, ^{i}: Different from SMS block 5. A single letter denotes differences at p ≤0.05 level, whilst p ≤0.001 is represented by two of the same letter. Data are presented as mean ± standard deviation.

5.3.3 Other physiological responses

For mean ($F_{(3,32)}$ = 602.057, p ≤0.001, partial-eta^2 = 0.980) and peak ($F_{(4,46)}$ = 216.234, p ≤0.001, partial-eta^2 = 0.947) HR (Table 5.1), warm-up (all p ≤0.001, ES: 2.72-5.44, *very large*) and SMS (all p ≤0.001, ES: 5.20-10.20, *very large*) responses exceeded all rewarm-up values, with mean HR also being greater for each SMS block compared with the warm-up (all p ≤0.001, ES: 2.76-4.66, *very large*). Mean HR increased from SMS blocks one to two (p ≤0.001, ES: 1.78 [1.02-2.54], *large*) and two to three (p ≤0.001, ES: 0.84 [0.17-1.51, *moderate*), before stabilising. For RPE ($F_{(2,30)}$ = 192.254, p ≤0.001, partial-eta^2 = 0.941), Table 5.1 shows that warm-up values exceeded each rewarm-up (p ≤0.001, ES: 1.97-2.11, *large* to *very large*), and all SMS blocks elicited higher values than the warm-up and rewarm-ups (p ≤0.05, ES: 1.42-8.11, *large* to *very large*). Moreover, RPE was similar after SMS blocks one and two, before increases from blocks two to three (p ≤0.001, ES: 0.66 [0.00-1.32], *moderate*), and blocks three to four (p = 0.032, ES: 0.56 [-0.09-1.22], *small*).

Blood lactate concentrations ($F_{(1,16)}$ = 76.953, p ≤0.001, partial-eta^2 = 0.881) were elevated post-warm-up (all p ≤0.001, ES: 1.48-2.52, *large* to *very large*) and after ~15 min and ~30 min of simulated match-play (all p ≤0.001, ES: 3.02-4.30, *very large*), compared with all other time-points (Figure 5.3A). Although blood lactate concentrations were similar following ~15 min and ~30 min of exercise, both values exceeded post-warm-up levels (both p ≤0.05, ES: 2.26-2.83, *very large*). For blood glucose ($F_{(2,30)}$ = 8.944, p ≤0.001, partial-eta^2 = 0.427), concentrations at pre-RWU1 (p = 0.024, ES: 1.35 [0.64-2.07], *large*), and after ~15 min (p = 0.009, ES: 1.79 [1.03-2.55], *large*) and ~30 min (p = 0.015, ES: 1.70 [0.95-2.46], *large*) of simulated match-play, exceeded post-warm-up (Figure 5.3B). When corrected for fluid intake and losses, body mass declined ~0.9% from pre-warm-up to post-SMS ($t_{(12)}$ = 3.91, p = 0.002, ES: 0.07 [-0.58-0.71], *trivial*), whilst urine osmolality decreased by ~68.4% ($t_{(12)}$ = 5.175, p ≤0.001, ES: 2.28 [1.38-3.17], *very large*).

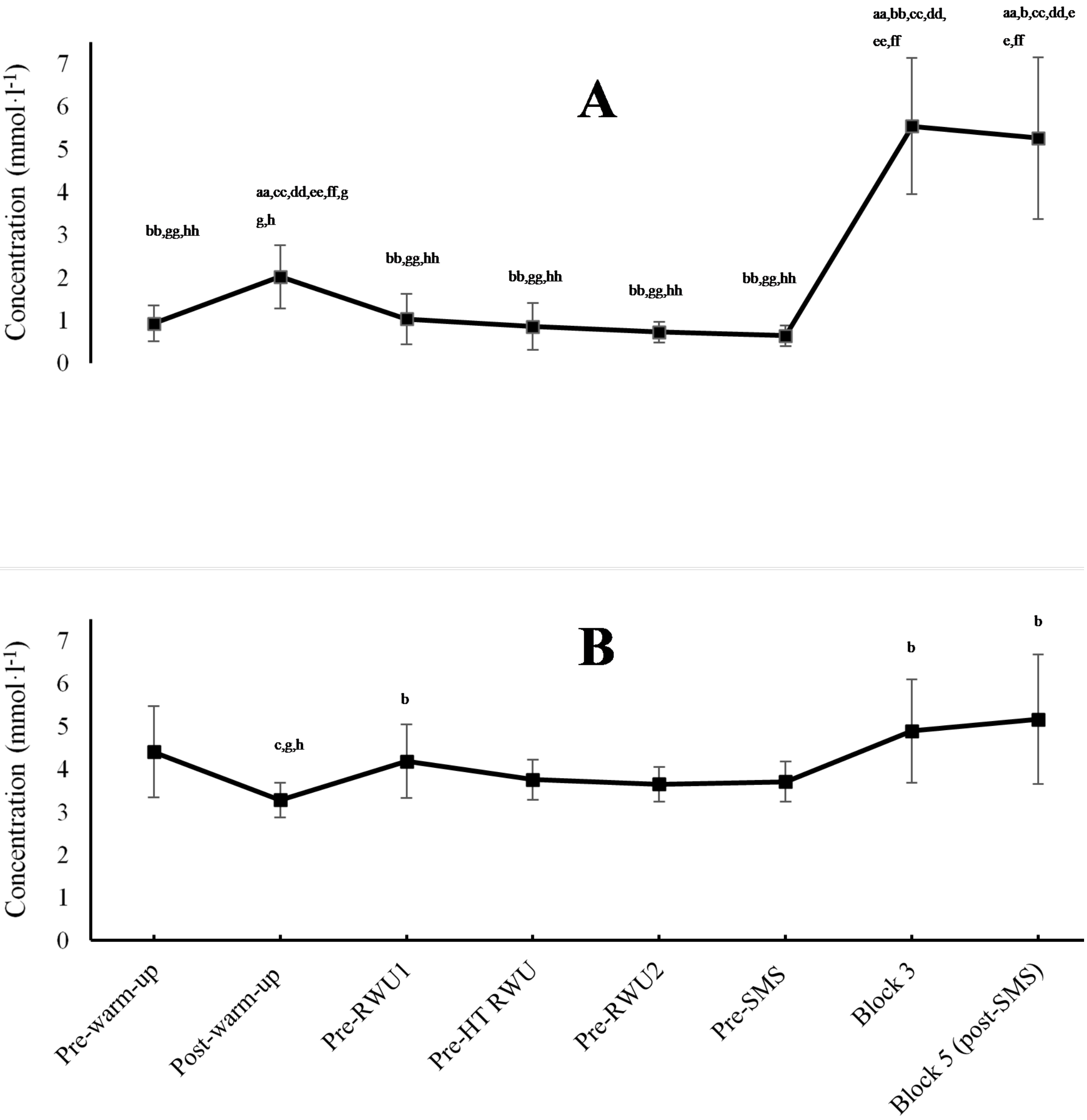

Figure 5.3: Time-course of changes in blood lactate (panel A) and blood glucose (panel B) concentrations during a simulated match-day for substitutes (n = 13)

RWU: Rewarm-up, SMS: Soccer match simulation, [a]; Different from pre-warm-up, [b]: Different from post-warm-up, [c]: Different from pre-RWU1, [d]: Different from pre-half-time RWU, [e]: Different from pre-RWU2, [f]: Different from pre-SMS, [g]: Different from block 3, [h]: Different from block 5. A single letter denotes differences at the p ≤0.05 level, whilst p ≤0.001 is represented by two of the same letter. Data are presented as mean ± standard deviation.

5.4 Discussion

This study examined the physiological and performance responses to practices that replicated the typical match-day activities of professional soccer substitutes (i.e., those observed in chapter four). Despite three rewarm-ups being performed, warm-up-induced elevations in T_{core} were not maintained at the time of simulated second-half pitch-entry. Moreover, alongside ~1.6% lower T_{core} values, CMJ (~7.2-9.4%) and 15 m sprint (~3.9%) performances were also reduced when assessed pre-SMS compared with post-warm-up. Whilst simulated match-play elicited progressive T_{core} increases, T_{core} did not reach post-warm-up values until ~10 min into exercise. Sprint times remained unchanged throughout ~30 min of simulated match-play and CMJ peak power output increased as a function of exercise. These novel findings question the efficacy of current practice for maximising physical performance capacity upon match-introduction and may therefore benefit practitioners seeking to optimise the acute pre-pitch-entry preparatory strategies of substitutes. Likewise, such insight into post-pitch-entry responses could help to inform tailored training and recovery protocols for substitute soccer players.

Whilst T_{core} was elevated by the initial warm-up, these benefits had dissipated well in advance of simulated second-half pitch-entry. Several investigations have highlighted declines in T_{core} and T_m when periods of inactivity follow exercise (Kilduff et al., 2013b; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c), responses that are typically accompanied by decreases in physical performance capacity and potential elevation of injury-risk factors such as reduced dynamic eccentric hamstring strength (Kilduff et al., 2013b; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017; Russell et al., 2015c). Contrary to studies reporting reductions within ~10-15 min of exercise cessation (Kilduff et al., 2013b; Mohr et al., 2004; Russell et al., 2017), T_{core} was maintained relative to post-warm-up values until the start of half-time (~50 min post-warm-up). It has been suggested that where ≥15 min separates the end of the pre-match warm-up and a player's introduction into a match, performing short bouts of rewarm-up activity may help to preserve body temperature and attenuate declines in explosive physical performance compared with passive rest (Silva et al., 2018). Although values did not increase significantly from pre-RWU1 to post-RWU1, it is possible that RWU1 may have helped to slow the rate at which T_{core} declined following warm-up cessation. Notwithstanding, T_{core} declined from post-warm-up and had returned to pre-warm-up levels prior to simulated pitch-entry, whilst CMJ and 15 m sprint performances worsened during this time. Acknowledging that rewarm-up practices may vary, replicating the pattern of activities performed by professional soccer substitutes (chapter four) did not maintain T_{core} and physical performance responses from post-warm-up values until the time of pitch-entry when assessed in ambient conditions reflecting average air temperatures during late spring to early autumn in the UK (Statistica, 2020). Such findings suggest that the effects of modifying the pre-pitch-entry activities currently adopted by substitute players warrants further investigation.

Rewarm-ups each lasted approximately five min and consisted of dynamic stretching alongside low to moderate intensity movements such as jogging and side-stepping. Although such practices reflect observations from professional soccer players (chapter four), warm-up and rewarm-up intensity may modulate physical performance during subsequent exercise (Ingham et al., 2013; Silva et al., 2018; Zois et al., 2011). For example, 800 m running performance was enhanced by ~1% when preceded by combined striding and race-pace running, compared with an equidistant bout of striding alone (Ingham et al., 2013). Moreover, achieving ~90% of an individual's maximum HR during prior exercise can benefit subsequent performance during explosive tasks such as jumps and sprints (Silva et al., 2018). Although HR during the warm-up peaked at >90% of maximum HR, mean and peak HR during rewarm-ups were ~26-31 beats·min^{-1} and ~48-50 beats·min^{-1} lower, respectively. Speculatively, as RPE values were also lower for rewarm-ups, increasing rewarm-up intensity while remaining within tolerable limits (Bishop et al., 2001) could elicit favourable physiological responses (e.g., improved T_{core} and T_m maintenance, PAP) that may help to attenuate the reductions in physical performance observed presently between warm-up cessation and pitch-entry. Moreover, acknowledging the potential for detrimental effects in hot or humid (e.g., temperatures ≥25 °C, humidity ≥60%) conditions (Beaven et al., 2018), it is possible that combining appropriate rewarm-up activity with passive heat maintenance techniques (e.g., wearing heated or insulated garments) may provide additional performance benefits in cold or thermoneutral environments compared with active rewarm-ups alone (Russell et al., 2017).

Rewarm-up strategies reflected the fact that practical and regulatory barriers may modulate the activities that substitutes can perform between kick-off and pitch-entry. The design of modern stadia often limits the space that is available for rewarm-ups, which could partly explain observations in chapter four that professional substitutes covered <2 m·min^{-1} at >5.5 m·s^{-1} during each bout of pre-pitch-entry activity and did not exceed 7 m·s^{-1} at any time prior to match-introduction. Although theoretical, practitioners have postulated that providing more space within which to perform rewarm-ups may facilitate improvements in pre-pitch-entry preparations that could translate favourably into enhanced physical performance and/or reduced injury-risk thereafter (chapter three). Moreover, regulations in many competitions require team officials to remain within a designated technical area whilst match-play is underway (FIFA, 2019/20). Acknowledging that different teams provide substitutes with varying levels of guidance in relation to pre-pitch-entry strategies (chapter three), the content of any rewarm-up activity must therefore ultimately be determined by the players themselves. Being named as a substitute has been associated with reduced motivation to prepare (Woods & Thatcher, 2009), whilst observations from chapter four highlight how events unfolding in the match appear to affect the self-selected activities performed by players awaiting pitch-entry. As superior outcomes have been realised following coach-supervised compared with unsupervised training (Mazzetti et al., 2000), it is possible that allowing members of team staff to accompany substitutes during rewarm-ups may enable more varied and better structured pre-pitch-entry preparations compared with when exclusively player-led activities are performed. Indeed, this suggestion was largely supported by practitioners when surveyed in chapter three.

Despite elevated blood lactate concentrations and progressive increases in RPE, sprint times were not reduced throughout ~30 min of simulated match-play. Acknowledging that adherence to audio signals to control exercise tempo precluded the adoption of self-pacing strategies for participants in the present study, these observations conflict with match-play data whereby professional substitutes have demonstrated transient changes in physical outputs following pitch-entry (chapter three, Bradley et al., 2014). Bradley et al. (2014) reported a tendency for TD and HSR for substitutes to increase as the second-half progressed, whereas defining five min epochs relative to the moment of a player's introduction into a match (i.e., rather than relative to the match kick-off) highlighted up to ~39% reductions in physical outputs between the first and second post-pitch-entry epoch, before a plateau (chapter four). Given that the current study highlights T_{core} declines from post-warm-up to pre-SMS, and that ~10 min of simulated match-play was required to restore T_{core} to post-warm-up values, it may be possible that the observed match-play responses could reflect a pacing strategy that partly influenced by efforts to 'warm-up' having already entered the pitch. Speculatively, alongside facilitating enhanced high-intensity performance immediately after introduction, improved body temperature maintenance between kick-off and pitch-entry could facilitate a higher and more even post-pitch-entry pacing profile that may allow a substitute to provide a greater and more sustained impact upon a match. Practitioners appear to support this suggestion (chapter three), indicating that poor pre-pitch-entry preparation may risk a substitute negatively influencing team performance following match-introduction.

In addition to a potential ergogenic effect of exercise-induced increases in body temperature, maintenance of CMJ jump height and sprint performance alongside ~7.8% improvements in CMJ peak power output from pre-SMS to post-SMS appears to suggest the absence of substantial acute fatigue during ~30 min of simulated match-play. Acknowledging that specific responses may differ according to the timing of a player's introduction into a match, these observations support the notion that substitutes may benefit from bespoke post-match training and recovery practices compared with whole-match players. For example, it may be important for partial match-players to undertake 'top-up' conditioning sessions to help maintain appropriate physical loading patterns that promote favourable adaptations and minimise injury-risk throughout a season (chapter three, Buchheit, 2019). Moreover, whilst ≤45 min of match-play is unlikely to reduce fibre-specific muscle glycogen concentrations to the extent of 90+ min of soccer-specific exercise (Krustrup et al., 2006), practical considerations associated with the uncertainty surrounding team selection and/or the likely extent of their upcoming match-play exposure often requires substitutes to adopt the same high-carbohydrate pre-match fuelling strategies as members of the starting team. Achieving desired energy balance may therefore require substitute-specific post-match nutritional strategies that account for likely reductions in energy and/or carbohydrate utilisation for second-half substitutes relative to whole-match players.

5.5 Conclusion

In ambient air temperatures of ~16 °C, a rewarm-up protocol reflecting the typical match-day practices of soccer substitutes did not maintain body temperature or physical performance responses between warm-up cessation and simulated second-half pitch-entry. Indeed, despite three rewarm-ups being performed during the intervening period, T_{core} had declined from post-warm-up and returned to pre-warm-up values at the point of simulated second-half pitch-entry, whilst 15 m sprint (~3.9%) and CMJ (~7.2-9.4%) performances also reduced during this time. To maximise physical performance upon match-introduction, practitioners should therefore consider whether a substitute's existing pre-pitch-entry strategies are optimal and consider practice modification if necessary. Progressive increases in T_{core} were observed after simulated pitch-entry, although ~10 min of exercise was required to restore T_{core} to post-warm-up values. Notably, CMJ and sprint performance maintenance or improvement during ~30 min of simulated match-play suggests the absence of substantial performance-limiting fatigue and a possible warming-up effect throughout exercise. Such observations further highlight the importance of pre-pitch-entry preparations and indicate that bespoke post-match training and recovery strategies are likely warranted for substitutes.

Chapter 6.0 Profiling the post-match top-up conditioning practices of professional soccer substitutes: An analysis of contextual influences

Chapter summary

- Soccer practitioners often implement 'top-up' conditioning sessions to compensate for substitutes' limited match-play exposure. Although perceived to be valuable for reducing injury-risk and augmenting positive physical adaptations, little research has considered the demands elicited during such sessions.
- To quantify post-match top-up responses, 31 professional soccer players wore 10 Hz MEMS following 37 matches whereby they were selected in the match-day squad as substitutes (184 observations; 6 ± 5 observations·player^{-1}). The influence of contextual factors on 23 physical performance variables was assessed.
- Top-ups lasted ~17.3 min, eliciting TD, HSR, and SPR distances of ~1.7 km, ~0.4 km, and ~0.03 km, respectively.
- Practical barriers exist in relation to post-match top-ups, and each contextual factor (i.e., playing position, substitution timing, match location, result, time of day, stage of the season, and fixture density) influenced at least four of the dependent variables profiled.
- These data provide potentially important information for practitioners when considering the aims and design of substitute top-up conditioning sessions, particularly with reference to contextual influences.

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6.1 Introduction

Chapter three highlighted that professional soccer team managers or coaching staff often use substitutions to provide a physical or tactical impact upon a match, and thus potentially improve scoreline differentials. Strategic substitutions (i.e., replacements that are not made due to injuries sustained by players already on the pitch) are most often made at half-time or during the second-half of match-play (Bradley et al., 2014; Del Corral et al., 2008; Myers, 2012), with those individuals entering the pitch typically exceeding the relative TD and/or HSR responses of players who started a match (Bradley et al., 2014; Mohr et al., 2003). However, substitutes consistently experience substantially lower absolute match-play demands compared with players who complete the full 90 min (Bradley & Noakes, 2013; Carling et al., 2010) and their reduced playing time may also restrict a substitute's opportunity to attain the 'peak' HSR responses of their whole-match counterparts (Hills et al., 2020).

For outfield players who play a full match, match-days typically represent the most physically demanding (i.e., in absolute terms) days within a training week (Anderson et al., 2016b; Malone et al., 2015). Indeed, in-season preparatory strategies are often designed with the aim of maximising recovery and minimising fatigue prior to competition (Anderson et al., 2016b; Malone et al., 2015). Because such objectives may require a reduction in weekly training volume or intensity compared with the pre-season period, it has been proposed that match-play itself could represent an important stimulus for several sport-specific physical adaptations (Morgans et al., 2018; Silva et al., 2011). In support, improvements in sprint speed and lower-limb strength have been associated with an individual's playing time during a professional soccer season (Silva et al., 2011), whilst the amount of HSR recorded during English Premier League fixtures acutely benefitted CMJ height and peak power output when assessed three days post-match (Morgans et al., 2018). Given that match-day may account for up to >95% of a squad's HSR and SPR during certain in-season microcycles, particularly when teams are required to fulfil multiple matches per week (Anderson et al., 2016b), these observations may highlight the potential for sub-optimal loading patterns with regard to partial-match or non-selected soccer players. If an individual's exposure to HSR and SPR is restricted by a lack of playing time, and these deficits are not addressed through training, a lesser stimulus for the promotion of physical adaptation could be experienced which may increase injury-risk due to declines in ongoing loading (Bowen et al., 2017; Buckthorpe et al., 2019; Colby et al., 2018). Notably, when combined match-play and training load was quantified across an English Premier League season, habitual ‘non-starters’ (defined as individuals who were selected in the starting team in <30% of matches) accumulated significantly lower HSR (19.9-25.1 $km \cdot h^{-1}$; ~19 km vs. ~35 km), and SPR (>25.2 $km \cdot h^{-1}$; ~3 km vs. ~11 km) distances compared with players who started in ≥60% of matches (Anderson et al., 2016a). Discrepancies in internal and external loads between starters and non-starters have also been observed during periods of fixture congestion in the Italian Serie A League (Gualtieri et al., 2020).

The principle of reversibility suggests potential negative adaptations flowing from substantial fluctuations or ongoing reductions in physical loading (Buckthorpe et al., 2019; Colby et al., 2018; Mujika & Padilla, 2000), thus chapter three confirmed that practitioners working in professional soccer frequently implement extra ‘top-up’ conditioning sessions for unused and partial-match players (Buchheit, 2019; Buckthorpe et al., 2019). In these scenarios, assuming that a period of reduced loading is not desired as part of the periodised training program, squad members who face limited match-play demands (i.e., typically determined based upon the number of minutes played, or assessments of the absolute physical demands experienced) undergo additional training in an effort to compensate for their lack of playing time (chapter three).

Whilst their unique match demands may suggest a benefit to implementing bespoke training and nutrition strategies for substitutes and non-selected players throughout the training week, uncertainty about an individual’s future match-play exposure often requires practitioners to ensure that all players are equally prepared for the physical, tactical, and psychological demands of completing a full match (chapter three). For example, managers may not reveal the final team selection until the day before a game, whereas players named in the match-day squad as substitutes could be required to play for anything from zero (i.e., if not introduced during a match) to 90+ min (i.e., if a starting player suffers injury or illness prior to or shortly after the match kick-off). Therefore, acknowledging that extra conditioning sessions may occasionally be undertaken at a team's training facility during the subsequent days, a desire to ensure adequate recovery prior to the next fixture while avoiding prolonged periods of reduced physical loading means that top-ups are typically performed on the pitch immediately after the conclusion of a match (chapter three).

Although match-day may represent an important opportunity to provide a conditioning stimulus for players who receive little or no match-play exposure, several practical and logistical considerations may modulate the activities that can be performed directly after a match. Professional soccer fixtures are often contested late at night and/or at venues that are situated long distances away from home, whilst the pitch-protection policies adopted by specific teams and/or governing bodies may restrict pitch-usage during the immediate post-match period (FA, 2019/2020). Despite practitioners in chapter three recognising the potential importance of top-up sessions for helping to maintain an appropriate degree of physical loading for all players within a team, limited information is available with regard to responses elicited by the post-match conditioning practices of players selected in the match-day squad as substitutes. Therefore, the aim of this study was to quantify the physical responses of professional soccer substitutes during post-match top-up sessions, whilst investigating contextual influences. Such information would represent a valuable addition to the limited literature concerning the preparatory practices of this under-researched population of soccer players and may help practitioners and regulators in optimising current approaches for substitutes.

6.2 Methods

6.2.1 Participants

Following approval from the School of Social and Health Sciences Research Ethics Committee at Leeds Trinity University (Appendix 4), 31 professional players from an English Championship soccer club (age: 26 ± 5 years, stature: 1.82 ± 0.07 m, body mass: 77.0 ± 7.2 kg) volunteered to participate in this study. Of the 46 first-team fixtures that were profiled over 12 months, post-match top-ups were performed on 37 occasions, from which 184 individual player observations were analysed (6 ± 5 observations·player^{-1}, range: 1-17 observations·player^{-1}). Top-up session data were recorded for both ‘used’ (i.e., players who had been introduced at some time during the match) and ‘unused’ (i.e., players who were named in the match-day squad but did not participate in any match-play) substitutes. All players were briefed about the risks and benefits of participation before providing their written informed consent in advance of data-collection taking place during the 2018/2019 and 2019/2020 English Championship seasons.

6.2.2 Activity monitoring

Players were monitored via wearable microtechnology during the ~60 min immediately following fixtures in which they were named in the match-day squad as substitutes. To maintain consistent treatment of all squad members on ‘match day plus one’ and to ensure adequate recovery prior to upcoming fixtures, the reference team targeted the immediate post-match period as the primary opportunity to undertake top-up conditioning sessions. Top-ups were designed and overseen by physical performance coaches working with the team and aimed to ensure that players achieved individualised weekly physical loading targets by offsetting their limited match-play exposure. Post-match sessions typically consisted of ~15-30 s straight-line timed running intervals performed between the halfway line and the goal line, during which a player’s distance to be covered per interval was prescribed based upon an appropriate percentage (i.e., according to the stage of the periodised program) of their maximum aerobic speed.

Players’ movements during top-up sessions were quantified via MEMS (10 Hz; S5, Optimeye, Catapult Innovations, Melbourne, Australia), which were worn beneath the playing jersey and harnessed between the scapulae in a vest designed to minimise movement artefacts. Sampling at 10 Hz has produced acceptable reliability (CV% = 2.0-5.3%) when assessing instantaneous velocity (Varley et al., 2012b), alongside small-to-moderate typical errors of the estimate (1.87-1.95%) versus a radar gun when measuring sprinting speed (Roe et al., 2017). The 100 Hz accelerometers within the MEMS devices have also demonstrated good intra (CV% = 0.9-1.1%)

and inter-unit (CV% = 1.0-1.1%) reliability within both laboratory and field test scenarios (Boyd et al., 2011). All players were familiar with this form of activity monitoring as part of routine practices at the club, and each player wore the same MEMS unit on each occasion to avoid potential inter-unit variation.

The MEMS devices were activated according to the manufacturer's guidelines ~30 min prior to the pre-match warm-up, and raw data files were exported after the conclusion of exercise using proprietary software (Sprint 5.1.7, Catapult Innovations, Melbourne, Australia). Files were trimmed on an individual player basis to ensure that only data pertaining to post-match conditioning activities were retained for analysis. Session duration, as well as a combination of GPS- and accelerometer-derived variables relating to TD, LSR, MSR, HSR, SPR, PL, maximum velocity achieved, repeated high-intensity efforts (RHIEs), accelerations, and decelerations, were profiled (Table 6.1). In keeping with the observational nature of the study, no attempt was made to influence players' responses. For this chapter, data arose as part of routine monitoring practices at the professional soccer club. The lead researcher was responsible for obtaining ethical approval, clipping and exporting MEMS data files for each individual player observation, selecting the outcome variables of interest (in consultation with senior sport science staff at the club), and analysing the data with reference to the specific research questions posed in this chapter. Members of the PhD supervisory team provided guidance at all stages of study design, whilst sports science staff at the club ran the post-match sessions and provided access to the relevant MEMS data.

Table 6.1: Operational definition for Microelectromechanical Systems (MEMS)-derived outcome variables

Measurement	Variable	Definition
Distance covered	TD (m)	Total amount of distance covered by any means
	Relative TD (m·min^{-1})	Total amount of distance covered per min
	LSR (m)	Distance covered at a speed of ≤4 m·s^{-1}
	Relative LSR (m·min^{-1})	Distance covered per min at a speed of ≤4 m·s^{-1}
	MSR (m)	Distance covered at a speed of >4 to ≤5.5 m·s^{-1}
	Relative MSR (m·min^{-1})	Distance covered per min at a speed of >4 to ≤5.5 m·s^{-1}
	HSR (m)	Distance covered at a speed of >5.5 to ≤7 m·s^{-1}
	Relative HSR (m·min^{-1})	Distance covered per min at a speed of >5.5 to ≤7 m·s^{-1}
	SPR (m)	Distance covered at a speed of >7 m·s^{-1}
	Relative SPR (m·min^{-1})	Distance covered per min at a speed >7 m·s^{-1}
Running speed	Peak velocity (m·s^{-1})	Highest running speed attained
PL	PL (AU)	Quantification of external workload: Square root of the summed rates of change in instantaneous velocity in each of the three (forwards, sideways, upwards) vectors, divided by a scaling factor of 100
	Relative PL (AU·min^{-1})	Player load accumulated over X number of min, divided by X number of min
Acceleration/deceleration count	High-intensity accelerations (#)	Count of the number of accelerations >3 m·s^{-2} for a period of ≥0.4 s
	High-speed decelerations (#)	Count of the number of decelerations <−3 m·s^{-2} for a period of ≥0.4 s
	Moderate-speed accelerations (#)	Count of the number of accelerations >2 to ≤3 m·s^{-2} for a period of ≥0.4 s
	Moderate-speed decelerations (#)	Count of the number of decelerations <−2 to ≥−3 m·s^{-2} for a period of ≥0.4 s
Acceleration/deceleration distance	High-speed acceleration (m)	Distance covered whilst accelerating at >3 m·s^{-2}
	High-speed deceleration (m)	Distance covered whilst decelerating at <−3 m·s^{-2}
	Moderate-speed acceleration (m)	Distance covered whilst accelerating at >2 to ≤3 m·s^{-2}
	Moderate-speed deceleration (m)	Distance covered whilst decelerating at <−2 to ≥−3 m·s^{-2}
RHIEs	RHIEs (#)	Count of the number of occasions in which ≥3 qualifying efforts (qualifying effort defined as attaining a speed of >5.5 m·s^{-1}, accelerating at >2 m·s^{-2}, or decelerating at <−2 m·s^{-2}) are performed over a ≤21 s period.
Time	Duration (min)	Length of time for any given period

AU: Arbitrary units, HSR: High-speed running, LSR: Low-speed running, MEMS: Microelectromechanical Systems, MSR: Moderate-speed running, PL: PlayerLoad™, RHIEs: Repeated high-intensity efforts, SPR: Sprinting, TD: Total distance.

6.2.3 Data analyses

Linear mixed models were used to assess the influence of several contextual factors on the physical responses elicited during post-match top-ups. Separate models were constructed for each dependent variable, whereby ‘player’ and ‘match-day’ were modelled as random effects in all instances. Contextual factors reflecting *playing position* (‘midfielders’, ‘attackers’, ‘defenders’, ‘goalkeepers’), *substitution timing* during the match immediately beforehand (‘unused’, ‘introduced at 75:00+ min’, ‘introduced at 60:00-74:59 min;’ note that no post-match top-ups were performed by substitutes introduced prior to 60:00 min of match-play in any given instance), *stage of the season* (‘early-season’: August-October; ‘mid-season’: November-January; ‘late-season’; February-April), *match result* (‘win’, ‘draw’, ‘loss’), *location* (‘home’, ‘away’), and *time of day* (‘early’: kick-off at 12:00-14:59 h; ‘afternoon’: kick-off at 15:00-17:59 h, ‘evening’: kick-off later than 18:00 h) were separately specified as fixed effects. *Fixture density* was also entered as a fixed effect and was defined on a rolling basis as the number of additional (i.e., not including the match completed on the same day as the top-up session) fixtures scheduled for the reference team within the preceding and subsequent seven-day periods combined (‘high-density’: three additional matches; ‘moderate-density’: two additional matches; ‘low-density’: one additional match). Pairwise comparisons were made using least squares means tests to assess differences between each level of any given fixed effect, before standardised ES were calculated and interpreted as: 0.00-0.19, *trivial*; 0.20-0.59, *small*; 0.60-1.20, *moderate*; 1.21–2.0, *large*; and >2.01, *very large* effects (Hopkins et al., 2009). Analyses were conducted within R Studio (v R-3.6.1.) using the lme4 package (Bates et al., 2015). Descriptive statistics are presented as mean ± standard deviation and ES are presented with 90% CIs.

6.3 Results

6.3.1 Influence of playing position and substitution timing

Table 6.2 indicates the overall physical demands recorded during post-match top-ups and highlights the influences of playing position and substitution timing. Top-ups for unused substitutes were longer in duration and elicited greater absolute TD and LSR responses, alongside more RHIEs compared with sessions performed by players who had been introduced at 75:00 min of match-play or later (all p ≤0.05, ES: 0.38-0.40, *small*). Unused substitutes also accumulated more MSR than substitutes introduced between 60:00-74:59 min (p = 0.029, ES: 0.73 [0.27-1.20], *moderate*). Irrespective of substitution timing, midfielders produced greater relative TD and PL responses, but performed less absolute MSR and fewer high-speed accelerations compared with defenders (all p ≤0.05, ES: 0.42-0.66, *small* to *moderate*). Midfielders also exceeded attackers for relative TD (p = 0.023, ES: 0.48 [0.17-0.79], *small*), whilst the responses of goalkeepers did not differ from any outfield position for any dependent variable.

Table 6.2: Descriptive statistics for substitutes' post-match top-up responses on an overall basis, according to substitution timing, and by playing position

Variable		Overall	Substitute timing			Playing position			
			Unused	75:00+ min	60:00-74:59 min	Midfielders	Attackers	Defenders	Goalkeepers
Duration	(min)	17.13 ± 7.44	17.76 ± 6.80 [b]	14.80 ± 8.28 [a]	16.31 ± 10.46	16.24 ± 7.85	17.61 ± 8.07	18.72 ± 7.36	16.28 ± 5.30
TD	Absolute (m)	1695 ± 624	1763 ± 587 [b]	1504 ± 748 [a]	1474 ± 574	1670 ± 647	1697 ± 689	1796 ± 595	1636 ± 496
	Relative (m·min^{-1})	102.8 ± 18.6	101.7 ± 14.8	107.7 ± 23.9	103.2 ± 32.8	108.5 ± 20.2 [e, f]	99.5 ± 16.9 [d]	97.8 ± 12.0 [d]	103.7 ± 21.4
LSR	Absolute (m)	874 ± 505	921 ± 477 [b]	722 ± 518 [a]	765 ± 672	819 ± 498	899 ± 587	929 ± 488	876 ± 375
	Relative (m·min^{-1})	50.0 ± 13.0	51.3 ± 13.0	46.9 ± 11.8	44.2 ± 12.9	49.1 ± 11.8	48.9 ± 12.8	48.5 ± 9.6	54.8 ± 17.0
MSR	Absolute (m)	361 ± 189	377 ± 185 [c]	341 ± 210	258 ± 132 [a]	338 ± 198 [f]	357 ± 153	433 ± 245 [d]	338 ± 149
	Relative (m·min^{-1})	22.9 ± 10.3	22.4 ± 9.2	25.8 ± 13.7	20.7 ± 11.4	23.1 ± 12.0	22.4 ± 9.3	23.6 ± 8.1	22.6 ± 10.9
HSR	Absolute (m)	427 ± 173	432 ± 170	410 ± 191	427 ± 166	474 ± 195	408 ± 146	407 ± 154	399 ± 181
	Relative (m·min^{-1})	28.1 ± 13.8	26.2 ± 10.9	32.7 ± 17.6	36.8 ± 22.5	33.8 ± 15.9	26.3 ± 13.0	24.2 ± 10.9	25.0 ± 10.7
SPR	Absolute (m)	32 ± 61	33 ± 63	31 ± 56	24 ± 36	39 ± 66	34 ± 57	27 ± 62	22 ± 56
	Relative (m·min^{-1})	1.9 ± 3.7	1.8 ± 3.7	2.3 ± 4.1	1.5 ± 1.8	2.4 ± 3.9	1.9 ± 3.6	1.6 ± 3.8	1.2 ± 3.1
PL	Absolute (AU)	159.79 ± 64.26	163.71 ± 60.38	145.80 ± 79.18	145.72 ± 61.96	158.82 ± 62.53	160.41 ± 70.92	167.85 ± 67.17	149.01 ± 52.6
	Relative (AU·min^{-1})	9.57 ± 1.85	9.37 ± 1.55	10.20 ± 2.10	10.08 ± 3.25	10.32 ± 2.14 [f]	9.28 ± 1.44	9.04 ± 1.74 [d]	9.29 ± 1.70
Peak Velocity	(m·s^{-1})	7.0 ± 0.5	7.0 ± 0.6	7.0 ± 0.4	7.0 ± 0.4	7.1 ± 0.5	7.1 ± 0.5	7.0 ± 0.7	6.8 ± 0.5
ACCdist	High (m)	28 ± 15	29 ± 16	26 ± 15	27 ± 11	27 ± 14	28 ± 15	35 ± 18	25 ± 12
	Moderate (m)	43 ± 20	44 ± 19	38 ± 23	37 ± 16	41 ± 21	44 ± 19	48 ± 20	38 ± 17
DECdist	High (m)	10 ± 7	10 ± 7	9 ± 7	10 ± 8	10 ± 7	9 ± 7	10 ± 7	10 ± 7
	Moderate (m)	24 ± 14	24 ± 13	25 ± 18	22 ± 13	25 ± 14	26 ± 15	26 ± 14	19 ± 10
#ACC	High (#)	13 ± 6	13 ± 7	11 ± 7	13 ± 5	12 ± 6 [f]	12 ± 6	15 ±7 [d]	12 ± 6
	Moderate (#)	15 ± 8	15 ± 8	13 ± 9	12 ± 7	14 ± 8	15 ± 8	17 ± 8	13 ± 7
#DEC	High (#)	5 ± 4	5 ± 4	5 ± 4	5 ± 5	5 ± 4	5 ± 5	6 ± 4	6 ± 4
	Moderate (#)	12 ± 7	12 ± 7	12 ± 9	11 ± 7	12 ± 8	12 ±8	13 ± 7	9 ± 5
RHIEs	(#)	6 ± 4	6 ± 4 [b]	5 ± 3 [a]	5 ± 4	5 ± 3	6 ± 4	6 ± 4	5 ± 3

$_{ACC}$dist:: Acceleration distance, AU: Arbitrary units, $_{DEC}$dist: Deceleration distance, HSR: High-speed running, LSR: Low-speed running, MSR: Moderate-speed running, PL: Player Load, RHIEs: Repeated high-intensity efforts, SPR: Sprinting, TD: Total Distance, $\#_{ACC}$: Number of accelerations, $\#_{DEC}$: Number of decelerations, ^{a}: different from unused substitutes, ^{b}: different from 75:00+ min substitutes, ^{c}: different from 60:00-74:59 min substitutes, ^{d}: different from midfielders, ^{e}: different from attackers, ^{f}: different from defenders (a single letter indicates differences at $p \leq 0.05$ level, whereas two of the same letter denotes differences at $p \leq 0.001$ level). Data are presented as mean ± standard deviation.

6.3.2 Influence of the stage of the season

As indicated in Table 6.3, early-season top-ups lasted longer than mid-season and late-season sessions (both p ≤0.05, ES: 0.50-0.54, *small*). Early-season sessions also produced the greatest values for absolute TD, MSR, and PL, high- and moderate-speed acceleration distance, the number of moderate-speed accelerations, and the number of RHIEs performed (all p ≤0.05, ES: 0.34-0.76, *small* to *moderate*). Compared with mid-season, players during early-season top-ups performed more absolute LSR and high-speed decelerations, covered greater distance while decelerating at high-speed, yet recorded lower relative values for TD, PL, and HSR (all p ≤0.05, ES: 0.40-0.69, *small* to *moderate*). Moreover, top-ups conducted early in the season elicited more absolute SPR, alongside an increased number of high-speed accelerations and moderate-speed decelerations, compared with late-season sessions (all p ≤0.05, ES: 0.44-0.57, *small*). Although late-season sessions exceeded mid-season for absolute MSR (p = 0.013, ES: 0.67 [0.35-0.99], *moderate*), greater relative TD, HSR, and PL values were observed during mid-season sessions (all p ≤0.05, ES: 0.47-0.69, *small* to *moderate*).

Table 6.3: Descriptive statistics for substitutes' post-match top-up responses, with comparisons between different stages of the season and according to fixture density

Variable		Stage of season			Fixture density		
		Early	Mid	Late	Low	Moderate	High
Duration	(min)	19.48 ± 6.84 $^{b, c}$	15.46 ± 9.05 ^{a}	16.43 ± 4.10 ^{a}	17.61 ± 5.1 ^{f}	15.21 ± 5.81 ^{ff}	20.83 ± 10.09 $^{d, ee}$
TD	Absolute (m)	1878 ± 658 $^{b, c}$	1573 ± 641 ^{a}	1631 ± 490 ^{a}	1883 ± 530 ^{e}	1557 ± 536 $^{d, f}$	1857 ± 779 ^{e}
	Relative ($m\cdot min^{-1}$)	97.3 ± 12.6 ^{bb}	110.4 ± 22.3 $^{aa, c}$	99.1 ± 15.4 ^{b}	108.2 ± 16.4 ^{ff}	105.7 ± 17.8 ^{f}	93.3 ± 18.4 $^{dd, e}$
LSR	Absolute (m)	989 ± 523 ^{b}	807 ± 582 ^{a}	820 ± 291	1030 ± 498 ^{e}	751 ± 381 ^{d}	1027 ± 656
	Relative ($m\cdot min^{-1}$)	48.3 ± 12.4	51.7 ± 14.2	49.5 ± 11.5	56.2 ± 13.7 $^{ee, f}$	48.6 ± 12.4 ^{dd}	48.5 ± 12.6 ^{d}
MSR	Absolute (m)	420 ± 234 $^{bb, c}$	289 ± 100 $^{aa, c}$	391 ± 190 $^{a, b}$	387 ± 147	343 ± 175	381 ± 235
	Relative ($m\cdot min^{-1}$)	22.3 ± 9.5	22.8 ± 11.6	23.9 ± 9.4	22.8 ± 8.7	24.3 ± 10.8	19.9 ± 9.7
HSR	Absolute (m)	429 ± 157	442 ± 201	403 ± 145	419 ± 174	434 ± 162	419 ± 195
	Relative ($m\cdot min^{-1}$)	24.4 ± 12.6 ^{bb}	33.6 ± 16.1 $^{aa, c}$	24.9 ± 7.8 ^{b}	26.0 ± 14.7 ^{e}	31.1 ± 13.2 $^{d, ff}$	23.3 ± 12.9 ^{ee}
SPR	Absolute (m)	41 ± 70 ^{c}	34 ± 63	17 ± 35 ^{a}	47 ± 76	28 ± 59	29 ± 52
	Relative ($m\cdot min^{-1}$)	2.3 ± 4.0	2.2 ± 4.1	0.9 ± 1.9	3.1 ± 5.1 ^{e}	1.6 ± 3.3 ^{d}	1.6 ± 3.0
PL	Absolute (AU)	183.19 ± 69.15 $^{b, cc}$	144.37 ± 64.56 ^{a}	148.85 ± 45.93 ^{aa}	181.26 ± 56.04 $^{e, ff}$	143.56 ± 53.94 $^{d, f}$	176.86 ± 79.94 $^{dd, e}$
	Relative ($AU\cdot min^{-1}$)	9.42 ± 1.36 ^{b}	10.03 ± 2.13 $^{a, c}$	9.09 ± 1.84 ^{b}	10.39 ± 2.01 ^{e}	9.68 ± 1.77 $^{d, f}$	8.79 ± 1.63 ^{e}
Peak Velocity	($m\cdot s^{-1}$)	7.1 ± 0.5	7.0 ± 0.6	6.9 ± 0.5	7.1 ± 0.5	7.0 ± 0.6	7.0 ± 0.6
$_{ACC}$dist	High (m)	33 ± 18 $^{b, c}$	28 ± 14 ^{a}	23 ± 11 ^{a}	23 ± 14 $^{e, ff}$	28 ± 12 $^{d, f}$	34 ± 19 $^{dd, e}$
	Moderate (m)	49 ± 22 $^{b, c}$	39 ± 20 ^{a}	39 ± 14 ^{a}	37 ± 15 ^{ff}	41 ± 17 ^{f}	50 ± 26 $^{dd, e}$
$_{DEC}$dist	High (m)	12 ± 8 ^{b}	8 ± 6 ^{a}	10 ± 6	5 ± 4 $^{ee, ff}$	10 ± 6 $^{dd, f}$	13 ± 9 $^{dd, e}$
	Moderate (m)	26 ± 14	24 ± 15	23 ± 10	17 ± 8 $^{ee, ff}$	24 ± 11 $^{dd, f}$	31 ± 18 $^{dd, e}$
$\#_{ACC}$	High (#)	14 ± 7 ^{c}	12 ± 6	11 ± 5 ^{a}	10 ± 6 $^{e, ff}$	12 ± 5 ^{d}	15 ± 8 ^{dd}
	Moderate (#)	17 ± 8 $^{bb, c}$	13 ± 9 ^{aa}	13 ± 5 ^{a}	13 ± 6 ^{f}	14 ± 7 ^{f}	18 ± 10 $^{d, e}$
$\#_{DEC}$	High (#)	6 ± 5 ^{b}	4 ± 4 ^{a}	5 ± 3	3 ± 3 $^{ee, ff}$	5 ± 4 ^{dd}	7 ± 5 ^{dd}
	Moderate (#)	13 ± 7 ^{c}	12 ± 8	10 ± 5 ^{a}	9 ± 5 ^{ff}	10 ± 5 ^{f}	15 ± 10 $^{dd, e}$
RHIEs	(#)	7 ± 4 $^{bb, cc}$	5 ± 4 ^{aa}	5 ± 2 ^{aa}	6 ± 2	5 ± 4	6 ± 5

$_{ACC}$dist:: Acceleration distance, AU: Arbitrary units, $_{DEC}$dist: Deceleration distance, HSR: High-speed running, LSR: Low-speed running, MSR: Moderate-speed running, PL: Player Load, RHIEs: Repeated high-intensity efforts, SPR: Sprinting, TD: Total Distance, $\#_{ACC}$: Number of accelerations, $\#_{DEC}$: Number of decelerations, ^{a}: different from early-season, ^{b}: different from mid-season, ^{c}: different from late-season, ^{d}: different from low fixture density, ^{e}: different from moderate fixture density, [f]: different from high fixture density (a single letter indicates differences at $p \leq 0.05$ level, whereas two of the same letter denotes differences at $p \leq 0.001$ level). Data are presented as mean ± standard deviation.

6.3.3 Influence of fixture density

With regard to fixture density (Table 6.3), players recorded higher absolute TD, PL, and LSR values, alongside greater relative LSR, SPR, and PL responses, during top-ups performed when fixture density was low, compared with moderate (all p ≤0.05, ES: 0.34-0.69, *small* to *moderate*). Conversely, periods of moderate fixture density exceeded low fixture density for relative HSR, the number of high-speed accelerations and decelerations performed, high-speed acceleration distance, and distance covered while decelerating at high- and moderate-speed (all p ≤0.05, ES: 0.37-0.87, *small* to *moderate*).

Although greater relative TD, LSR, and PL responses were observed during low fixture density, top-ups were shorter and produced lesser values for all acceleration and deceleration variables when fixture density was low, compared with high (all p ≤0.05, ES: 0.4-0.107, *small* to *moderate*). High fixture density exceeded moderate fixture density for session duration, absolute TD, absolute PL, high- and moderate-speed acceleration and deceleration distance, and the number of moderate-speed accelerations and decelerations performed (all p ≤0.05, ES: 0.40-0.68, *small* to *moderate*). In contrast, relative values for TD, HSR, and PL were greater when fixture density was moderate compared with high (all p ≤0.05, ES: 0.39-0.68, *small* to *moderate*).

6.3.4 Influence of match location, match result, and time of day

Match location, result, and time of day, each influenced certain physical responses (Table 6.4). Top-ups completed following home matches were longer and elicited greater absolute values for TD, LSR, and HSR, as well as an increased number of moderate-speed accelerations, more RHIEs, and more moderate-speed decelerations, compared with away matches (all p ≤0.05, ES: 0.25-0.89, *small* to *moderate*). When the reference team had won the preceding match, players recorded more high-speed decelerations, alongside producing greater responses for absolute and relative MSR, moderate-speed acceleration distance, high-speed deceleration distance, and moderate-speed deceleration distance, compared with top-ups performed following losses (all p

≤0.05, ES: 0.34-0.45, *small*). Wins and losses each exceeded draws for absolute HSR, relative LSR was higher following draws than following wins, whilst top-ups performed immediately after losses elicited greater absolute and relative SPR responses compared with draws (all p ≤0.05, ES: 0.35-0.68, *small* to *moderate*). Compared with evening matches, greater absolute and relative MSR, and relative LSR values were observed following afternoon fixtures (all p ≤0.05, ES: 0.50-0.53, *small*). Moreover, top-ups conducted after afternoon matches elicited less absolute HSR, less absolute and relative SPR, and lower peak velocities compared with evening matches, while also producing lower peak velocities along with less moderate-speed deceleration distance than early matches (all p ≤0.05, ES: 0.43-1.26, *small* to *large*).

Table 6.4: Descriptive statistics for substitutes' post-match top-up responses, with comparisons between match location, result, and time of day

Variable		Match location		Match result			Time of day		
		Home	Away	Win	Draw	Loss	Afternoon	Early	Evening
Duration	(min)	18.99 ± 9.24 [bb]	15.14 ± 4.02 [aa]	17.56 ± 8.75	15.71 ± 5.19	17.25 ± 5.98	17.04 ± 7.54	15.32 ± 2.71	17.79 ± 7.59
TD	Absolute (m)	1859 ± 764 [bb]	1521 ± 357 [aa]	1708 ± 719	1658 ± 530	1697 ± 492	1699 ± 622	1594 ± 269	1693 ± 684
	Relative (m·min^{-1})	103.1 ± 20.5	102.6 ± 16.3	102.1 ± 19.9	107.2 ± 13.7	101.4 ± 18.6	103.8 ± 18.9	104.8 ± 12.2	98.5 ± 17.4
LSR	Absolute (m)	1002 ± 637 [bb]	738 ± 246 [aa]	854 ± 559 [d]	902 ± 498 [c]	893 ± 404	885 ± 504	677 ± 202	858 ± 543
	Relative (m·min^{-1})	50.4 ± 11. 8	49.5 ± 14.2	47.3 ± 12.4	55.2 ± 14.6	51.4 ± 11.8	51.3 ± 13.2 [h]	43.7 ± 7.0	44.8 ± 11.3 [f]
MSR	Absolute (m)	373 ± 225	348 ± 140	383 ± 222 [e]	379 ± 160	311 ± 123 [c]	379 ± 195 [h]	352 ± 108	282 ± 146 [f]
	Relative (m·min^{-1})	22.2 ± 11.3	23.6 ± 9.1	23.8 ± 11.0 [e]	24.2 ± 8.6	20.3 ± 9.6 [c]	23.8 ± 10.4 [h]	22.6 ± 3.3	18.8 ± 9.6 [f]
HSR	Absolute (m)	447 ± 179 [b]	406 ± 163 [a]	445 ± 187 [d]	363 ± 143 [c, e]	437 ± 156 [d]	410 ± 169 [h]	542 ± 113	487 ± 181 [f]
	Relative (m·min^{-1})	28.5 ± 15.2	27.7 ± 12.2	29.4 ± 14.1	26.5 ± 15.9	26.8 ± 11.7	27.1 ± 13.3	36.8 ± 11.9	31.5 ± 15.4
SPR	Absolute (m)	36 ± 66	28 ± 54	26 ± 53	14 ± 29 [e]	55 ± 80 [d]	25 ± 51 [h]	22 ± 17	66 ± 88 [f]
	Relative (m·min^{-1})	2.0 ± 3.7	1.8 ± 3.6	1.6 ± 3.3	1.3 ± 2.9 [e]	2.9 ± 4.4 [d]	1.6 ± 3.4 [h]	1.5 ± 1.3	3.3 ± 4.7 [f]
PL	Absolute (AU)	175.42 ± 78.48	141.83 ± 37.66	159.66 ± 72. 29	153.72 ± 56.21	161.82 ± 53.81	159.63 ± 64.18	149.97 ± 23.00	158.59 ± 69.99
	Relative (AU·min^{-1})	9.63 ± 2.10	9.52 ± 1.55	9.46 ± 1.92	9.82 ± 1.23	9.61 ± 2.06	9.65 ± 1.86	9.98 ± 1.86	9.16 ± 1.80
Peak Velocity	(m·s^{-1})	7.0 ± 0.5	7.0 ± 0.6	7.0 ± 0.5	7.0 ± 0.7	7.1 ± 0.6	6.9 ± 0.5 [h, g]	7.7 ± 1.4 [f]	7.2 ± 0.5 [f]
ACCdist	High (m)	30 ± 17	27 ± 13	30 ± 17	26 ± 11	27 ± 14	28 ± 16	41 ± 7	28 ± 13
	Moderate (m)	45 ± 23	40 ± 16	46 ± 23 [e]	39 ± 14	39 ± 16 [c]	42 ± 20	55 ± 13	43 ± 19
DECdist	High (m)	10 ± 8	9 ± 7	11 ± 8 [e]	9 ± 5	8 ± 6 [c]	9 ± 8	12 ± 5	10 ± 5

	Moderate (m)	26 ± 16	23 ± 11	27 ± 16[e]	23 ± 11	21 ± 11[c]	24 ± 14[g]	38 ± 8[f]	24 ± 11
#$_{ACC}$	High (#)	13 ± 7	12 ± 6	13 ± 7	12 ± 5	12 ± 6	12 ± 7	18 ± 3	13 ± 6
	Moderate (#)	16 ± 9[b]	13 ± 6[a]	16 ± 9	14 ± 6	13 ± 7	15 ± 8	18 ± 6	15 ± 8
#$_{DEC}$	High (#)	6 ± 5	5 ± 3	6 ± 5[e]	5 ± 3	4 ± 4[c]	5 ± 4	5 ± 3	5 ± 4
	Moderate (#)	13 ± 8[b]	10 ± 5[a]	13 ± 8	11 ± 5	10 ± 6	12 ± 7	17 ± 3	11 ± 7
RHIEs	(#)	6 ± 4[b]	5 ± 3[a]	6 ± 4	5 ± 3	6 ± 3	5 ± 4	3 ± 1	7 ± 4

$_{ACC}$dist:: Acceleration distance, AU: Arbitrary units, $_{DEC}$dist: Deceleration distance, HSR: High-speed running, LSR: Low-speed running, MSR: Moderate-speed running, PL: Player Load, RHIEs: Repeated high-intensity efforts, SPR: Sprinting, TD: Total Distance, #$_{ACC}$: Number of accelerations, #$_{DEC}$: Number of decelerations, [a]: different from home matches, [b]: different from away matches, [c]: different from wins, [d]: different from draws, [e]: different from losses, [f]: different from afternoon matches, [g]: different from early matches, [h]: different from evening matches (a single letter indicates differences at $p \leq 0.05$ level, whereas two of the same letter denotes differences at $p \leq 0.001$ level). Data are presented as mean ± standard deviation.

6.4 Discussion

This study quantified the physical demands of professional soccer substitutes during post-match 'top-up' conditioning sessions, while assessing contextual influences. On average, top-ups lasted for ~17 min and elicited ~1.7 km of TD. However, sessions were longest for unused squad members, who typically produced greater absolute physical responses compared with substitutes who had been introduced into the preceding match. Observations of heightened demands during top-ups conducted at home versus away, alongside the influence of contextual variables such as fixture density, the stage of the season, time of day, and match result, highlight practical and logistical considerations relating to post-match conditioning; factors which may be important for practitioners when designing and monitoring top-up sessions.

Top-ups are typically prescribed with the aim of helping to compensate for deficits in physical loading for individuals who receive either no match-play exposure, or substantially less than that of whole-match players (chapter three). In particular, although differences in the availability of resources and/or fixture scheduling may lead to substantial between-team variation, providing a HSR stimulus often represents a primary objective during these sessions (chapter three). Players in the current study performed ~0.4 km of HSR during post-match top-ups, values which fall substantially below the ~0.8-1.0 km typically accumulated by professional soccer players throughout a 90 min match (Bradley et al., 2009; Di Salvo et al., 2009; Rampinini et al., 2007). Given the role of top-ups as a means of offsetting discrepancies in match-play demands, it is unsurprising that unused members of the match-day squad recorded generally greater absolute top-up responses compared with players who had experienced partial match-play (i.e., those substitutes who were deployed during the immediately preceding match). However, acknowledging that any match-exposure must also be considered when assessing an individual's overall match-day loading, and that considerable variation may exist in relation to a substitute's match demands, substitutions are often made with very limited time remaining in a match and thus experience minimal match-play loads (Bradley et al., 2014; Carling et al., 2010; Del Corral et al., 2008; Myers, 2012). Moreover, chapter four observed little or no HSR or SPR during preparatory activities performed prior to match-introduction, with many practitioners in chapter three deeming a substitute's pre-pitch-entry responses to be too minimal to warrant inclusion within assessments of match-day loading. As match-play may represent an important stimulus for promoting sport-specific physical adaptations (Morgans et al., 2018; Silva et al., 2011), the likely reduction in absolute match-day loading for unused or partial-match players compared with their whole-match counterparts has the potential to negatively influence an individual's adaptive responses, particularly for those who are repeatedly omitted from the starting team over the course of multiple fixtures.

Whereas absolute HSR in the current study equates to <50% of whole-match values for players who occupy outfield players (Bradley et al., 2009; Di Salvo et al., 2009; Rampinini et al., 2007), relative HSR of ~28.1 $m \cdot min^{-1}$ far exceeds the ~4.8-10.1 $m \cdot min^{-1}$ typically recorded across a playing bout for both partial- and whole-match players (Bradley et al., 2014; Bradley et al., 2009). Indeed, such values broadly reflect the relative HSR responses reported during the 'peak' 2-3 min period of match-play (Delaney et al., 2018; Fereday et al., 2019; Hills et al., 2020). Although the role of HSR 'intensity' in physical preparation and injury-management remains to be determined, it may be important for practitioners to consider the potential for differing physiological responses when substantially overloading relative HSR compared with typical match-play demands, and to assess the volume of HSR that can be safely accumulated in the limited time available for post-match conditioning (Buchheit, 2019). Within the context of the overall periodised training program, such decisions may be informed on an individual player basis with reference to factors such as a player's ongoing HSR loads and perceived physical development priorities (Buchheit, 2019).

Large fluctuations in physical loading may increase injury-risk amongst team sports players (Duhig et al., 2016; Malone et al., 2017a; Malone et al., 2017b), while the presence of low ongoing loads may exacerbate such effects (Colby et al., 2018; Malone et al., 2017a; Malone et al., 2017b). Therefore, if an appropriate volume of top-up training is not performed, a reduction in a player's match-day demands could promote an increased susceptibility to injury as a consequence of declines in absolute loading over time (Anderson et al., 2016a; Buchheit, 2019). Acknowledging that the presence of sufficient training and match-play loads may be vital for developing tolerance to very high-speed efforts (Colby et al., 2018; Malone et al., 2017b), ensuring that players are regularly exposed to maximum or near-maximum velocity running could represent an important strategy for injury-risk reduction (Colby et al., 2018; Malone et al., 2017b; McGrath et al., 2019). However, as tactical preparations and fatigue-management often represent a team's primary foci during the days between competitive fixtures, the types of drills (e.g., small-sided games) typically adopted during squad training sessions may afford limited opportunities for a player to sprint during a professional soccer season (Ade et al., 2014; Anderson et al., 2016b). Indeed, excluding match-day responses (i.e., typically ~0.2-0.3 $km \cdot player^{-1} \cdot match^{-1}$ for whole-match players (Anderson et al., 2016b; Bradley et al., 2009; Di Salvo et al., 2009; Rampinini et al., 2007)), professional players may at times perform as little as <0.01 $km \cdot player^{-1} \cdot week^{-1}$ of SPR throughout an entire seven day microcycle (Anderson et al., 2016b). As top-ups in the current study elicited just ~0.03 km of SPR and players reached peak velocities of ~7.0 $m \cdot s^{-1}$, these data highlight the importance of ensuring appropriate SPR exposure during other training sessions throughout the week. Alternatively, or in conjunction, such observations could highlight an opportunity to address current practices by tailoring the design of post-match conditioning sessions to promote greater SPR responses. Notably, increasing a player's SPR volume could also provide a valuable stimulus for developing explosive physical performance, with improvements in 40 m sprint and maximum aerobic speed having been observed when professional players performed repeated sprints and high-intensity interval training once per week throughout 10 weeks of the season (Dupont et al., 2004).

Notwithstanding the potential benefits to emphasising HSR and SPR during top-up conditioning sessions, several practical and logistical considerations may limit what can be achieved during the immediate post-match period. For example, The English Football Association handbook stipulates that activities performed after the conclusion of the match "shall last for no longer than 15 minutes" and gives discretion to ground staff to dictate which areas of the pitch can and cannot be used for this purpose (FA, 2019/2020). When one considers the likely need for unused substitutes to undertake appropriate warm-up or rewarm-up activity prior to performing very high-speed activities following a match, alongside the fact that team management staff may wish to deliver tactical debriefing to all squad members immediately after the conclusion of play, the existence of spatial and temporal restrictions could at least partly explain the HSR and SPR responses observed in the current study. Indeed, given the limited time often available for post-match top-ups, practitioners may choose to prioritise other stimuli such as developing aerobic capacity, which can be achieved in a more time-efficient manner and may be perceived to carry a lower acute injury-risk in the circumstances (i.e., when ≥120 min may have elapsed following cessation of the pre-match warm-up). If this approach is taken, it may be particularly important for practitioners to ensure that players are exposed to maximum or near-maximum velocity running elsewhere within the microcycle.

Following home matches, top-ups lasted longer and elicited greater values for absolute TD, LSR and HSR, alongside the number of moderate-speed accelerations, RHIEs, and moderate-speed decelerations performed, compared with away matches. Such observations may appear unsurprising when one considers that return travel arrangements are likely to represent the main priority for players and team staff after the conclusion of away matches, particularly when played large distances from home. Moreover, post-match activities at away venues could be further limited by a reduced number of traveling support staff, tighter restrictions on pitch-usage, and/or the potential for increased hostility from opposition supporters. Whereas a longer session duration might explain the greater absolute responses observed, heightened RHIE, acceleration, and deceleration demands could partly reflect practitioners' increased freedom to prescribe activities that incorporate changes of direction and potentially small-sided games when sessions are performed on home turf (Ade et al., 2014). In contrast, pitch-protection policies at away grounds may limit post-match conditioning strategies to the use of primarily straight-line running drills. Acknowledging that restrictions may also be imposed by home ground staff and/or the terms of competition-wide legislation, it seems likely that more favourable treatment may be afforded to the home team. In support, whereas away sessions lasted for the ~15 min stipulated in The Football Association handbook (FA, 2019/2020), top-ups performed at home extended to an average of ~19 min in duration. Irrespective of the underlying reasons, the potential for discrepancies in physical responses following home and away fixtures may need to be borne in mind by practitioners when assessing and prescribing training loads for players who receive limited match-play exposure.

The influence of contextual factors on post-match conditioning prescription is further highlighted by observations that early-season top-ups typically elicited greater absolute demands compared with sessions conducted during the mid- or late-season periods. Although the primary focus of ‘topping-up’ often surrounds addressing deficits in match-play stimulus on an acute (i.e., per match) basis (chapter three), these data may indicate the importance of considering a player’s physical loading within the context of the overall training cycle. If an individual has experienced particularly high loads during the preceding days or weeks (e.g., having completed multiple matches), or a period of reduced loading is desired within the periodised training program, it may not be appropriate to prescribe a substantial volume of extra conditioning in these scenarios. For example, although the use of substitutions often reflects an effort to positively influence the outcome of a specific match, there may be instances in which certain players are named as substitutes (i.e., as opposed to being selected within the starting team) as part of a ‘rotation policy’ designed to reduce their overall loading or prevent the accumulation of fatigue across a whole squad (chapter three). Moreover, acknowledging the potential role of other factors such as the likely deteriorating pitch condition over the course of a season, the generally heightened absolute demands observed during early-season top-up sessions may partly reflect the team’s broader periodisation strategy. It seems likely that promoting physical adaptations may represent a primary training objective for a squad during the early stages of the season, whereas the continued accumulation of load over multiple matches means that fatigue-management may be increasingly prioritised as the season progresses (Anderson et al., 2016a; Kelly et al., 2020; Malone et al., 2015).

For certain variables, particularly those relating to acceleration and deceleration responses, top-ups performed during periods of high fixture density elicited greater demands compared with sessions conducted under moderate- or low-density conditions. Top-ups were also longer in duration when fixture density was high. Whilst such observations may seem surprising, these patterns may be attributable to the fact that an increase in fixture congestion typically reduces the amount of whole-team training that can be conducted within a given period (i.e., when travel and recovery considerations may account for a greater proportion of the time between fixtures). Therefore, because overall training demands may be limited when fixture density is high, greater importance may be attributed to post-match conditioning sessions as an opportunity to elicit a substantial stimulus, particularly for players who rarely feature in the starting team. Notably, fixture congestion may also restrict the volume of technical and tactical training that can be performed throughout the week. Acknowledging that time and space may often be limited during the post-match period, incorporating activities such as small-sided games within top-up sessions may allow practitioners simultaneously to provide stimuli for the development or maintenance of physical capacity and soccer-specific skills.

Midfielders typically accumulate the greatest absolute and relative match-play distances of any playing position (Bradley et al., 2014; Bradley & Noakes, 2013; Bradley et al., 2009; Mohr et al., 2003). Such discrepancies appear to suggest in favour of taking a position-specific approach to training prescription and may also warrant consideration in relation to post-match top-ups (Reilly et al., 2009). In support, given the objective of compensating for deficits in loading compared with a player's typical whole-match demands, it seems appropriate that the physical loads of midfielders may need to be 'topped-up' to a greater degree than players in other positions (Buchheit, 2019). That said, whilst midfielders in the current study produced the greatest relative TD and PL values during post-match top-ups, defenders surpassed midfielders for absolute MSR and the number of high-speed accelerations completed. As position-specific session design was not adopted during the observation period for the current study, such heightened relative demands may be attributable primarily to extraneous factors such as a greater physical capacity amongst midfielders (Mohr et al., 2003) and/or differences in individualised weekly loading targets, as opposed to reflecting conscious differences in training prescription between positional groups.

Although top-ups for outfield players elicited substantially lower absolute running demands compared with those typically observed throughout 90 min of match-play, the same may not be true for goalkeepers. Goalkeepers in the current study produced similar physical responses to players in outfield positions, accumulating ~0.4 km at >5.5 m·s^{-1} during post-match top-ups. However, professional goalkeepers have been reported to cover just ~0.1 km of HSR throughout a whole-match, even when a position-specific HSR threshold of >4.17 m·s^{-1} was emplyed (White et al., 2020). Given the increased injury-risk associated with rapid increases in HSR load (Buckthorpe et al., 2019; Duhig et al., 2016), caution must be exercised when goalkeepers participate in post-match conditioning sessions alongside outfield players, particularly for individuals who are unaccustomed to this form of running-based activity within their typical position-specific training (White et al., 2020). Moreover, as match-play may require goalkeepers to perform several position-specific tasks such as jumps, dives, and high-velocity kicking actions (White et al., 2020), the adoption of bespoke top-up strategies that emphasise these explosive actions may help to provide an additional stimulus for the promotion of such crucial adaptations.

Several limitations should be noted when interpreting the findings of the current study. Although useful for monitoring specific aspects of external loading, MEMS data in isolation cannot quantify all contributions to a player's internal and external physical load. Unfortunately, due to the sample of professional soccer players that were recruited for this study (as well as the studies in chapters four and seven), it was not possible to assess physiological responses as part of these investigations. Nonetheless, given that top-ups often target specific objectives such as providing a HSR stimulus (chapter three, Buchheit, 2019), direct measurement of these external load metrics gives valuable insight into the responses elicited during post-match sessions. Moreover, the use of PL, which represents a three-dimensional measure of instantaneous rate of change in acceleration, may provide an indication of external loading on a more holistic level. Empirical observations suggest that PL is widely used by practitioners as a marker of overall external load, and this variable has demonstrated strong relationships with HR and RPE-based training load measures (Scott et al., 2013). However, future research examining substitutes' internal loading on an acute and ongoing basis would further benefit practitioners when prescribing training and monitoring individual player responses. Although the influence of substitution timing was analysed, this study assessed the responses to top-up conditioning sessions in isolation and did not monitor changes in physical loading over a longer period of time. A player's training and match-play demands over several days or weeks may be an important factor in determining what constitutes an appropriate degree of 'topping-up' and may thus influence the responses elicited during post-match sessions. Similarly, as data were collected only from substitutes who performed top-ups following any given match, contextual influences may have been partly obfuscated by the exclusion of instances in which a player or group of players did not undertake post-match conditioning. That said, this study provides novel insights into the match-day top-up conditioning practices of professional soccer substitutes while demonstrating the influence of several contextual variables. Such information may be useful to highlight the barriers currently existing in relation to post-match top-up sessions and could help applied practitioners to assess then address current practices.

6.5 Conclusion

This study quantified the physical responses of professional soccer substitutes during post-match top-up conditioning sessions. The importance of top-up sessions is highlighted by the fact that because team training programmes are often designed on the basis that match-activities are expected to represent a substantial contributor to a player's physical loads during a season, there exists the potential for individuals who are repeatedly omitted from the starting team to experience reductions in overall loading compared with whole-match players. Notably, such declines may be associated with decreases in sport-specific physical performance adaptations and/or an increased risk of sustaining soft tissue injury (Bowen et al., 2017; Buckthorpe et al., 2019; Colby et al., 2018; Morgans et al., 2018; Silva et al., 2011). As several contextual variables such as substitution timing, match location, result, time of day, playing position, fixture density, and the stage of the season each influenced the demands of post-match sessions, practitioners should specifically consider the presence of practical or logistical barriers when designing or evaluating match-day top-ups. Moreover, because direct and indirect restrictions on the time and space available for training may limit what can be achieved during the immediate post-match period, management and support staff may decide that performing top-up sessions the next day and/or modifying training prescription throughout a microcycle (e.g., to ensure maximum or near-maximum velocity running elsewhere during the week) may offer greater flexibility to safely achieve the desired volume and intensity of stimulus. That said, the suitability of this approach must be assessed on case-by-case basis with reference to factors such as player and staff psychology, existing training and recovery demands, fixture scheduling/travel arrangements, and the availability of resources.

Chapter 7.0 The effects of modifying the pre-pitch-entry practices of professional soccer substitutes

Chapter summary

- Modifying a soccer substitute's pre-pitch-entry activities may provide an opportunity to maximise subsequent physical performance and minimise injury-risk.
- This study investigated the effects of a modified match-day protocol that included substitutes; 1) performing a new pre-match warm-up alongside members of the starting team (as opposed to a separate substitute-only warm-up), 2) participating in a staff-led half-time rewarm-up (as opposed to player-led half-time activities), and 3) receiving ongoing education emphasising the value of substitutes highlighting and the importance of (re)warm-up activities.
- The modified pre-match warm-up and staff-led half-time rewarm-up elicited generally greater absolute movement demands compared with the substitute-specific warm-up and player-led half-time rewarm-up that had previously been adopted in chapter four, whilst heightened relative TD was typically observed during player-led pitch-side rewarm-ups.
- Post-pitch-entry physical outputs were greater than the responses observed in chapter four, whilst movement profiles were better maintained throughout a substitute's playing bout and favourable match scoreline responses were also observed.
- Practitioners should note the potential importance of substitute match-day activities and, if deemed necessary, consider adapting their pre-pitch-entry routines accordingly.

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7.1 Introduction

Although specific substitution regulations vary between competitions, soccer teams are permitted to replace a number of starting players during a match, on either a permanent or 'rolling' basis. For example, English Football League rules currently allow up to three substitutions to be made from a maximum of seven nominated players (EFL, 2019). Aside from replacements that are enforced due to injury, coaches/managers typically introduce substitutes at half-time or during the second-half of match-play, often with the primary objectives of providing physical impetus and/or changing team tactics (chapters three and four, Bradley et al., 2014; Myers, 2012). However, it is acknowledged that the use of substitutions may also reflect other motivations, such as decisions to replace players adjudged to be injured or underperforming, or a desire to allow playing time for youth players or those returning from injury (chapter three).

For outfield players who start the match on the pitch, progressive declines in indices of physical and technical performance are observed over the course of 90 min (Mohr et al., 2003; Rampinini et al., 2009; Waldron & Highton, 2014). As the use of substitutions often represents a means by which coaches and managers seek to offset such negative responses via the introduction of 'fresh legs' (chapter three), a substitute's post-pitch-entry physical output may be an important indicator of match performance (chapter three, Bradley et al., 2014). Indeed, empirical evidence suggests that the execution of specific locomotor actions such as the amount of HSR and SPR performed by a player and/or team often represents a key performance indicator during professional soccer match-play (Bangsbo et al., 1991; Mohr et al., 2003), with these actions being frequently involved in many of the most decisive periods of a match (Faude et al., 2012). Notably, although players introduced as substitutes may typically exceed the relative TD and/or HSR distances that they habitually adopt during the equivalent second-half period when the same individuals complete a whole match (Bradley et al., 2014; Mohr et al., 2003), they may be unable to surpass the movement responses that they would ordinarily produce during the first-half of matches in which they start (Bradley et al., 2014; Carling et al., 2010). Whilst team tactics, self-pacing strategies, and changes in other contextual factors (i.e., the match scoreline or the activities of other players on the pitch) are likely to influence the running demands experienced during match-play (Bradley & Noakes, 2013; Waldron & Highton, 2014), it is possible that these observations may partly reflect differences in the pre-pitch-entry preparations undertaken by substitutes compared with members of the starting eleven. In support, match-day strategies appear to vary markedly between teams and between individuals, with practitioners having noted the potential for sub-optimal pre-pitch-entry preparations to negatively influence team performance following a substitute's introduction into a match (chapter three).

Notwithstanding the benefits of an active pre-match warm-up to help starting players transition from a state of rest to a state of exercise (Bishop, 2003; Hammami et al., 2016; McGowan et al., 2015; Silva et al., 2018), subsequent inactivity may induce physiological responses (e.g., decreases in T_m and T_{core}) that could compromise muscular performance during high-intensity exercise performed thereafter, at least in cold or thermoneutral environments (Galazoulas et al., 2012; Kilduff et al., 2013b; Lovell et al., 2013; Russell et al., 2017; Russell et al., 2015d; Silva et al., 2018; West et al., 2013b; West et al., 2016). For this reason, half-time research has highlighted how extended periods of passive rest may not represent optimal preparation for the second-half of team sport match-play. Indeed, performing an active rewarm-up at half-time may help to attenuate body temperature declines, maintain physical performance, and potentially reduce the risk of injury when the second-half commences (Bixler & Jones, 1992; Hammami et al., 2016; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2017). As substitutes typically face lengthy delays (i.e., often ≥75-120 min) between the end of the pre-match warm-up and their introduction into a match (Bradley et al., 2014; Del Corral et al., 2008; Myers, 2012), it is possible that the practices adopted during this time may have direct relevance to a player's physical performance and/or injury-risk following pitch-entry.

Although substitutes awaiting introduction may perform short bouts of rewarm-up activity whilst the match is underway and potentially at half-time, chapter four showed that much of the period between kick-off and pitch-entry is typically spent seated beside the pitch. Notably, observations from chapter five suggested that current pre-pitch-entry practices were unable to maintain body temperature and physical performance responses from post-warm-up until simulated second-half pitch-entry. It has been suggested that the intensity of warm-up activity represents an important factor in determining the effectiveness of any preparatory strategy employed (Anderson et al., 2014; Ingham et al., 2013; McGowan et al., 2015; Silva et al., 2018; Zois et al., 2011). For example, amongst team sport players, beneficial effects on repeated sprint ability have been observed following a warm-up incorporating actions conducted above, versus below, the anaerobic threshold (Anderson et al., 2014). In chapter four, professional substitutes covered <2 $m \cdot min^{-1}$ of HSR during each bout of pre-pitch-entry warm-up or rewarm-up activity performed and recorded no SPR at any time prior to match-introduction. Acknowledging that these reports were limited to players from a single club, and that other non-pitch-based activities (e.g., dynamic stretching) may also have been performed, such observations alongside the findings of chapter five highlight the need for further research in this area; a statement supported in by applied practitioners (chapter three). Therefore, this follow-up study aimed to profile the pre- and post-pitch-entry movement responses of professional soccer substitutes after attempts had been made to address existing deficiencies via modification of their pre-pitch-entry routine. Such information would add to the currently limited literature existing in relation to soccer substitutes and may aid practitioners seeking to improve the match-day preparations of this playing group.

7.2 Methods

7.2.1 Participants

After receipt of ethical approval from the School of Social and Health Sciences Research Ethics Committee at Leeds Trinity University (Appendix 6), 15 outfield players (age: 26 ± 5 years, stature: 1.82 ± 0.05 m, body mass: 79.1 ± 5.8 kg) from a professional soccer club were monitored during 13 English Championship matches in which they entered the pitch as substitutes. From the sample consisting of four defenders (six observations), eight midfielders (18 observations), and three attackers (11 observations), a total of 35 individual player observations were yielded (2 ± 1 $observations \cdot player^{-1}$, range: 1-6 $observations \cdot player^{-1}$). As per the methods outlined in chapter four, data from unused substitutes (i.e., members of the match-day squad who were not introduced onto the pitch during a match) were not included in the analyses. All players were fully briefed about the risks and benefits of participation before providing written consent prior to data-collection, which took place during the 2018/2019 season.

7.2.2 Activity monitoring

Activity monitoring was conducted as per previous chapters (i.e., chapters four and six), whereby substitutes' movements were captured by 10 Hz MEMS (S5, Optimeye, Catapult Innovations, Melbourne, Australia) worn between the scapulae and beneath the playing jersey in a vest designed to minimise movement artefacts. As noted previously, MEMS sampling at 10 Hz have demonstrated acceptable reliability (CV% = 2.0-5.3%) for measuring instantaneous velocity (Varley et al., 2012b), whilst the specific models used have produced small-to-moderate typical errors of the estimate (1.87-1.95%) versus a radar gun when assessing sprinting speed (Roe et al., 2017). The accelerometers within the devices have also demonstrated good intra (CV% = 0.9-1.1%) and inter-unit (CV% = 1.0-1.1) reliability (Boyd et al., 2011). All players were familiar with this form of activity monitoring, with six of the included players having participated in the initial substitute profiling study in chapter four. Each individual wore the same MEMS unit in each match to avoid potential inter-unit variation.

The MEMS devices were activated according to the manufacturer's guidelines ~30 min prior to the pre-match warm-up, and raw data files were exported post-match using proprietary software (Sprint 5.1.7, Catapult Innovations, Melbourne, Australia). The dependent variables of interest are outlined in Table 7.1. Individual data files were processed separately to allow organisation of pre-pitch-entry data into periods reflecting each bout of warm-up/rewarm-up activity performed, and the grouping of post-pitch-entry data into five min epochs from the moment a player entered the pitch (i.e., as per chapter four). For each substitution, contextual information relating to match scoreline, playing position, and the timing of a player's introduction, was also recorded. For this chapter, data arose as part of routine monitoring practices at the professional soccer club. The lead researcher was responsible for obtaining ethical approval, clipping and exporting pre- and post-pitch-entry MEMS data files in accordance with the specific research questions of this study, selecting the outcome variables of interest in consultation with senior sport science staff at the club, and analysing the data. Members of the PhD supervisory team provided input at all stages of study design, whilst sports science staff at the club helped to design and implement the intervention and provided access to the MEMS data.

Table 7.1: Operational definition for Microelectromechanical Systems (MEMS)-derived outcome variables

Measurement	Variable	Definition
Distance covered	TD (m)	Total amount of distance covered by any means
	Relative TD ($m \cdot min^{-1}$)	Total amount of distance covered per minute
	LSR (m)	Distance covered at a speed of ≤4 $m \cdot s^{-1}$
	Relative LSR ($m \cdot min^{-1}$)	Distance covered per minute at a speed of ≤4 $m \cdot s^{-1}$
	MSR (m)	Distance covered at a speed of >4 to ≤5.5 $m \cdot s^{-1}$
	Relative MSR ($m \cdot min^{-1}$)	Distance covered per minute at a speed of >4 to ≤5.5 $m \cdot s^{-1}$
	HSR (m)	Distance covered at a speed of >5.5 to ≤7 $m \cdot s^{-1}$
	Relative HSR ($m \cdot min^{-1}$)	Distance covered per minute at a speed of >5.5 to ≤7 $m \cdot s^{-1}$
	SPR (m)	Distance covered at a speed of >7 $m \cdot s^{-1}$
	Relative SPR ($m \cdot min^{-1}$)	Distance covered per minute at a speed >7 $m \cdot s^{-1}$
Running speed	Peak velocity ($m \cdot s^{-1}$)	Highest running speed attained
PL	PL (AU)	Quantification of external workload: Square root of the summed rates of change in instantaneous velocity in each of the three (forwards, sideways, upwards) vectors, divided by a scaling factor of 100
	Relative PL ($AU \cdot min^{-1}$)	PL accumulated over X number of minutes, divided by X number of minutes
	$PL \cdot m^{-1}$ ($AU \cdot m^{-1}$)	PL accumulated over X number of metres, divided by X number of metres
Acceleration/deceleration distance	High-speed acceleration (m)	Distance covered whilst accelerating at >3 $m \cdot s^{-2}$
	High-speed deceleration (m)	Distance covered whilst decelerating at <−3 $m \cdot s^{-2}$
	Moderate-speed acceleration (m)	Distance covered whilst accelerating at >2 to ≤3 $m \cdot s^{-2}$
	Moderate-speed deceleration (m)	Distance covered whilst decelerating at <−2 to ≥−3 $m \cdot s^{-2}$
Time	Duration (min)	Length of time for any given period

AU: Arbitrary units, HSR: High-speed running, LSR: Low-speed running, MEMS: Microelectromechanical Systems, MSR: Moderate-speed running, PL: PlayerLoad™, SPR: Sprinting, TD: Total distance.

This study profiled the movement responses of soccer substitutes following modification of their match-day pre-pitch-entry routine compared with the practices reported previously in chapter four. Modification to substitutes' match-day preparations reflected the combined effects of; undertaking an amended pre-match warm-up alongside members of the starting team (compared with the isolated low-intensity substitute-only warm-ups adopted previously), and performing an extended (~13 min) staff-led group rewarm-up on the pitch at half-time (compared with ~6 min of individual player-led half-time practices). Moreover, as part of an educational programme at the club, all players were briefed prior to, and regularly throughout, the season regarding the importance of warm-up and rewarm-up activities for enhancing physical performance and potentially reducing the risk of injury.

The modified integrated pre-match warm-up began with ~5 min of jogging and activation drills, before players performed ~5 min of free passing sequences in small groups with an emphasis on movement around one half of the pitch. Approximately 10 min of moderate-paced change of direction drills and dynamic stretching followed, before the warm-up concluded with ~10 min high-tempo acceleration and deceleration activities, close-quarter possession games, and tactical set plays. The modified half-time rewarm-up was also directed by members of sports science staff at the club and lasted for the full duration of half-time (i.e., ~13 min; excluding brief transition periods immediately following the end of the first-half and prior to the second-half commencing). During this period, substitutes completed ~7.5 min of jogging and dynamic activities across the width of the pitch, followed by ~5 min of position-specific balls skills whereby groups of 2-4 players performed free moving and passing sequences. It was emphasised to players during this latter phase that movement around the pitch was an important objective and that they should perform actions specific to their own typical positional role.

Due to competition regulations preventing team officials from leaving their own technical area whilst a match is in play (FA, 2019/2020), the timing, content, and duration of any rewarm-up activities undertaken during the first- or second-halves were self-directed by the individual players without direct input from club staff. That said, as part of the modification to substitute practices in the current study, an educational programme was implemented in an attempt to promote positivity around the role of role of substitutes, highlight the importance of warm-up and rewarm-up activity for potentially improving performance and reducing injury-risk in this group of players, and encourage players to embrace the notion that substitutions represent an opportunity to positively contribute to the overall team success. Specifically, during the pre-season period, all squad members received a 10 min oral presentation from the senior sports scientist and team manager. The manager outlined the fact he wanted substitutes to feel valued and to consider themselves an important part of the team. Indeed, when stating the key values for the season, it was emphasised that players should not think of themselves as individuals, but that everything they do should be geared towards maximising the team as a whole. As part of this change in approach, the terminology of 'finishers' was adopted by team coaching staff in place of the word 'substitutes'. The pre-season presentation also involved the senior sports scientist notifying players of the importance of warm-up and rewarm-up activity in potentially allowing 'finishers' to contribute to the team in a positive way, before outlining the characteristics of an effective warm-up or rewarm-up. These key messages were re-enforced via the permanent display of posters at the team's training facility and frequent informal reminders to new and existing players throughout the season (e.g., by referring them to and reminding them of the posters on display).

7.2.3 Data analyses

Due to the nested nature of data sampled via repeated observations of individuals across multiple matches, linear mixed modelling was used to assess changes in outcome variables over time. In all models, 'match' and 'player' were entered as random effects to allow for natural variation between individual players and matches. Time (i.e., 'epoch' or 'bout') was modelled as a fixed effect, with the first time-period (i.e., 'initial warm-up' for pre-pitch-entry data, and '0-5 min' for post-pitch-entry data) representing the reference category for comparison. Match scoreline at the time of pitch-entry (i.e., 'winning', 'losing', 'drawing') was added to the pre- and post-pitch-entry models as a fixed effect, whilst playing position (i.e., 'midfielders', 'attackers', 'defenders') was also included as a fixed effect in the post-pitch-entry analyses. For the fixed effect of position, midfielders were used as the baseline comparator, whilst situations in which a player entered the pitch with the team being ahead in a match (i.e., 'winning') was specified as the reference category for the scoreline variable (chapter four). Where significant fixed effects were identified, Bonferroni-adjusted pairwise comparisons were performed using least squares means tests to compare outcomes at each level of the fixed effect. Analyses were conducted in R Studio statistical software version 3.6.1 (2019-07-05) using the lme4 package (Bates et al., 2015). Data are presented as mean ± standard deviation unless otherwise indicated, whilst magnitude of change is demonstrated by effect estimates with associated 95% CIs. To allow comment on the potential influence of the modified versus existing practices, non-statistical comparisons were drawn with data from chapter four (i.e., responses observed prior to modification).

7.3 Results

The maximum allocation of three substitutions was used in 10 out of the 13 matches observed. Two further matches involved the use of two substitutes and there was a single instance in which only one replacement was made. On average, the first, second, and third substitutions occurred after 69 ± 11 min, 78 ± 7 min, and 86 ± 4 min of match-play, respectively. The reference team won nine, drew three, and lost one of the 13 matches profiled, scoring 30 and conceding 13 goals in total. In 24 of the 35 substitutions observed, a player entered the pitch when their team was ahead in terms of match scoreline. There were four instances in which a substitute was introduced when the team was losing, and the remaining seven substitutions were made when the match scores were level. The mean scoreline at the time of pitch-entry was 2 ± 1 goals scored and 1 ± 1 goal conceded by the reference team. On nine occasions (26%), the team goal differential (i.e., goals scored minus goals conceded) improved during the time between a substitution being made and the end of the match. The goal differential became less favourable following four of the substitutions (11%) and had not changed by the end of the match (i.e., the same number of goals were scored by each team) in 22 instances (63%).

7.3.1 Pre-pitch-entry responses

Substitutes performed an initial pre-match warm-up of ~30 min in duration, before completing 3 ± 1 bouts·player^{-1}·match^{-1} of rewarm-up activity (range: 1-5 bouts·player^{-1}·match^{-1}) between kick-off and pitch-entry. The mean number of rewarm-ups performed independently by players during the first-half and second-half was 1 ± 1 bouts·player^{-1}·match^{-1} (range: 0-2 bouts·player^{-1}·match^{-1}) and 1 ± 1 bouts·player^{-1}·match^{-1} (range: 0-3 bouts·player^{-1}·match^{-1}), respectively. All participants in this study performed a staff-led group rewarm-up of ~13 min in duration on the pitch during half-time in each match.

Table 7.2 provides movement data relating to the pre-pitch-entry activities undertaken, whilst Table 7.3 indicates effect estimates and 95% CIs for rewarm-up responses when compared with the initial warm-up. To allow broad comparison, previous data from chapter four are reproduced in Table 7.2. Compared with the initial warm-up, each subsequent rewarm-up was shorter while eliciting less absolute TD and lower PL values (all $p \leq 0.001$). Less absolute LSR was also observed during all rewarm-ups compared with the initial warm-up, alongside reductions in distance covered whilst accelerating or decelerating at moderate-speed, and distances covered whilst accelerating at high-speed (all $p \leq 0.05$). Absolute MSR and distance covered while decelerating at high-speed, were lower than the initial warm-up during all rewarm-ups except for the fourth rewarm-up performed independently (i.e., individual player-led) whilst a match was underway (all $p \leq 0.05$). Expressed relative to bout duration (i.e., m·min^{-1}), and excluding the single instance of a fourth self-directed rewarm-up, substitutes covered more relative TD and LSR during all rewarm-ups (all $p \leq 0.001$) compared with the initial warm-up. Higher relative PL values were observed during all rewarm-ups except for the fourth independent rewarm-up and the staff-led half-time rewarm-up (all $p \leq 0.05$). Compared with the initial warm-up, absolute HSR and SPR distances values were higher during half-time (all $p \leq 0.05$). The initial warm-up also elicited less relative HSR compared with substitutes' second player-led rewarm-up, and less relative SPR than the half-time rewarm-up (all $p \leq 0.05$). Peak velocity remained below initial warm-up values during all rewarm-ups except for the fourth player-led rewarm-up (all $p \leq 0.001$), whereas the peak velocity attained during the half-time rewarm-up was similar to the initial warm-up.

Table 7.2: Descriptive statistics for physical performance variables for substitutes prior to pitch-entry, including data recorded from the same soccer club during the preceding season (chapter four)

Variable		**Initial warm-up**		**RWU1**		**Half-time rewarm-up**		**RWU2**		**RWU3**		**RWU4**	
		(*n=32*)	***Chapter four data, (n=35)***	**(*n=25 first-half, n=6 second-half*)**	***Chapter four data, (n=34 first-half, n=1 second-half)***	**(*n=35*)**	***Chapter four data, (n=27)***	**(*n=15 first-half, n=8 second-half*)**	***Chapter four data, (n=6 first-half, n=22 second-half)***	**(*n=3 second-half*)**	***Chapter four data, (n=1 first-half, n=7 second-half)***	**(*n=1 second-half*)**	***Chapter four data, (n=2 second-half)***
Duration	(min)	30.15 ± 4.40	*26.25 ± 2.43*	4.99 ± 1.87 ^{b}	*6.51 ± 2.39* ^{b}	12.99 ± 2.37 ^{b}	*5.51 ± 2.31* ^{b}	5.08 ± 4.07 ^{b}	*5.96 ± 3.74* ^{b}	2.94 ± 1.72 ^{b}	*3.14 ± 1.68* ^{b}	10.93 ± 0.00 ^{b}	*3.23 ± 0.39* ^{b}
TD	Absolute (m)	1498 ± 168	*992 ± 218*	337 ± 96 ^{b}	*386 ± 143* ^{b}	800 ± 183 ^{b}	*423 ± 170* ^{b}	454 ± 315 ^{b}	*428 ± 286* ^{b}	233 ± 136 ^{b}	*229 ± 93* ^{b}	495 ± 0 ^{b}	*321 ± 44* ^{b}
	Relative ($m \cdot min^{-1}$)	50.3 ± 7.3	*37.9 ± 7.8*	71.8 ± 19.4 ^{b}	*64.3 ± 23.5* ^{b}	62.2 ± 11.6 ^{a}	*83.0 ± 30.3* ^{b}	107.5 ± 34.8 ^{b}	*80.2 ± 28.9* ^{b}	92.0 ± 41.8 ^{b}	*89.3 ± 40.2* ^{b}	45.3 ± 0	*99.5 ± 1.6* ^{b}
LSR	Absolute (m)	1418 ± 158	*963 ± 210*	315 ± 98 ^{b}	*369 ± 131* ^{b}	748 ± 161 ^{b}	*394 ± 159* ^{b}	412 ± 307 ^{b}	*378 ± 259* ^{b}	216 ± 135 ^{b}	*198 ± 100* ^{b}	434 ± 0 ^{b}	*280 ± 45* ^{b}
	Relative ($m \cdot min^{-1}$)	47.7 ± 6.9	*36.8 ± 7.5*	66.5 ± 16.9 ^{b}	*61.1 ± 19.8* ^{b}	58.1 ± 10.1 ^{a}	*76.1 ± 22.9* ^{b}	93.3 ± 24.9 ^{b}	*70.7 ± 25.6* ^{b}	81.7 ± 37.7 ^{b}	*72.3 ± 28.1* ^{b}	39.7 ± 0	*86.5 ± 3.4* ^{b}
MSR	Absolute (m)	74 ± 31	*15 ± 31*	19 ± 25 ^{b}	*15 ± 22*	37 ± 29 ^{b}	*18 ± 28*	40 ± 32 ^{b}	*42 ± 39* ^{b}	17 ± 9 ^{b}	*27 ± 26*	61 ± 0	*37 ± 6*
	Relative ($m \cdot min^{-1}$)	2.5 ± 1.1	*0.6 ± 1.2*	4.8 ± 7.4	*2.9 ± 5.5*	2.9 ± 2.1	*4.5 ± 8.7* ^{a}	12.6 ± 13.7 ^{b}	*8.6 ± 9.3* ^{b}	10.3 ± 12.1	*14.7 ± 18.0* ^{b}	5.6 ± 0	*11.3 ± 0.6* ^{b}
HSR	Absolute (m)	5 ± 8	*1 ± 4*	2 ± 6	*2 ± 6*	15 ± 20 ^{b}	*3 ± 6*	2 ± 6	*6 ± 10* ^{a}	0 ± 0	*3 ± 5*	0 ± 0	*5 ± 7*
	Relative ($m \cdot min^{-1}$)	0.1 ± 0.2	*0.0 ± 0.1*	0.6 ± 1.4	*0.3 ± 1.0*	1.1 ± 1.4	*0.5 ± 1.3*	1.4 ± 1.4 ^{a}	*0.8 ± 1.2* ^{a}	0 ± 0	*1.9 ± 3.9* ^{b}	0 ± 0	*1.7 ± 2.4* ^{a}
SPR	Absolute (m)	0 ± 0	*0 ± 0*	0 ± 0	*0 ± 0*	1 ± 2 ^{a}	*0 ± 0*	0 ± 0	*0 ± 0*	0 ± 0	*0 ± 0*	0 ± 0	*0 ± 0*
	Relative ($m \cdot min^{-1}$)	0.0 ± 0.0	*0.0 ± 0.0*	0.0 ± 0.0	*0.0 ± 0.0*	0.1 ± 0.2 ^{a}	*0.0 ± 0.0*	0.0 ± 0.0	*0.0 ± 0.0*	0.0 ± 0.0	*0.0 ± 0.0*	0.0 ± 0.0	*0.0 ± 0.0*
Peak Velocity	($m \cdot s^{-1}$)	5.4 ± 0.4	*n/a*	4.6 ± 1.0 ^{b}	*n/a*	5.7 ± 0.9	*n/a*	4.9 ± 0.7 ^{a}	*n/a*	4.5 ± 0.1 ^{a}	*n/a*	4.8 ± 0	*n/a*
PL	Absolute (AU)	168.04 ± 20.91	*127.64 ± 24.10*	33.99 ± 9.37 ^{b}	*38.54 ± 12.56* ^{b}	84.27 ± 19.73 ^{b}	*40.19 ± 19.29* ^{b}	39.93 ± 22.72 ^{b}	*42.50 ± 27.31* ^{b}	20.02 ± 13.49 ^{b}	*20.54 ± 9.26* ^{b}	55.03 ± 0.00 ^{b}	*30.27 ± 1.87* ^{b}
	Relative ($AU \cdot min^{-1}$)	5.64 ± 0.86	*4.88 ± 0.90*	7.27 ± 1.96 ^{a}	*6.58 ± 2.79* ^{b}	6.55 ± 1.34	*7.54 ± 2.05* ^{b}	9.97 ± 3.58 ^{b}	*7.90 ± 2.77* ^{b}	9.01 ± 4.02 ^{a}	*7.82 ± 3.72* ^{b}	5.04 ± 0.00	*9.42 ± 0.55* ^{b}
ACCdist	High (m)	11 ± 4	*2 ± 2*	1 ± 1 ^{b}	*1 ± 1* ^{a}	3 ± 3 ^{b}	*2 ± 3*	2 ± 3 ^{b}	*1 ± 4*	1 ± 2 ^{b}	*1 ± 1*	2 ± 0 ^{a}	*1 ± 0*
	Moderate (m)	23 ± 5	*11 ± 6*	4 ± 4 ^{b}	*3 ± 3* ^{b}	9 ± 5 ^{b}	*5 ± 4*	6 ± 5 ^{b}	*6 ± 7*	3 ± 2 ^{b}	*2 ± 1*	9 ± 0 ^{a}	*7 ± 1*
DECdist	High (m)	3 ± 2	*0 ± 1*	0 ± 1 ^{b}	*0 ± 1*	1 ± 1 ^{b}	*0 ± 1*	1 ± 2 ^{b}	*1 ± 1* ^{b}	0 ± 0 ^{b}	*0 ± 0*	1 ± 0	*0 ± 0*

	Moderate (m)	10 ± 3	*3 ± 2*	2 ± 2 [b]	*1 ± 2*	3 ± 3 [b]	*2 ± 2*	3 ± 3 [b]	*4 ± 4* [b]	0 ± 1 [b]	*1 ± 1*	2 ± 0 [a]	*2 ± 1*

$_{ACC}$dist: Acceleration distance, AU: Arbitrary units, $_{DEC}$dist: Deceleration distance, HSR: High-speed running, LSR: Low-speed running, MSR: Moderate-speed running, n/a: Not applicable, PL: PlayerLoad™, RWU: Self-directed rewarm-up, SPR: Sprinting, TD: Total distance, [a] different from initial warm-up at p ≤0.05 level (within-study comparison), [b] different from initial warm-up at p ≤0.001 level (within-study comparison). Descriptive statistics from chapter four are provided for illustrative purposes. Data are presented as mean ± standard deviation.

Table 7.3: Magnitude of change relative to initial warm-up values in physical performance variables for substitutes prior to pitch-entry

Variable		**Initial warm-up (*n=32*)**	**RWU1 (*n=25 first-half, n=6 second-half*)**	**Half-time rewarm-up (*n=35*)**	**RWU2 (*n=15 first-half, n=8 second-half*)**	**RWU3 (*n=3 second-half*)**	**RWU4 (*n=1 second-half*)**	**Scoreline effects**
Duration	(min)	REF	-25.16 (-26.74 to -23.58) [b]	-17.16 (-18.70 to 16.62) [b]	-25.10 (-26.82 to -23.38) [b]	-27.13 (-30.95 to -23.32) [b]	-19.15 (-25.54 to -12.75) [b]	None
TD	Absolute (m)	REF	-1160.90 (-1251.02 to -1070.74) [b]	-695.89 (-783.34 to -608.66) [b]	-1044.51 (-1143.02 to -945.83) [b]	-1256.74 (-1479.38 to -1034.67) [b]	-990.11 (-1365.96 to-615.07) [b]	None
	Relative (m·min^{-1})	REF	21.62 (12.06 to 31.12) [b]	11.95 (2.68 to 21.16) [a]	57.05 (46.66 to 67.42) [b]	42.28 (19.01 to 65.49) [b]	-2.51 (-42.38 to 37.01)	None
LSR	Absolute (m)	REF	-1102.74 (-1188.95 to -1016.53) [b]	-669.50 (-753.31 to -586.05) [b]	-1005.28 (-1099.29 to -910.97) [b]	-1210.65 (-1423.33 to -998.99) [b]	-990.01 (-1346.97 to -634.01) [b]	None
	Relative (m·min^{-1})	REF	18.95 (11.44 to 26.39) [b]	10.65 (3.36 to 17.85) [a]	45.38 (37.23 to 53.50) [b]	34.43 (16.21 to 52.65) [b]	-5.45 (-36.72 to 25.53)	None
MSR	Absolute (m)	REF	-55.19 (-68.17 to -42.21) [b]	-38.04 (-50.60 to -25.45) [b]	-33.44 (-47.65 to -19.25) [b]	-59.70 (-91.81 to -27.68) [b]	-16.26 (-70.27 to 37.69)	LO<WI*
	Relative (m·min^{-1})	REF	2.30 (-1.94 to 5.79)	0.34 (-3.05 to 3.74)	10.45 (6.66 to 14.25) [b]	7.55 (-0.92 to 16.03)	2.88 (-11.30 to 17.07)	None
HSR	Absolute (m)	REF	-2.35 (-7.64 to 2.97)	9.90 (4.78 to 15.04) [b]	-2.48 (-8.29 to 3.38)	-3.59 (-16.96 to 9.66)	-2.77 (-25.30 to 19.61)	None
	Relative (m·min^{-1})	REF	0.31 (-0.65 to 1.29)	0.82 (-0.11 to 1.77)	1.11 (0.04 to 2.19) [a]	0.16 (-2.30 to 2.61)	0.31 (-3.85 to 4.45)	None
SPR	Absolute (m)	REF	<0.01 (-0.57 to 0.57)	0.65 (0.10 to 1.21) [a]	0.01 (-0.61 to 0.63)	-0.05 (-1.45 to 1.33)	-0.05 (-2.38 to 2.27)	None
	Relative (m·min^{-1})	REF	<0.01 (-0.04 to 0.04)	<0.01 (0.01 to 0.08) [a]	<0.01 (-0.04 to 0.04)	<0.01 (-0.10 to 0.10)	<0.01 (-0.17 to 0.16)	None
Peak Velocity	(m·s^{-1})	REF	-0.81 (-1.15 to -0.46) [b]	0.26 (-0.07 to 0.60)	-0.43 (-0.81 to -0.05) [a]	-0.89 (-1.77 to -0.02) [a]	-0.54 (-2.02 to 0.92)	None
PL	Absolute (AU)	REF	-134.39 (-142.30 to -126.43) [b]	-83.77 (-91.44 to -76.10) [b]	-128.01 (-136.75 to -119.25) [b]	-146.29 (-166.29 to -126.26) [b]	-114.37 (-148.19 to -80.52) [b]	None
	Relative (AU·min^{-1})	REF	1.63 (0.65 to 2.61) [a]	0.91 (-0.04 to 1.86)	4.34 (3.26 to 5.40) [b]	3.40 (1.00 to 5.81) [a]	-0.42 (-4.46 to 3.62)	None
ACCdist	High (m)	REF	-10.57 (-11.89 to -9.25) [b]	-7.69 (-8.97 to -6.41) [b]	-9.30 (-10.75 to -7.87) [b]	-10.65 (-13.87 to -7.44) [b]	-9.06 (-14.54 to -3.61) [a]	None
	Moderate (m)	REF	-19.78 (-21.95 to -17.61) [b]	-14.02 (-16.12 to -11.91) [b]	-17.37 (-19.72 to -15.01) [b]	-21.17 (-26.38 to -15.95) [b]	-14.82 (-23.58 to -5.98) [a]	LO<WI* LO<DR*
DECdist	High (m)	REF	-2.76 (-3.42 to -2.11) [b]	-2.61 (-3.25 to -1.98) [b]	-1.91 (-2.62 to -1.21) [b]	-3.28 (-4.87 to -1.68) [b]	-2.28 (-4.93 to 0.38)	LO<WI*
	Moderate (m)	REF	-7.64 (-8.92 to -6.35) [b]	-6.97 (-8.21 to -5.72) [b]	-6.17 (-7.59 to -4.78) [b]	-9.79 (-12.95 to -6.66) [b]	-8.10 (-13.37 to -2.84) [a]	LO<WI*

$_{ACC}$dist: Acceleration distance, AU: Arbitrary units, DR: Scores level at the time of pitch-entry, $_{DEC}$dist: Deceleration distance, HSR: High-speed running, LO: Team losing at the time of pitch-entry, LSR: Low-speed running, MSR: Moderate-speed running, PL: PlayerLoad™, REF: Reference category, RWU: Self-directed rewarm-up, SPR: Sprinting, TD: Total distance, WI: Team winning at the time of pitch-entry, $\#_{ACC}$: Number of accelerations, $\#_{DEC}$: Number of decelerations, [a] different from initial warm-up at $p \leq 0.05$ level, [b] different from initial warm-up at $p \leq 0.001$ level.,*: Significant effect at $p \leq 0.05$ level. Data are reported as effect estimates (95% CI).

Pairwise contrasts revealed that the new staff-led half-time group rewarm-up was longer in duration (1.98 to 7.94 min) and elicited greater absolute TD (313.79 to 578.42 m), LSR (320.51 to 541.14 m), and PL (30.61 to 62.53 AU) values compared with all player-led rewarm-ups, except for the fourth (all $p \leq 0.05$). In addition, substitutes during the half-time rewarm-up performed more absolute HSR (12.24 to 12.37 m) and attained a higher peak velocity (0.69 to 1.07 $m \cdot s^{-1}$) compared with the first and second independent rewarm-ups, whilst also covering greater high- (2.89, CI: 0.92 to 4.84 m) and moderate-speed (5.76, CI: 2.53 to 8.99 m) acceleration distances than during the first player-led rewarm-up only (all $p \leq 0.05$). Relative values for TD (45.10, CI: 29.63 to 60.59 $m \cdot min^{-1}$), LSR (34.74, CI: 22.61 to 46.86 $m \cdot min^{-1}$), MSR (10.11, CI: 4.45 to 15.78 $m \cdot min^{-1}$), and PL (3.42, CI: 1.83 to 5.02 $AU \cdot min^{-1}$) were higher for players' second unaccompanied rewarm-up compared with the half-time rewarm-up (all $p \leq 0.05$). With regard to comparisons between player-led rewarm-ups performed whilst a match was underway (i.e., not including staff-led activities performed prior to kick-off or at half-time), substitutes covered less absolute MSR (-21.76, CI: -43.40 to -0.14 $m \cdot min^{-1}$), and recorded lower values for relative TD (-35.43, CI: -51.28 to -19.59 $m \cdot min^{-1}$), LSR (-26.43, CI: -38.83 to -14.02 $m \cdot min^{-1}$), MSR (-8.16, CI: -13.96 to -2.35 $m \cdot min^{-1}$), and PL (-2.71, CI: -4.34 to -1.08 $AU \cdot min^{-1}$) during the first independent rewarm-up compared with the second (all $p \leq 0.05$).

Match scoreline at the time of pitch-entry influenced some, but not all, of the outcome variables profiled (Table 7.3). When the reference team was losing at the moment of a player's introduction, substitutes performed less absolute MSR (-21.78, CI: -38.78 to -4.59 m), covered smaller distances whilst decelerating at high- (-0.85, CI: -1.58 to -0.11 m) and moderate-speed (-2.56, CI: -4.07 to -1.07 m), and accumulated less distance whilst accelerating at moderate-speed (-4.23, CI: -6.63 to -1.80 m) per rewarm-up, compared with when the team was winning (all $p \leq 0.05$). On a per rewarm-up basis, substitutes also covered less moderate-speed acceleration distance (-4.28, CI: -7.85 to -0.70 m) when their team was losing at the time of pitch-entry, compared with when the match scores were level ($p = 0.013$).

7.3.2 Post-pitch-entry responses

Once introduced onto the pitch, substitutes played an average of 17.90 ± 10.71 min and covered 2081 ± 1111 m·match^{-1} (Table 7.4). Tables 7.4 and 7.5 demonstrate that compared with the initial five min following a player's introduction, TD and PL were lower for all subsequent match epochs (all $p \leq 0.05$). In addition, MSR was less than 0-5 min values during all epochs except for those reflecting 25-30 min and 35-40 min post-pitch-entry, whereas LSR was lower during all, except the 30-35 min, epochs (all $p \leq 0.05$). High-speed acceleration distance was less for 35-40 min compared with 0-5 min post-pitch-entry, and moderate-speed acceleration distance was lower than 0-5 min between 10-15 min and 15-20 min (all $p \leq 0.05$). Moderate-speed deceleration distance was less than 0-5 min values during the 10-15 min post-pitch-entry epoch only ($p \leq 0.05$). Variables relating to the amount of HSR or SPR performed, peak velocity achieved, PL·m^{-1}, and high-speed deceleration distance were maintained relative to the initial five min following pitch-entry. Moreover, no differences were observed between any other match epochs with respect to any outcome measure profiled.

On a per epoch basis, attackers returned lower values for TD (-16.74, CI: -27.10 to -6.42 m·min^{-1}), LSR (-10.06, CI: -17.23 to -2.90 m·min^{-1}), and MSR (-7.67, CI: -12.73 to -2.61 m·min^{-1}), compared with midfielders (all $p \leq 0.05$). In addition, defenders performed less TD (-16.28, CI: -29.51 to -3.05 m·min^{-1}) and MSR (-9.17, CI: -15.65 to -2.70 m·min^{-1}) per epoch than midfielders, alongside covering less distance (-2.36, CI: -2.52 to -0.01 m) whilst decelerating at moderate-speed (all $p \leq 0.05$). On occasions in which players entered the pitch when the match scores were level, substitutes performed less HSR (-3.39, CI: -6.57 to -0.41 m·min^{-1}) and covered less distance whilst decelerating at moderate-speed (-2.60, CI: -3.29 to 0.00 m), per epoch, compared with when the reference team was winning at the time of introduction (all $p \leq 0.05$). Moreover, when a substitute was introduced in a winning scenario, greater moderate-speed deceleration distance (2.32, CI: 0.01 to 2.68 m) was recorded per post-pitch-entry epoch, compared with when the team was behind in the match ($p = 0.014$).

Table 7.4: Descriptive statistics for physical performance variables for substitutes from timing of pitch-entry to the end of match-play, including data recorded from the same soccer club during the preceding season (chapter four)

Variable		Whole bout	0-5 min		5-10 min		10-15 min		15-20 min		20-25 min		25-30 min		30-35 min		35-40 min	
			(*n=33*)	*Chapter four data, (n=33)*	(*n=28*)	*Chapter four data, (n=32)*	(*n=18*)	*Chapter four data, (n=30)*	(*n=11*)	*Chapter four data, (n=26)*	(*n=9*)	*Chapter four data, (n=19)*	(*n=4*)	*Chapter four data, (n=11)*	(*n=3*)	*Chapter four data, (n=7)*	(*n=2*)	*Chapter four data, (n=4)*
Duration	(min)	17.90 ± 10.71	5.00	*5.00*	5.00	*5.00*	5.00	*5.00*	5.00	*5.00*	5.00	*5.00*	5.00	*5.00*	5.00	*5.00*	5.00	*5.00*
TD	Absolute (m)	2081 ± 1111	646 ± 100	*599 ± 75*	579 ± 92 [b]	*527 ± 66 [b]*	584 ± 80 [a]	*527 ± 81 [b]*	546 ± 63 [b]	*531 ± 59 [b]*	535 ± 97 [b]	*527 ± 60 [b]*	488 ± 106 [a]	*508 ± 72 [b]*	511 ± 32 [a]	*507 ± 110 [b]*	462 ± 25 [a]	*521 ± 56 [a]*
	Relative (m·min^{-1})	121.8 ± 18.2	129.3 ± 20.0	*120.0 ± 14.8*	115.8 ± 18.5 [b]	*105.3 ± 13.3 [b]*	116.7 ± 16.0 [a]	*105.6 ± 16.5 [b]*	109.2 ± 12.6 [b]	*106.0 ± 11.5 [b]*	107.0 ± 19.3 [b]	*105.2 ± 11.8 [b]*	97.5 ± 21.1 [a]	*101.7 ± 14.5 [b]*	102.1 ± 6.2 [a]	*101.4 ± 22.1 [b]*	92.3 ± 4.9 [a]	*104.2 ± 11.2 [a]*
LSR	Absolute (m)	1581 ± 897	474 ± 69	*438 ± 55*	431 ± 44 [b]	*414 ± 49*	442 ± 64 [a]	*414 ± 66*	422 ± 46 [a]	*413 ± 7*	418 ± 48 [a]	*402 ± 48 [a]*	387 ± 97 [a]	*405 ± 51*	415 ± 59	*425 ± 80*	380 ± 71 [a]	*431 ± 58*
	Relative (m·min^{-1})	90.4 ± 9.5	94.9 ± 11.7	*87.6 ± 11.0*	86.2 ± 8.9 [b]	*82.9 ± 9.8*	88.4 ± 12.8 [a]	*82.8 ± 13.2*	84.3 ± 9.1 [a]	*82.5 ± 9.3*	83.6 ± 9.6 [a]	*80.5 ± 9.5 [a]*	77.4 ± 19.5 [a]	*81.1 ± 10.3*	83.0 ± 11.8	*84.9 ± 16.0*	76.0 ± 14.1 [a]	*86.1 ± 11.5*
MSR	Absolute (m)	336 ± 182	116 ± 43	*105 ± 34*	96 ± 44 [a]	*72 ± 27 [b]*	96 ± 43 [a]	*78 ± 38 [b]*	86 ± 50 [a]	*78 ± 29 [b]*	78 ± 42 [a]	*84 ± 36 [a]*	67 ± 30	*68 ± 33 [b]*	51 ± 32 [a]	*58 ± 28 [b]*	59 ± 17	*72 ± 29 [a]*
	Relative (m·min^{-1})	21.0 ± 8.7	23.3 ± 8.5	*20.9 ± 6.8*	19.2 ± 8.8 [a]	*14.3 ± 5.4 [b]*	19.1 ± 8.5 [a]	*15.5 ± 7.5 [b]*	17.2 ± 10.0 [a]	*15.7 ± 5.8 [b]*	15.6 ± 8.4 [a]	*16.8 ± 7.1 [a]*	13.3 ± 6.0	*13.6 ± 6.6 [b]*	10.3 ± 6.4 [a]	*11.5 ± 5.5 [b]*	11.8 ± 3.4	*14.3 ± 5.8 [a]*
HSR	Absolute (m)	133 ± 76	48 ± 36	*51 ± 29*	40 ± 23	*31 ± 22 [b]*	37 ± 21	*28 ± 19 [b]*	31 ± 19	*30 ± 20 [b]*	31 ± 18	*36 ± 22 [a]*	28 ± 13	*24 ± 18 [b]*	27 ± 24	*20 ± 19 [b]*	9 ± 9	*18 ± 14 [b]*
	Relative (m·min^{-1})	8.4 ± 4.8	9.5 ± 7.1	*10.1 ± 5.9*	8.1 ± 4.6	*6.2 ± 4.5 [b]*	7.4 ± 4.1	*5.7 ± 3.9 [b]*	6.2 ± 3.7	*6.1 ± 4.0 [b]*	6.2 ± 3.7	*7.1 ± 4.4 [a]*	5.7 ± 2.7	*4.9 ± 3.6 [b]*	5.5 ± 4.8	*3.9 ± 3.7 [b]*	1.8 ± 2.0	*3.7 ± 2.8 [b]*
SPR	Absolute (m)	32 ± 41	8 ± 13	*6 ± 10*	12 ± 25	*10 ± 15*	9 ± 16	*7 ± 11*	7 ± 20	*10 ± 12*	9 ± 18	*5 ± 10*	6 ± 5	*11 ± 14*	17 ± 29	*5 ± 9*	14 ± 19	*1 ± 2*
	Relative (m·min^{-1})	2.0 ± 3.2	1.6 ± 2.6	*1.3 ± 1.9*	2.4 ± 4.9	*2.1 ± 3.1*	1.8 ± 3.1	*1.4 ± 2.1*	1.4 ± 4.0	*2.0 ± 2.5*	1.7 ± 3.6	*1.1 ± 2.0*	1.2 ± 1.1	*2.2 ± 2.8*	3.4 ± 5.9	*1.1 ± 1.8*	2.7 ± 3.8	*0.2 ± 0.3*
Peak Velocity	(m·s^{-1})	7.3 ± 0.8	6.8 ± 0.8	*n/a*	6.7 ± 0.8	*n/a*	6.9 ± 0.7	*n/a*	6.6 ± 0.8	*n/a*	6.6 ± 1.0	*n/a*	7.1 ± 0.6	*n/a*	7.0 ± 1.6	*n/a*	7.1 ± 2.2	*n/a*
PL	Absolute (AU)	206.28 ± 108.74	65.92 ± 11.07	*61.21 ± 8.43*	59.07 ± 12.97 [b]	*53.94 ± 6.80 [b]*	56.37 ± 10.85 [b]	*52.78 ± 9.65 [b]*	54.49 ± 8.05 [b]	*53.04 ± 8.17 [b]*	51.15 ± 12.61 [b]	*52.90 ± 7.07 [b]*	49.06 ± 9.74 [a]	*49.67 ± 6.28 [b]*	48.97 ± 7.58 [a]	*46.31 ± 10.35 [b]*	43.79 ± 2.47 [a]	*45.76 ± 10.38 [b]*

	Relative (AU·min^{-1})	12.31 ± 2.57	13.18 ± 2.21	*12.25 ± 1.67*	11.61 ± 2.59 [b]	*10.77 ± 1.39* [b]	11.27 ± 2.17 [b]	*10.59 ± 1.94* [b]	10.90 ± 1.61 [b]	*10.59 ± 1.61* [b]	10.23 ± 2.52 [b]	*10.55 ± 1.41* [b]	9.81 ± 1.95 [a]	*9.93 ± 1.25* [b]	9.79 ± 1.52 [a]	*9.26 ± 2.07* [b]	8.76 ± 0.49 [a]	*9.15 ± 2.08* [b]
	Per metre (AU·m^{-1})	0.10 ± 0.01	0.10 ± 0.01	*n/a*	0.10 ± 0.01	*n/a*	0.10 ± 0.01	*n/a*	0.10 ± 0.01	*n/a*	0.10 ± 0.01	*n/a*	0.10 ± 0.01	*n/a*	0.10 ± 0.01	*n/a*	0.10 ± 0.00	*n/a*
$_{ACC}$dist	High (m)	19 ± 13	6 ± 3	*8 ± 3*	5 ± 3	*6 ± 3* [a]	4 ± 2	*5 ± 3* [b]	4 ± 4	*5 ± 3* [b]	4 ± 3	*7 ± 4*	5 ± 5	*6 ± 2*	5 ± 7	*3 ± 3* [b]	1 ± 1 [a]	*6 ± 4*
	Moderate (m)	50 ± 28	16 ± 4	*16 ± 5*	14 ± 4	*13 ± 5* [b]	13 ± 4 [a]	*13 ± 4* [b]	12 ± 5 [a]	*13 ± 4* [b]	13 ± 4	*14 ± 5* [a]	13 ± 1	*13 ± 4* [a]	11 ± 3	*10 ± 2* [b]	10 ± 11	*11 ± 2* [a]
$_{DEC}$dist	High (m)	18 ± 12	5 ± 3	*5 ± 2*	5 ± 2	*4 ± 3* [a]	4 ± 3	*3 ± 1* [a]	4 ± 3	*4 ± 3*	4 ± 3	*5 ± 3*	2 ± 1	*4 ± 1* [a]	4 ± 7	*3 ± 2* [a]	5 ± 6	*3 ± 3* [a]
	Moderate (m)	32 ± 17	10 ± 3	*10 ± 4*	9 ± 3	*8 ± 5*	8 ± 3 [a]	*8 ± 3* [a]	8 ± 5	*8 ± 3*	8 ± 6	*8 ± 4*	7 ± 2	*8 ± 3*	7 ± 2	*7 ± 4*	5 ± 5	*7 ± 4*

$_{ACC}$dist: Acceleration distance, AU: Arbitrary units, $_{DEC}$dist: Deceleration distance, HSR: High-speed running, LSR: Low-speed running, MSR: Moderate-speed running, n/a: Not applicable, PL: PlayerLoad™, SPR: Sprinting, TD: Total distance, [a] different from 0-5 min at p ≤0.05 level (within-study comparison), [b] different from 0-5 min at p ≤0.001 level (within-study comparison). Descriptive statistics from chapter four are provided for illustrative purposes. Data are presented as mean ± standard deviation.

Table 7.5: Magnitude of change from 0-5 min values in physical performance variables for substitutes from timing of pitch-entry to the end of match-play

Variable		0-5 min (*n=33*)	5-10 min (*n=28*)	10-15 min (*n=18*)	15-20 min (*n=11*)	20-25 min (*n=9*)	25-30 min (*n=4*)	30-35 min (*n=3*)	35-40 min (*n=2*)	Position effects	Scoreline effects
TD	Absolute (m)	REF	-70.02 (-105.59 to -34.62) [b]	-65.75 (-107.18 to -24.53) [a]	-95.14 (-145.06 to -44.98) [b]	-98.04 (-152.72 to -43.58) [b]	-119.97 (-196.38 to -44.05) [a]	-92.44 (-180.19 to -5.52) [a]	-110.39 (-216.27 to -5.68) [a]	ATT<MID** DEF<MID*	None
	Relative ($m\cdot min^{-1}$)	REF	-14.01 (-21.12 to -6.93) [b]	-13.15 (-21.44 to -4.91) [a]	-19.03 (-29.01 to -9.00) [b]	-19.61 (-30.54 to -8.72) [b]	-23.97 (-39.24 to -8.79) [a]	-18.49 (-36.03 to -1.11) [a]	-22.08 (-43.25 to -1.14) [a]	ATT<MID** DEF<MID*	None
LSR	Absolute (m)	REF	-45.24 (-69.02 to -21.62) [b]	-37.80 (-65.38 to -10.11) [a]	-53.06 (-86.51 to -19.56) [a]	-55.65 (-92.21 to -19.20) [a]	-74.30 (-125.27 to -23.41) [a]	-54.89 (-113.11 to 3.46)	-70.40 (-140.82 to -0.33) [a]	ATT<MID*	None
	Relative ($m\cdot min^{-1}$)	REF	-9.05 (-13.80 to -4.32) [b]	-7.56 (-13.08 to -2.02) [a]	-10.61 (-17.30 to -3.91) [a]	-11.13 (-18.44 to -3.84) [a]	-14.86 (-25.05 to -4.68) [a]	-10.97 (-22.62 to 0.69)	-14.07 (-28.16 to -0.06) [a]	ATT<MID*	None
MSR	Absolute (m)	REF	-20.75 (-36.95 to -4.67) [a]	-20.60 (-39.60 to -1.80) [a]	-26.84 (-49.67 to -4.03) [a]	-32.00 (-56.90 to -7.14) [a]	-32.79 (-67.58 to 1.91)	-42.02 (-82.03 to -2.38) [a]	-19.68 (-67.58 to 28.05)	ATT<MID** DEF<MID*	None
	Relative ($m\cdot min^{-1}$)	REF	-4.15 (-7.39 to -0.93) [a]	-4.12 (-7.92 to -0.36) [a]	-5.37 (-9.93 to -0.80) [a]	-6.40 (-11.38 to -1.43) [a]	-6.56 (-13.52 to 0.38)	-8.40 (-16.41 to -0.48) [a]	-3.93 (-13.54 to 5.61)	ATT<MID** DEF<MID*	None
HSR	Absolute (m)	REF	-7.17 (-18.67 to 4.38)	-8.62 (-22.17 to 4.72)	-15.78 (-32.97 to 0.64)	-13.36 (-31.05 to 4.41)	12.77 (-37.55 to 11.89)	-7.80 (-36.32 to 20.40)	27.54 (-61.68 to 6.53)	None	DR<WI*
	Relative ($m\cdot min^{-1}$)	REF	-1.43 (-3.73 to 0.88)	-1.73 (-4.43 to 0.94)	-3.16 (-6.39 to 0.12)	-2.67 (-6.21 to 0.89)	-2.55 (-7.51 to 2.78)	-1.56 (-7.26 to 4.08)	-5.51 (-12.34 to 1.31)	None	DR<WI*
SPR	Absolute (m)	REF	2.71 (-4.86 to 10.52)	1.56 (-7.36 to 10.51)	0.26 (-10.55 to 11.12)	3.47 (-8.33 to 15.24)	1.19 (-15.37 to 17.61)	14.17 (-4.71 to 32.89)	9.02 (-13.60 to 31.58)	None	None
	Relative ($m\cdot min^{-1}$)	REF	0.54 (-0.97 to 2.10)	0.31 (-1.47 to 2.10)	0.05 (-2.11 to 2.22)	0.69 (-1.67 to 3.04)	0.23 (-3.07 to 3.52)	2.83 (-0.94 to 6.58)	1.80 (-2.72 to 6.32)	None	None
Peak Velocity	($m\cdot s^{-1}$)	REF	-0.07 (-0.46 to 0.34)	0.13(-0.32 to 0.59)	-0.19 (-0.73 to 0.38)	-0.16 (-0.76 to 0.45)	0.31 (-0.56 to 1.11)	0.38 (-0.62 to 1.30)	0.30 (-0.86 to 1.46)	None	None
PL	Absolute (AU)	REF	-7.23 (-11.21 to -3.12) [b]	-8.69 (-13.38 to -4.08) [b]	-10.47 (-16.10 to -4.87) [b]	-12.31 (-18.45 to -6.23) [b]	-13.91 (-22.47 to – 5.40) [a]	-12.71 (-22.47 to -3.03) [a]	13.61 (-25.34 to -1.98 [a]	None	None

	Relative (AU·min^{-1})	REF	-1.44 (-2.24 to -0.66) [b]	-1.74 (-2.68 to -0.82) [b]	-2.09 (-3.22 to -0.97) [b]	-2.46 (-3.69 to -1.25) [b]	-2.78 (-4.49 to -1.08) [a]	-2.54 (-4.49 to -0.61) [a]	-2.72 (-5.07 to -0.40) [a]	None	None
	Per metre (AU·m^{-1})	REF	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	None	None
$_{ACC}$dist	High (m)	REF	-0.24 (-1.66 to 1.18)	-1.36 (-3.00 to 0.28)	-0.86 (-2.83 to 1.12)	-1.31 (-3.46 to 0.85)	-0.95 (-3.94 to 2.04)	-0.01 (-3.44 to 3.44)	-4.62 (-8.80 to -0.46) [a]	None	None
	Moderate (m)	REF	-2.09 (-4.10 to 0.08)	-3.49 (-5.82 to -1.18) [a]	-3.35 (-6.17 to -0.58) [a]	-2.60 (-5.70 to 0.41)	-2.69 (-6.92 to 1.54)	-3.82 (-8.79 to 0.96)	-4.15 (-10.07 to 1.69)	None	None
$_{DEC}$dist	High (m)	REF	0.34 (-0.91 to 1.59)	-0.75 (-2.20 to 0.70)	-1.24 (-3.00 to 0.56)	-0.92 (-2.83 to 1.04)	-2.48 (-5.15 to 0.22)	0.21 (-2.84 to 2.28)	0.31 (-3.36 to 4.04)	None	None
	Moderate (m)	REF	-0.85 (-2.40 to 0.71)	-2.04 (-3.85 to -0.25) [a]	-1.48 (-3.64 to 0.71)	-0.85 (-3.22 to 1.54)	-1.57 (-4.84 to 1.70)	-1.35 (-5.17 to 2.42)	-1.07 (-5.66 to 3.48)	DEF<MID*	LO<WI* DR<WI*

$_{ACC}$dist: Acceleration distance, ATT: Attackers, AU: Arbitrary units, DR: Scores level at the time of pitch-entry, $_{DEC}$dist: Deceleration distance, DEF: Defenders, HSR: High-speed running, LO: Team losing at the time of pitch-entry, LSR: Low-speed running, MID: Midfielders, MSR: Moderate-speed running, PL: PlayerLoad™, REF: Reference category, SPR: Sprinting, TD: Total distance, WI: Team winning at the time of pitch-entry, [a] different from 0-5 min at $p \leq 0.05$ level, [b] different from 0-5 min at $p \leq 0.001$ level,*: Significant effect at $p \leq 0.05$ level, **: Significant effect at $p \leq 0.001$ level. Data are reported as effect estimates (95% CI).

7.4 Discussion

Considering both the pre- and post-pitch-entry periods, this study profiled the movement responses of substitute players from an English professional soccer club following the implementation of a modified pre-pitch-entry protocol. Substitutes performed 3 ± 1 rewarm-up bouts·player^{-1}·match^{-1} between kick-off and pitch-entry, with all rewarm-ups being shorter and eliciting less absolute TD compared with the whole-team pre-match warm-up. Significant increases in relative values for TD, LSR, MSR, and PL were observed between the first and second bouts of player-led rewarm-up activity performed whilst the match was underway, whereas the new staff-led half-time group rewarm-up elicited the greatest absolute responses of any pre-pitch-entry rewarm-up. Although match scoreline appeared to influence substitution timing, substitutes were typically introduced for ~18 min of match-play, with the initial five min following pitch-entry eliciting greater TD, MSR, and PL values than all subsequent epochs. In contrast, no such decline was observed for HSR, which remained similar to 0-5 min post-pitch-entry values throughout. Acknowledging that limitations exist when drawing conclusions from interventions implemented within an applied setting rather than tightly controlled laboratory environment, these data may aid applied practitioners when designing specific preparation strategies for substitute soccer players. Specifically, although the influence of other team- and match-specific factors cannot be discounted, this investigation observed potential benefits (i.e., compared with the responses in chapter four) to specific movement-related key performance indicators when substitutes were included within a new whole-team pre-match warm-up, undertook a supervised half-time rewarm-up, and received ongoing player education emphasising the value of substitutes and the importance of rewarm-up activities.

It is widely accepted that warming-up may be beneficial for improving physical performance and potentially reducing the risk of injury during subsequent high-intensity activity (for reviews, please see: (Bishop, 2003; Hammami et al., 2016; McGowan et al., 2015; Silva et al., 2018)), with elevations in T_m and T_{core} likely representing the major mechanistic contributor to the ergogenic effects of an active warm-up undertaken prior to team sport-specific exercise (Bishop, 2003; McGowan et al., 2015; Silva et al., 2018). Indeed, a positive relationship exists between increases in body temperature and improvements in explosive exercise performance, with a 1°C change in T_m having been associated with up to a ~2-10% augmentation of muscular power output (McGowan et al., 2015; Sargeant, 1987). During the previous competitive season, chapter four reported that substitutes from the same soccer club covered ~1 km at ~37.9 $m \cdot min^{-1}$ during their initial pre-match warm-up (chapter four); values that fall substantially below the ~1.5 km at ~50.3 $m \cdot min^{-1}$ observed in the current investigation. Notably, whereas substitutes formerly conducted much of their pre-match warm-up separtely from members of the starting team, this case study indicates comparatively heightened warm-up physical responses (i.e., in absolute terms) when an integrated approach was taken. These findings suggest that if practitioners wish to increase the absolute physical outputs of substitute players during their initial warm-up, and they are not already doing so, including substitutes within the same activities performed by members of the starting team may represent a viable strategy to achieve this objective. Moreover, the ability to complete a routine warm-up has been identified as a valuable coping mechanism to help maintain task-focus amongst international soccer players (Holt & Hogg, 2002). It is therefore plausible that including substitutes within the whole-team pre-match warm-up may have conferred important psychological benefits, irrespective of the physical or physiological responses elicited.

Although beneficial for enhancing muscular responses during high-intensity exercise performed shortly thereafter, the ergogenic effects of a pre-match warm-up do not exist *ad infinitum.* Indeed, progressive decreases in T_{core} and T_m alongside concomitant reductions in muscular performance have been recorded during the ~10-45 min following cessation of an active warm-up (Galazoulas et al., 2012; Silva et al., 2018; West et al., 2013b; Zochowski et al., 2007). Notably, performing short bouts of rewarm-up activity during prolonged (i.e., ≥10-15 min) transition periods may help to attenuate body temperature declines and thus maintain team sports-specific physical performance when compared with passive rest (Lovell et al., 2013; Mohr et al., 2004; Silva et al., 2018). Half-time research has also demonstrated a potential reduction in second-half injury-risk when an active rewarm-up was performed during the time separating consecutive exercise bouts (Bixler & Jones, 1992; Lovell et al., 2013). Although the first substitution in the current study was typically made after ~69 min of match-play, this value does not include the ~15 min half-time period, the likelihood of first-half stoppage time, or the fact that the English Football Association pitch-protection policy requires that the pre-match warm-up "shall end no later than 10 minutes before the kick-off time" (FA, 2019/2020). Accounting for these additional considerations, it is possible that ~69 min of match-play may have equated to upwards of ~100 min following cessation of the initial warm-up. Given such lengthy delays, there exists the clear potential for physiological processes (e.g., restoration of temperature homeostasis) to negatively influence physical performance capacity and possibly increase the risk of injury upon a substitute's introduction into a match (Galazoulas et al., 2012; West et al., 2013b); especially if minimal rewarm-up activity is performed between kick-off and pitch-entry. Indeed, chapter five demonstrated that T_{core} and physical performance capacity were not maintained from post-warm-up values at the time of simulated second-half pitch-entry (i.e., ~90 min following initial warm-up cessation).

As part of the intervention strategy adopted, all participants in the current study undertook a ~13 min staff-led rewarm-up on the pitch at half-time. This differed from previous practices within the same club, whereby substitutes chose the characteristics of any half-time activities (i.e., if any were performed) based upon their own perceived needs (chapter four). Although it is not possible to definitively comment on the relative merits of these diverging strategies, chapter four reported that previous half-time rewarm-ups lasted only ~6 min and elicited ~50% of the TD observed in the current study. Given that T_m and T_{core} increase progressively during the initial ~15-20 min of muscular activity (McGowan et al., 2015; Russell et al., 2015d), it is plausible that when combined with the modified pre-match warm-up and provision of ongoing player education, the longer staff-led half-time rewarm-up may have elicited more pronounced and/or longer lasting physiological responses compared with when players themselves determined the activities performed. Further research will be required to substantiate such suggestions, and to assess the potential implications for physical performance and injury-risk following a player's introduction into a match. However, it is notable that the current investigation observed greater physical responses for substitutes entering the pitch during the second-half, compared with when previous pre-pitch-entry practices (i.e., prior to modification) were followed.

Consistent with values observed in chapter four, substitutes in the current study performed 3 ± 1 rewarm-up bouts·player^{-1}·match^{-1} between the match kick-off and pitch-entry (i.e., including the half-time rewarm-up). Acknowledging that other non-pitch-based and/or static activities may also have been performed, players covered ~62.2 m·min^{-1} to ~107.5 m·min^{-1} during these rewarm-ups, which each lasted for between ~3 min and ~13 min. Notably, because regulations in many soccer competitions require team officials to remain within a designated 'technical area' whilst a match is underway (FA, 2019/2020; FIFA, 2019/20), the precise characteristics of any rewarm-up activities performed in these scenarios must ultimately be determined by the players themselves. Whereas some practitioners may provide substitutes with firm instructions with regard to the expected timing, content, and/or intensity of rewarm-up activity (chapter three), the findings of chapter three suggested that a more 'hands-off' approach (e.g., providing broad guidelines, or allowing players full autonomy to decide upon their own preparations) appears to be more common in professional soccer. All players received ongoing education throughout the season, delivered both orally (i.e., in one-to-one consultations and group presentation formats) and via the use of posters, regarding the importance of warming-up prior to exercise and emphasising the role of substitutes for contributing to overall team performance. Whilst a causal relationship cannot be directly inferred from the data presented, and not considering the single instance of a fourth player-led rewarm-up, relative TD during self-directed rewarm-ups exceeded the values previously reported by up to ~34%, without appearing to negatively affect the post-pitch-entry movement responses observed thereafter.

Substitutes performed <2 m·min^{-1} of HSR and ≤0.1 m·min^{-1} of SPR during each warm-up and/or rewarm-up undertaken prior to pitch-entry. Despite the ongoing focus on player education, such relative values reflect the responses observed prior to pre-pitch-entry modification. Speculatively, in addition to the potential influence of regulations restricting the level of input from team staff (FA, 2019/2020; FIFA, 2019/20), it is possible that a lack of space may have limited the ability to perform high-speed activities during any rewarm-ups undertaken whilst the match is underway (i.e., during the first-half and/or second-half). Whereas substitutes attained lower peak velocities during their independent pitch-side rewarm-ups compared with values recorded during the initial pre-match warm-up, peak velocity was similar between the initial warm-up and the half-time rewarm-up; both of which were led by team staff and conducted on the pitch. Furthermore, 74% of applied practitioners surveyed in chapter three either 'agreed' or 'strongly agreed' that substitutes should be provided with more space within which to perform their pre-pitch-entry preparations. Although the design of modern stadia may often represent a barrier to implementation, many practitioners believed that providing additional space and/or permitting staff to accompany substitutes during their rewarm-up activities, may enable more structured rewarm-ups to be conducted at higher intensities than otherwise; potentially enhancing the efficacy of pre-pitch-entry preparations. Whilst some competitions have sought to make such provisions (FIFA, 2018), it remains unclear whether or not the presence of additional personnel (e.g., team coaching staff), and/or larger rewarm-up spaces (i.e., that may allow the use of equipment, or facilitate more HSR and/or SPR), might positively influence the preparatory strategies adopted by substitutes prior to pitch-entry, and thus possibly translate into improved performance and reduced injury-risk upon a player's introduction into a match.

When playing time was divided into five min epochs from the moment of a substitute's entry onto the pitch, the current study appears to indicate generally greater movement demands (i.e., per epoch) compared with former observations from the same club (chapter four). Indeed, except for returning similar HSR values to those previously reported during the initial five min period following introduction, substitutes in the current investigation substantially exceeded existing findings in relation to TD (~7-10%) and HSR (~23-24%) per epoch for at least the first ~15 min post-pitch-entry, with higher PL values also being recorded. Speculatively, a shorter average playing time for participants in the current study (i.e., the mean timing of introduction for the first, second and third substitutions being ~69 min, ~78 min, and ~86 min, respectively, compared with ~59 min, ~71 min, and ~77 min, respectively) may be somewhat responsible for such data. Team sport players may employ conscious or subconscious self-pacing strategies, based upon the anticipated end-point of exercise, producing relatively greater physical outputs for tasks expected to be shorter in duration (Ferraz et al., 2018; Gabbett et al., 2015; Waldron & Highton, 2014). However, preliminary analysis indicated that substitution timing (i.e., when categorised as 'early', 'medium', or 'late' substitutions according to 15 min match epochs) did not influence any post-pitch-entry physical performance indicator when assessed on a per epoch basis. Substitution timing was not included in the final linear mixed models due to its consistent non-significance and the fact that it did not improve the model fit based upon either 'Akaike information criterion' or 'Bayesian information criterion' assessments. It is also possible that modification to pre-pitch-entry preparations may have contributed to the differences in post-pitch-entry responses between studies. Practitioners in chapter three and the findings of chapter five highlighted substantial uncertainty as to whether substitutes' match-day preparations promote optimal readiness for match-introduction, and this study reports the responses following deliberate modification to substitutes' pre-pitch-entry protocols. Acknowledging the absence of mechanistic data, it is plausible that substitutes in the current investigation were better physically and/or psychologically prepared to produce greater movement responses upon pitch-entry compared with when existing practice was followed. Moreover, substitutes have been reported to experience negative emotions such as a lack of task-focus and reduced motivation (Woods & Thatcher, 2009). It is therefore possible that the modified pre-pitch-entry practices and the increased emphasis on substitutes as an important part of the team meant that players entering the pitch in the current study were more focused and motivated to perform (i.e., feeling valued as 'finishers' as opposed to feeling overlooked in favour of members of the starting team).

For players who start a match on the pitch, the highest relative running demands (e.g., TD, HSR, etc.) are typically recorded during the opening ~10-15 min of play (Akenhead et al., 2013; Bradley et al., 2010; Bradley & Noakes, 2013; Bradley et al., 2009; Carling & Dupont, 2011; Mohr et al., 2003; Russell et al., 2016; Waldron & Highton, 2014). Moreover, the findings of chapter four suggest that such elevated initial physical outputs may be at least partly specific to the time of pitch-entry for any given individual, rather than necessarily the proximity to match kick-off. In the current study, although TD, LSR, MSR, and PL decreased between 0-5 min and 5-10 min post-pitch-entry, substitutes' physical outputs were maintained to a greater extent than previously. For example, whereas chapter four highlighted ~12%, ~31%, and ~39% reductions in TD, MSR, and HSR, respectively, the between-epoch decreases following pre-pitch-entry modification were ~10% for TD and ~17% for MSR, while HSR remained similar to 0-5 min values throughout. Although the match-specific consequences of these responses remain unclear, a substitute's ability to make an immediate and sustained physical impact upon pitch-entry is highly valued amongst practitioners (chapter three) and supports the playing philosophy of the club recruited in the study (empirical evidence).

Substitute midfielders covered an additional ~17 $m \cdot min^{-1}$ and ~16 $m \cdot min^{-1}$ per epoch compared with attackers and defenders, respectively. These findings are consistent with a body of literature indicating that amongst both whole- and partial-match players, midfielders typically cover the greatest relative distances of any playing position (chapter four, Bradley & Noakes, 2013; Carling et al., 2010; Di Salvo et al., 2007). Acknowledging that the use of substitutions can also reflect several other objectives, for coaches/managers seeking to maintain physical output across a team, this phenomenon could suggest a benefit to replacing midfielders during the second-half of match-play and perhaps partly explains why midfielders represent the position most often substituted in professional soccer (Del Corral et al., 2008; Myers, 2012). Due to sample size considerations, it was not possible in this thesis to compare physical responses between sub-categories of each position. However, despite the sample in the current study containing six of the same players and reflecting a broadly similar positional profile to that recruited previously in chapter four (i.e., 18, 11, and six observations from midfielders, attackers and defenders, respectively, compared with the 16, 14, and five observations reported in chapter four for the same positional groups), there exists the potential that differences in the 'style' of players sampled may have influenced the physical responses observed following pitch-entry. Future research investigating substitutes' positional responses in greater detail may provide valuable information for informing and assessing substitution strategies.

Although substitutes typically spent ~18 min on the pitch, the average for players introduced when the team was ahead in the match was just ~14 min. In contrast, ~32 min and ~23 min were played by individuals who entered the pitch when the reference team was either losing or drawing, respectively. Alongside highlighting the need for players entering the pitch to be appropriately conditioned to provide a sustained impact for upwards of ~30 min of match-play, such observations confirm that scoreline may represent an important factor influencing the timing of substitutions (Myers, 2012); apparently indicating a greater willingness for teams to make personnel changes when they are behind in a match. Indeed, as the ultimate objective of soccer is to outscore the opposition, it seems likely that coaches and managers typically value the role of substitutes more highly at times when their team is losing compared with when the players already on the pitch have managed to produce a lead. Match scoreline may also influence a player's running demands, and this study reflects chapter four observations that substitutes covered the greatest TD and/or HSR per epoch when the reference team was winning at the time of pitch-entry. Compared with chapter four in which the team was leading at the time of the ~37% of substitutions made, the fact that ~69% of substitutions in the current investigation occurred in winning scenarios could at least partly explain the between-study differences in substitution timing and may also have contributed to elevating the physical outputs of players entering the pitch.

Between the timing of a player's pitch-entry and the end of the match, the team goal differential (i.e., the number of goals scored minus the number of goals conceded in the match) improved following 26% of the substitutions observed. As this percentage is identical to that reported in chapter four, it seems that modification of pre-pitch-entry practices was not detrimental to this crucial marker of team performance. Moreover, such values occurred in the current study with substitutes having been introduced on average ~7-10 min later in the match. Notably, whereas chapter four reported a worsening match scoreline following 20% of substitutions, this figure was almost halved (i.e., 11%) in the present investigation. Acknowledging that such findings may be attributable to a range of contextual factors (e.g., the relative quality of the opposition, team tactics, the performance of players already on the pitch, etc.), these patterns indicate more favourable overall team responses following the introduction of substitutes undertaking the modified practices presented here, when compared with the outcomes previously reported.

The findings of this study highlight several avenues for future investigation. Whilst analysing a player's movement profiles provides valuable insight into the preparatory practices undertaken, controlled research determining the physiological (e.g., body temperature etc.) and performance (i.e., physical, technical, cognitive, etc.) responses to different pre-pitch-entry modifications would allow greater comment on the efficacy of such strategies for maximising a substitute's readiness for match-introduction. Moreover, investigation into the effects of certain regulatory conditions (e.g., pitch-protection policies, restrictions on staff involvement with rewarm-up activity, etc.) may help policy makers to reach fully informed decisions when defining the terms of competition legislation. Nevertheless, this case study observed greater HSR and peak velocity values during the staff-led half-time group rewarm-up compared with those recorded during numerous player-directed pitch-side rewarm-ups. Such responses may suggest that the presence of team staff during rewarm-ups and/or the availability of enough space within which to perform HSR could represent important factors influencing the physical preparations of awaiting substitutes.

Practitioners value the introduction of 'fresh legs' as a means of providing a physical impact upon a match (chapter three), and the amount of HSR performed is often considered to be an important indicator of physical performance in soccer (Bangsbo et al., 1991; Mohr et al., 2003). However, whilst useful for quantifying the locomotor demands experienced on match-day, MEMS data in isolation cannot determine whether a period of heightened activity in fact represents a useful contribution to team success. Although it is notable that favourable match scoreline responses were observed compared with those previously reported, future research into the specific tactical impact of substitutions would be beneficial for informing team strategy. Indeed, taking an integrated approach in combining physical, technical, and tactical indices of match performance, may allow more holistic assessment of a substitute's value to their team (Bradley & Ade, 2018).

7.5 Conclusion

On match-day, substitutes from a professional soccer club performed a pre-match warm-up followed by ~3 bouts·player^{-1}·match^{-1} of rewarm-up activity between kick-off and pitch-entry. After involvement in the substitute profiling research reported in chapter four, a club-wide modification of substitutes' pre-pitch-entry practices was implemented in an effort to improve the preparations of this unique playing population. Modification involved the combined intervention of, substitutes; completing an amended pre-match warm-up alongside members of the starting team, performing ~13 min of staff-led activity on the pitch at half-time, and receiving an ongoing educational programme emphasising the value of substitutes and focusing on the importance of (re)warm-up activity as preparation for match-play. Although a direct causal link cannot be established from the data presented in the current study, this investigation observed generally heightened movement responses in substitutes before and after pitch-entry, compared with those previously reported. Furthermore, alongside equivalent rates of improvement in team goal differential (i.e., following 26% of substitutions observed) despite players having been introduced later in the match, the incidence of a worsening scoreline following a substitution was almost halved (i.e., 11% versus 20%) in the present investigation.

Future research into the specific physiological, psychological, and isolated performance test responses of partial-match players will be important to help practitioners seeking to optimise the match-day preparations of this unique playing population. Notably, regulatory and/or practical considerations may represent a barrier to rewarm-up activity; factors that could contribute to the limited amount of HSR and/or SPR performed prior to pitch-entry despite practice modification. Once introduced into a match, substitutes covered ~122 m·min^{-1} during their ~18 min playing bout, with substantial reductions in TD between the first and second five min epochs following pitch-entry. However, values generally remained higher than those reported previously in chapter four and no significant between-epoch decline was observed for HSR. Investigation into the tactical impact of making a replacement would provide further valuable insight, while quantifying post-match fatigue responses may help to inform the design of preparatory and recovery strategies based upon the unique match-day demands faced by substitutes.

Chapter 8.0 General discussion, practical applications, and directions for future research

This thesis took an "assess then address" approach to investigating the performance and physiological responses of substitute soccer players on match-day, with the aim of adding to the limited body of knowledge that existed and ultimately helping to improve match-day and non-match-day preparation strategies for this bespoke category of soccer players. Specifically, the three primary thesis objectives were to: a) examine practitioner perceptions regarding the practices of substitutes whilst identifying potential barriers to the uptake of future research findings, b) quantify the match-day responses of professional soccer substitutes before and after pitch-entry including post-match conditioning sessions, and c) explore the efficacy of modified practices associated with improving match-day preparations for substitutes.

Broadly aligning with the model for applied football research that was proposed by Drust and Green (2013), descriptive studies in chapters three to six aimed to elucidate current perceptions and responses with regard to substitutes' match-day activities ('assess'), before chapter seven addressed observed deficiencies by modifying existing pre-pitch-entry preparatory strategies in a real world scenario ('address'). It is hoped that the findings of this thesis may help players and applied practitioners seeking to optimise the strategies employed in relation to substitutes. As the thesis has highlighted the role of practical and regulatory factors in potentially influencing substitute practices throughout match-day (i.e., alongside non-match-day influences that were not directly assessed), such observations may also allow regulators and policy makers to make more informed decisions when defining the terms of competition legislation. The current chapter sought to synthesise the findings of the foregoing studies in light of the stated objectives, with a view to highlighting their practical relevance and identifying areas for future research. An overview is provided in Figure 8.1.

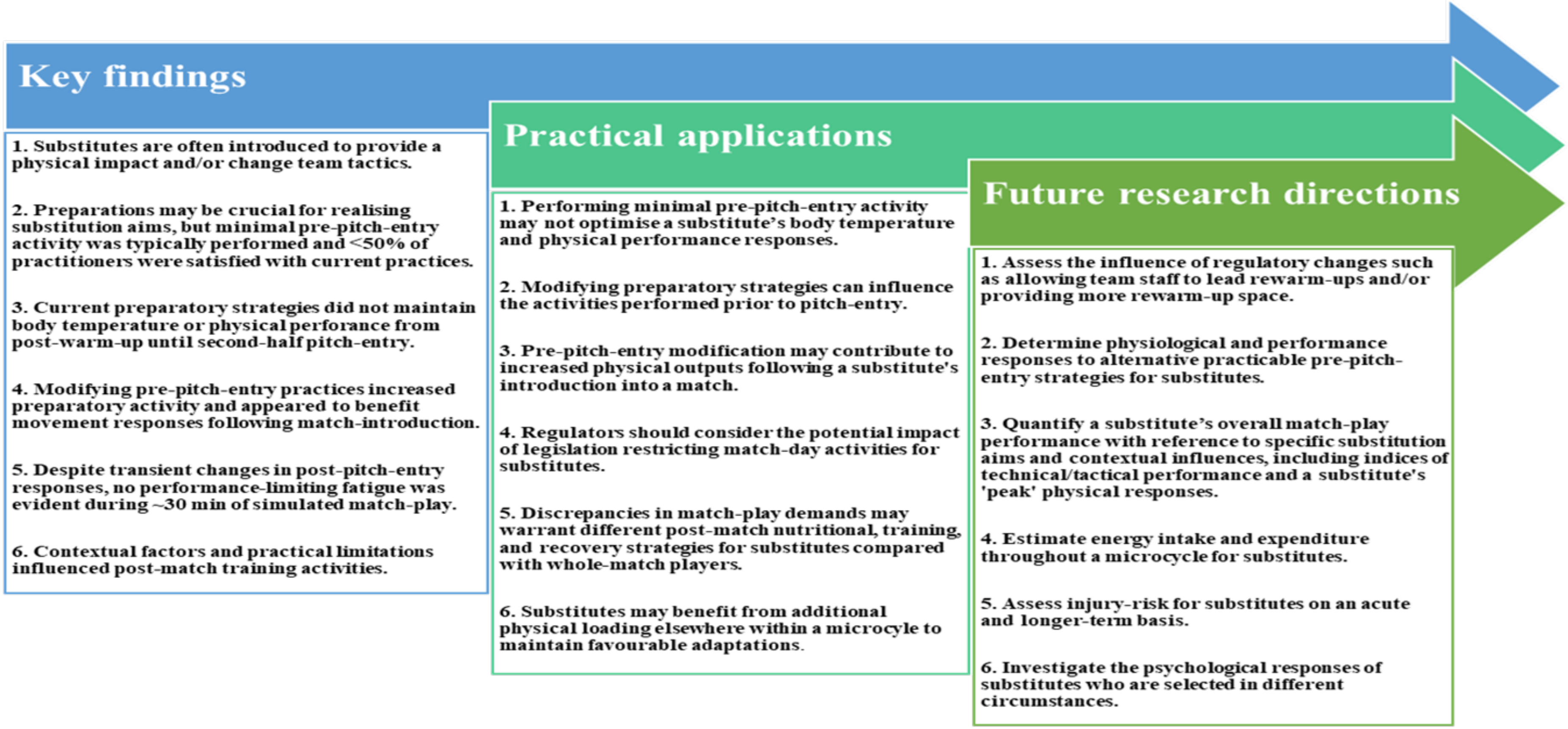

Figure 8.1: Overview of main findings and practical applications

8.1 Realisation of thesis aims

Chapter three highlighted the importance that practitioners attribute to the role of substitutes as a means by which it may be possible to positively influence match outcomes. Although changing team tactics and increasing the pace of play relative to starting players were identified as primary factors typically motivating the use of substitutions, practitioners expressed concerns that such objectives may be realised only if an incoming player enters the match having completed appropriate pre-pitch-entry preparations (Figure 8.1). Less than half of practitioners surveyed were satisfied that substitutes' current pre-pitch-entry practices were sufficient to prepare players for subsequent match performance, and substitute preparatory strategies were identified by 100% of survey respondents as an important area for future research. Whilst practitioners often implement post-match top-up conditioning sessions in an effort to maintain favourable physical loading patterns amongst substitutes, logistical considerations such as scarcity of resources often limit the extent to which other bespoke preparation and recovery strategies are adopted.

When the current match-day activities of professional soccer substitutes were profiled in chapter four, substitutes performed a pre-match warm-up separately from the starting team before typically completing ~3 bouts$\cdot$player$^{-1}\cdot$match^{-1} of ~3-6 min self-directed rewarm-up activity between the match kick-off and their entry onto the pitch (Figure 8.1). The warm-up and rewarm-ups consisted primarily of low-speed movements, with minimal HSR and no SPR performed prior to pitch-entry. For 10 out of 20 physical variables measured after a player's introduction into the match, values reduced from 0-5 min to 5-10 min post-pitch-entry before a plateau thereafter, with substitutes covering more TD and HSR during their first five min of match-play versus all subsequent five min epochs (Figure 8.1).

Replicating current pre-pitch-entry practices (chapter five) produced T_{core} responses that were characterised by decreases from post-warm-up values and a return to pre-warm-up levels well in advance of simulated second-half pitch-entry (i.e., pitch-entry occurring ~90 min after warm-up completion). These changes were accompanied by ~3.9% declines in 15 m sprint performance alongside ~7.2-9.4% reductions in CMJ height and peak power output at the time of simulated pitch-entry compared with when assessed post-warm-up (Figure 8.1). Despite progressive increases in RPE during exercise, evidence of performance-limiting fatigue was absent during ~30 min of simulated soccer match-play (Figure 8.1).

For players named in the match-day squad as substitutes, chapter six assessed the demands of post-match top-up conditioning sessions. Top-ups lasted ~17 min on average, eliciting absolute TD, HSR, and SPR demands of ~1.7 km, ~0.4 km, and ~0.03 km, respectively. Practical and/or regulatory restrictions may limit top-up session prescription, and contextual influences were demonstrated by the fact that playing position, substitution timing, match location, result, time of day, stage of the season, and fixture density, each affected at least four of the dependent variables profiled (Figure 8.1). For example, sessions performed following home fixtures were longer and elicited greater demands relative to away matches, whilst lower absolute physical responses were observed during late-season top-ups compared with early and mid-season sessions.

Finally, chapter seven evaluated the effectiveness of a modified pre-pitch-entry strategy amongst professional substitutes. The modified pre-match warm-up and staff-led half-time rewarm-up elicited generally greater absolute movement demands compared with the substitute-specific warm-up and player-led half-time rewarm-up that had been adopted in chapter four, whilst heightened relative TD was typically observed during player-led pitch-side rewarm-ups (Figure 8.1). After a substitute's introduction into a match, physical outputs were greater for at least the first ~15 min post-pitch-entry compared with the responses observed in chapter four (Figure 8.1). Moreover, post-pitch-entry movement profiles were better maintained throughout a substitute's playing bout relative to chapter four and favourable match scoreline responses were also observed.

8.2 Pre-pitch-entry responses of substitutes

Substantial uncertainty exists with regard to the efficacy of substitutes' pre-pitch-entry match-day preparations (chapter three), and practitioners seeking to optimise preparation strategies may also face challenges during the days prior to match-day. Indeed, the provision of bespoke training and nutritional strategies throughout a training week is often limited by practical considerations such as team selection not being announced until the day prior to a match and/or uncertainty about the length of a player's likely match-play exposure even for individuals whose status as a substitute is known in advance of the upcoming fixture (chapter three). Such difficulties were reflected in chapter three observations that <50% of practitioners reported implementing bespoke non-match-day preparatory strategies for substitutes (i.e., compared with members of the starting team) 'often' or 'all of the time'.

The results of chapter four suggest that substitutes often perform minimal physical activity on match-day prior to being introduced onto the pitch. Acknowledging that practices may vary, empirical observations indicate that many teams appear to implement a broadly similar match-day strategy to that observed in chapter four. Indeed, 60% of practitioners in chapter three deemed the amount of pre-pitch-entry activity performed by substitutes to be so negligible that they 'never' (15%), 'rarely' (15%), or only 'sometimes' (30%), accounted for such responses within assessments of a player's physical loading. As T_m and T_{core} increase relative to the amount of work performed by the muscle (Bishop, 2003; Saltin et al., 1968), and movement intensity appears to represent an important factor influencing the extent to which warm-up and/or rewarm-up activity can benefit subsequent exercise performance (Anderson et al., 2014; Ingham et al., 2013; McGowan et al., 2015; Silva et al., 2018; Zois et al., 2011), the effectiveness of this observed pre-pitch-entry strategy for maximising physical performance and/or minimising a substitute's injury-risk upon match-introduction may be questioned based upon existing physiological theory. In support, although a player's specific responses are likely to be influenced by factors such as substitution timing and ambient temperatures, chapter five indicated that in ~16 °C ambient conditions current pre-pitch-entry practices were insufficient to maintain initial warm-up-induced body temperature elevations and physical performance benefits from post-warm-up until the time of simulated second-half pitch-entry (~85 min after post-warm-up assessments).

The limited amount of activity typically performed by substitutes prior to pitch-entry may partly reflect the existence of practical and regulatory barriers, which policy-makers could review in light of the data presented. A lack of space may restrict the movements that a substitute can safely perform during any rewarm-ups undertaken whilst the match was underway, whilst regulations requiring team staff to remain within a technical area whilst the match is underway (FA, 2019/2020; FIFA, 2019/20) often mean that the content and intensity of any pitch-side rewarm-ups must ultimately be determined by the individual players themselves. This may be an important consideration given that reduced motivation to prepare has been reported amongst players selected as substitutes (Woods & Thatcher, 2009). Many practitioners believed that permitting staff to accompany substitutes during their rewarm-up activities and/or providing additional space within which players can prepare may enable more structured rewarm-ups to be conducted at higher intensities than otherwise; potentially enhancing the efficacy of pre-pitch-entry preparations (chapter three). Whilst some competitions such as the 2018 FIFA World Cup have implemented these suggestions (FIFA, 2018), it remains unclear whether or not the presence of additional personnel and/or larger rewarm-up spaces might positively influence the preparatory strategies that can be adopted by substitutes prior to pitch-entry, and thus possibly translate into improved performance and/or reduced injury-risk upon a player's introduction into a match. This could be a valuable area for future research to allow policy makers to make fully informed decisions regarding the likely effects of certain regulatory provisions when drafting the terms of competition legislation.

The results of chapter five suggest that current pre-pitch-entry practices (i.e., those observed in chapter four) may not optimise a substitute's physical performance capacity upon match-introduction. Acknowledging that physical responses represent only one component of overall soccer performance, team management staff often use substitutions as a means by which to provide a physical impact on a match. Practitioners wishing to maximise a player's physical performance ability upon pitch-entry should therefore assess the acute match-day preparation strategies that are currently adopted by substitutes within their organisation, considering modification if current practices are deemed to be potentially sub-optimal. Notably, modifying pre-pitch-entry practices (i.e., by prioritising the pre-match and half-time periods as opportunities for substitutes to perform staff-led preparatory activity, alongside emphasising an ongoing player education policy and seeking to change player perceptions of substitutes) for professional soccer substitutes in chapter seven produced generally heightened movement responses prior to match-introduction, when compared with the activity profiles recorded prior to modification (chapter four). Whilst it is not possible to draw a firm causal link or to comment on the physiological or psychological responses to this modified strategy, chapter seven also observed greater post-pitch-entry physical outputs and improved maintenance of movement responses during a substitute's on-pitch playing bout relative to the values recorded in chapter four.

The modified pre-pitch-entry strategy implemented in chapter seven was designed having undertaken prior descriptive research (chapters three and four) and reflected a combination of measures that were believed to be practically achievable in the specific context of the reference team. Further investigation is warranted to investigate the physiological, psychological, and performance responses to other modified match-day preparatory strategies that may be more suited to adoption within other organisations. For example, within the constraints that often currently exist in professional soccer (i.e., a lack of space and potential requirement for rewarm-ups to be largely individual player-led) it may at times be possible for substitutes to implement pre-pitch-entry strategies such as passive heat maintenance techniques, the increased use of isometric exercises, or activities targeted at eliciting PAP. Moreover, whilst regulations may often restrict the use of a ball during pitch-side rewarm-ups, performing activities that incorporate the execution of specific technical skills where possible (e.g., on the pitch at half-time) may plausibly contribute towards improved technical performance during subsequent match-play (Zois et al., 2013); a statement supported by practitioners in chapter three. Alongside controlled studies that allow causal links to be established, researchers should consider taking a similar approach to the research design adopted in chapter seven to analyse the effectiveness and feasibility of practice modification within an applied sporting environment (Drust & Green, 2013).

8.3 Post-pitch-entry responses of substitutes

Transient changes in post-pitch-entry physical outputs were observed amongst professional substitutes in chapter four, with ~12.2% and ~38.6% declines in relative values for TD and HSR, respectively, between the first and second five min epochs following a player's introduction into a match. These responses were followed by an apparent plateau (i.e., values remaining within ~1 $m \cdot min^{-1}$ of each other over the next four five min epochs), perhaps suggesting that mechanisms other than progressive or transient physical fatigue are primarily responsible for such findings. In support, chapter five highlighted the apparent absence of substantial performance-limiting fatigue during ~30 min of simulated match-play as sprint times were not reduced throughout and CMJ peak power output increased from pre- to post-exercise. For outfield players who start a match on the pitch, the initial stages of play often elicit the greatest running demands of any match period (Akenhead et al., 2013; Bradley et al., 2010; Bradley & Noakes, 2013; Bradley et al., 2009; Carling & Dupont, 2011; Mohr et al., 2003; Russell et al., 2016). As such responses have been attributed largely to players' desire to register their presence and engage with the opposition (Carling, 2013; Rahnama et al., 2002), similar factors may also have influenced the immediate post-pitch-entry movement profiles of substitutes. Alternatively, or in conjunction, it is possible that the observed match-play responses could reflect a pacing strategy that is at least partly influenced by efforts to 'warm-up' having already entered the pitch. Notably, when T_{core} had not been maintained from post-warm-up until simulated pitch-entry, chapter five showed that ~10 min of simulated match-play was required to restore T_{core} to post-warm-up values.

Throughout their respective playing periods, second-half substitutes typically surpass the relative TD and/or HSR outputs of players who have started a match on the pitch (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010). However, players entering the pitch as substitutes may at times be unable to match (Carling et al., 2010) or exceed (Bradley et al., 2014) the movement responses that the same individuals would typically produce during the first-half of matches in which they start. Moreover, when five min epochs were defined relative to the match kick-off (i.e., as opposed to defining epochs on an individual basis relative to the moment of a substitute's pitch-entry as was the approach in this thesis), Bradley et al. (2014) observed a tendency for TD and HSR covered by substitutes to increase as the second-half progressed. The apparent conflict between these data and the findings of the current thesis (i.e., chapters four and seven observed declines in movement responses following a substitute's pitch-entry) highlight how discrepancies in match analysis techniques can influence the way in which data are reported. That said, acknowledging the potential influence of factors such as changes in team tactics and the amount of time for which the ball is in play (Lago-Peñas et al., 2012; Paul et al., 2015), such observations appear to lend further credence to the suggestion that current pre-pitch-entry practices may not optimise a substitute's physical performance capacity immediately upon introduction into a match.

Apart from similar HSR values during the initial five min period following a substitute's match-introduction, chapter seven observed greater TD (~7-10%) and HSR (~23-24%) outputs per epoch for at least the first ~15 min post-pitch-entry compared with the responses recorded in chapter four. Acknowledging that a firm causal link cannot be drawn from the data presented in this thesis, and that factors such as differences in substitution timing or the relative quality of the opposition may also have contributed to these findings (Ferraz et al., 2018; Gabbett et al., 2015; Waldron & Highton, 2014), it is plausible that practice modification had the desired effect of ensuring that substitutes were better physically and/or psychologically prepared to produce greater movement responses in chapter seven compared with previously in chapter four. In addition, post-pitch-entry physical outputs in chapter seven were maintained to a greater extent than the declines observed in chapter four. Whilst the match consequences of these responses remain unclear, a substitute's ability to make an immediate and sustained physical impact upon pitch-entry is highly valued amongst practitioners (chapter three) and supports the playing philosophy of the club that was recruited in this thesis. Part of the intervention implemented in chapter seven involved an effort to change players' perceptions of substitutes by referring to them as 'finishers' and emphasising how they should view their role as an opportunity to contribute to the success of the team. Whilst it is not clear what effect this may have had on player psychology, it is possible that substitutes in chapter seven entered the pitch with improved focus and greater motivation to make an impact on the match.

The post-pitch-entry analyses conducted in this thesis were appropriate to the aim of assessing transient changes in a substitute's running responses from the moment of a substitute's introduction into a match. However, fixed time-periods (e.g., the discrete five min epochs used in this thesis) lack sampling resolution and thus underestimate the most demanding periods of soccer match-play by up to ~25% compared with rolling averages (Fereday et al., 2019; Varley et al., 2012a). Given that managers often wish for substitutes to make a physical impact on a match (and may thus be interested in maximising the running intensity that a player is able to achieve following pitch-entry), using rolling averages to quantify the 'peak' physical responses of individuals entering the pitch may provide further opportunities for management staff to assess then address substitution strategies in light of this aim (Hills et al., 2020). Notably, whereas a substitute's rolling average-derived peak five min TD and HSR demands appear to exceed the relative responses observed in this thesis during the five min period immediately following pitch-entry (Hills et al., 2020), it has been suggested that professional substitutes may produce lower peak HSR and/or TD values over 60 s to 600 s rolling epochs compared with reports from whole-match players (Delaney et al., 2018; Fereday et al., 2019; Hills et al., 2020). In addition to highlighting the potential role of discrepancies in preparatory strategies between substitutes and players who start a match, such observations may indicate the need to further modify training strategies (e.g., top-up conditioning sessions) to ensure that substitutes receive appropriate exposure to training activities that reflect the typical peak demands (i.e., alongside considering discrepancies in the volume of activity performed) of whole-match players if adequate stimulus is not provided to substitutes during their limited match-play. Moreover, several practitioners in chapter three espoused the opinion that a substitute's ability to provide the desired impact may be conditional upon them being introduced with enough time remaining in the match. Managers making substitutions in the hope of maximising a player's physical outputs may therefore wish to consider the fact that the fact that peak HSR and acceleration responses may generally be lowest for substitutes entering the pitch during the final ~15 min of play (Hills et al., 2020).

It is important to emphasise that this thesis has focussed on physical and physiological responses. Whilst post-pitch-entry movement profiles are often deemed to represent a key performance indicator for substitutes, a player's technical and tactical contributions represent crucial components of overall soccer performance (Bradley et al., 2013; Lago-Penas et al., 2010; Rampinini et al., 2009). It would be valuable for future research to take a more holistic approach to assessing and potentially addressing a substitute's ability to influence a match through technical, tactical, or other means. Moreover, as substitutions are typically made earlier in situations when their team is losing (i.e., in terms of match scoreline) compared with when ahead (Del Corral et al., 2008; Myers, 2012), management staff appear to value the role of substitutes more highly when the team is behind in a match compared with instances in which those players already on the pitch have managed to produce a lead. Future studies should investigate a substitute's match-play performance by incorporating subjective performance ratings from both players and managers, and with reference to the match context and the precise rationale for any given substitution. For instance, whilst practitioners in chapter three were asked to indicate the factors that *most often* motivate the use of substitutions, there may be times when other objectives such as a desire to provide playing time to youth players or those returning from injury, offset the accumulation of fatigue across a squad, use up time in the match in order to protect a lead, or replace a player who has received a caution or sustained an injury, may also be influential.

8.4 Post-match responses of substitutes

Due to a likely reduction in weekly training volume and/or intensity during a competitive season compared with the pre-season period (Jeong et al., 2011; Malone et al., 2015), match-play itself may represent an important stimulus for promoting positive adaptations and maintaining appropriate physical loading patterns that could help to reduce a player's risk of injury (Duhig et al., 2016; Malone et al., 2017a; Malone et al., 2017b; Morgans et al., 2018; Silva et al., 2011). However, their reduced playing time means that substitutes and unused squad members typically experience substantially lower absolute match-play demands compared with whole-match players (Bradley & Noakes, 2013; Carling et al., 2010). If these deficits (i.e., particularly HSR and SPR loads) are not appropriately addressed through training, players who are selected in the match day squad as substitutes could experience a reduced stimulus for adaptation and a potential increase in injury-risk via declines in their ongoing physical loads (Buchheit, 2019; Colby et al., 2018; Malone et al., 2017a; Malone et al., 2017b).

Practitioners in chapter three overwhelmingly believed that there was a need for different post-match treatment of substitutes relative to players who started a match, and 96% of survey respondents reported implementing ‘top-up’ conditioning sessions to account for a substitute’s limited match-play exposure. Partly to ensure adequate recovery time in advance of the next fixture and partly to avoid the perceived negative psychological responses that may result if certain players and staff were asked to attend the training facility on the day after a match when other squad members (i.e., members of the starting team) have been given the day off, these sessions are typically completed on the pitch immediately following the conclusion of a match. However, chapter six reported that top-ups elicited limited absolute HSR and SPR demands whilst also highlighting the existence of temporal and special restrictions with regard to post-match training for substitutes. Acknowledging that physical loads were not assessed over multiple days or weeks, and that there may be instances where a period of reduced loading is desirable as part of a player’s overall periodised programme, the findings of chapter six may suggest the importance of ensuring that players who experience limited match-play demands are appropriately exposed to HSR and/or SPR elsewhere within a microcycle if individual physical loading targets cannot be achieved safely on match-day. However, as such exposures risk eliciting additional fatigue and heightened recovery demands, practitioners should determine the suitability of this approach with reference to factors such as fixture scheduling and the likelihood of an individual’s participation in the upcoming match or series of matches. Moreover, caution must be exercised if goalkeepers are included within top-up sessions to ensure that performing an running-based conditioning drills alongside outfield players does not unduly increase a goalkeeper's injury-risk by imposing novel physical demands that may not form part of their normal position-specific training and match-play activities (White et al., 2020). Future research investigating injury rates amongst substitute players on an acute (e.g., match-day) and ongoing (e.g., throughout a season) basis may help to determine whether diverging pre-pitch-entry preparations and/or discrepancies in physical loading patterns could influence a substitute's risk of injury (e.g., per unit of playing or training time) compared with players who typically start a match. Moreover, investigation into substitutes' internal loading (e.g., via the use of RPE- or HR-based assessments) during match-play and training would likely benefit practitioners when prescribing training and/or recovery strategies based upon ongoing monitoring of individual player responses.

Although no research has yet quantified the magnitude of the post-match fatigue response amongst partial-match soccer players, it seems likely that substitutes typically experience less post-match fatigue than their whole-match counterparts. Indeed, this assumption largely underpins the use of substitutes as part of squad rotation policies intended to offset fatigue accumulation across a squad. Given the differences in match-play demands and likely discrepancies in post-match fatigue responses between substitutes relative to whole-match players, practitioners may need to consider implementing tailored recovery strategies where possible for substitutes on account of their often limited playing time. For example, it may not be necessary or desirable for substitutes to engage in cold water immersion or other specialised recovery techniques that may at times be warranted for players who have completed 90 min of match-play. Moreover, the potential importance of tailored post-match nutrition strategies for substitutes is highlighted by reports in chapter three that uncertainty surrounding team selection and/or the likely extent of their upcoming match-play exposure often requires substitutes to adopt the same high-carbohydrate pre-match fuelling strategies as members of the starting team. Unless a substantial volume of top-up conditioning is performed on match-day (or an increase in body mass represents a specific goal for any given player), achieving desired energy balance may therefore require post-match nutritional strategies that account for likely reductions in energy and/or carbohydrate utilisation for second-half substitutes relative to whole-match players. Research that estimates energy intake and expenditure amongst substitutes may allow for more targeted nutritional guidelines to be developed for this unique playing population.

Finally, although being named as a substitute has been linked with several negative emotions (Gilbourne & Richardson, 2006; Holt & Hogg, 2002; Woods & Thatcher, 2009), it seems likely that a player's psychological responses may differ depending upon the circumstances in which they have been named 'on the bench' (e.g., a player who has been dropped from the starting team compared with a player named as a substitute after an injury layoff, a designated 'impact substitute', a youth player making their first-team debut, etc.). Acknowledging that mental responses may be largely unique to any given individual, if future research is able to establish the existence of diverging psychological states based upon the context and/or frequency of a player's selection as a substitute, it may be possible to provide more individualised treatment in all aspects of preparation.

Chapter 9.0 Conclusion

The introduction of substitutes offers a valuable means by which soccer coaches and managers can attempt to positively influence match outcomes. Survey findings and empirical observations indicated that substitutions are typically made at half-time or later in a match, often in an effort to increase the pace of play and/or change team tactics. As such, acknowledging that substitutions may be made for several different reasons (e.g., to replace underperforming or injured players, to provide playing time to youth players or individuals returning from previous injury, fatigue-management, etc.) practitioners often consider a substitute's post-pitch-entry physical outputs to be key performance indicators. Notably, although practitioners highlighted the importance of appropriate acute pre-pitch-entry preparations for allowing substitutes to positively influence a match (and avoid exerting a *negative* influence), delays of ~75-120 min are common following cessation of the pre-match warm-up before a substitute's pitch-entry. If appropriate preventative measures are not taken, these timeframes could elicit physiological responses such as restoration of temperature homeostasis that negatively influence physical performance capacity and potentially increase a substitute's injury-risk upon introduction into a match. Indeed, professional substitutes were observed to typically perform minimal activity (~3 rewarm-up bouts$\cdot$player$^{-1}\cdot$match^{-1}) between initial warm-up completion and match-introduction, practices which when replicated in controlled conditions failed to maintain body temperature (~1.6% decrease) and physical performance capacity (~3.9-9.4% decrease) from post-warm-up until the time of simulated second-half pitch-entry.

Transient changes in physical outputs were recorded after actual match-introduction, but evidence of performance limiting fatigue was absent during ~30 min of simulated match-play. As such, it must be concluded that factors other than acute physical fatigue underpin the observed match-play responses. Crucially, modifying pre-pitch-entry practices by 1) performing a new pre-match warm-up alongside members of the starting team (as opposed to a separate substitute-only warm-up), 2) participating in a staff-led half-time rewarm-up (as opposed to player-led half-time activities), and 3) receiving ongoing education focusing on the efficacy of (re)warm-up activities, increased the activity completed by substitutes before pitch-entry whilst appearing to benefit post-pitch-entry physical performance responses and potentially match scoreline differentials. The findings of this thesis therefore suggest that players, practitioners and policy-makers should assess current preparatory strategies for substitutes and, where necessary, consider modifying existing practice. Moreover, although substitutes often perform post-match 'top-up' conditioning sessions to help maintain favourable physical loading patterns by avoiding unwanted reductions in a player's ongoing loads, contextual factors influenced session demands and absolute HSR and SPR responses during top-ups remained substantially below typical whole-match values. Given the practical and regulatory barriers existing on match-day, ensuring appropriate exposure to high-speed activities throughout a training week may be important for players who experience a limited volume of competitive match-play over time.

10.0 References

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11.0 Appendices

11.1 Appendix 1: Confirmation of ethical approval (chapter three data collection)

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Date: 6.12.18

Dear Sam,

Re: SSHS-2018-044 – Practitioner perceptions regarding the practices of soccer substitutes.

Thank you for your recent application for ethical approval for the above named project.

After reviewing the application it has been resolved that the research project is granted ethical approval.

I wish you well in your study,

Yours sincerely

Prof Helen Stain
Associate Head for Research and Knowledge Exchange

11.2 Appendix 2: Tactically focused survey questions

Question 1 of 12

Please take the time to answer the following questions in relation to your own practices and perceptions.

Please provide as much detail as possible when accounting for your responses.

To what extent do you agree with the following statement? *"Substitutes are an important factor in determining success in soccer match play"* ✱ *Required*

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Please add details to justify your response: ✱ *Required*

Question 2 of 12

How frequently does the introduction of substitutes substantially influence the outcome of a match? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

Please add details to justify your response: ✱ *Required*

Question 3 of 12

For what reasons are substitute players typically introduced into a match (please select all that apply)? ✱ *Required*

- [ ] Change team tactics e.g., formation
- [ ] Increase the pace of play relative to other players
- [ ] Replace underperforming/tired players
- [ ] Replace injured players
- [ ] Give playing time to youth/returning players
- [ ] Squad rotation/reduce accumulated fatigue across the squad
- [ ] Other (please state)

If other, please specify:

Question 4 of 12

How important do you perceive each of the following reasons to be in inducing the decision to use substitutions? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 7 answer(s).

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Change team tactics (e.g., formation)	☐	☐	☐	☐	☐
Increase the pace of play relative to other players	☐	☐	☐	☐	☐
Replace underperforming players	☐	☐	☐	☐	☐
Replace fatigued players	☐	☐	☐	☐	☐
Replace injured players	☐	☐	☐	☐	☐
Give playing time to youth/returning players	☐	☐	☐	☐	☐
Squad rotation/reduce fatigue across a squad	☐	☐	☐	☐	☐
Other (please state)	☐	☐	☐	☐	☐

If other, please specify:

Question 5 of 12

From the list provided, please identify the two most important and two least important factors in inducing the decision to use substitutions ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select exactly 4 answer(s).

Please don't select more than 2 answer(s) in any single column.

	Most important	Least important
Change team tactics (e.g., formation)	☐	☐
Increase the pace of play relative to other players	☐	☐
Replace underperforming players	☐	☐
Replace fatigued players	☐	☐
Replace injured players	☐	☐
Give playing time to youth/returning players	☐	☐
Squad rotation/reduce fatigue across a squad	☐	☐
Other (please state)	☐	☐

If other, please specify:

Question 6 of 12

To what extent do you agree with the following statement? *"The role of substitutes is an important consideration during pre-match planning (e.g., discussions at meetings in the days leading up to a match)"* ✱ *Required*

- ○ Strongly disagree
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Strongly agree

Please add details to justify your response: ✱ *Required*

Question 7 of 12

a. How frequently is the likely timing of substitutions planned in advance of the match kick-off? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

Please add details to justify your response: ✱ *Required*

b. If planned, how frequently is the likely timing of substitutions communicated to the players themselves in advance of the match kick-off? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time
- N/A

Please add details (e.g., when/how players are informed) to justify your response: ✱ *Required*

c. For players who are not informed prior to kick-off, typically how far in advance of pitch-entry are substitutes informed of when they will be introduced? ✱ *Required*

- 00:00-03:59 min
- 04:00-07:59 min
- 08:00-11:59 min
- 12:00-15:59 min
- 16:00-19:59 min
- 20:00 min or more
- N/A

Please add details to justify your response: ✱ *Required*

Question 8 of 12

a. How frequently is the identity of the players who are likely to be introduced/replaced planned in advance of the match kick-off? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

Please add details to justify your response: ✱ *Required*

b. If planned, how frequently is the identity of the players who are likely to be introduced and/or replaced communicated to the players themselves in advance of the match kick-off? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time
- N/A

Please add details (e.g., when/how players are informed) to justify your response: ✱ *Required*

Question 9 of 12

How important do you consider each of the following contextual factors to be in inducing the decision to make a substitution during a match? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 8 answer(s).

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Scoreline (team winning)	☐	☐	☐	☐	☐
Scoreline (team losing)	☐	☐	☐	☐	☐
Scoreline (scores level)	☐	☐	☐	☐	☐
Time played in a match (e.g., 60 min of play)	☐	☐	☐	☐	☐
Relative quality of opposition (higher standard of opposition)	☐	☐	☐	☐	☐
Relative quality of opposition (lower standard of opposition)	☐	☐	☐	☐	☐
Relative quality of opposition (similar standard of opposition)	☐	☐	☐	☐	☐
Amount of activity performed by a player in the match (e.g., using Global Positioning Systems data)	☐	☐	☐	☐	☐
Other (please state)	☐	☐	☐	☐	☐

If other, please specify:

Question 10 of 12

From the list provided, please identify the two most important and two least important factors in inducing the decision to make a substitution during a match

Please don't select more than 1 answer(s) per row.

Please select exactly 4 answer(s).

Please don't select more than 2 answer(s) in any single column.

	Most important	Least important
Scoreline (team winning)	☐	☐
Scoreline (team losing)	☐	☐
Scoreline (scores level)	☐	☐
Time played in the match (e.g., 60 min of play)	☐	☐
Relative quality of opposition (higher standard of opposition)	☐	☐
Relative quality of opposition (lower standard of opposition)	☐	☐
Relative quality of opposition (similar standard of opposition)	☐	☐
Amount of activity performed by a player in the match (e.g., using Global Positioning Systems data)	☐	☐
Other (please state)	☐	☐

If other, please specify:

Question 11 of 12

a. How many substitutions do you believe should be permitted during a competitive (i.e., non-friendly) 90 min match? ✱ *Required*

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10
- ○ 11+

Please add details to justify your response: ✱ *Required*

b. How many *additional* substitutions do you believe should be permitted when competitive (i.e, non-friendly) matches progress to extra-time? ✱ *Required*

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10
- ○ 11+

Please add details to justify your response: ✱ *Required*

Question 12 of 12

How important do you consider the following as areas for future research in relation to substitutes? *
Required

Please don't select more than 1 answer(s) per row.

Please select at least 7 answer(s).

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Fatigue responses	☐	☐	☐	☐	☐
Tactical impact	☐	☐	☐	☐	☐
Substitution timing	☐	☐	☐	☐	☐
Technical performance	☐	☐	☐	☐	☐
Physical performance	☐	☐	☐	☐	☐
Injury epidemiology	☐	☐	☐	☐	☐
Psychological impact	☐	☐	☐	☐	☐
Other (please state)	☐	☐	☐	☐	☐

If other, please specify:

11.3 Appendix 3: Physically focused survey questions

Question 1 of 16

Please take the time to answer the following questions in relation to your own practices and perceptions.

Please provide as much detail as possible when accounting for your responses.

To what extent do you agree with the following statement? *"Substitutes are an important factor in determining success in soccer match-play"* ✱ *Required*

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Please add details to justify your response: ✱ *Required*

Question 2 of 16

How frequently does the introduction of substitutes substantially influence the outcome of a match? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

Please add details to justify your response: ✱ *Required*

Question 3 of 16

How frequently is the design of non match-day training and preparation strategies (physical, nutritional etc.) different for substitute players when compared with for the starting team? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

Please add details to justify your response: ✱ *Required*

Question 4 of 16

a. On match-day, how frequently are substitutes provided with input from club staff in relation to the pre-match warm-up (e.g., information/suggestions relating to content, length, timing etc.)? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

b. On match-day, how frequently are substitutes accompanied by at least one member of club staff during the pre-match warm-up? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

Please add details to justify your responses to a and b: ✱ *Required*

Question 5 of 16

How important do you consider each of the following practices to be, when implemented during the break that separates the end of the pre-match warm-up and a substitute's entry onto the pitch? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 5 answer(s).

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Energy provision (e.g., sports gels, carbohydrate drinks)	☐	☐	☐	☐	☐
Hydration	☐	☐	☐	☐	☐
Active rewarm-up activity	☐	☐	☐	☐	☐
Passive heat maintenance techniques (e.g., heated or insulated garments)	☐	☐	☐	☐	☐
Tactical preparations (e.g., formation, tactical advice)	☐	☐	☐	☐	☐
Other (please state)	☐	☐	☐	☐	☐

If other, please specify:

Question 6 of 16

From the list provided, please indicate the two most important practices, when implemented during the period that separates the end of the pre-mach warm-up and a substitute's entry onto the pitch ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select exactly 2 answer(s).

Please don't select more than 2 answer(s) in any single column.

	Most important
Energy provision (e.g., sports gels, carbohydrate drinks)	☐
Hydration	☐
Active rewarm-up activity	☐
Passive heat maintenance techniques (e.g., heated or insulated garments)	☐
Tactical preparations (e.g., formation, tactical advice)	☐
Other (please state)	☐

If other, please specify:

Question 8 of 16

a. How frequently are substitutes provided with input from club staff in relation to any rewarm-up activity performed following kick-off but prior to pitch-entry (e.g., information/suggestions pertaining to content, frequency, timing etc.)? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

b. Considering only the occasions on which rewarm-up recommendations are provided, how frequently are the recommendations implemented by the players? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time
- N /A

Please add details to justify your responses to a and b: ✱ *Required*

Question 7 of 16

How frequently are the following practices implemented during the period that separates the end of the pre-match warm-up and entry onto the pitch? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 5 answer(s).

	Never	Rarely	Sometimes	Often	All of the time
Energy provision (e.g., sports gels, carbohydrate drinks)	☐	☐	☐	☐	☐
Hydration	☐	☐	☐	☐	☐
Active rewarm-up activity	☐	☐	☐	☐	☐
Passive heat maintenance techniques (e.g., heated or insulated garments)	☐	☐	☐	☐	☐
Tactical preparations (e.g., formation, tactical advice)	☐	☐	☐	☐	☐
Other (please state)	☐	☐	☐	☐	☐

If other, please specify:

Question 9 of 16

a. How important is accounting for any activity performed by substitutes prior to pitch-entry when considering the overall physical load that players are exposed to? ✱ *Required*

- ◯ Not at all important
- ◯ Slightly important
- ◯ Moderately important
- ◯ Very important
- ◯ Extremely important

b. How frequently is activity performed by substitutes prior to pitch-entry accounted for when considering the overall physical load that players are exposed to? ✱ *Required*

- ◯ Never
- ◯ Rarely
- ◯ Sometimes
- ◯ Often
- ◯ All of the time

Please add details to justify your responses to a and b: ✱ *Required*

Question 10 of 16

a. How frequently are substitutes provided with guidance as to what clothing to wear during the period between the end of the pre-match warm-up and the point of pitch-entry? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time

b. Considering only the occasions on which clothing recommendations are provided, how frequently are the recommendations implemented by the players? ✱ *Required*

- Never
- Rarely
- Sometimes
- Often
- All of the time
- N/A

Please add details to justify your responses to a and b: ✱ *Required*

Question 11 of 16

How satisfied are you that the match-day pre-pitch-entry activities undertaken by substitutes are sufficient to prepare for subsequent match performance? ✱ *Required*

- Not at all satisfied
- Slightly satisfied
- Neither satisfied nor unsatisfied
- Very satisfied
- Extremely satisfied

Please add details to justify your response: ✱ *Required*

Question 12 of 16

a. Do you believe there is a need for different post-match recovery practices between substitutes and starting players? ✱ *Required*

- ○ Yes
- ○ No

b. How frequently are substitutes given specific/tailored post-match recovery recommendations, which differ from the starting eleven? ✱ *Required*

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ All of the time

Please add details to justify your responses to a and b: ✱ *Required*

Question 13 of 16

a. Do your substitutes perform ‘top-up’ conditioning sessions to account for their only partial match exposure? (please select all that apply) * *Required*

- ☐ Yes, on match-day
- ☐ Yes, the next day
- ☐ No
- ☐ Other (please state)

If other, please specify:

b. How frequently do your substitutes perform ‘top-up’ conditioning sessions to account for their only partial match exposure? * *Required*

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ All of the time

Please add details (e.g., modality, how is intensity/volume determined, why not etc.) to justify your responses to a and b: * *Required*

Question 14 of 16

How many substitutions do you believe should be permitted during a competitive (i.e., non-friendly) 90 min match? ✱ *Required*

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10
- ○ 11+

Please add details to justify your response: ✱ *Required*

How many *additional* substitutions do you believe should be permitted when competitive (i.e, non-friendly) matches progress to extra-time? ✱ *Required*

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10
- ○ 11+

Please add details to justify your response: ✱ *Required*

Question 15 of 16

a. To what extent do you agree with the following statements? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 3 answer(s).

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Coaches/support staff should be permitted to accompany substitutes for rewarm-ups during the match	☐	☐	☐	☐	☐
More space should be provided for players to use for rewarm-up activity during a match	☐	☐	☐	☐	☐
Players should be permitted to use a ball during rewarm-ups whilst the match is underway	☐	☐	☐	☐	☐

Please add details to justify your responses: ✱ *Required*

b. What (if any) specific regulatory changes would you like to see in relation to substitutes/substitutions, and why?

Question 16 of 16

How important do you consider the following as areas for future research in relation to substitutes?

Please don't select more than 1 answer(s) per row.

Please select at least 7 answer(s).

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Fatigue responses	☐	☐	☐	☐	☐
Physiological responses	☐	☐	☐	☐	☐
Recovery modalities	☐	☐	☐	☐	☐
Nutritional strategies	☐	☐	☐	☐	☐
Preparatory strategies	☐	☐	☐	☐	☐
Injury epidemiology	☐	☐	☐	☐	☐
Psychological impact	☐	☐	☐	☐	☐
Other (please state)	☐	☐	☐	☐	☐

If other, please specify:

11.4 Appendix 4: Confirmation of ethical approval (chapters four and six data collection)

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Dr Mark Russell
Chair of SSHS Ethics Committee
Tel: 0113 283 7100 ext 649
E-mail: m.russell@leedstrinity.ac.uk

Date: 7th February 2018

Dear Samuel

Re: SSHS-2017-077 - Activity profiles of soccer substitute players prior to entering onto the pitch

Thank you for your recent application for ethical approval for the above named project.

After reviewing the application it has been resolved that the research project is granted ethical approval.

I wish you well in your study,

Yours sincerely

Dr Mark Russell
Chair of School of Social and Health Sciences Ethics Committee

11.5 Appendix 5: Confirmation of ethical approval (chapter five data collection)

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Dr Mark Russell
Chair of SSHS Ethics Committee
Tel: 0113 283 7100 ext 649
E-mail: m.russell@leedstrinity.ac.uk

Date: 22nd March 2018

Dear Samuel

Re: SSHS/2018/001 - The influence of a modified half time protocol on second half performance during soccer match simulation

Thank you for your recent application for ethical approval for the above named project.

After reviewing the application it has been resolved that the research project is granted ethical approval.

I wish you well in your study,

Yours sincerely

Dr Martin Barwood
Vice Chair of School of Social and Health Sciences Ethics Committee

11.6 Appendix 6: Confirmation of ethical approval (chapter seven data collection)

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Samuel Hills

Professor Mark Russell
Chair of SSHS Ethics Committee
Tel: 0113 283 7100 ext 649
E-mail: m.russell@leedstrinity.ac.uk

Date: 26th March 2019

Dear Sam

Re: SSHS/2019/003
Movement responses to a 'modified' pre-pitch entry strategy compared with current practice, amongst professional soccer substitutes

Thank you for your recent application for ethical approval for the above named project.

After reviewing the application it has been resolved that the research project is granted ethical approval.

I wish you well in your study.

Yours sincerely

Prof. Mark Russell
Chair of School of Social and Health Sciences Ethics Committee