SPEED ENDURANCE TRAINING IN ELITE YOUTH SOCCER PLAYERS

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ABSTRACT

The physical demands of soccer match play have significantly increased in recent years. As such, training methods must evolve to ensure players are able to cope with these demands over the course of a season. Speed endurance training is recommended to improve physical performance in elite soccer players, however scientific investigations into different protocols and modalities are sparse.

The aim of Study 1 was to determine the exposure to speed endurance training over a season relative to all other conditioning drills. Secondary data was quantified over a 42-week season in an elite youth soccer team using five different conditioning drill categorisations. Speed endurance maintenance and extensive endurance where the most prominent conditioning drills whilst speed endurance production was the least frequent. Nonetheless, the relative distribution of running drills and small-sided games were almost equal for both speed endurance protocols. An investigation into different speed endurance modes and protocols in Study 2 revealed running drills elicit greater heart rate, blood lactate concentration and subjective ratings of perceived exertion than respective small-sided games. Players covered less total distance and high-intensity running distance in the small-sided games, but greater high-intensity acceleration/deceleration distance than in the respective running drills. Additionally, the speed endurance production drills produced greater blood lactate concentrations and high speed running demands than the respective maintenance protocols. These findings suggest speed endurance small-sided games could be used to train the anaerobic energy system, however a greater physiological response may be possible with soccer drills that expose players to greater high speed running demands.

The aim of study 3 was to quantify movement patterns, technical skills and tactical actions associated with high speed running efforts during elite match play to provide information for position-specific speed endurance drills. Twenty individual English Premier

League players high-intensity running profiles were observed multiple times using a computerised tracking system. Data was coded using a novel 'High-intensity Movement Programme' and revealed position-specific trends in and out of possession. This investigation was the first study to contextualise why playing positions perform high-intensity running efforts rather than simply reporting distances covered. In possession, wide midfielders executed more tricks post effort than centre backs and central midfielders whilst fullbacks and wide midfielders performed more crosses post effort than other positions. Out of possession, forwards completed more efforts closing down the opposition but less efforts tracking opposition runners than other positions. Distinct movement patterns were also evident out of possession with forwards performing more arc runs before efforts compared to centre backs, fullbacks and wide midfielders, however centre backs completed more 0-90° turns compared to fullbacks, central and wide midfielders.

The data from Study 3 was used to design five individual position-specific speed endurance drills with the aim of exposing players to high speed running and the associated technical and tactical actions performed during a match. An investigation into the position-specific speed endurance drills in Study 4 revealed players covered greater distances across all speed thresholds attaining greater peak and average running speeds during the speed endurance production protocol compared to the maintenance drill. Mean and peak heart rate responses were greater in the maintenance protocol whilst blood lactate concentrations were higher following the production protocol. Minimal differences in neuromuscular function and ratings of perceived recovery were evident following either protocol up to 24 h post drill. The findings suggest position-specific speed endurance production drills should be prescribed to achieve a greater anaerobic stimulus and expose players to high running speeds whilst the maintenance protocol should be administered when a greater cardiovascular load is desirable with a concomitant reduction in high speed running.

This research programme provides novel information comparing the physiological response and physical demands of various speed endurance drills in soccer. These studies were the first to report seasonal speed endurance practice and detail generic and position-specific speed endurance soccer drills based on contextualised match data. It is hoped the data from this research project can help applied staff understand the most appropriate speed endurance practices for elite youth players.

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PUBLICATIONS

Peer Reviewed First Author Publications from this series of Investigations

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2. **Ade J.D.**, Harley J.A., & Bradley P.S. (2014). Physiological response, time–motion characteristics, and reproducibility of various speed-endurance drills in elite youth soccer players: Small-sided games versus generic running. *International Journal of Sports Physiology and Performance, 9*(3), 471-479.
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Other Publications related to this series of Investigations

1. Bradley, P.S., Di Mascio, M., Mohr, M., Fransson, D., Wells, C., Moreira, A., Castellano, J., Diaz, A. G., & **Ade, J, D.** (2018). Can modern football match demands be translated into novel training and testing modes? *Aspetar Sports Medicine Journal*, *7,* 46-52.
2. Bradley P.S., Evans M., Laws A., & **Ade J.D.** (2018). 'Context is King' when interpreting match physical performances. *Football Medic & Scientist Magazine, 24*, 42-45.
3. Bradley, P.S., Laws, A., & **Ade, J.** (2018). How AI could help football managers spot weak links in their teams. *The Conversation*.
4. Bradley, P. S., Martin-Garcia, A., **Ade, J. D.**, & Diaz, A. G. (2019). Position-specific and positional play training in elite football: context matters. *Football Medicine & Performance Magazine, 19,* 31-35.

Other Publications

1. Bradley, P.S., & **Ade, J.D.** (2018). Are Current Physical Match Performance Metrics in Elite Soccer Fit for Purpose or is the Adoption of an Integrated Approach Needed? *International Journal of Sports Physiology and Performance, 13*(5), 656-664.
2. Bradley, P.S., Carling, C., Diaz, A.G., Hood, P., Barnes, C., **Ade, J.**, Boddy, M., Krustrup, P., & Mohr, M. (2013). Match Performance and Physical Capacity of Players in the Top Three Competitive Standards of English Professional Soccer. *Human Movement Science, 32*(4), 808-821.
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4. Di Mascio, M., **Ade, J.**, Musham, C., Girard, O., & Bradley, P.S. (2017). Soccer-Specific Reactive Repeated-Sprint Ability in Elite Youth Soccer Players: Maturation Trends and Association with Various Physical Performance Tests. *Journal of Strength and Conditioning Research,* (in press).

5. Ingebrigtsen, J., Holterman, P.A., **Ade, J.**, Bradley, P., & Krustrup, P. (2014). Relationships between field performance tests in high-level soccer players. *The Journal of Strength and Conditioning Research*, *28*(4), 942-949.

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LIST OF ABBREVIATIONS

AHI, Aerobic high-intensity

ATP, Adenosine triphosphate

A.U., Arbitrary units

B, Mesocycle block

Ca^{2+}, Calcium ions

CAM, Central attacking midfielder

CB, Centre back

CDM, Central defensive midfielder

CM, Central midfielder

CV, Coefficient of variation

DF, Defender

EE, Extensive endurance

ES, Effect size

FB, Fullback

FT:CT, Flight time contraction time ratio

FW, Forward

GPS, Global positioning systems

H^{+}, Hydrogen ions

HCMJ, Horizontal countermovement jump

HIMP, High-intensity movement programme

HR, Heart rate

HR_{max}, Maximum heart rate

HSR, High speed running

IE, Intensive endurance

ISO, Isometric strength

K^+, Potassium ions

LPS, Local positioning systems

MCT, Monocarboxylate cotransporter

MD, Match day

MEMS, Microelectromechanical system

MF, Midfielder

Na^+, Sodium ions

NHE, Na^+-H^+ exchangers

PRS, Perceived recovery scale

RSI, Reactive strength index

RPE, Subjective ratings of perceived exertion

SE, Speed endurance

SEM, Speed endurance maintenance

SEP, Speed endurance production

SPR, Sprinting

SSG's, Small-sided games

SWC, Smallest worthwhile change

TE, Typical error

TRIMP, Training impulse

VCMJ, Vertical countermovement jump

VDJ, Vertical drop jump

VHSR, Very high speed running

VID, Semi-automatic computerised multiple-camera video tracking systems

$\dot{V}O_2$, Oxygen uptake

$\dot{V}O_{2max}$, Maximum oxygen uptake

Yo-Yo IR1 / 2, Yo-Yo intermittent recovery test level 1 / 2

WM, Wide midfielder

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 BACKGROUND

Soccer is the most popular sport in the world played by approximately 265 million people consisting of over 112,000 registered professionals and 21 million youth players (Kunz, 2007). The popularity of professional soccer and financial rewards for success have never been greater with the average English Premier League game watched by over 12 million people and TV companies reportedly paying $13 billion to broadcast the action in 212 territories worldwide from 2016-19 (Curley & Roeder, 2016; Rohde & Breuer, 2016).

The game of soccer is scheduled to last 90 min in duration consisting of two 45 min halves interspaced by a 15 min period of rest referred to as half time. It may be necessary to play extra time in cup competitions should the teams draw, increasing the playing duration to 120 min with the addition of two further 15 min halves (FIFA, 2018). Two teams compete against one another with the aim of outscoring the opponent. Teams are permitted to field eleven players consisting of one goalkeeper and ten outfield players. The goalkeeper can handle the ball within a designated 18 yd box in an effort to prevent the opposition from scoring a goal. The outfield players may be organised into numerous formations in and out of possession based on the tactical instructions of the coach. The categorisation of playing positions will be dependent on the playing formation and style of play, however typically most professional soccer teams employ some variation of a 4-4-2, 4-3-3, or 3-5-2 playing formation (Tierney et al., 2016; Memmert et al., 2019).

Professional soccer clubs seek to recruit the most skilful players and employ the most knowledgeable coaches and support staff to optimise performance on the pitch to maximise the chances of success. Research has highlighted the evolution of professional soccer in the English Premier League both technically and physically (Barnes et al., 2014; Bush et al., 2015a; Bush et al., 2015b; Bradley et al., 2016). Over a period of seven seasons, players covered 30-35% more high-intensity running and sprint distance in 2012-13 compared to 2006-07. It is unclear whether the increase in these physical outputs are due to recruitment strategies focusing on players with greater athletic attributes, changes in the styles of play which may be more physically demanding, or whether training methodologies have developed to elevate the players' physical capacities and athleticism (Sarmento et al., 2018; Memmert et al., 2019; Nevill et al., 2019).

In order to outperform the opposition, the training process is of paramount importance to prepare the team and individual players for matches. Soccer training is a multifaceted process in which technical, tactical, physical and psychological factors can be developed simultaneously (Morgans et al., 2014; Walker & Hawkins, 2017). Depending on the philosophy of the coach, physical development sessions may be incorporated into specific soccer drills or performed in isolation as running drills. Such drills typically occur as part of a team's daily training sessions, however there is also a need to deliver conditioning sessions to squad players not readily participating in matches or players during a period of rehabilitation from injury. Improvements in physical performance following a period of aerobic high-intensity soccer training either through small-sided games or running drills is well established in the literature (Stolen et al., 2005; Stone & Kilding, 2009). More recently, the benefits of other conditioning modalities such as speed endurance training have received growing attention (Mohr & Krustrup, 2016; Fransson et al., 2018; Vitale et al., 2018). However, when commencing this research programme, investigations into the physiological responses and locomotive demands of different speed endurance protocols and modalities in soccer were limited (Iaia, Rampinini & Bangsbo, 2009; Thomassen et al., 2010).

Speed endurance training is recommended to improve performance of maximal exercise for a relatively short period of time and maintain exercise intensity during repeated high-intensity efforts (Mohr & Iaia, 2014; Bangsbo, 2015). Training protocols encompass relatively short exercise durations (10-90 s) interspaced by a range of rest periods that tax both aerobic and anaerobic pathways (Iaia & Bangsbo, 2010). Peripheral adaptations in the muscle are proposed to delay fatigue by maintaining homeostasis during intense exercise (Hostrup & Bangsbo, 2017). Therefore, speed endurance training may enable players to tolerate intense periods of play and enhance the ability to perform supramaximal exercise considered critical to the outcome of a match (Tenga et al., 2010; Faude, Koch & Meyer, 2012). However, to date most research has been performed in moderately trained runners or cyclists, thus it is difficult to transfer the physiological responses and performance adaptations associated to speed endurance training to well-trained soccer players. Furthermore, many of the modes were performed seated on a bike or running in a straight line which is in contrast to soccer which requires multiple changes of direction and explosive actions such as jumping and kicking (Bloomfield, Polman & O'Donoghue, 2007; Murtagh et al., 2019). Therefore, it is proposed speed endurance drills should incorporate soccer specific movements patterns to ensure adaptations at the muscle are movement specific whilst simultaneously training technical skills and tactical decisions under fatigue.

Speed endurance drills appeal to practitioners working in elite soccer as they are more time efficient than aerobic high-intensity drills and the relatively low volume enables them to be prescribed in and around a complex training programme (Walker & Hawkins, 2017). However, to date, there has not been an investigation into the current speed endurance practices in elite youth soccer and although some have suggested small-sided games could be potentially used as speed endurance drills (Reilly & Bangsbo, 1998; Little 2009), information on the associated physiological responses is sparse (Aroso, Rebelo & Gomes-Pereira, 2004). Furthermore, although it is well established in the literature that individual playing positions have unique physical demands during a match (Sarmento et al., 2014), no scientific investigations have constructed and examined the physiological and physical demands of position-specific speed endurance drills. Such drills would be advantageous to ensure players elicit the required physiological response whilst training the associated specific technical and tactical actions performed during a match. Finally, it is currently not known how performing speed endurance training drills may effect subsequent neuromuscular function and subjective ratings of perceived recovery. Such information would allow practitioners to better understand when to prescribe speed endurance drills within the training programme so not to compromise performance in a match (Martin-Garcia et al., 2018b). Therefore, this thesis aims to investigate current speed endurance practices and develop speed endurance soccer drills that elicit the appropriate physiological response whilst ensuring the physical, technical and tactical demands are specific to individual playing positions.

1.2 AIMS AND OBJECTIVES

The main aim of this research programme was to understand and develop current speed endurance practice in elite youth soccer players. By understanding the current speed endurance practice in elite youth soccer, the main objective was to develop position-specific speed endurance drills that expose players to the necessary movement patterns, technical skills and tactical actions associated to high speed running efforts during match play.

The specific objectives of the thesis are as follows:

1. To determine speed endurance exposure in elite youth soccer players over a season relative to all on-pitch conditioning drills.
2. To establish the physiological response, time-motion characteristics and reproducibility of speed endurance small-sided games and running drills.
3. To quantify the position-specific movement patterns, technical skills and tactical actions associated with high speed running efforts during elite match play to aid speed endurance drill design.
4. To investigate the physiological characteristics, physical demands and subsequent effect on neuromuscular function of position-specific speed endurance soccer drills.

CHAPTER TWO

REVIEW OF THE LITERATURE

2.1 INTRODUCTION

Soccer performance is influenced by physical, technical, tactical and psychological factors (Bangsbo, 2015). Soccer is not a science, however scientific investigations into the game of soccer may improve performance and reduce the chance of injury (Bangsbo, 1994). Physical training modes should be based on the individual demands of playing positions whilst practitioners need to understand when, how and why to prescribe specific training drills (Mohr & Iaia, 2014; Turner et al., 2016; Walker & Hawkins, 2017). The following literature review will identify the unique match demands associated to individual playing positions before discussing potential reasons for fatigue development. The complex nature of soccer training will then be considered to understand how and when physical development training could be prescribed in a multifaceted programme. Finally, the effect of different high-intensity training modalities in soccer will be discussed with a focus on speed endurance training.

2.2 MATCH PHYSICAL DEMANDS

Soccer is an intermittent sport that requires players to perform brief high-intensity activities interspaced by longer periods of low-intensity exercise (Bangsbo, Mohr & Krustrup, 2006). Players are typically required to play a match once or twice a week during the season. The physical demands of elite matches have been extensively researched (Carling et al., 2008; Sarmento et al., 2014). Early work involved video and notational analysis, however the majority of research relating to elite match play has used semi-automatic computerised multiple-camera video tracking systems (VID) due to its widespread use in elite clubs (Castellano, Alvarez-Pastor & Bradley, 2014). Recently, the emergence of radio-based local (LPS) and global positioning systems (GPS) provides further information on the match demands by quantifying accelerations, decelerations and tri-axial loads (Scott, Scott & Kelly, 2016; Whitehead et al., 2018). Most elite clubs use GPS devices to monitor physical load during training sessions (Akenhead, Harley & Tweddle, 2016; Martin-Garcia et al., 2018b). A recent rule change now allows players to wear GPS devices during competitive matches which appeals to clubs as they can standardise training and match data. Although VID are not used during training sessions (Carling et al., 2008), the availability of large data sets across many elite clubs over numerous seasons has provided valuable insight into the evolution of many physical and technical aspects during match play (Barnes et al., 2014; Bush et al., 2015a, 2015b; Bradley et al., 2016).

Typically, elite male players cover 9-14 km during a match, of which 600-1200 m (~6-12%) is performed running at very high speed (>19.7 $km \cdot h^{-1}$) (Sarmento et al., 2014). Players perform 150-250 brief intense actions during a game such as sprinting, changes of direction, jumping, tackling, shooting and passing (Mohr, Krustrup & Bangsbo, 2003; Stolen et al., 2005). At a very basic level, time-motion analysis is used by coaches to compare physical and technical data with the opposition whilst benchmarking collective and individual performances. Performance analysis has evolved considerably over the years by providing information on playing formations and styles of play in addition to contextual factors such as the state of the game and standard of the opposition (Castellano, Blanco-Villasenor & Alvarez, 2011; Fernandez-Navarro et al., 2018). Match demands research is necessary to ensure training methods are specific in preparing the players to perform optimally (Reilly, 2005). It has been well established that the physical and technical demands are different across playing positions due distinct tactical requirements (Sarmento et al., 2014).

Table 2.1. Positional differences in very high speed running and sprinting during competitive match play.

Reference	Standard	Sample	Method	Variable (Mean ± SD)		Main Findings
Mohr et al. (2003)	Elite Italian Age (26 ± 1 yr)	18 Players 7 Games 42 Observations CB (*n*=11) FB (*n*=9) MF (*n*=13) FW (*n*=9)	Video Analysis - Manual Coding	**HSR Dis (15-18 km·h^{-1})** CB 1690 ± 100 m FB 2460 ± 130 m MF 2230 ± 150 m FW 2280 ± 140 m	**VHSR (18-30 km·h^{-1})** CB 440 ± 30 m FB 640 ± 60 m MF 440 ± 40 m FW 690 ± 80 m	MF, FB & FW covered greater HSR distance than CB (P<0.05). FW & FB covered a greater SPD than MF & CB (P<0.05).
Di Salvo et al. (2007)	Elite Spanish La Liga and European Champions League 2002-03 2003-04	300 Players 30 Games CB (*n*=63) FB (*n*=60) CM (*n*=67) WM (*n*=58) FW (*n*=52)	Computerised semi-automated multiple-camera system – AMISCO Pro (25 Hz)	**VHSR Dis (19.1-23 km·h^{-1})** CB 397 ± 114 m FB 652 ± 179 m CM 627 ± 184 m WM 738 ± 174 m FW 621 ± 161 m	**SPD (>23 km·h^{-1})** CB 215 ± 100 m FB 402 ± 165 m CM 248 ± 116 m WM 446 ± 161 m FW 404 ± 140 m	WM covered greater VHSR distance whilst CB covered less VHSR distance compared to all other positions (P<0.05). WM, FB & FW covered greater SPR distance than CM & CB (P<0.05).
Bradley et al. (2009)	Elite English Premier League 2005-06	370 Players 28 Games CB (*n*=92) FB (*n*=84) CM (*n*=80) WM (*n*=52) FW (*n*=62)	Computerised semi-automated multiple-camera system – Prozone (10 Hz)	**VHSR (>19.7 km·h^{-1})** CB 603 ± 132 m FB 984 ± 195 m CM 927 ± 245 m WM 1214 ± 251 m FW 955 ± 239 m	**SPD (>25.2 km·h^{-1})** CB 152 ± 50 m FB 287 ± 98 m CM 204 ± 89 m WM 346 ± 115 m FW 264 ± 87 m	WM covered greater VHSR distance than all positions (P<0.05). WM & FB covered greater SPR distance than CB, CM & FW (P<0.05).
Di Salvo et al. (2009)	Elite English Premier League 2003-04 2004-05 2005-06	563 Players 7355 Observations CB (*n*=1840) FB (*n*=1648) CM (*n*=1725) WM (*n*=1006) FW (*n*=1136)	Computerised semi-automated multiple-camera system – Prozone (10 Hz)	**VHSR (>19.7 km·h^{-1})** CB 681 ± 128 m FB 911 ± 123 m CM 928 ± 124 m WM 1049 ± 106 m FW 968 ± 143 m	**SPD (>25.2 km·h^{-1})** CB 167 ± 53 m FB 238 ± 55 m CM 217 ± 46 m WM 260 ± 47 m FW 262 ± 63 m	WM covered more whilst CB covered less VHSR distance compared to all other positions (P<0.05). WM & FW covered more SPD than FB, CM & CB whilst FB covered more SPD than CM & CB (P<0.05). CB covered less SPD than all other positions (P<0.05).

Reference	Standard	Sample	Method	Variable (Mean ± SD)		Main Findings
Dellal et al. (2010)	Elite French First League 2005-06	5938 Observations CB (*n*=1000) FB (*n*=756) CDM (*n*=952) CAM (*n*=166) WM (*n*=202) FW (*n*=464)	Computerised semi-automated multiple-camera system – AMISCO Pro (25 Hz)	**VHSR Dis (21-24 km·h^{-1})** CB 230 ± 56 m FB 274 ± 63 m CDM 302 ± 69 m CAM 335 ± 62 m WM 336 ± 64 m FW 300 ± 57 m	**SPD (>24 km·h^{-1})** CB 199 ± 66 m FB 241 ± 70 m CDM 221 ± 76 m CAM 235 ± 72 m WM 235 ± 85 m FW 290 ± 75 m	WM & CAM covered more whilst CB & FB covered less VHSR distance compared to all other positions (*P*<0.05). FW covered more whilst CB covered less SPD compared to all other positions (*P*<0.05).
Carling et al. (2012)	Elite French League 1 2007-08 2008-09 2009-10 2010-11	20 Players 80 Games 353 Observations CB (*n*=73) FB (*n*=80) CM (*n*=70) WM (*n*=80) FW (*n*=50)	Computerised semi-automated multiple-camera system – AMISCO Pro (25 Hz)	**VHSR (>19.7 km·h^{-1}) mean recovery time (s)** CB 194.6 ± 48.4 FB 115.8 ± 18.6 CM 134.7 ± 28.5 WM 120.5 ± 24.1 FW 129.3 ± 27.6	**VHSR (>19.7 km·h^{-1}) recovery time <30 s (%)** CB 14.0 ± 6.5 FB 21.6 ± 6.3 CM 21.0 ± 6.4 WM 20.2 ± 6.1 FW 16.9 ± 6.6	CB had a greater mean recovery time compared to all other positions (*P*<0.01). FB had a shorted recovery time than CB and CM (*P*<0.01). Mean percentage recovery time <30 s was greater in FB & CM than CB & FW (*P*<0.05). WM had a higher percentage of recovery time < 30 s compared to CB (*P*<0.01).
Varley & Aughey (2013)	Elite Australian A-League 2010-11	2 Teams 34 Games 126 Observations CB (*n*=5, 31 files) FB (*n*=3, 17 files) CM (*n*=7, 33 files) WM (*n*=6, 25 files) FW (*n*=8, 20 files)	GPS units: SPI Pro, GPSports, Australia (5Hz)	**No. HI Efforts (>15 km·h^{-1})** CB 104 ± 28 FB 156 ± 22 CM 125 ± 41 WM 141 ± 31 FW 127 ± 23	**No. SPR Efforts (>25 km·h^{-1})** CB 5 ± 3 FB 12 ± 5 CM 4 ± 4 WM 8 ± 4 FW 14 ± 6	FB performed a greater number of HSR efforts than CB & CM (*P*<0.05). WM performed more HSR efforts than CB & FW (*P*<0.05). FB & FW performed more SPR efforts than WM, CB & CM (*P*<0.05). CB & CM performed fewer SPR efforts than all other positions (*P*<0.05).
Andrezejewski et al. (2015)	Elite Europa League – Poland 2008-09 to 2010-11	147 Players 10 Games CB (*n*=39) FB (*n*=35) CM (*n*=35) WM (*n*=20) FW (*n*=18)	Computerised semi-automated multiple-camera system – AMISCO Pro (25 Hz)	**SPD (>24 km·h^{-1})** CB 186 ± 82 m FB 265 ± 121 m CM 167 ± 87 m WM 314 ± 123 m FW 346 ± 130 m	**SPD relative TD (%)** CB 1.8 ± 0.7 FB 2.4 ± 1.0 CM 1.4 ± 0.7 WM 2.7 ± 1.1 FW 3.1 ± 1.1	FW & WM covered the most whilst CM & CB covered the least SPD (*P*<0.05). The percentage of SPD relative to TD was greater for FW compared to all positions (*P*<0.05).

Reference	Standard	Sample	Method	Variable (Mean ± SD)		Main Findings
Ade et al. (2016)	Elite English Premier League 2010-11 to 2013-14 Seasons	20 Players 46 Games 100 Observations CB (*n*=5, 20 files) FB (*n*=5, 20 files) CM (*n*=5, 20 files) WM (*n*=5, 20 files) FW (*n*=5, 20 files)	Computerised semi-automated multiple-camera system – AMISCO Pro (25 Hz)	**No. VHI Efforts (>21 km·h^{-1})** CB 20.3 ± 6.5 FB 30.6 ± 10.2 CM 29.4 ± 9.3 WM 38.7 ± 14.4 FW 33.6 ± 10.0	**Mean VHI Effort Dis** CB 16.6 ± 3.0 m FB 20.2 ± 2.6 m CM 18.5 ± 2.8 m WM 20.3 ± 3.5 m FW 17.8 ± 2.2 m	WM performed more VHSR efforts than CB, FB & CM (ES: >0.6). CB performed less VHSR efforts compared to all positions (ES: >0.6). Mean VHSR distance per effort was greater for WM & FB than CB & FW (ES: >0.6). CB mean distance was less than WM, FB & CM (ES: >0.6).
Baptista et al. (2018)	Elite Norwegian Eliteserien League 2016-17 to 2017-18	23 Games 18 Players 138 Observations CB (*n*=3, 35 files) FB (*n*=5, 34 files) CM (*n*=6, 30 files) WM (*n*=3, 18 files) FW (*n*=4, 13 files)	Stationary radio-based tracking system (ZXY Sport Tracking System, Trondheim Norway, 20 Hz)	**VHSR Dis (>19.7 km·h^{-1})** CB 5.2 ± 1.6 m/min FB 8.1 ± 1.7 m/min CM 8.0 ± 3.5 m/min WM 9.2 ± 1.8 m/min FW 9.4 ± 1.6 m/min	**SPD Dis (>25.2 km·h^{-1})** CB 0.9 ± 0.5 m/min FB 2.0 ± 0.6 m/min CM 1.4 ± 1.0 m/min WM 1.7 ± 0.7 m/min FW 2.5 ± 1.0 m/min	CB covered lower VHSR and SPR distance than all other positions (ES: 0.26-0.55). FB & WM SPR distance were greater than CM (ES: 0.24-0.37).
Martin-Garcia et al. (2018a)	Elite Youth Spanish 2nd B division Season 2015-2016 Age (20 ± 2 years)	37 Games 23 Players 605 Observations CB (*n*=3, 95 files) FB (*n*=5, 139 files) CM (*n*=3, 101 files) WM (*n*=5, 110 files) FW (*n*=7, 160 files)	Portable 10 Hz GPS units (Viper Pod, StatSports, Northern Ireland)	**Most intense 1 min period: VHID (>19.7 km·h^{-1})** CB 35.5 ± 24.2 m/min FB 47.2 ± 24.0 m/min CM 29.8 ± 22.1 m/min WM 35.8 ± 19.9 m/min FW 37.8 ± 21.6 m/min	**Most intense 1 min period: SPD (>25.2 km·h^{-1})** CB 11.6 ± 19.1 m/min FB 14.0 ± 17.3 m/min CM 6.1 ± 11.0 m/min WM 7.2 ± 12.5 m/min FW 11.5 ± 14.2 m/min	FB performed more VHSR during the most intense 1 min period of a match than CM (*P*<0.01, ES: 0.4). FB performed the greatest whilst CM performed the lowest SPR distance during the most intense 1 min period of a match (ES: 0.1-0.5).

Abbreviations: CB, centre back; FB, Fullback; CM, central midfielder; CAM, central attacking midfielder; CDM, central defensive midfielder; WM, wide midfielder; MF = midfielder; FW, forward; Dis, distance; TD, total distance; HSR, high speed running, HI, high-intensity; VHSR, very high speed running; VHI, very high-intensity; SPD, sprint distance; SPR, sprint; No., number; IP, in possession; OP, out of possession; CV, coefficient of variation. Data presented as means ± standard deviations.

2.2.1 High Speed Running and Sprinting Demands

In an effort to quantify the physical demands of soccer, performance analysis research will often report distances covered above pre-defined speed thresholds termed high speed running (HSR >14.4 $km \cdot h^{-1}$), very high speed running (VHSR >19.7 $km \cdot h^{-1}$) and sprinting (SPR >25.2 $km \cdot h^{-1}$). To provide some context, professional and elite youth male soccer players are reported to achieve maximal running speeds of ~31 $km \cdot h^{-1}$ during a 40-m sprint test (Haddad et al., 2015; Djaoui et al., 2017). Therefore, these pre-defined thresholds roughly equate to HSR ~45%, VHSR 65% and SPR 80% of maximal speed. Metabolic rate is known to increase linearly with running speed (Margaria et al., 1963; Helgerud, Storen & Hoff, 2010), thus it stands to reason VHSR and SPR performance indicates physically demanding efforts during match play. Some research suggests the distance covered at high-intensity is related to training status (Krustrup et al., 2005; Bradley et al., 2013) however conflicting findings have been reported when comparing competitive playing standards (Mohr et al., 2003; Bradley et al., 2013). Nonetheless, these metrics are considered important for practitioners to prepare players for the demands of the game by ensuring training is specific to individual playing positions.

Numerous studies in the literature have investigated the HSR and SPR demands across playing positions (Table 2.1). Typically, VID research reports wide midfielders (WM) cover the greatest VHSR and SPR distance during a match across positions (Di Salvo et al., 2007; Bradley et al., 2009; Di Salvo et al., 2009; Di Salvo et al., 2010; Ade, Fitzpatrick & Bradley, 2016). However, the SPR demands of fullbacks (FB) and forwards (FW) are inconsistent with some authors reporting greater demands for FW (Di Salvo et al., 2009; Ade et al., 2016), whilst others report greater demands for FB (Bradley et al., 2009) or similar demands between positions (Di Salvo et al., 2007). This could be due to teams playing various styles and formations (Bradley et al., 2011; Tierney et al., 2016; Aquino et al., 2018). Additionally, much of the literature does not account for specialised positions. When CM have been split into attacking (CAM) or defensive (CDM) roles, large variations in physical demands have been apparent with CAM covering similar VHSR distances as WM (Dellal et al., 2010; Dellal et al., 2011a). Such information could be provided for all positions, for instance comparing the demands of a CB playing in a back four compared to a back 3, FB playing behind a WM in a midfield four compared to a wide FW in a 4-3-3 formation, or FW playing as a lone striker compared to playing with a second striker. These intra-positional differences also need to account for how physical profiles vary according to styles of play which have been shown to be dependent on the match status, venue and quality of the opposition (Fernandez-Navarro et al., 2016, 2018). Furthermore, most of the research does not account for the opposition formation or transient changes that occur in and out of possession but also across periods of game (Bradley et al., 2013; Lago-Penas, Gomez & Pollard, 2017).

In contrast to VID, studies using LPS and GPS technology have reported WM to perform fewer sprints and cover less distance sprinting than FB (Dalen et al., 2016), FW (Andrezejewski et al., 2015) or both positions (Varley & Aughey 2013). These discrepancies are likely due to different technologies using various methods to establish each player's XY-position on the pitch whilst employing a range of sampling frequencies (5-25 Hz) to monitor locomotion (Carling et al., 2008). Limited studies have investigated the validity of VID (Di Salvo et al., 2006; Zubillaga, 2006; Rodriguez de la Cruz, Croisier & Bury, 2010; Linke et al., 2018). Possible reasons for the lack of research include the absence of a 'gold standard' system and previous laws of the game prohibiting players to wear electronic tracking devises during matches (Carling et al., 2008). Recently, Linke et al. (2018) compared the position, speed and distance measurement accuracy of the STATS SportVU system (3 cameras, 16 Hz) with a gold standard criterion motion capture system that used 33 infrared cameras sampling at 100 Hz (VICON, Oxford, UK). Measurements were taken during a sport-specific course, 20 m shuttle run test and small-sided games (SSG's). Data demonstrated that spatial and speed errors were ~60 cm and 0.4 $m \cdot s^{-1}$, respectively across all exercises. The error increased with speed (VHSR: 20-25 and SPR >25 $km \cdot h^{-1}$ equal to 0.5 and 0.6 $m \cdot s^{-1}$, respectively), however VICON can only measure movement in a 30 x 30 m area which is far smaller than a full-size pitch (~105 x 67 m). As such, the VHSR and SPR distances covered during the sport-specific course and SSG's were below that reported in match analysis studies. Exercises generating greater VHSR and SPR distances may reduce the error associated with these speeds.

Unlike VID, the reliability and validity of GPS units have received significant attention (Scott et al., 2016; Roe et al., 2017; Beato et al., 2018). A review of the literature by Scott et al. (2016) concluded 10 Hz units to be optimum compared to 5 and 15 Hz when analysing high-intensity short distance running. However, as with all units, the accuracy of the 10 Hz units, established by the coefficient of variation (CV), worsened with increasing speed thresholds over moderate distances (CV's for HSR: ~5%, and VHSR: ~10%). Near perfect correlations were reported between 10 Hz units and a criterion measurement (radar gun, 50 Hz) for maximum velocity during 40 m sprints (Roe et al., 2017). Nevertheless, previous research comparing VID, GPS and LPS technologies indicate the systems should not be used interchangeably without the use of correction equations (Randers et al., 2010; Harley et al., 2011; Buchheit et al., 2014; Linke et al., 2018).

Further reasons for the discrepancies in positional data across the time-motion analysis studies include a lack of consistency when defining speed thresholds (VHSR >19.7 vs 21.0, SPR >24.0 vs 25.2 $km \cdot h^{-1}$) and minimum dwelling time necessary to register an effort (0.5 vs 1.0 s). Additionally, the standard of the opposition and success of the team will affect the positional demands, for instance, CB and FB are reported to cover less HSR distance during matches won compared to lost, whilst FW cover more HSR distance during matches won compared to drawn or lost (Rampinini et al., 2007a; Di Salvo et al., 2009; Andrezejewski et al., 2016). Moreover, research investigating locomotor match demands of a single successful team that regularly compete against a lower standard of opposition will have greater possession of the ball which has been shown to increase VHSR demands of the FW and WM (Di Salvo et al., 2009; Lago-Penas & Dellal, 2010; Bradley et al., 2013). The natural match-to-match and player-to-player variability within each position must also be acknowledged. Match-to-match variability has been reported to increase at greater speed thresholds (CV's for VHSR: ~20%; SPD 35%) and be position dependent with WM and FW typically experiencing more uniformed demands than other playing positions (Gregson et al., 2010; Bush et al., 2015b; Carling et al., 2016).

Although there are limitations to the above research, there are some consistent findings that differentiate the HSR and SPR demands between positions. However, these measures in isolation underestimate the overall work rate of players as sudden changes in the rate of speed when performing high-intensity accelerations do not often reach the minimum speed thresholds to be considered HSR (~85%) yet are considered to be more metabolically and mechanically taxing due to increased ground contact time requiring greater muscular force (Osgnach et al., 2010; Akenhead et al., 2015). To ensure a complete activity profile, the positional differences in acceleration and deceleration demands need to be considered.

2.2.2 Acceleration and Deceleration Demands

Due to the intermittent nature of soccer requiring regular changes of speed and direction, accelerations and decelerations frequently occur as players increase or decrease running speeds. Similar to HSR and SPR, players in lateral positions such as FB and WM have greater acceleration and deceleration demands over the course of match when quantified by the number of efforts (Varley & Aughey, 2013; Dalen et al., 2016; Baptista et al., 2018). In contrast, one study found no positional differences in high-intensity accelerations (Tierney et al., 2016) whilst another measuring total distance covered accelerating reported the greatest demands for FW (Baptista et a., 2018). The main aim of the study by Tierney et al.

(2016) was to identify the physical demands across five different playing formations which revealed FW covered ~50% more accelerations in a 4-3-3 compared to a 4-2-3-1 formation whilst FB performed ~20% more decelerations in a 3-5-2 compared to a 4-4-2 formation. However, a subsection of the study compared acceleration/deceleration demands across positions for which playing formation was not accounted for and is therefore a major limitation.

Accelerations and decelerations have typically been quantified as 'total' (>1/-1 $m \cdot s^{-2}$) or 'high-intensity' (>2.8/-2.8 $m \cdot s^{-2}$) in the literature. High-intensity rather than total acceleration and deceleration demands during matches are of greater interest when aiming to develop current speed endurance training practice in elite players due the higher metabolic and mechanical demands (Osgnach et al., 2010). However, as with measurements of instantaneous speed, accuracy of accelerations and decelerations are compromised at greater magnitudes though validity is improved using GPS technology with a greater sampling rate (Varley, Fairweather & Aughey, 2012; Scott et al., 2016; Hoppe et al., 2018). Validation studies investigating the accuracy of GPS units to measure decelerations are limited though a greater margin of error has been reported compared to accelerations when validating 10 Hz devices against a lazar (CV: 11 vs 4%) during straight line running (Varley et al., 2012b). However, in contrast, no differences were reported for high-intensity deceleration distance between GPS (15 Hz) devices and the VICON system during a sport-specific circuit (Linke et al., 2018).

2.2.3 Technical Skills and Movement Patterns

Technical skills consist of actions performed in possession of the ball such as passes, shots, headers and tricks, but also out of possession when performing actions such as tackles and headers (Hughes et al., 2012). Movement patterns involve reacting to the ball or an opponent to be in the required position to influence play, for instance, turning at specific angles, back pedalling, side shuffling, or swerving when running at higher speeds (Bloomfield, Polman & O'Donoghue, 2007). Technical skills and movement patterns have been shown to differentiate competitive playing standards (Bradley et al., 2013) with demands affected by playing formation and ball possession (Carling, 2011; Bradley, Lago-Penas & Sampaio, 2014). Furthermore, technical skills vary according to playing position due to distinct tactical roles (Hughes et al., 2012). For instance, CAM, WM and FW have been reported to have the greatest number of touches per possession compared to all other positions, whilst CAM and WM were reported to have the greatest duration per action compared to all other positions with CB the shortest duration (Dellal et al., 2010). Furthermore, defenders (DF) and midfielders (MF) perform more long passes in the air than FW whilst MF play more short passes on the ground than DF (Bloomfield et al., 2007).

The ability to move efficiently will enable players to better execute technical skills and physical demands during match play. Information on movement patterns such as the frequency of turns at specific angles or number of actions in a backward or lateral direction can be used to devise specific training programmes to develop distinct qualities necessary for each position. For instance, DF have been reported to perform more lateral and backwards movements compared to MF and FW during a match (Bloomfield et al., 2007). Furthermore, CB have been reported to perform less >90 and 181-270° turns than FB and WM whilst FW performed less 271-360° turns than CB and FB (Baptista et al., 2018). These data can be used by practitioners to design position-specific speed endurance drills that incorporate the most frequent movement patterns.

2.3 PHYSIOLOGICAL MATCH DEMANDS

Energy for muscle contraction is provided by the hydrolysis of adenosine triphosphate (ATP) which is resynthesised via anaerobic and aerobic pathways (Gastin, 2001; Egan & Zierath, 2013). During a match, aerobic metabolism is the predominant energy source with players performing >70% of activities at low-intensity (Bangsbo et al., 2006). Average oxygen uptake is estimated to be 70-75% of a player's maximum ($\dot{V}O_{2max}$) due to mean and peak heart rate values of 85 and 98%, respectively (Bangsbo et al., 2006; Krustrup et al., 2011; Mohr et al., 2016). Although aerobic metabolism dominates energy provision during a match, individual concentrations of blood lactate have been reported above 12 $mmol \cdot L^{-1}$ indicating elevated anaerobic metabolism when performing intense actions such as sprinting, shooting or tackling, which are often decisive during a match (Krustrup et al., 2006).

2.3.1 Aerobic Demands

Due to long periods of low-intensity exercise during a soccer match, ~90% of a player's energy is provided by aerobic metabolism (Stolen et al., 2005). Research reports the $\dot{V}O_{2max}$ of elite male players is ~60 $mL \cdot kg^{-1} \cdot min^{-1}$, which has remained stable between 1967 and 2012 (Shalfawi & Tjelta, 2016). Differences in $\dot{V}O_{2max}$ according to playing position are evident with the majority of research reporting the highest and lowest mean values in CM and CB, respectively (Reilly, Bangsbo & Franks, 2000; Stolen et al., 2005; Tonnssen et al., 2013). However, low to moderate correlations exist between $\dot{V}O_{2max}$ and intermittent running capacity (Bangsbo & Lindquist, 1992; Castagna, Belardinelli & Abt, 2003; Aziz, Tan & Teh, 2005), thus some question its importance for elite players (Bradley et al., 2011).

Similar positional differences in heart rate responses during a match are evident with the greatest absolute values reported in MF and lowest in CB (Ali & Farrally, 1991; Stroyer, Hansen & Klausen, 2004). An investigation by Coelho et al. (2011) in 44 Brazilian youth players revealed MF spent more time playing at 85-90% of maximum heart rate (HR_{max}) than CB, FB and FW whilst also spending more time playing at 90-95% HR_{max} compared to CB and FW. This is not surprising, as CM players cover the most total distance during a match and have the greatest $\dot{V}O_{2max}$ (Di Salvo et al., 2007; Bradley et al., 2009; Tonnssen et al., 2013). Additionally, FB spent the most time playing at 95-100% HR_{max} compared to other positions but also spent a more time working at lower intensities (<70% HR_{max}). These data support time-motion analysis studies that report FB perform VHSR actions both during attacking and defensive phases of the game, possibly explaining the need to spend greater time recovering at lower intensities (Bradley et al., 2009; Varley & Aughey, 2013; Baptista et al., 2018).

2.3.2 Anaerobic Demands

Short duration infrequent high-intensity activities predominantly rely on the ATP and creatine phosphate pathway to provide a substantial amount of energy. Anaerobic glycolysis becomes more prominent when activities are more frequent and/or longer in duration as the metabolism of oxygen in the blood and muscle alone is insufficient to meet demands (Baker, McCormick & Robergs, 2010). Based on muscle biopsies following intense periods of match play, it is estimated that creatine phosphate concentration during a match is approximately 60% of resting levels and could be lower than 30% during the most intense periods (Krustrup et al., 2006; Bangsbo, Iaia & Krustrup, 2007). Average blood lactate concentrations during a match have been reported to be anywhere between 2 and 10 $mmol{\cdot}L^{-1}$ with individual values >12 $mmol{\cdot}L^{-1}$ shown to peak in the first 15 min (Roi et al., 2004; Krustrup et al., 2006; Aslan et al., 2012). Following intense periods of play, blood and muscle lactate have been reported to increase from 1.3 to 6.0 $mmol{\cdot}kg^{-1}$ and 4.2 to 16.9 $mmol{\cdot}kg^{-1}$ d.w., respectively, compared to pre-game values (Krustrup et al., 2006). Furthermore, muscle pH dropped from 7.2 to 6.9 -log H^+ whilst H^+ increased from 57 to 111 $nmol{\cdot}kg^{-1}$ d.w. However, the samples were taken from sub-elite fourth division Danish soccer players competing in three friendly games so it is not known whether these responses would be representative of elite players taking part in competitive matches, whilst the authors did not specify how an intense period of play was identified.

Positional variation for blood lactate concentrations and distances covered at speeds above fixed blood lactate thresholds have been reported in elite youth players during nonofficial tournament matches (Aslan et al., 2012). Blood lactate concentration was assessed six times during a 90 min match (every 15 min) and revealed higher concentrations for FW compared to defenders (4.6 vs 3.2 mmol$\cdot$L^{-1}). The average blood lactate concentration across all positions and time points was approximately 4 mmol$\cdot$L^{-1} while individual values showed a range between 1.6 and 11.9 mmol$\cdot$L^{-1}. MF covered 66% of total distance at speeds below aerobic threshold (<2 mmol$\cdot$L^{-1}), 10% between aerobic threshold and anaerobic threshold (2-4 mmol$\cdot$L^{-1}), and 23% at speeds above anaerobic threshold (>4 mmol$\cdot$L^{-1}). DF and MF covered greater distances than FW at running speed corresponding to <2 mmol$\cdot$L^{-1}, however no differences were evident at speeds corresponding to 2-4 and >4 mmol$\cdot$L^{-1} (Aslan et al., 2012). Monitoring speeds corresponding to fixed blood lactate concentrations has been shown to be related to total distance, however no relationship exists with HSR distance covered in a match which questions its validity to evaluate physical performance (Bangsbo & Lindquist, 1992; Castagna, Abt & D'ottavio, 2002; Aslan et al., 2012). Furthermore, the use of fixed blood lactate concentrations such as 4 mmol$\cdot$L^{-1} does not take into account considerable inter individual differences thereby underestimating anaerobically trained athletes or overestimating aerobically trained athlete's endurance capacity (Stegmann, Kindermann & Schnabel, 1981; Faude, Kindermann & Meyer, 2009).

2.3.3 Fatigue Development in Soccer

Mechanical energy is needed to move the body at the required intensity (Ament & Verkerke, 2009). Numerous physiological systems are stressed to ensure energy is supplied to the exercising muscle in the form of ATP (Gastin, 2001; Egan & Zierath, 2013). During periods of high-intensity exercise or when exercising for prolonged periods of time, muscle contraction speed and/or force is reduced to prevent the harmful consequences of ATP depletion (Cheng, Place & Westerblad, 2018). Research suggests the decline in muscle function during exercise may be due to 'central' fatigue such as impaired motor neuron activity or ‘peripheral’ fatigue at the muscle due to the accumulation of metabolites (Westerblad, Bruton & Katz, 2010).

A robust finding in the literature is that high-intensity physical performance diminishes over the course of a match, whilst the ability to perform repeated sprints and neuromuscular assessments of strength and power is attenuated after compared to before a match (Carling et al., 2008; Silva et al., 2018). Fatigue is multi-faceted, and a number of reasons have been proposed to explain why the work rate of players is compromised during the later stages of a match or for a period following very intense play referred to as temporary fatigue decrement (Bangsbo et al., 2007; Marques-Jimenez et al., 2017).

2.3.3.1 Fatigue Throughout the Game

The majority of time-motion analysis studies reveal the amount of HSR and SPR declines in the second compared to the first half of a match and during the last compared to the first 15 min period of a match (Mohr et al., 2003; Bradley et al., 2010; Russell et al., 2014). Similarly, a decrease in accelerations, decelerations, number of headers, pass distributions and individual possessions has been reported in the second compared to the first half and during the last compared to the first 15 min period of a match (Akenhead et al., 2013; Russell, Rees & Kingsley, 2013; Dalen et al., 2016). However, analysis of 15-min periods to indicate fatigue may be flawed as it can be argued the first 15 min period of a match is not representative of the preceding 75 min during which time the two teams are becoming accustomed to one another and the environment before imposing their style of play (Carling et al., 2008).

Physical performance evaluated during and following a competitive or simulated soccer match consistently show a reduction in strength, power, sprint and intermittent endurance capabilities indicating the development of fatigue (Nedelec et al., 2012; Marques-Jimenez et al., 2017; Silva et al., 2018). Depletion of muscle glycogen stores in specific muscle fibres has been attributed to reduced physical performance during the latter stages of the game (Bangsbo et al., 2006; Krustrup et al., 2006; Nedelec et al., 2013). A study by Krustrup et al. (2006) reported mean sprint time during a repeated sprint test increased by ~3% immediately following a match. Muscle glycogen decreased by ~42% whilst plasma free fatty acid concentrations increased 3 fold. The post-match muscle glycogen content is in agreement with other studies indicating glycogen availability (Krustrup et al., 2011; Mohr et al., 2016), however analysis of individual muscle fibres revealed ~40% were almost empty with ~10% completely empty of glycogen.

Additionally, Krustrup et al. (2011) reported maximal voluntary contraction isometric muscle force and skeletal muscle sarcoplasmic reticulum Ca^{2+} release to be impaired immediately following a competitive match. The authors suggest lower muscle glycogen may affect sarcoplasmic reticulum function as the Ca^{2+} release rate has been shown to be associated with glycogen in the intramyofibrillar compartment (Ortenblad, Westerblad & Nielson, 2013; Gejl et al., 2017). These findings along with research indicating increased muscle glycogen achieved through consumption of carbohydrates enhances prolonged exercise performance suggests a player's ability to spare muscle glycogen stores may be advantageous in delaying fatigue towards the end of a match (Reilly, Drust & Clarke, 2008; Nedelec et al., 2012).

2.3.3.2 Temporary Running Decrements During the Game

Temporary running decrements during a match is a common finding. The amount of HSR following the most intense 5 min period has been reported to decrease by ~6-12% compared to the average 5 min period during the match (Mohr et al., 2003; Bradley et al., 2009, Figure 2.1). However, predefined 5 min periods have been found to underestimate peak periods of HSR by up to 25% whilst overestimating the subsequent period by up to 31% when compared with rolling periods, indicating temporary fatigue may reduce work rate by as much 52% (Varley, Elias & Aughey, 2012). In agreement, recent research investigating the real peak HSR distances during 1-, 2- and 5-min periods from a large sample of elite players revealed temporary running decrements below match averages in all positions except CB (Fransson, Krustrup & Mohr, 2017).

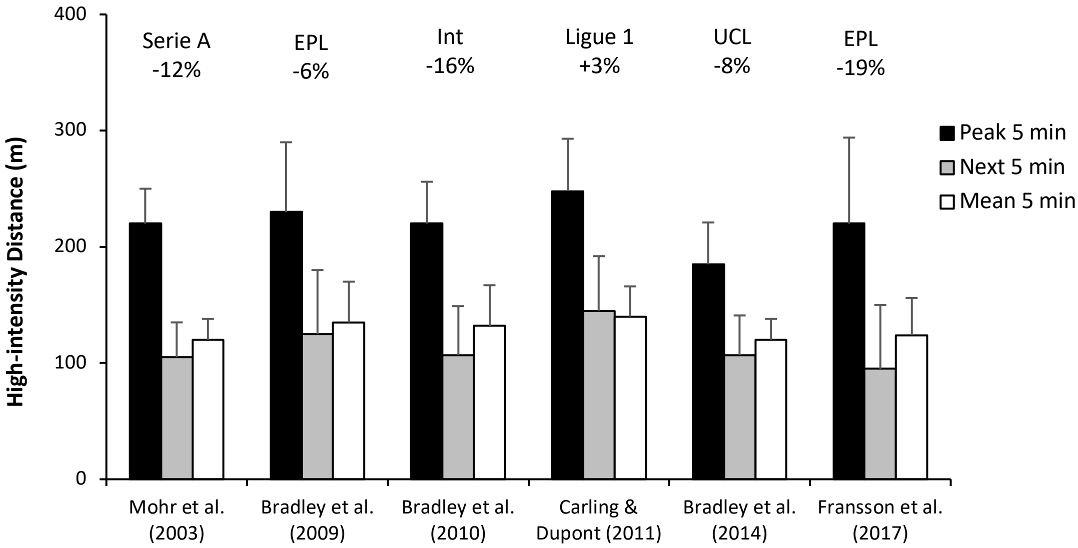


Figure 2.1. Temporary running decrements during periods of a game. Abbreviations: EPL, English Premier League; UCL, UEFA Champions League.

It has been suggested that temporary fatigue decrements in HSR is not due to physiological fatigue given soccer is a submaximal sport (Paul, Bradley & Nassis, 2015). Instead it is proposed players adopt pacing strategies (Bradley & Noakes, 2013) or experience mental fatigue following periods of highly demanding cognitive activity (Knicker et al., 2011; Smith et al., 2015). Muscle biopsies taken 30 s before the repeated sprint test found no relationship between muscle lactate or pH with performance which is in agreement with other studies (Cairns, 2006). Thus, this may indicate that high muscle lactate and low muscle pH are not the primary cause of temporary fatigue and that other factors could be contributory factors (Bangsbo & Juel, 2006; Krustrup et al., 2006). It is possible depletion of creatine phosphate stores may contribute to temporary fatigue during a match as it is suggested muscle concentration may drop to below 30% of resting levels following intense periods of play whilst individual muscle fibres have been found to be fully depleted following intense exercise (Soderlund & Hultman, 1991; Mohr et al., 2007).

A growing body of research suggests the major cause of temporary fatigue following intense exercise may be a result of metabolic and ionic perturbations that impair excitation-contraction coupling of skeletal muscle thereby reducing muscle force (McKenna, Bangsbo & Renaud, 2008; Iaia & Bangsbo, 2010; Hostrup & Bangsbo, 2017). In support of this hypothesis, muscle biopsies revealed a high expression of Na^+-K^+ ATPase proteins have been found to correlate with VHSR and SPR distance during peak 5 min match periods (Mohr et al., 2016). Research in soccer recommends speed endurance training to improve a player's ability to perform, sustain, and recover from intense periods of play during a match (Iaia, Rampinini & Bangsbo, 2009; Bangsbo, 2015). Such training is performed at intensities close to or above $\dot{V}O_{2max}$ for relatively short durations (10-90 s) with varied recovery periods (1:≥5 exercise to rest ratio) to predominantly stimulate the anaerobic energy system and improve muscle ion handling (Bangsbo, 2015; Hostrup & Bangsbo, 2017). The specific physiological adaptations associated with improved fatigue resistance following high-intensity training are presented in Figure 2.2.

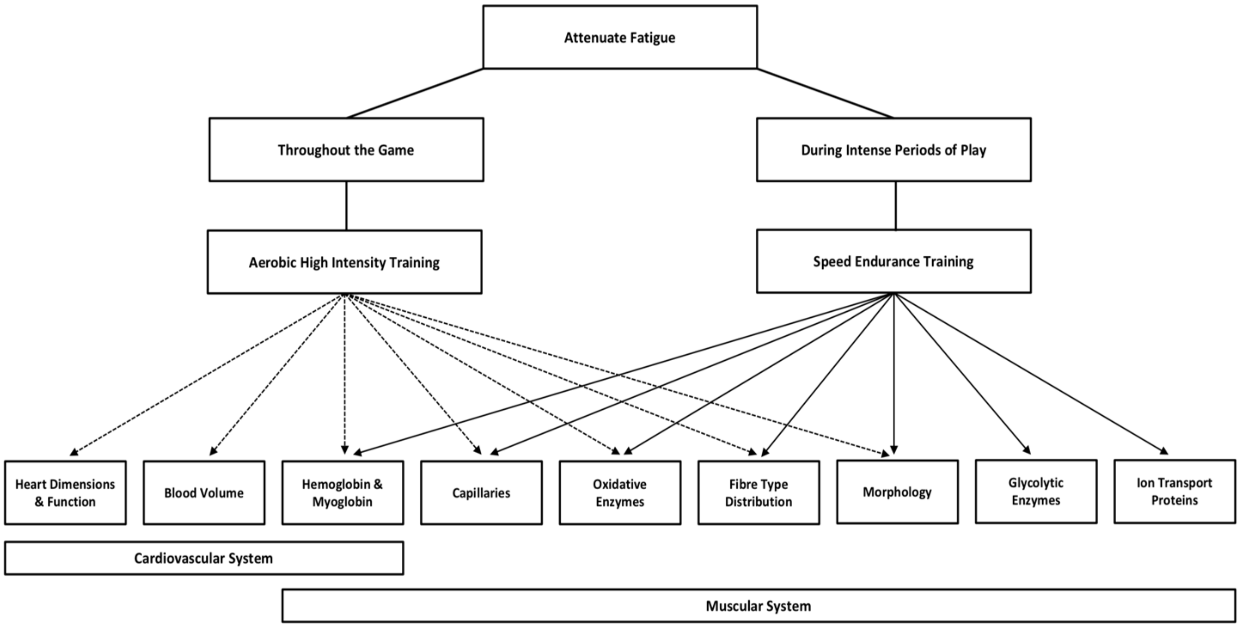


Figure 2.2. Physiological adaptations associated to different training categories suggested to attenuate fatigue during a match. This figure is adapted from Mohr & Iaia (2014).

2.4 SOCCER TRAINING

The game of soccer is multifaceted as it requires high levels of technical skill, tactical understanding, physical performance and psychosocial capabilities to succeed at an elite level (Williams & Reilly, 2000). There are multiple ways to structure soccer training as the content will depend on the philosophy of the Club, head coach, individual needs of the players and match schedule, amongst numerous other factors (Morgans et al., 2014; Walker & Hawkins, 2017). Some teams may aim to develop all of these facets simultaneously through soccer drills whilst others perform physical sessions as isolated running drills (Dupont, Akakpo & Berthoin, 2004; Fransson et al., 2018; Sarmento et al., 2018). Practitioners need to have a detailed knowledge of the demands and complexities of training to understand when to prescribe drills aimed at improving physical performance.

Typically, a season spans 11 months, though the exact duration may vary by a couple of weeks due to performance in cup competitions. Players can be involved in >50 competitive fixtures per season. Thus, manipulating training intensity and volume for each player around matches and tournaments is a challenging task (Bannister et al., 1991; Borresen & Lambert, 2009; Mujika et al., 2018). Training principles such as specificity, progressive overload, variation and recovery need to be carefully considered within periodisation models to allow adaptation and supercompensation of physical qualities (Mujika et al., 2018).

2.4.1 Soccer Training Load

Training load refers to the stress endured by the body when performing physical activity (Impellizzeri, Rampinini & Marcora, 2005). Load is typically subdivided into 'internal' and 'external' categories (Drew & Finch, 2016; Impellizzeri, Marcora & Coutts, 2019). Internal training load represents the load experienced by an athlete, such as a physiological or perceptual response, whilst external load quantifies what the athlete has done, for instance distance covered or number of efforts performed (Jones, Griffiths & Mellalieu, 2017).

The quantification of training load in soccer can be broken down into three periodisation phases (Matveyev, 1981; Issurin, 2010; 2016). The macrocycle is the entire year comprising of pre-season (5-6 weeks), the competitive season (41-42 weeks) and the off-season (6 weeks). The season can then be broken down into 6-8 week mesocycles, whilst microcycles typically occur every seven days (Malone et al., 2015b; Akenhead et al., 2016; Owen et al., 2017). The primary aim during the pre-season period and early competitive season is to increase physical capacity and performance while during the competitive season the priority is to maintain fitness levels (Reilly, 2007; Mujika et al., 2018). Only one study has examined the training load during pre-season, revealing no differences in total distance, VHSR distance, average speed, $\%HR_{max}$ and subjective ratings of perceived exertion (RPE) across the 6 x 1 week periods (Malone et al., 2015b). Nonetheless, positional differences were evident with CB and FW covering less total distance than CM and FB whilst also training at a lower average running speed than CM. No positional differences were found for VHSR distance, $\%HR_{max}$ or RPE. The lack of positional variation in VHSR is surprising given the distinct differences in activity profiles during competitive match play (Bradley et al., 2009; Di Salvo et al., 2009; Ade et al., 2016).

2.4.1.1 Mesocycles

Research quantifying training load over a season using set periods termed mesocycles has revealed minimal variation (Malone et al., 2015b; Los Arcos, Mendez-Villanueva & Martinez-Santos, 2017; Oliveira et al., 2019a). Respiratory and muscular RPE has been reported to remain stable throughout the season (Los Arcos et al., 2017) whilst total distance has been found to be greater in the first compared to the last period of the season, though this was not mirrored by any other external load variables or RPE (Malone et al., 2015b). Similarly, Oliveira et al. (2019a) reported greater total distance, HSR distance and RPE load in the first month compared to the last month of the competitive season. Thus, it would appear training load analysed in mesocycles is relatively stable. Nonetheless, research investigating physical load across mesocycles based on match exposure indicates supplementary training is necessary (Anderson et al., 2016; Los Arcos et al., 2017). Anderson et al. (2016) compared total training and match external load between regular match starters (starting ≥60% of games), fringe players (starting 30-60% of games) and nonstarters (starting <30% of games) in an English Premier League team over the whole season and split into 7 x 7-8 week periods. There were no differences in total distance covered or training duration between starters and nonstarters, however, starters covered significantly more HSR and SPR distance. Furthermore, starters covered more SPR distance than fringe players. These data were supported by research in a Dutch Eredivisie team that reported nonstarters covered ~30% less HSR during a one game week than starters (Stevens et al., 2017). Though this data set represents only two teams, it supports the need for players not regularly starting matches to perform additional conditioning drills that expose them to HSR and SPR (Walker & Hawkins, 2017; Martin-Garcia et al., 2018a).

2.4.1.2 Microcycles

Investigations into training loads in close proximity to matches have received growing attention in recent years (Martin-Garcia et al., 2018b; Clemente et al., 2019; Oliveira et al., 2019a; 2019b). As the fixture schedule is largely out of the control of the soccer clubs and dependent on success in knock out cup competitions, it is difficult to plan mesocycles to target specific physical qualities. A seven day microcycle may consist of one, two or three matches in a week, therefore due to the nonuniform weekly structure, practitioners refer to training days using the "match day minus / plus" format whereby match day minus 1 (MD-1) indicates a session one day before the match (Malone et al., 2015b; Akenhead et al., 2016). Studies have examined microcycle training load across various leagues using an array of training periodisation strategies (Akenhead et al., 2016; Owen et al., 2017; Martin-Garcia et al., 2018b). The data for each study is unique to the individual team investigated during that specific period in time. Although external load variables may be similar in some instances, failure to report the content of soccer drills or internal response to training such as heart rate make comparisons between studies difficult. However, what is consistent across all the studies regardless of the weekly periodisation model employed by the club is the external training load and RPE is reduced on MD-1 compared to MD-4 and MD-3 training sessions earlier in the microcycle (Impellizzeri et al., 2004; Owen & Wong, 2009; Oliveira et al., 2019b). The only exception was in the study by Owen et al. (2017) that quantified all external load variables relative to match values using a multi-modal mechanical approach finding no difference between MD-2 and MD-1 though both were lower than MD-3 and MD-4.

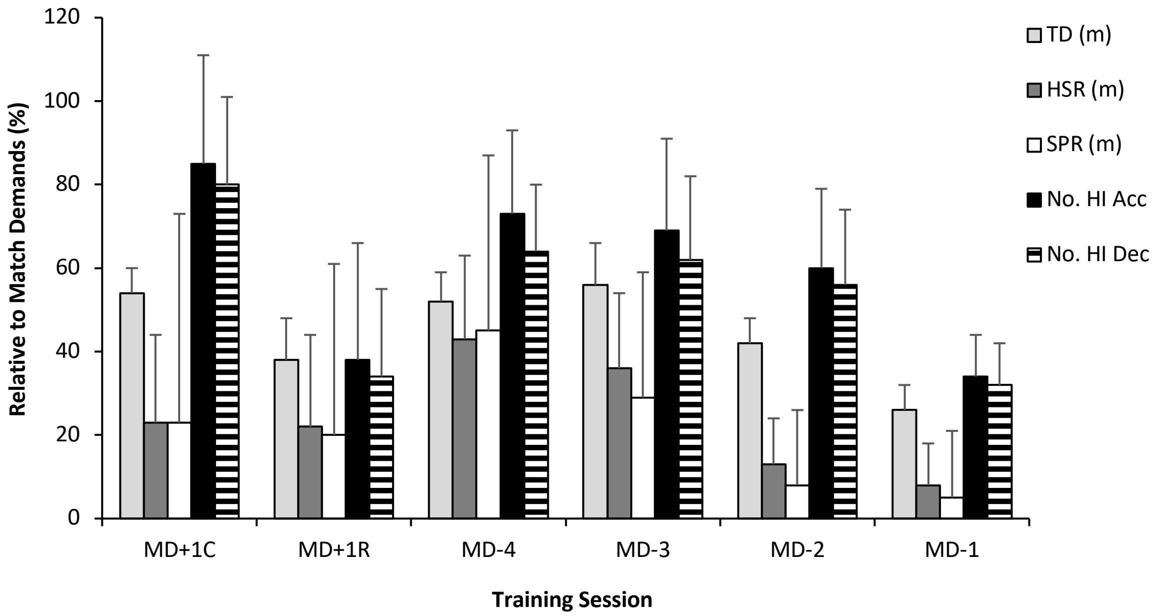


Figure 2.3. Training load data during a microcycle relative to a competitive match. Data from Martin-Garcia et al., (2018b). Abbreviations: TD, total distance; HSR, high speed running distance (>19.7 km·h^{-1}); SPR, sprint distance (>25.2 km·h^{-1}); No. HI Acc, number of high-intensity accelerations (>3 m·s^{-2}); No. HI Dec, number of high-intensity decelerations (<-3 m·s^{-2}); MD, match day; C, conditioning; R, recovery. Values presented as means ± standard deviations.

External training load across 6 x 1 week microcycles during the competitive season has been reported to be stable (Los Arcos et al., 2017; Owen et al., 2017). In contrast, research examining weekly external training load over a 42-week season reported CV's of ~20% for total distance and >85% for VHSR and SPR distance (Martin-Garcia et al., 2018b). Furthermore, the CV for MD-4 and MD-3 ranged from 41-45% when averaged across all external load metrics and positions (Martin-Garcia et al., 2018b). The authors attribute the variation to players schedule, physical recovery status and conditioning requirements. Additionally, some fixtures require extensive travelling whilst environmental factors and the intensity of the preceding match can also effect the recovery status of the players requiring a reduction in training load (Nedelec et al., 2012; Varley et al., 2017). This indicates a need for training programmes to be adaptable and specific to the needs of individual players (Walker & Hawkins, 2017).

2.4.2 Monitoring Training Status

Fatigue monitoring following a soccer match has been extensively researched in the literature (Silva et al., 2018). However, investigations into acute and residual fatigue following training sessions throughout a microcycle (Malone et al., 2015b; Thorpe et al., 2015; Buchheit et al., 2018) or high-intensity training drills are limited (Sjokvist et al., 2011; Sparkes et al., 2018). Recent advancements in technology allow for numerous non-invasive cardiovascular, neuromuscular, biomechanical, metabolic, immunoendocrine, haematological and psychosomatic assessments that have been proposed to monitor fatigue (Halson, 2014; Thorpe et al., 2017). However, several factors need to be considered when implementing fatigue assessments such as the validity, reliability and sensitivity to detect whether a change is actually considered meaningful to soccer performance (Hopkins et al., 2009; Carling et al., 2018; Fitzpatrick et al., 2019b). This can inform decisions regarding the magnitude of physical stimulus necessary for individual training programmes (Claudino et al., 2012; 2016; Ward et al., 2018).

The monitoring of elite youth players vertical countermovement jump (VCJM) height following training sessions throughout a typical microcycle reported no negative effects of training load on performance with some reporting improvements following HSR exposure (Malone et al., 2015a; Thorpe et al., 2015; Buchheit et al., 2018). However, the data is only representative of one to two training weeks whilst two studies had a small sample size (*n*=9). Furthermore, jump performance was assessed using a portable photoelectric cell system which estimates jump height using flight time. Estimating jump height through impulse on a force platform may have been more sensitive to changes in training status as it has a greater degree of agreement with kinematic assessment using video analysis (gold standard) than flight time (Dias, et al., 2011). Additionally, the research failed to monitor variables that indicate changes in movement strategies during the VCMJ, such as the ratio between flight time and contraction time (FT:CT) which has been shown to be a more sensitive and useful measurement of fatigue compared to jump height alone (Cormack, Newton & McGuigan, 2008; Gathercole et al., 2015). Perceived ratings of fatigue were found to be sensitive to daily variation in HSR (Thorpe et al., 2016) across the training microcycle whilst small decreases in adductor strength (7-12%) were evident following MD-4, MD-3 and MD-2 sessions (Buchheit et al., 2018). In contrast, vertical stiffness assessed using GPS embedded accelerometers (typical error of 6%) during standardised submaximal exercise increased by 7-16% across MD-4 to MD-2 with the authors again attributing the changes to a potentiation effect (Buchheit et al., 2018). Thus, it would appear a typical training week has minimal detrimental effects on the training status of individual players. This may be due to the players being accustomed to the regular cyclic loading patterns as proposed in the 'tactical periodisation model' to ensure the principle of performance stabilisation (Delgado-Bordonau & Mendez-Villanueva, 2012; Jankowski, 2016).

Due to the physically demanding nature of high-intensity training drills in which the aim is to disrupt homeostasis to promote physiological adaptation, it may be possible players experience a period of residual fatigue (Chiu & Barnes, 2003; Twomey et al., 2017). It is therefore of interest to establish the effect of high-intensity training drills on neuromuscular function and investigate the associated time-course of recovery. Such information would help practitioners to prescribe drills within a session or throughout the microcycle so not to impact on subsequent performance. Sparkes et al. (2018) revealed high-intensity training consisting of 4v4 SSG's (6x7min) reduced elite players VCMJ height immediately (-9%) and 24 h (-7%) post session. Furthermore, creatine kinase increased immediately post and 24 h post session (41% & 39%, respectively). The total VHSR exposure was low (~40 m) whilst no data on acceleration/deceleration demands were reported. Nonetheless, the elevated creatine kinase and detriment in VCMJ performance is likely due to the high deceleration demands of SSG's resulting in eccentric muscle damage (Hodgson, Akenhead & Thomas, 2014; de Hoyo et al., 2016; Harper & Kiely, 2018). Likewise, Sjokvist et al. (2011) found VCMJ height of elite players was reduced (-4%) 24 h following a high-intensity training session of 4v4 SSG's (4x4min) and soccer specific interval running with and without a ball (4x4min). Though performance was not assessed immediately post session, VCMJ height had returned to baseline at 48 and 72 h post drill. Additionally, no differences in 20 m sprint time was evident 24, 48 or 72 h post drill compared to baseline measurements. Measurements immediately post drill may have shown a decrement in sprint performance although this was not measured and it is not possible to understand the locomotive demands of the drills as no external load data was reported (Sjokvist et al., 2011). Furthermore, the study failed to report the noise of each test, so it's difficult to know whether the reduction in VCMJ performance 24 h post drill is due to fatigue or natural day to day biological variation (Hopkins, 2004). To date, the effect of speed endurance drills on subsequent neuromuscular function and subjective ratings of recovery is unknown. The research literature would benefit from an investigation into the acute fatigue associated to different speed endurance training protocols.

2.5 HIGH-INTENSITY TRAINING IN SOCCER

Soccer players are frequently required to perform high-intensity exercise for varying periods of time throughout a match (Fransson et al., 2017). High-intensity training is performed close to or above $\dot{V}O_{2max}$ in order to promote physiological adaptations that improve the physical performance of soccer players (Iaia et al., 2009b). It is necessary to administer the exercise in intervals to maintain the required intensity, however the duration of the repetitions and the exercise to rest ratio can be manipulated to target specific aerobic or anaerobic pathways

(Bangsbo, 2015). In addition to considering positional demands, microcycle loading patterns, recovery kinetics, and individual player training status, practitioners need to understand how various drills can be manipulated to achieve the desired physical stimulus (Buchheit & Laursen, 2013; Bujalance-Moreno, Latorre-Román & García-Pinillos, 2019; Kunz et al., 2019).

2.5.1 Drill Considerations

Soccer drills in the form of SSG's have been extensively researched (Hill-Haas et al., 2011; Sarmento et al., 2018; Bujalance-Moreno et al., 2019). Typically, lower playing numbers (1v1-4v4) increase the physiological demands compared to medium (5v5-8v8) or large-sized games (9v9-11v11; Little & Williams, 2007; Katis & Kellis, 2009; Owen et al., 2011) with a concomitant increase in the number of technical actions performed per player when numbers are reduced (Clemente et al., 2014; Owen et al., 2014; Joo, Hwang-Bo & Jee, 2016). Increasing relative pitch area results in higher physiological responses (Hodgson et al., 2014; Castellano et al., 205; Castagna et al., 2019) whilst also reducing the number of technical actions (Almeida et al., 2012; Hodgson et al., 2014; Joo et al., 2016). Larger pitch areas result in more total distance, HSR distance and total number of accelerations and decelerations (Hodgson et al., 2014; Olthof, Frencken & Lemmink, 2018; Castagna et al., 2019). Furthermore, physiological responses and total distances covered have been shown to be greater when using mini goals compared to full size goals with goalkeepers, whilst the greatest values are evident with no goals requiring players to stop the ball over a line (Clemente et al., 2014; Halouani et al., 2014; Koklu et al., 2015). Rules and task constraints can be implemented to manipulate the physiological response and external load variables of drills, such as restricting the number of ball touches per possession (Dellal et al., 2011b; San Roman-Quintana et al., 2013) or stipulating man to man marking (Clemente et al., 2016; Aasgaard & Kilding, 2018). The training format administered may also impact the internal and external load associated with SSG's. Longer bout durations elicit a greater heart rate response but lower blood lactate concentrations and RPE compared to shorter bout durations (Koklu et al., 2017). Passive recovery between games results in greater blood lactate concentration and RPE than active recovery (Arslan et al., 2017), whilst verbal encouragement from the coach increases heart rate, blood lactate concentrations and RPE (Rampinini et al., 2007a). Thus, practitioners need to consider a multitude of factors when prescribing SSG's (Figure 2.4).

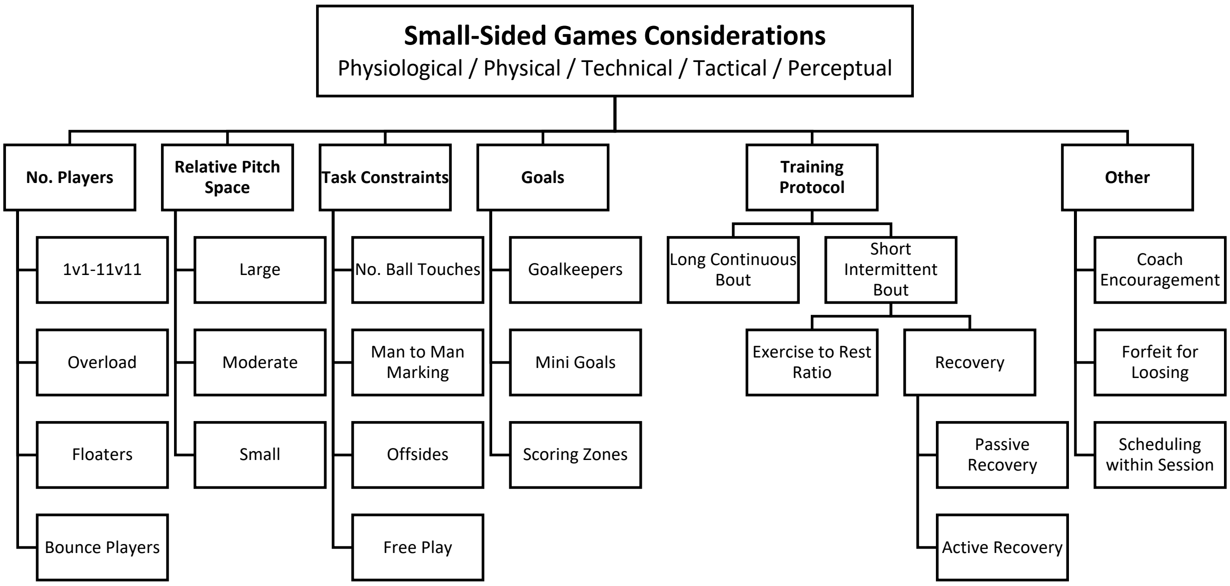


Figure 2.4. Considerations when prescribing small-sided games in soccer. Adapted from Sarmento et al. (2018).

As with soccer drills, running drill parameters can be manipulated to induce a specific physiological stimulus (Akenhead et al., 2015; Fessi et al., 2018). A comprehensive review by Buchheit and Laursen (2013a, 2013b) provides detailed information on how to adapt high-intensity running drills to achieve the desired aerobic, anaerobic and neuromuscular response. Similar to SSG's, modifying exercise and recovery intervals, the number and duration of repetitions, the rest between repetitions and sets, in addition to the inclusion of changes of direction influence the physiological response. Inconsistent terminology associated to high-intensity intermittent running drills make comparisons between research articles difficult (Tschakert & Hofmann, 2013). Buchheit and Laursen (2013a, 2013b) categorise high-intensity interval drills as either long bout duration (2-4 min), short bout duration (<45 s), short repeated-sprint (<10 s) or long all-out sprint interval (>20-30 s) sessions. The literature discussed in the review is from a number of sports and a range of populations. Some research defines high-intensity interval training as near maximal efforts (~85-90% HR_{max}) whilst sprint interval training consists of 'all-out' or supramaximal efforts at an intensity equal to or greater than $\dot{V}O_{2peak}$ (Weston, Wisloff & Commbes, 2014; MacInnis & Gibala, 2017). However, the participants were typically sedentary or recreationally active whilst the training mode was predominantly cycling (Sloth et al., 2013; Gist et al., 2014). The majority of high-intensity training in soccer investigating elite and sub-elite players refers to long bout durations (2-4min) with a ~2:1 exercise to rest ratio as aerobic high-intensity training, short bout duration (10-90 s) with a 1:1-3 exercise to rest ratio as speed endurance maintenance training, short repeated-sprints (<10 s) with an exercise to rest ratio 1:1-6 as 'repeated sprint training', and long all-out sprint interval (20-40 s) with a 1:≥5 exercise to rest ratio as speed endurance production training (Bangsbo, 1994; Iaia et al., 2009b; Iaia & Bangsbo, 2010; Bangsbo, 2015; Hostrup & Bangsbo, 2017; Fransson et al., 2018).

2.5.2 Aerobic High-intensity Training in Soccer

Aerobic high-intensity (AHI) training aims to improve a soccer players ability to perform prolonged high-intensity exercise and increase the ability to recover quickly between high-intensity bouts (Bangsbo, 1994; Bangsbo, 2015). The training requires the player to perform exercise intervals at ~90%HR_{max} for 2-4 min using an exercise to rest ratio ~2:1 (Bangsbo et al, 2006b; Mohr & Iaia, 2014) and has been shown to increase the left-ventricular volume of the heart, oxygen uptake, transport, utilization and artery distensibility (Bangsbo et al., 2006; Laughlin & Roseguini, 2008; Rakobowchuk et al., 2009). These adaptations improve the delivery of oxygen to the working muscles resulting in faster $\dot{V}O_2$ kinetics and higher $\dot{V}O_{2max}$ (Helgerud et al., 2001; Krustrup, Hellsten & Bangsbo, 2004). Further adaptations include upregulation of mitochondrial oxidative enzymes and increased muscular glycogen sparing through greater metabolism of fat (Ross & Leveritt, 2001; Iaia et al., 2009a). However, performance improvements in well-trained individuals are not always associated with increases in skeletal muscle glycolytic or oxidative enzyme activities. Instead performance improvements may be due to an enhanced muscle buffering capacity (Weston et al., 1997) improved ventilatory and lactate thresholds (Hoogeveen, 2000; Driller et al., 2009), and an increased ability to engage a greater volume of muscle mass (Creer et al., 2004).

Numerous research studies have investigated the effect of AHI training in soccer with and without the ball (Tables 2.2 & 2.3). Physiological adaptations were investigated in ~75% of the studies with all but two reporting meaningful changes following training. The most prevalent measurement was $\dot{V}O_{2max}$ which improved by ~7% in all but three investigations (Hill-Haas et al., 2009; Radziminski et al., 2013; Jastrzebski et al., 2014). Interestingly, the three studies were comprised of players with the youngest age across the running interventions. However, age and maturation status do not influence the effects of training on $\dot{V}O_{2max}$ in children (Baxter-Jones & Maffulli, 2003; Carazo-Vargas & Moncada-Jiménez, 2015) whilst two studies revealed improvements following 3v3 SSG's indicating age was not a limiting factor (Radziminski et al., 2013; Jastrezebski et al., 2014). A lower exercise intensity is a more likely reason for the lack of change following the running drills as the heart rate response was lower than values reported in previous research shown to improve $\dot{V}O_{2max}$ (Helgerud et al., 2001; Impellizzeri et al., 2006; Ferrari Bravo et al., 2008) whilst also being lower than in the respective 3v3 SSG's (Radziminski et al., 2013; Jastrezebski et al., 2014). The greater heart rate response during the SSG's may be attributed to the competitive nature of the drills (Hill-Haas et al., 2011; Los Arcos et al., 2015). Nonetheless, the appropriateness of $\dot{V}O_{2max}$ testing to assess changes in soccer specific fitness is questionable as it is unable to distinguish differences in competitive playing standards (Mohr et al., 2003; Di Salvo et al., 2009) whilst the linear running performed during the test is not specific to the intermittent multi-directional nature of the game (Stolen et al., 2005; Jemni, Prince & Baker, 2018).

Training interventions that measured both $\dot{V}O_{2max}$ and high-intensity intermittent running capacity assessed using the Yo-Yo intermittent recovery test level 1 / 2 (Yo-Yo IR1 / IR2) reported 6-10% greater performance improvements in the intermittent field test (Jensen et al., 2007; Ferrari Bravo et al., 2008; Impellizzeri et al., 2008). All the training intervention reported improvements in high-intensity intermittent running capacity (IR1, *n*=5, 14%; IR2, *n*=2, 20%), however two of the studies were administered during pre-season and revealed very large improvements. These are likely due to a period of detraining during the off-season, thus with these data omitted, the typical performance improvements were 13% and 15%, respectively. Although physical performance during a match was reported to improve throughout two training interventions, with no changes in a control group (Helgerud et al., 2001) or similar changes in a SSG's training group (Impellizzeri et al., 2006), these data should be treated with caution due to inherently high match-to-match variability and small number of observations (*n*=2-3) (Bush et al., 2015b; Gregson et al., 2010; Carling et al., 2016).

Table 2.2. Effects of aerobic high-intensity training in soccer without the ball.

Reference	Participants	n	Exercise Mode	Protocol	Intensity	Duration	Period	Physiological Adaptation	Performance Changes
Helgerud et al. (2001)	Elite Norwegian Youth Age (18 ± 1 yr)	9	Running	4 x 4 min, 3 min active rest, 2 x wk	Run: 90-95% HR_{max} Active Rest: 60-70% HR_{max}	8 wk	Pre-season	↑ 11% $\dot{V}O_{2max}$ ↑ 22% Speed @ LT ↑ 16% $\dot{V}O_2$ @ LT ↑ 7% RE	Match: ↑ 20% TD ↑ 100% No. Sprints ↑ 24% No. ball involvements
Impellizzeri et al. (2006)	Elite Italian Youth Age (17 ± 1 yr)	15	Running	4 x 4 min, 3 min active rest, 2 x wk	Run: 90-95% HR_{max} Active Rest: 60-70% HR_{max}	12 wk	4 wk pre-season + 8 wk in-season	↑ 8% $\dot{V}O_{2max}$ ↑ 9% Speed @ LT ↑ 13 % $\dot{V}O_2$ @ LT ↑ 3% RE	↑ 14% SSC time Match: ↑ 6% TD ↑ 20% HSR (>14km·h^{-1})
Ferrari Bravo et al. (2008)	Sub-elite Age (21 ± 1 yr)	13	Running	4 x 4 min, 3 min active rest, 2 x wk	Run: 90-95% HR_{max} Active Rest: 60-70% HR_{max}	8 wk	In-season 7 wk training 1 wk taper	↑ 7% $\dot{V}O_{2max}$ ↑ 4% $\dot{V}O_2$ @ RCP	↑ 12% Yo-Yo IR1 ↔ RSA ↔ 10 m sprint time
Impellizzeri et al. (2008)	Junior - Not specified Age (18 ± 1 yr)	11	Running	4 x 4 min, 3 min active rest, 2-3 x wk Wk 1: 2 x wk Wk 2-4: 3 x wk	Run: 90-95% HR_{max} Active Rest: Not specified	4 wk + 1 wk taper	Post competitive season	↑ 4% $\dot{V}O_{2max}$ ↑ 4% HR in 5 min HIS	↑ 12% Yo-Yo IR1 ↑ 18% LSPT penalty time ↔ LSPT time ↔ LSPT total performance
Radziminski et al. (2013)	Elite Polish Youth Age (15 ± 1 yr)	9	Running	5 x 4 min, 3 min active rest, 2 x wk	Run: 88.7±5.2% HR_{max} Active Rest: Not specified	8 wk	Pre-season	↔ $\dot{V}O_{2max}$	↑ 5% Wingate PP (W·kg^{-1}) ↑ 5% Wingate TWC (J·kg^{-1}) ↔ DFB SSTT
Jastrezebski et al. (2014)	Competitive Youth Age (16 ± 1 yr)	11	Running	7 x 3 min (15 s HI running, 15 s jogging), 1.5 min active rest, 2 x wk	Run: 85-90% HR_{max} Active Rest: Not specified	8 wk	In-season	↑ 3% HR_{max} @ AT ↔ $\dot{V}O_{2max}$	↔ 5 m & 30 m sprint time ↔ Wingate PP (W·kg^{-1})
Los Arcos et al. (2015)	Elite Spanish Youth Age (16 ± 1 yr)	8	Running	3 x 4 min, 3 min active rest, 2 x wk	Run: 90-95% HR_{max} Active Rest: 50-60% HR_{max}	6 wk	Last weeks of season	-	↑2% UM-TT MAS (possibly small)
Belegisanin (2017)	Professional Serbia Age (25 ± 8 yr)	23	Running	6-12min x 30 s run, 30 s active rest / 15 s run, 15 s active rest, 1-2 x wk Wk 1&2: 30:30 - 2 x wk Wk 3&4: 30:30, 15:15 1 x wk Wk 5&6: 15:15 - 1 x wk	30 s Run / 30 s Active rest: 100% / 50% $v\dot{V}O_{2max}$ 15 s Run / 15 s Active rest: 110% / 70% $v\dot{V}O_{2max}$	8 wk	In-season	↑ 6% $\dot{V}O_{2max}$	-

Table 2.3. Effects of aerobic high-intensity training in soccer with the ball.

Reference	Participants	n	Exercise Mode	Protocol	Intensity	Duration	Period	Physiological Adaptation	Performance Changes
Chamari et al. (2005)	Elite Norwegian Youth Age (14±0 yr)	18	Dribble Track & Possession Games (4v4)	4 x 4 min, 3 min active rest, 2 x wk	Dribble Track: 90-95% HR_{max} Active Rest: 60-70% HR_{max}	8 wk	In-season	↑ 8% $\dot{V}O_{2max}$ ↑ 10% RE	↑ 10% Distance covered during dribble track
McMillan et al. (2005)	Elite Scottish Youth Age (17 ± 0 yr)	11	Dribble track	4 x 4 min, 3 min active rest, 2 x wk	Dribble Track: 90-95% HR_{max} Active Rest: 70% HR_{max}	10 wk	End of season	↑ 9% $\dot{V}O_{2max}$ ↑ 5% submaximal HR ↔ submaximal RE	↔ 10 m sprint time
Impellizzeri et al. (2006)	Elite Italian Youth Age (17 ± 1 yr)	14	SSG's (3v3-5v5)	4 x 4 min, 3 min rest, 2 x wk	SSG's: 90-95% HR_{max}	12 wk	4 wk pre-season + 8 wk in-season	↑ 7% $\dot{V}O_{2max}$ ↑ 10% Speed @ LT ↑ 11% $\dot{V}O_2$ @ LT ↑ 3% RE	↑ 16% SSC Match: ↑ 4% TD ↑ 26% HSR (>14km·h^{-1})
Jensen et al. (2007)	Elite Scandinavian Youth Age (17 - 20 yr)	16	SSG's	30 min (2-4 min, 1-2 min rest) 1 x wk	Not specified	12 wk	In-season	↑ 5% $\dot{V}O_{2max}$	↑ 15% Yo-Yo IR2 ↑ 21% RSA fatigue index ↔ 30 m sprint time
Sporis et al. (2008a)	Elite Croatian Youth Age (19 ± 2 yr)	24	Running and technical drills with a ball	3 x 20 m; 3 x 40 m; 3 x 60 m; 2 min active rest, 3 x wk	Drill: 90-95% HR_{max} Active Rest: 55-65% HR_{max}	13 wk	Pre-season + In-season	↑ 5% $\dot{V}O_{2max}$	↑ 6% 200 m test ↑ 4% 400 m test ↑ 8% 800 m test ↑ 7% 1200 m test ↑ 7% 2400 m test
Sporis et al. (2008b)	Elite Croatian Age (26 ± 3 yr)	11	Running and technical drills with a ball	4 x 4 min, 3 min rest, 3 x wk	Dribble Track: 90-95% HR_{max}	8 wk	Pre-season	↑ 14% BLC post 300-yard shuttle run test	↑ 2% 300-yard shuttle run
Hill-Haas et al. (2009)	Elite Australian Youth Age (15 ± 1 yr)	10	SSG's (2v2-7v7)	3-6 x (6-13 min, 1-2 min rest), 2 x wk	SSG's: >80% HR_{max}	7 wk	Pre-season	↔ $\dot{V}O_{2max}$	↑ 17% Yo-Yo IR1 ↔ RSA ↔ 5 m & 20 m sprint time
Dellal et al. (2012b)	Amateur French Fifth Division Age (26 ± 5 yr)	11	SSG's (1v1-2v2)	5 x (1.5-2.5 min, 1.5-2.0 min rest) 2 x wk	Not specified	6 wk	In-season	-	↑ 7% Vameval Test Velocity ↑ 5% $V30\text{-}15_{IFT}$
Owen et al. (2012)	Elite Scottish Age (25 ± 4 yr)	15	SSG's (3v3)	5-11 x (3 min, 2 min passive rest) 1-2 x wk (7 sessions)	SSG's: >90% HR_{max}	4 wk	In-season	↑ 5% $\dot{V}O_2$ @ 9 km·h^{-1} ↑ 4% $\dot{V}O_2$ @ 11 km·h^{-1} ↑ 4% $\dot{V}O_2$ @ 14 km·h^{-1} ↑ 13% HR @ 9 km·h^{-1} ↑ 9% HR @ 11 km·h^{-1} ↑ 6% HR @ 14 km·h^{-1}	Small Effect Size: ↑ 1% RSA best sprint time Moderate Effect Size: ↑ 2% RSA total sprint time ↑ 39% RSA % decrement

Reference	Participants	n	Exercise Mode	Protocol	Intensity	Duration	Period	Physiological Adaptation	Performance Changes
Radziminski et al. (2013)	Elite Polish Youth Age (15 ± 1 yr)	9	SSG's (3v3)	5 x 4 min, 3 min active rest, 2 x wk	SSG's: 92% HR_{max}	8 wk	Pre-season	↑ 8% $\dot{V}O_{2max}$	↑ 6% Wingate PP ($W \cdot kg^{-1}$) ↑ 4% Wingate TWC ($J \cdot kg^{-1}$) ↑ 11% DFB SSTT
Jastrezebski et al. (2014)	Competitive Youth Age (16 ± 1 yr)	11	SSG's (3v3 no GKs)	7 x 3 min, 90 s active rest	SSG's: >89% HR_{max}	8 wk	In-season	↑ 9% $\dot{V}O_{2max}$ ↑ 4% AT HR ↑ 13% AT $\dot{V}O_2$	↔ 5 m & 30 m sprint time ↔ Wingate PP ($W \cdot kg^{-1}$)
Wahl et al. (2014)	Semi-professional German Sixth Division Age (26 ± 5 yr)	12	Running, dribble track and SSG's	4 x 4 min, 3 min active recovery, 6 x wk Running 2 x wk Dribble track 2 x wk SSG's 2 x wk	Drills: 90-95% HR_{max}	2 wk	Pre-season	-	↑ 24% Yo-Yo IR2 ↑ 2% RSA mean time ↑ 46% RSA fatigue index ↔ RSA best time
Selmi et al. (2017)	Elite Tunisia Age (18 ± 0 yr)	12	SSG's (3v3)	4 x 4 min, 3 min passive rest, 2 x wk	Not specified	7 wk	In-season	↔ POMS	↑12% Yo-Yo IR1 ↔ 10 m sprint time
Paul et al. (2019b)	Concentrated Group: Elite Qatari Youth Age (16 ± 1 yr)	12	SSG's (4v4) + HI Running	Concentrated (5 x wk): SSG's: 4 x 4 min, 1 min passive rest, 4 x wk. HI Running: 2 x (4-6 min, 90 s rest) 1 x wk	Drills: 84% HR_{max}	4 wk	In-season	-	↑ 8% $V30\text{-}15_{IFT}$ ↔ Agility
	Regular Group: Elite Qatari Youth Age (16 ± 1 yr)	7	SSG's (4v4) + HI Running	Regular (2 x wk): SSG's: 4 x 4 min, 1 min passive rest, 1 x wk. HI Running: 2 x (4-6 min, 90 s rest) 1 x wk	Drills: 73% HR_{max}				↔ $V30\text{-}15_{IFT}$ ↔ Agility

Abbreviations: $30\text{-}15_{IFT}$, 30-15 Intermittent Fitness Test; AT, anaerobic thresholds; BLC, blood lactate concentration; DFB, Deutscher Fussball Bund; GKs, Goalkeepers; HIS, high-intensity simulation; LSPT, Loughborough Soccer Passing Test; LT, lactate threshold; MAS, maximal aerobic speed; No., number; PP, peak power; RCP, respiratory compensation point; RE, running economy; RSA, repeated sprint ability; SSC, soccer specific circuit; SSTT, sport-specific technical test; TD, total distance; TWC, total work completed; UM-TT, University of Montreal Track Test; V, velocity; $\dot{V}O_2$, oxygen uptake; $v\dot{V}o_{2max}$, velocity of $\dot{V}O_{2max}$; wk, week. Changes in physiological adaptation and performance changes only presented for statistically significant measures (P<0.05).

2.5.3 Speed Endurance Training in Soccer

Speed endurance (SE) training is predominantly a form of anaerobic training performed at 'all out' intensity for relatively short periods of time (10-90 s) with the aim to improve physical performance during the most intense periods of play in a match (Iaia et al., 2009b; Mohr & Iaia, 2014). Speed endurance training with a short exercise to rest ratio (1:1-1:3) is termed speed endurance maintenance (SEM) and was designed to improve the ability to repeatedly perform high-intensity efforts (Mohr & Iaia, 2014). Speed endurance protocols with a reduced exercise duration (20-40 s) and greater exercise to rest ratio (1:≥5) is referred to as speed endurance production (SEP) and is developed to improve the ability to perform maximally for a relatively short period of time (Bangsbo, 2015).

Recent research investigating the physiological response to SE training and its effects on physical performance have received growing attention (Iaia & Bangsbo, 2010; Hostrup & Bangsbo, 2017) whilst training intensity has been suggested to have a greater influence on performance improvements than volume or frequency (Mujika et al., 1995). Supramaximal drills require players to have a well-developed aerobic capacity, however much of the early work investigating SE training has been performed on untrained and recreationally active individuals resulting in augmented $\dot{V}O_{2max}$, $\dot{V}O_2$ kinetics, capillarisation and mitochondrial function of skeletal muscle (Jensen, Bangsbo & Hellsten, 2004; Gibala et al., 2006; Burgomaster et al., 2008; Jacobs et al., 2013; Christensen et al., 2016). These physiological adaptations are not often replicated in already trained individuals (Hostrup & Bangsbo, 2017). Instead, enhanced physical performance is attributed to improved K^+ handling (Bangsbo et al., 2009), lactate$^-$-H^+ transport capacity (Gunnarsson et al., 2013), H^+ regulation (Skovgaard et al., 2014) and Ca^{2+} handling function (Ortenblad et al., 2000) necessary to maintain force production (Cairns et al., 2015). An enhanced ability to maintain ion homeostasis is desirable to delay the fatigue induced decline in muscular function necessary to prevent the harmful consequences of ATP depletion (Cheng, Place & Westerblad, 2018).

Defining and discussing SE training interventions in soccer is problematic due to the large variations in protocols. Some interventions prescribe different modes of training whilst others administer training protocols concurrently or consecutively. Repeated short duration sprint (<10 s) protocols are known to promote different metabolic and morphological adaptations than longer duration sprints (Ross & Leveritt, 2001; Fiorenza et al., 2018, 2019), thus in line with recent SE training recommendations such drills were not considered appropriate (Bangsbo, 2015). Nonetheless, a review of the literature found thirteen studies that administered fifteen SE training interventions to soccer players (Tables 2.4-2.5).

2.5.3.1 Physiological Adaptations

Physiological adaptations were measured in seven interventions of which four performed muscle biopsies. Consistent with research in trained individuals, SE training appears to have limited impact on $\dot{V}O_{2max}$ and $\dot{V}O_2$ kinetics in soccer players. Interventions reporting improved $\dot{V}O_{2max}$ were performed during a winter preparation period (Sperlich et al., 2011) or administered to sub-elite players with low levels of baseline fitness (Macpherspon & Weston, 2015; Schmitz et al., 2018). Nonetheless, it would appear SE training may result in small improvements in running economy (~3-6%) during a submaximal run (Christensen et al., 2011; Gunnarsson et al., 2012).

Performance improvements following SE training may be in part attributed to improved ion handling capabilities (Hostrup & Bangsbo, 2017). However, it is difficult to draw clear conclusions regarding the effect of SE training on specific ion handling capabilities in soccer players based on the four mechanistic studies available in the literature. A greater expression of Na^+-K^+ subunits was evident in three of the studies indicating an increase in Na^+-K^+ pumps thought to lower concentrations of extracellular and femoral venous K^+ known to impair muscle excitability (Nielsen et al., 2004; Iaia et al., 2008; Bangsbo et al., 2009). However, these studies were performed during pre-season with very poor levels of baseline fitness (Fransson et al., 2018), concurrently with AHI drills (Thomasson et al., 2010) or with a concomitant reduction in overall training volume (Thomasson et al., 2010; Hostrup et al., 2019). In contrast, when SE training was performed once a week over a 5-week period during the in-season, with training volume maintained, there was a reduction in Na^+-K^+ subunit β_1 and no change in subunits α_1 & α_2 (Gunnarsson et al., 2012). Instead, performance improvements were attributed to an increased expression of lactate$^-$ and H^+ monocarboxylate cotransporter (MCT1), indicating better buffering capacity, in addition to possibly greater capillarisation. Due to the lack of consistency in mechanistic measurements investigated across studies it is difficult to draw definitive conclusions on physiological adaptations as only one study examined changes in capillary density whilst only two studies investigated MCT1 (Thomassen et al., 2010; Gunnarsson et al., 2012).

Research investigating the effect of SE training following a 40-day familiarisation period indicates many of the initial physiological adaptations plateau (Skovgaard, Almquist & Bangsbo, 2018). This information supports the notion that physiological adaptations during pre-season may not be representative of during the competitive season when players have higher levels of fitness. Furthermore, the number of high-intensity training sessions performed over the intervention period in many of the studies is not representative of a typical training programme in elite soccer players (Martin-Garcia et al., 2018b). Therefore, the relevance of the physiological adaptations witnessed following the aforementioned studies is questionable due to the lack of transference to an elite soccer training programme. It is unfortunate that more muscle biopsy data is not available from elite players during the in-season, especially investigating SEM protocols for which information on possible changes in protein and enzyme activity is currently lacking in soccer. However, an unavoidable drawback of muscle biopsy studies is that it is not possible to perform such invasive measures on elite players.

Performance enhancements have also been attributed to an increased expression of Na^+-H^+ exchangers (NHE1) following SE training (Iaia et al., 2008; Skovgaard et al., 2014). Greater expression of NHE1 is thought to increase Na^+ uptake and reduce H^+ within the cell which may in turn increase the number of Na^+-K^+ pumps and the influx of K_{ATP} channels, respectively, thereby reducing extracellular K^+ and counteracting sarcolemmal depolarization (Xu et al., 2001; Street et al., 2005). However, none of the three interventions investigating NHE1 expression reported any changes following SE training in soccer players (Thomassen et al., 2010; Gunnarsson et al., 2012; Fransson et al., 2018). SE training is also proposed to improve Ca^{2+} handling by increasing the sarcoplasmic reticulum Ca^{2+} release during intense exercise, thus delaying declines in muscle performance (Hostrup & Bangsbo, 2017; Cheng, Place & Westerblad, 2018). Interestingly, the study by Hostrup et al. (2019) reported a tendency for dihydropyridine receptor to increase indicating greater Ca^{2+} handling. However, to date this is the only study that has investigated protein activity associated to Ca^{2+} handling in soccer players for which the subjects were amateurs, thus more research is required investigating traditional SE training protocols to make firm conclusions. These data support the concept that fatigue is a highly complex phenomenon and it is likely an interaction of multiple physiological systems that contribute to enhanced performance following a period of SE training.

Table 2.4. Effects of concurrent speed endurance and aerobic high-intensity training in soccer.

Reference	Participants	n	Exercise Mode	Protocol	Intensity	Duration	Period	Physiological Adaptation	Performance Changes
Thomassen et al. (2010); Christensen et al. (2011)	Sub-elite Danish second division Age (23 ± 4 yr)	7	HIA: SSG's SEP: running w/ CODs & parts with ball contacts SEM: running w/ CODs & parts with ball contacts	5 x AHI sessions: 4v4 SSG's, 8 x 2min, 1 min rest 4 x SEP (1:6) sessions: 10-12 x 25-30 s, 3 min rest 1 x SEM (1:1) session: 16 x 40-60 s. ~30% total training time reduced during intervention	AHI SSGs: Mean HR: 88% HR_{max} SEP drills: All out Peak HR: 88% HR_{max} SEM drills: All out Mean HR: 84% HR_{max}	2 wk	After last match of the season	***Submaximal Run: 4 min @75% MAS:*** ↔ $\dot{V}O_2$ kinetics, HR & RER ↑ 2.5% RE during last 30s ***Potassium transporting proteins:*** ↑ 14.5% Na^+-K^+ pump subunits α_2 ↔ Na^+-K^+ pump subunits α_1 & β_1 ↔ AB_FXYD1 signal ↑ 27.3% FXYD1ser68-to-FXYD1 ratio ***pH regulatory proteins:*** ↑ (13.3%) MCT1 ↔ MCT4, NHE1 & NKCC1 expression ***Muscle enzymes & fibre distribution:*** ↔ CS, HAD maximal activity ↑ 17% PDH	↔ Yo-Yo IR2 ↑ 1.9% RSA total time ↔ RSA best 20 m time ↔ RSA fatigue index
Sperlich et al. (2011)	Elite German Youth Age (14 ± 0 yr)	9	Running	6 x (4 x 4 min, 3 min rest) 1 x (6 x 1-4 min, 2 min rest) 4 x (6-8 x 1-2 min, 1-2 rest) 2 x (12 x 30 s, 30 s rest) 3 x (5-15 x 200-800 m, 80-140 s rest)	90-95% HR_{max} Arterial BLC: 8.6 ± 3.5 $mmol \cdot L^{-1}$	5 wk	Winter preparation period	↑ 6.9% $\dot{V}O_{2max}$	↑ 4.2% 1000 m time ↑ 4.3% 20 m sprint time ↑ 4.4% 30m sprint time ↑ 2.8% 40m sprint time
Dellal et al. (2012)	Amateur French Fifth Division Age (26 ± 5 yr)	11	SSG's (no GKs)	AHI 2v2 SSG's: 2 x wk 5 x 2.5 min, 2 min rest, SEM 1v1 SSG's: w x wk 5 x 1.5 min, 1.5 min rest,	Not specified	6 wk	In-season	-	↑ 6.6% vVameval ↑ 5.1% $V30\text{-}15_{IFT}$
Chaouachi et al. (2014)	Elite Tunisian Youth Age (14 ± 1 yr)	12	SSG's (no GKs)	AHI: 3v3 SSG's (1:1) 1-2 x (2 min, 2 min rest) SEM: 2v2 SSG's (1:1-2) 2 x (2-4 x 1 min, 1-2 min rest) SEM: 1v1 SSG's (1:4) 2 x (2-4 x 30 s), 2 min rest	Not specified	6 wk	In-season		↑ 2.1% 15 m sprint time ↑ 2.8% 15 m COD time ↑ 9.1% 15 m COD time w/ ball ↑ 2.5% 20 m zig zag time ↑ 4.8% Reactive agility ↑ 7.5% Reactive agility w/ ball
Hostrup et al. (2019)	Sub-elite Danish Amateurs Age (23 ± 2 yr)	12	Running	2-3 x (5 x 30 s jogging, 20 s moderate speed, 10 s sprint), 4 min rest btw sets ~20% total training time reduced during intervention	Mean HR: ~85% HR_{max} Venous BLC: 10-23 $mmol \cdot L^{-1}$ Venous K^+: 5.5-6.2 $mmol \cdot L^{-1}$	10 wk	In-season	***Muscle MHC-isoform distribution:*** ↔ MHCI & MHCII ***Muscle ion handling & metabolic proteins:*** ↑ 33% Na^+-K^+ pump subunits α_2 ↑ 27% Na^+-K^+ pump subunits β_1 ↑ 24% HAD content ↑ 40% PDH-E1α content ↑ 50% ETC complex I-V ↔ PFK ↑ (11%) DHPR	↑ 18% Yo-Yo IR1 ↔ Agility (T Test) ↔ 30 m sprint time

Table 2.5. Effects of speed endurance production and maintenance training in soccer.

Reference	Participants	n	Exercise Mode	Protocol	Intensity	Duration	Period	Physiological Adaptation	Performance Changes
Gunnarsson et al. (2012)	Sub-elite Danish second division Age (24 ± 0 yr)	18	Drills with & without the ball	SEP (1:6) 1 x wk 1 x (5-9 x 30 s, 3 min rest)	90-95% max intensity	5 wk	In-season	↔ $\dot{V}O_{2max}$ (*n*=7) ***Submaximal Run (n=6):*** ↑ 6% $\dot{V}O_2$ @ 10 km·h^{-1} ↔ $\dot{V}O_2$ @ 14 km·h^{-1} ↔ Blood plasma K^+, BLC, pH ***Potassium transporting proteins (n=6):*** ↓ 13% Na^+-K^+ pump subunit β_1 ↔ Na^+-K^+ pump subunits α_1 ***pH regulatory proteins (n=6):*** ↑ 9% muscular MCT 1 ↔ Muscular MCT4 & NHE1 ***Muscle enzymes & fibre distribution (n=7):*** ↓ 6% Relative No. of Type IIx fibres ↑ (10%) Capillary density, ↔ PFK, CS and HAD	↑ 11% Yo-Yo IR2 ↔ Agility test ↔ 10 & 30 m sprint time
Ingebrigtsen et al., (2013)	Elite Norwegian Youth Age (17 ± 0 yr)	8	Running w/ ~ 1 x COD	SEP (1:6) 1 x wk 1 x (8-10 x 40 s, 4 min rest) 2 x (5-6 x 30 s, 3 min rest) 5 min btw sets	80-100% max running speed	6 wk	8 wk into a 15 wk pre-season	-	↑ 11% Yo-Yo IR2 ↑ 3% 10 m sprint time ↔ RSA mean time ↔ 35 m sprint time
Wells et al. (2014)	Elite English Age (21 ± 2 yr)	8	Running circuits w/ ~4 x COD	SEM (1:3) 3 x wk 1) 2 x (2-4 x 60 s) 2) 2 x (3-5 x 35 s) 3) 2 x (5-7 x 10 s) 2 min active rest btw sets	Runs: >95% HR_{max}	6 wk	In-season	↔ $\dot{V}O_{2max}$ ↔ $\dot{V}O_2$ kinetics ↔ Gas exchange threshold ↑ 8.7%% MART Anaerobic power	↑ 13.1% Yo-Yo IR2
Iaia et al. (2015)	Elite Youth Players Age (19 ± 1 yr)	7	Running w/ 1 COD	SEM: (1:2) 3 x wk 1 x (6-8 x 20 s, 40 s rest)	All out	3 wk	End of the season	-	↑ 3.8% Yo-Yo IR2 ↔ RSA total time ↑ 2.1% 200 m sprint time ↔ 20 & 40 m sprint time
		6		SEP: (1:6) 3 x wk 1 x (6-8 x 20 s, 120 s rest)					↑ 10% Yo-Yo IR2 ↑ 3% RSA total time ↔ 200 m sprint time ↔ 20 & 40 m sprint time
Macpherson & Weston (2015)	English Semi-professional Age (25 ± 4 yr)	14	Running	Development Period SEP: (1:8) 3 x wk 1 x (4-6 x 30 s, 4 min rest)	All out >92% HR_{max}	2 wk	In-season	↑ 3% $\dot{V}O_{2max}$	↑ 18% Yo-Yo IR1 ↑ 4% Time to exhaustion
		7	Running	Maintenance Period SEP: (1:8) 1 x wk 1 x (4-6 x 30 s, 4 min rest)		5 wk	In-season, post 2 wk SEP training	↔ $\dot{V}O_{2max}$	↔ Yo-Yo IR1 ↔ Time to exhaustion

Reference	Participants	n	Exercise Mode	Protocol	Intensity	Duration	Period	Physiological Adaptation	Performance Changes
Mohr & Krustrup (2016)	English sub-elite Age (19 ± 1 yr)	9	Individual drills with the ball to reflect game situations	SEP: (1:5) 2 x wk 1 x (8-10 x 30 s, 150 s rest)	All out Peak speed: 24.5 $km{\cdot}h^{-1}$ Mean speed: 15.5 $km{\cdot}h^{-1}$ Mean HR: 91% HR_{max}	4 wk	In-season	-	↑ 50% Yo-Yo IR2 ↑ 2% RSA mean time ↑ 2% RSA best time ↑ 1% RSA fatigue index
		9	2v2 SSG's	SEM (1:1) 2 x wk 1 x (8-10 x 45 s, 45 s rest)	Maximum effort Peak Speed: 19.2 $km{\cdot}h^{-1}$ Mean speed: 9.4 $km{\cdot}h^{-1}$ Mean HR: 86% HR_{max}				↑ 25.8% Yo-Yo IR2 ↑ 1.3% RSA mean time ↔ RSA peak sprint time ↔ RSA fatigue index
Fransson et al. (2018)	Semi-professional Swedish third division Age (21 ± 2 yr)	21	Running w/ 3 x COD	SEP (1:5) 3 x wk 6-10 x 30 s run, 150 s passive rest, 1 x 6 (wk 1), 1 x 8 (wk 2 & 3) 1 x 10 (wk 4)	Maximum effort Post drill BLC: 11.8 ± 2.8 $mmol{\cdot}L^{-1}$	4 wk	Pre-season (wk 2-6)	***Potassium transporting proteins:*** ↑ 19% α_1 Na^+-K^+ ATPase ↔ α_1, β_1 & FXYD1 Na^+-K^+ ATPase ***pH regulatory proteins:*** ↑ 30% MCT4 protein ↔ NHE1 protein expression & buffering ***Muscle metabolic enzymes:*** ↑ 18% CS maximal activity ↑ 21% HAD maximal activity ↔ Muscle PFK maximal activity	↑ 57% Yo-Yo IR2 ↔ RST mean time ↑ ~30% RSA fatigue index ↔ Arrowhead agility test

Abbreviations: 30-15_{IFT}, Intermittent Fitness Test; BLC, blood lactate concentration; Btw/, between; COD, change of direction; CS, citrate synthase; DHPR, dihydropyridine receptors; ETC, electron transport chain; FXYD1, Phospholemman; HAD, beta-hydroxyacyl-CoA-dehydrogenase; HR, heart rate; IR, intermittent recovery; MART, Maximal Anaerobic Running Test; MHC, myosin heavy chain; NHE1, Na^+/H^+ exchanger isoform 1; NKCC1, Na^+-K^+-2Cl- exchangers; MCT, monocarboxylate cotransporter; PDH, pyruvate dehydrogenase; PFK, phosphofructokinase; RE, running economy; RER, respiratory exchange ratio; RSA, repeated sprint ability; SEM, speed endurance maintenance; SEP, speed endurance production; SSG's, small-sided games; V, velocity; $\dot{V}O_2$, oxygen uptake; w/, with; wk, week. Changes in physiological adaptation and performance changes only presented for statistically significant measures (P<0.05).

2.5.3.2 Effects on Physical Performance

High-intensity intermittent running capacity was the most prevalent performance test assessed across the studies. The Yo-Yo IR1 or IR2 was evaluated in twelve interventions with eleven reporting meaningful improvements in performance. The only intervention that reported no changes in Yo-Yo IR2 performance was administered to elite players with high levels of fitness over a period of only two weeks (Thomassen et al., 2010; Christensen et al., 2011). Furthermore, the two-week intervention was performed at the end of the season when a lack of motivation to perform a maximal test may be a contributing factor, however no heart rate data was reported from the test so it is not possible to affirm this notion. Nonetheless, as with AHI training, greater improvements were evident in high-intensity running capacity compared to $\dot{V}O_{2max}$ and it would appear SE training is a potent method to improve this component of fitness. Positive performance improvements were also reported for continuous field based endurance tests following SE training interventions, however it should be acknowledged they were either performed during the winter preparation period (Sperlich et al., 2011), with amateurs (Dellal et al., 2012; Macpherson & Weston, 2015) or performed currently with AHI training (Sperlich et al., 2011). Performance during repeated sprint tests were assessed following eight SE training interventions with only four studies finding small positive changes, all of which administered SEP protocols, whilst it would appear sprint and agility performance was unchanged in the majority of studies.

Superior performance improvements have been reported following a period of SE training compared with 6v6 SSG's (Fransson et al., 2018). The SEP training drill incorporated three changes of directions and a 1:6 exercise to rest ratio. Significant between groups differences were reported for citrate synthase maximal activity and Yo-Yo IR2 performance following the SE training compared to the SSG's intervention. The SSG's group covered more total distance whilst the SE training group covered more HSR distance and performed more intense accelerations and decelerations (Fransson et al., 2018). It is unfortunate the SE training protocol was not compared to 3v3-4v4 SSG's which have been shown to induce significant improvements in physical performance, induce greater physiological responses and expose players to a greater number of intense accelerations and decelerations than 6v6 SSG's (Sarmento et al., 2018; Dalen et al., 2019).

Direct comparisons of SE training protocols have revealed greater improvements in Yo-Yo IR2 and repeated sprint performance following SEP compared to SEM training when administering matched duration 20 s all-out running bouts (Iaia et al., 2015). Both protocols prescribed 6-8 repetitions that incorporated a single 180° change of direction three times a week for a period of three weeks in elite players. Average running speed was greater during the SEP protocol across repetitions whilst there were no differences in RPE. In contrast, although no between group differences were reported, only the SEM training group improved 200 m sprint performance (Iaia et al., 2015). Similarly, another study reported a greater tolerance to fatigue during repeated shuttle running performance following 4 weeks of SEM compared to SEP training (Vitale et al., 2018). Due to the elite nature of the participants, both studies consisted of small sample sizes (*n*=7-8), however the limited data supports the notion that SEP training improves the ability to perform maximal efforts, whilst SEM training increases the ability to sustain exercise at high-intensity (Iaia & Bangsbo, 2010). Although there would appear to be unique performance improvements associated to both SE training protocols, differences in the specific physiological adaptations are yet to be investigated. Nonetheless, investigations into the physiological responses during specific training protocols provide useful information to indicate how each stimulus may improve physical performance (Ade et al., 2014; Castagna et al., 2017). The following section will discuss the physiological responses attributed to SE soccer drills and where applicable the associated improvements in physical performance.

2.5.3.3 Speed Endurance Soccer Drills

It is generally accepted that SSG's induce similar physiological adaptations and performance improvements as AHI running drills (Impellizzeri et al., 2006; Hill-Haas et al., 2011). However, to date there is limited research investigating the appropriateness of soccer drills as an alternative to all-out running bouts typically prescribed during SE interventions. A review of the literature found ten studies that incorporated soccer drills adhering to SE training parameters with seven reporting physiological response data (Table 2.6). Consistent with SE literature, SEP soccer drills results in greater blood lactate response indicating higher energy contribution from anaerobic metabolism whilst SEM soccer drills result in a higher mean cardiovascular response due to a greater involvement from aerobic pathways (Iaia & Bangsbo, 2010; Ade et al., 2014; Castagna et al., 2017). To date, physiological response data associated to SE SSG's available in the literature is still limited to heart rate and blood lactate concentration. Nonetheless, SSG's that adhere to SE training parameters have been reported to induce similar performance improvements in aerobic fitness and agility as a high-intensity intermittent running programme and pre-planned change of direction training programme (Dellal et al., 2012; Chaouachi et al., 2014). These data support the use of SE SSG's to improve physical performance whilst simultaneously training technical and tactical aspects of the game in addition to soccer specific movement patterns.

Table 2.6. Physiological response to speed endurance soccer drills.

Reference	Participants	n	Exercise Mode	Pitch Area	No. Repetitions	Repetition Duration (s)	Protocol	Mean HR_{max} (%)	Peak HR_{max} (%)	Blood Lactate ($mmol \cdot L^{-1}$)
Aroso et al. (2004)	National standard Age (15-16 yr)	14	2v2 SSG's w/ mini goals	Area: 30 x 20 m Relative: 150 m^2 PPl	3	90	SEM (1:1)	84	-	8.1
Thomassen et al. (2010); Christensen et al. (2011)	Sub-elite Danish second division Age (23 ± 4 yr)	7	All out running drills w/ CODs & parts with ball contacts	n/a	16	40-60	SEM (1:1)	84	-	-
					10-12	25-30	SEP (1:6)	-	88	-
Koklu et al. (2011)	Elite Turkish Youth Age (16 ± 0 yr)	16	1v1 SSG's No GKs	Area: 6 x 18 m Relative: 54 m^2 PPl	6	60	SEM (1:2)	86	-	9.4
Ade et al. (2014)	Elite English Youth Age (17 ± 1 yr)	13	2v2 SSG's w/ mini goals	Area: 27 x 18 m Relative: 122 m^2 PPl	8	60	SEM (1:1)	84	91	6.8
			1v1 SSG's w/ mini goals	Area: 27 x 18 m Relative: 243 m^2 PPl	8	30	SEP (1:4)	82	89	10.2
Mohr & Krustrup (2016)	Sub-elite English university players Age (19 ± 1 yr)	9	2v2 SSG's w/ GKs	Area: 20 x 20 m Relative: 100 m^2 PPl, w/GK = 67 m^2 PPl	8-10	45	SEM (1:1)	80	86	-
			Individual drills with balls to reflect game situations	n/a	8-10	30	SEP (1:5)	81	91	-
Castagna et al. (2017)	Amateur Italian Youth Age (18 ± 1 yr)	14	1v1 SSG's w/ mini goals	Area 30 x 20 m Relative: 300 m^2 PPl	4	30	SEM (1:2)	91	98	7.9
							SEP (1:5)	84	98	9.5
Castagna et al. (2019)	Elite Italian Youth Age (17 ± 0 yr)	19	1v1 SSG's w/ mini goals	Area 30 x 20 m Relative: 300 m^2 PPl	4	30	SEP (1:5)	83	91	11.4
				Area 20 x 20 m Relative: 200 m^2 PPl				79	90	8.8
				Area 20 x 10 m Relative: 100 m^2 PPl				76	86	5.3

Abbreviations: COD, change of direction; GKs, goalkeepers; HR, heart rate; PPl = per player; SSG's, small-sided games; w/, with. Date presented as means.

A recent study by Mohr & Krustrup (2016) compared the effects of SEM 2v2 SSG's and SEP individual drills with balls to reflect game situations. The SEP training resulted in superior performance improvements in not only high-intensity intermittent running capacity but also fatigue index during a repeated sprint test (Mohr & Krustrup, 2016). This data is at odds with previous research reporting SEM training results in an enhanced ability to sustain exercise at high-intensity (Iaia & Bangsbo, 2010; Iaia et al., 2015 Vitale et al., 2018). Greater peak and average running speeds attained during the SEP protocol is expected, however this was also accompanied by greater peak heart rate response compared to the SEM protocol which again is inconsistent with previous research (Ade et al., 2014; Castagna et al., 2017). Thus, it would appear performance improvements are not only influenced by SE protocol but also the mode of exercise. It is likely the individual nature of the drill enabled greater control to achieve maximal exercise intensities throughout each repetition. This is in agreement with an individual AHI soccer specific training drill based on the most intense 4 min period of match play found to exert a higher and less variable mean heart rate compared 4v4 SSG's (Kelly et al., 2013). Furthermore, the individual player SEP drill will have provided a greater opportunity to achieve high running speeds as players were not confined to a defined playing area as with the 2v2 SSG's. Likewise, SEP 1v1 SSG's with a greater relative pitch space resulted in more HSR distance, heart rate response and blood lactate concentrations compared to the same drill on smaller pitch dimensions (Castagna et al., 2019). Additionally, the greater number of players participating in the 2v2 SSG's compared to the individual drill may result in the exercise becoming more intermittent with periods of lower intensity exercise when not directly involved with the ball. This is supported by research indicating higher RPE during SSG's with reduced numbers of players (Little & Williams, 2007) and the large differences in mean running velocity between protocols (Mohr & Krustrup, 2016). Although the authors did not report blood lactate concentration, it can be speculated to have been greater in the SEP protocol, as running drills have been reported to elicit greater physiological responses compared to respective SSG's, with differences attributed to players covering greater HSR and SPR distance (Ade et al., 2014; Castagna et al., 2017). On the other hand, SSG's result in greater acceleration and deceleration distance which are important physical qualities when performing intermittent high-intensity efforts during soccer (Ade et al., 2014; Castagna et al., 2017). This data is consistent with research reporting 4v4 and 6v6 SSG's are insufficient at exposing players to the necessary HSR and SPR demands during peak periods of match play (Dilan et al., 2019). Furthermore, though heart rate and blood lactate responses during SEP SSG's are comparable with previous research shown to improve physical performance, blood lactate concentrations following SEM SSG's are lower than respective running drills in the literature (Mohr et al., 2007; Hostrup & Bangsbo, 2017). Therefore, individualised SE soccer drills that exposure players to HSR whilst training positional demands may be advantageous.

2.6 Summary

A review of the literature revealed physical and technical demands are unique to different playing positions and that typically players in lateral positions have the greatest HSR demands (Table 2.1). Fatigue is thought to occur throughout a match, however the cause for the decline in muscular function is not fully understood and is likely due to a number of complex physiological systems interacting with one another. Specific training methods are proposed to improve the resistance to fatigue, however the multifaceted nature of soccer training must be taken into consideration when administering any interventions. Nonetheless, SE training would appear to be a potent method to improve physical performance in soccer players (Table 2.4 & 2.5). Finally, soccer drills may have the potential to simultaneously train physical and technical qualities and therefore require further investigation.

Currently, no information exists on conditioning drill exposure and distribution throughout a competitive season. Such information would indicate the prevalence of SE training relative to other conditioning drills and identify when such drills are typically prescribed during a microcycle. Prior to the study in Chapter 4, no research had compared the physiological response, time-motion analysis characteristics and reproducibility of SE SSG's and running drills. This information allows practitioners to understand whether SSG's are an appropriate SE stimulus in place of generic running drills with the added benefit of training soccer specific movement patterns and technical skills under fatigue. Although time-motion analysis studies have identified unique position-specific physical and technical demands throughout a match, the data is from general match play. A detailed understanding of the most frequent technical and tactical actions associated to high-intensity running efforts would be advantageous in order to develop position-specific SE drills that represent match situations. Research indicates players not regularly starting matches require additional HSR exposure, however, to date no information exists on the appropriateness of individual position-specific drills to achieve sufficient internal and external load. Finally, it is suggested that high-intensity training induces a period of residual fatigue. Therefore, the time-course recovery kinetics of neuromuscular function should be investigated following SE drills to inform practitioners when best to prescribe such practices within a microcycle.

CHAPTER THREE

PITCH-BASED CONDITIONING EXPOSURE IN ELITE YOUTH SOCCER PLAYERS THROUGHOUT A COMPETITIVE SEASON WITH SPECIAL REFERENCE TO SPEED ENDURANCE TRAINING

PITCH-BASED CONDITIONING EXPOSURE IN ELITE YOUTH SOCCER PLAYERS THROUGHOUT A COMPETITIVE SEASON WITH SPECIAL REFERENCE TO SPEED ENDURANCE TRAINING

3.1 ABSTRACT

Purpose: Quantify the exposure to speed endurance training drills in elite youth soccer players across a competitive season. **Methods:** Secondary data were analysed from an elite male youth soccer team over a 42-week season (*n*=14, mean ± SD, age 17 ± 1 yr; stature 1.77 ± 0.05 m; body mass 72.5 ± 8.2 kg). Soccer conditioning and running drills were categorised as follows: Extensive Endurance (EE), Intensive Endurance (IE), Aerobic High-intensity (AHI), Speed Endurance Maintenance (SEM), and Speed Endurance Production (SEP). Conditioning drill exposure was quantified over the season, specifically across 7 x 6-week mesocycle blocks (B1-7) and ten typical 7-day microcycles (MD-5 to MD-1). **Results:** Drill exposure was greater in SEM and EE compared to IE, AHI and SEP over the season (P<0.01, ES: 0.7-5.6), whilst SEP was the least frequent (P<0.01, ES: 2.3-5.6). Both EE and SEM soccer drill exposure were greater than IE, AHI and SEP (P<0.01, ES: 1.5-6.7) whilst exposure to SEM running drills was greater than other running based drills (P<0.01, ES: 2.7-5.9). Mean heart rates (%HR_{max}) during small-sided games (SSG's) were higher during SEM than EE and IE (P<0.05; ES: 0.9-2.0). The SEM running drills elicited a higher mean %HR_{max} than AHI running drills and SEM SSG's (P<0.01; ES: 0.7-0.9). The SEM modality was the most prescribed drill in B1-2 and B6-7 (40-50% of sessions), whilst SEP was not prescribed at all during B1-3. Moreover, SEM was the second most frequent conditioning drill on MD-5, MD-4 and MD-2 (26-39%), with SEP training only been administered on MD-5 (23%). **Conclusions:** Soccer and running SEM conditioning drills are the most frequent and SEP the least frequent relative to other conditioning drills in elite youth players.

3.2 INTRODUCTION

Competitive matches typically occur once or twice a week interspaced by training sessions aimed to improve technical, tactical, physical and psychological components of the game (Reilly, 2007; Morgans et al., 2014). The primary aim during the pre-season period and early competitive season is to increase physical capacity and performance while during the competitive season the priority is to maintain fitness components (Mujika et al., 2018). Development and maintenance of these qualities requires systematic exposure to a training stimulus to promote physiological adaptation whilst preventing detraining, accommodation or mental staleness (Issurin, 2010; Turner, 2011). Training volume and intensity monitored through heart rate analysis, global position systems (GPS) and subjective ratings of perceived exertion (RPE) have been shown to peak and taper throughout the training week (microcycle) on days relative to a match in elite players (Akenhead, Harley & Tweddle, 2016; Martin-Garcia et al., 2018b). However, no information exists on the seasonal distribution and frequency of soccer drills thought to develop physical qualities.

In order to develop physical performance, various training methods are prescribed such as running and soccer drills (Iaia et al., 2009b). Soccer conditioning drills such as small-sided games (SSG's) ensure efficiency of training time as players are simultaneously exposed to technical skills, tactical actions and specific movement patterns under fatigue. Furthermore, conditioning drills with the ball have been reported to provide greater player motivation compared to running drills (Hill-Haas et al., 2011). Research investigating SSG's, medium and large sided games with the number of players ranging from 1v1 to 11v11 have reported large differences in the associated physiological response and time-motion characteristics (Little, 2009; Clemente et al., 2014). In general, a lower number of players results in a higher exercise intensity due to an increased density of accelerations, decelerations and sprints necessary to execute tackles and shots on goal (Owen et al., 2011). Typically, mean heart rate, blood lactate concentrations and RPE are reduced as the number of players increase from 1v1 to 10v10 (Little, 2009; Clemente et al., 2014). A review of the physiological responses associated to SSG's with different player numbers suggests the prescription of 5v5-8v8 SSG's for lactate threshold development (~85-90% HR_{max}), 3v3-4v4 SSG's for $\dot{V}O_{2max}$ development (90-95% HR_{max}), and 2v2 SSG's for anaerobic development (~8-12 $mmol \cdot L^{-1}$) (Little, 2009). These physiological responses are consistent with more recent research into SSG's (Clemente et al., 2014; Bujalance-Moreno et al., 2018) whilst the heart rate ranges and blood lactate concentrations are in agreement with values shown to improve physical performance in soccer players (Iaia et al., 2009b; Jemni et al., 2018). Thus, a periodization model that uses SSG's to progressively overload the aerobic and anaerobic energy systems at appropriate times throughout a training week and over the course of a season may be advantageous in promoting adaptations necessary for improvements and maintenance of physical performance (Impellizzeri et al., 2006; Hill-Haas et al., 2009; Owen et al., 2012).

Speed endurance (SE) is considered an important component of soccer fitness as it develops the players ability to perform maximal intensity exercise for relatively short periods of time and recover from repeated high-intensity exercise bouts (Iaia et al., 2009b; Bangsbo, 2015). These performance improvements will help players tolerate the most intense periods of play and execute powerful high-intensity actions critical to the outcome of a match (Tenga et al., 2010; Faude et al., 2012). Research investigating the effects of SE training has increased in recent years (Hostrup & Bangsbo, 2017; Fransson et al., 2018; Hostrup et al., 2019), however, to date the exposure to SE training relative to other conditioning drills in elite youth soccer players is unknown. Therefore, the study aimed to quantify the exposure to different modes and protocols of SE training drills performed by elite youth soccer players across a competitive season.

3.3 METHODS

3.3.1 Participants

Secondary data were analysed during an entire competitive season from twenty elite male soccer players representing an English Premier League youth team. Data were collected over 42 weeks from the start of pre-season until the final competitive match of the season (July - April) during which time 269 soccer training sessions (83 double sessions) and 53 matches (30 competitive and 23 friendlies) were scheduled over 201 days. Inclusion criteria for individual data sets specified players must participate in at least 80% of prescribed sessions (training / match) throughout the season. Six players were omitted from analysis due to factors such as leaving, promotion to a senior squad and injury. Therefore, fourteen players were included for analysis and consisted of 2 centre backs, 3 fullbacks, 3 central midfielders, 3 wide midfielders and 3 forwards (mean ± SD, age 17 ± 1 yr; stature 1.77 ± 0.05 m; body mass 72.5 ± 8.2 kg; body fat sum of 8 sites 71.0 ± 17.1 mm). These players had an average training and match time of 13913 ± 1143 and 2736 ± 749 min, respectively. Approval for the study was obtained from the professional club and the appropriate university research ethics committee.

3.3.2 Experimental Design

3.3.2.1 Conditioning Drills

Soccer conditioning drills in the form of small (1v1-4v4), medium (5v5-7v7) and large-sided games (8v8-11v11) were selected based on their widespread use within the applied domain (Van Dort, 1998; Little, 2009). These conditioning drills were delivered in accordance with a ‘football periodization’ model (Verheijen, 2011; 2014) used by numerous elite domestic and international teams (e.g. Holland, South Korea, Russia and Argentina in preparation for major tournaments). Drill parameters for the 1v1 and 2v2 SSG’s were based on anaerobic drill recommendations for SE training (Cable, 2002). The categorization of the conditioning drills was as follows; Extensive Endurance (EE), Intensive Endurance (IE), Aerobic High-intensity (AHI), Speed Endurance Maintenance (SEM) and Speed Endurance Production (SEP). The training parameters for each drill are presented in Table 3.1. Various SSG formats were included in the form of end zone games, games with mini goals and games with goalkeepers. It was not possible to control relative pitch space per player for every SSG throughout the entire season, however coach encouragement and the number of players has been reported to have a greater influence on physiological response than field dimensions (Rampinini et al., 2007a). Running drills were quantified using similar categorizations as the SSG's. Tabata running drills (20 s all out running, 10 s walking × 8 = 4 min) and 2 min runs (>4 repetitions) with an exercise to rest ratio of 2:1 were included as AHI drills alongside 4 min high-intensity runs. The SE running drills used a reduced minimum exercise duration compared to those prescribed for the SSG's (SEM: 10 s vs 30 s, SEP: 5 s vs 20 s, respectively) based on recommendations in the literature (Iaia & Bangsbo, 2010). Speed, agility and off-pitch conditioning were not included in the present study.

Table 3.1. Training parameters for soccer conditioning drills

Physical Categorisation	Drill	Sets & Reps	Rest
Extensive Endurance	8v8-11v11	2-6 × 10-30 min	2 min
Intensive Endurance	5v5-7v7	4-6 × 6-8 min	2-5 min
Aerobic High Intensity	3v3-4v4	6-10 × 3-4 min	1-3 min (2:1)
Speed Endurance Maintenance	1v1-2v2	6-10 × 10/30-90 s	(1:1-1:3)
Speed Endurance Production	1v1-2v2	8-12 × 5/20-40 s	(1:5)

Numbers in parenthesis indicate exercise to rest ratio. Soccer conditioning categories based on 'Football Periodisation' model and physiological response data in the literature (Van Dort, 1998; Little, 2009; Verheijen, 2011).

3.3.2.2 Exposure

The exposure to conditioning drills was quantified over the 42-week season. The season was split into seven six-week mesocycle blocks (B1-7) to investigate the frequency and distribution of conditioning drills in each mesocycle. The competitive season lasted 39 weeks, of which 27 weeks contained a single game (69%), 8 weeks featured 2 games, and 4 weeks featured no games. Of the 27 single-game weeks, 18 weeks were characterized by a 7-day microcycle (67%), and therefore represented the most prevalent microcycle within the season. The frequency and distribution of conditioning drills were analysed during a ‘typical’ seven-day microcycle consisting of a competitive match, six or seven training sessions and two rest days (Table 3.2). Ten typical microcycles took place in weeks 10-13, 15, 20, 32, 35, 39-40. The training sessions of the microcycles were categorized using the “match day minus / plus” format (Owen & Wong, 2009).

Table 3.2. Typical seven day microcycle.

Time	MD	MD +1 / -6	MD -5	MD -4	MD -3	MD -2	MD -1	MD
AM	Match	Off	Training	Training	College	Training	Training	Match
PM			Training	Training*		Training	Off	

Abbreviations: MD, match day. *MD-4 PM Training (*n*=6), Rest (*n*=4).

3.3.3 Heart Rate Response

Heart rate was recorded continuously in 5 s intervals throughout all training sessions and matches using radio telemetry (Polar Team System, Oy, Kempele, Finland). Each player's maximum heart rate (HR_{max}) was determined as the peak values reached in 5 s periods during the Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1) at the beginning of the competitive season. The Yo-Yo IRL1 has been shown to be reproducible and valid in determining the maximal heart rate of an individual (Krustrup et al., 2003; Bangsbo, Iaia & Krustrup, 2008). Mean percentage heart rate during high-intensity training drills was reported when requested from the coaching staff. Heart rate exertion as an indicator of internal training load was quantified using a training impulse (TRIMP) method which evaluates the session volume and intensity scores in predefined training zone. Each zone has a weighting factor for which time spent is multiplied. The accumulated scores from each zone is expressed as arbitrary units (A.U.). The heart rate zones and weighting factors were in line with club protocol based on a typical blood lactate response curve to increasing exercise intensity (Stagno, Thatcher & Somerson, 2007). The heart rate training zones and weighting factors were as follows: Zone 1 = 0-50% HR_{max} x 1.0; Zone 2 = 51-65% HR_{max} x 1.2; Zone 3 = 66-75% HR_{max} x 1.5; Zone 4 = 76-85% HR_{max} x 2.2; Zone 5 = 86-92% HR_{max} x 4.5; Zone 6 = 93-100% HR_{max} x 9.0. Additionally, as an indicator of training intensity, time spent >85% and >90% HR_{max} was calculated for all training drills, sessions and matches (Helgerud et al., 2001; Billows, Reilly & George, 2005). This study pre-dates the inception of the Premier League Elite Player Performance Plan and widespread use of GPS technology thus no external load data was available.

3.3.4 Statistical Analysis

All analyses were conducted using statistical software (SPSS, Chicago, IL, USA). Descriptive statistics were calculated using z scores to verify data normality. Repeated-measures ANOVA tests were used to evaluate differences between conditioning drills and heart rate throughout the season. If appropriate, Bonferroni post hoc tests were applied to identify any localized effects with statistical significance set at $P<0.05$. Differences in mean heart responses were investigated using a Welch's one-way ANOVA to account for the different sample sizes. Bonferroni post hoc tests were applied to identify any localized effects however Games-Howell comparisons were used to identify effects when equal variance was not assumed for heart responses across SSG's protocols. Effect sizes (ES) were calculated and the magnitude of the effect classified as trivial (<0.2), small (>0.2–0.6), moderate (>0.6–1.2), large (>1.2– 2.0), and very large (>2.0–4.0) (Batterham & Hopkins, 2006). Values are presented as means and standard deviations unless otherwise stated.

3.4 RESULTS

3.4.1 Season

Over the 42-week season (July – March), the players completed 77% of all prescribed conditioning sessions with an average of 22 ± 12 sessions missed due to injury (44%), training or playing a match with the U21's (27%) or U17's squad (9%), having a day off or being absent (7%), being ill, on international duty, completing a recovery session (4%) or training with the first team squad (1%). SEM accounted for 35% of all conditioning sessions while EE was the second most frequent conditioning session accounting for 30% of sessions with both performed more than IE, AHI or SEP (*P*<0.01, ES: 0.7-5.6). The least frequent conditioning session was SEP accounting for 8% of all conditioning sessions which was less than all other drills (*P*<0.01, ES: 2.3-5.6; Table 3.3). EE accounted for 50% of all soccer conditioning drills which was greater than any other soccer drill (*P*<0.01, ES: 3.9-6.7) while SEM was the second most frequent soccer drill accounting for 21% of sessions which was greater than IE, AHI and SEP exposure (*P*<0.05, ES: 1.5-3.5). The number of SEM running drills completed over the season was 50-100% greater than other running conditioning sessions (*P*<0.01, ES: 2.7-5.9). SEM accounted for 55% of all running drills while AHI was the second most frequent running drill accounting for 27% of running sessions which was greater than EE, IE and SEP running drill exposure (*P*<0.01, ES: 3.5-5.8). The mean heart rate responses to soccer and running conditioning drills are presented in Figures 3.1 and 3.2. Both AHI and SEM running drills elicited greater mean heart rate responses than the respective SSG's (*P*<0.01; ES = 0.9).

Table 3.3. Number of conditioning drills performed over the season, number of players and mean heart rate response.

	EE	IE	AHI	SEM	SEP	Effect Size
Exposure						
No. Conditioning Sessions	22.5 ± 3.9[$]	9.5 ± 1.3	10.5 ± 2.5	25.9 ± 5.5[$]	5.7 ± 1.4[#]	SEM > EE[a], IE[c], AHI[c], SEP[c]; EE > IE[c], AHI[c], SEP[c]; AHI > SEP[c]; IE > SEP[c]
No. Soccer Conditioning Sessions	22.5 ± 3.9[*]	6.6 ± 1.3	3.6 ± 1.5	9.6 ± 2.4[$]	3.0 ± 1.0	EE > IE[c], AHI[c], SEM[c], SEP[c]; SEM > IE[b], AHI[c], SEP[c]; IE > AHI[c], SEP[c]
No. Running Conditioning Sessions	0.0 ± 0.0[#]	2.9 ± 0.5	8.0 ± 1.9[£]	16.3 ± 3.8[*]	2.7 ± 0.9	SEM > EE[c], IE[c], AHI[c], SEP[c]; AHI > EE[c], IE[c], SEP[c]; IE > EE[c]; SEP > EE[c]
% Running Conditioning Sessions	0.0 ± 0.0[#]	30.6 ± 7.7	76.9 ± 11.1[*]	62.7 ± 7.1[&]	48.1 ± 13.7[&]	AHI > EE[c], IE[c], SEM[b], SEP[c]; SEM > EE[c], IE[c], SEP[b]; SEP > EE[c], IE[b]; IE > EE[c]
No. of Players Available						
No. Players (All Conditioning Sessions)	18.8 ± 1.7[^]	17.0 ± 2.4	13.7 ± 4.1	15.0 ± 2.7	15.5 ± 2.3	EE > IE[a], AHI[b], SEM[b], SEP[c]; IE > AHI[a], SEM[a], SEP[c]
No. Players (Soccer Drills)	18.8 ± 1.7	16.5 ± 2.7	11.4 ± 3.6	14.8 ± 3.3	14.5 ± 2.6	EE > IE[a], AHI[c], SEM[b], SEP[c]; IE > AHI[b], SEP[a]; SEM > AHI[a]; SEP > AHI[a]
No. Players (Running Drills)	-	18.3 ± 0.6	15.6 ± 3.2	15.2 ± 2.4	12.5 ± 1.7	IE > AHI[a], SEM[b], SEP[c]; AHI > SEP[a], SEM > SEP[a]
Heart Rate Response						
Soccer Drill Mean HRmax (%)	78.8 ± 4.7[#]	83.8 ± 4.4	85.9 ± 2.7[&]	87.7 ± 3.7[&]	-	SEM > EE[b], IE[a], AHI > EE[b]; IE > EE[a]
Running Drill Mean HRmax (%)	-	-	88.4 ± 3.0	90.9 ± 3.6[+]	-	SEM > AHI[a]

Abbreviations: EE, extensive endurance; IE, intensive endurance; AHI, aerobic high-intensity; SEM, speed endurance maintenance; SEP, speed endurance production. Data presented as means ± standard deviations. [*]Greater than all other conditioning drills (P<0.05). [$]Greater than IE, AHI and SEP (P<0.01). [£]Greater than EE, IE and SEP (P<0.01). [&]Greater than EE and IE (P<0.05). ^Greater than SEM and SEP (P<0.05). [+]Greater than AHI (P<0.01). [#]Lower than all other conditioning drills (P<0.01). Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

3.4.2 Mesocycles

Players performed a greater number of conditioning sessions during B2 than B1, B3, B6 and B7 (*P*<0.05, ES: 1.2-1.9). Greater conditioning exposure was also evident in B4 compared to B3 and B7 (*P*<0.05, ES: 1.3-1.4), and B1 compared to B3 (P<0.05; ES: 1.3) (Table 3.4). Soccer conditioning sessions were greater during B2 than B1, B3, B4 and B7 (*P*<0.05, ES: 1.2-4.1), whilst exposure during B1 was lower than all other mesocycles (*P*<0.01, ES: 2.7-4.1). Running drill exposure was greater during B1 than any other mesocycle (*P*<0.05, ES: 1.4-8.4) whilst running conditioning sessions were less frequent during B6 compared to B1, B2, B3, B4 and B5 (*P*<0.05, ES: 1.5-8.4). No EE drills were prescribed during B1, however the players participated in more matches than B2, B5 and B7 (*P*<0.01, ES: 1.3-2.4). SEM was the most prescribed conditioning drill within four of the seven six-week training cycles (B1, B2, B6, B7: 40-50%), ranking second in one (B5: 24%) and third in the other two blocks (B3 & B4: 12-20%; Table 3.5). SEP was not prescribed during B1-3 but was the second most frequent in B7 (16%). Heart rate responses were greatest in B1 compared to B2-B6 (*P*<0.05, ES: 1.3-1.8) whilst also being higher in B7 compared to B5 (*P*<0.05, ES: 1.1; Table 3.4). Time spent >85% HR_{max} was greatest during B1 compared to all other mesocycles (*P*<0.05, ES: 1.0-2.0) whilst time >90% HR_{max} was greater during B1 than all mesocycles except B2 (*P*<0.05, ES: 1.1-1.6).

Table 3.4. Number of conditioning drills performed and heart rate response across seven six-week mesocycles.

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Effect Size
Exposure								
No. training sessions	24.0 ± 2.9	24.1 ± 4.6	25.0 ± 5.3	20.3 ± 6.7	21.0 ± 6.7	28.8 ± 5.2	29.1 ± 5.0[^]	B7 > 1^{a}, 2^{a}, 3^{a}, 4^{b}, 5^{b}; B6 > 1^{a}, 2^{a}, 3^{a}, 4^{b}, 5^{b}; B3 > 4^{a}, 5^{a}; B2 > 4^{a}; B1 > 4^{a}
No. matches	8.8 ± 3.1[&]	5.3 ± 2.2	6.9 ± 2.1	5.6 ± 1.8	2.6 ± 1.7[#]	6.4 ± 1.9	4.8 ± 1.4	B1 > 2^{b}, 3^{a}, 4^{b}, 5^{c}, 6^{a}, 7^{b}; B3 > 2^{a}, 4^{a}, 5^{c}, 7^{a}; B6 > 5^{c}, 7^{a}; B4 > 5^{b}; B2 > 5^{b}; B7 > 5^{b}
No. conditioning sessions	11.1 ± 1.2	14.9 ± 4.0[$]	8.4 ± 2.5	13.7 ± 4.6[£]	10.1 ± 3.5	8.4 ± 3.4	8.9 ± 2.3	B2 > 1^{b}, 3^{b}, 5^{b}, 6^{b}, 7^{b}; B4 > 1^{a}, 3^{b}, 5^{a}, 6^{b}, 7^{b}; B1 > 3^{b}, 6^{a}, 7^{a}
No. soccer conditioning drills	1.9 ± 0.4[#]	10.2 ± 2.8[+]	5.9 ± 2.0	7.2 ± 2.1	6.9 ± 2.4	7.0 ± 2.5	6.5 ± 1.7	B2 > 1^{c}, 3^{b}, 4^{a}, 5^{b}, 6^{a}, 7^{b}; B4 > 1^{c}, 3^{c}; B6 > 1^{c}, B5 > 1^{c}; B7 > 1^{c}; B3 > 1^{c}
No. running conditioning drills	9.3 ± 1.0*	4.6 ± 1.5[€]	2.5 ± 0.7	6.5 ± 2.5[?]	3.1 ± 1.3	1.4 ± 0.8[#]	2.4 ± 0.9	B1 > 2^{c}, 3^{c}, 4^{b}, 5^{c}, 6^{c}, 7^{c}; B4 > 2^{a}, 3^{c}, 5^{b}, 6^{c}, 7^{c}; B2 > 3^{b}, 5^{a}, 6^{c}, 7^{b}; B5 > 3^{a}, 6^{b}, 7^{a}; B3 > 6^{b}, B7 > 6^{a}
% conditioning running drills	83.4 ± 2.8*	31.3 ± 6.2	31.4 ± 10.8	45.8 ± 6.9[>]	31.0 ± 7.6	13.9 ± 7.8[#]	26.3 ± 9.7	B1 > 2^{c}, 3^{c}, 4^{c}, 5^{c}, 6^{c}, 7^{c}; B4 > 2^{c}, 3^{b}, 5^{b}, 6^{c}, 7^{c}; B3 > 6^{b}; B2 > 6^{c}; B5 > 6^{c}; B7 > 6^{b}
Conditioning Drill								
No. EE conditioning sessions	0.0 ± 0.0[#]	4.7 ± 1.4[~]	3.4 ± 0.9	6.1 ± 1.5[@]	2.0 ± 1.2	3.1 ± 0.9	3.1 ± 0.9	B4 > 1^{c}, 2^{a}, 3^{b}, 5^{c}, 6^{c}, 7^{c}; B2 > 1^{c}, 3^{a}, 5^{b}, 6^{b}, 7^{b}; B3 > 1^{c}, 5^{b}, B6 > 1^{c}, 5^{a}; B7 > 1^{c}, 5^{a}; B5 > 1^{c}
No. IE conditioning sessions	3.8 ± 0.6[§]	1.7 ± 0.5	0.6 ± 0.5	0.0 ± 0.0	3.4 ± 1.2[§]	0.0 ± 0.0	0.0 ± 0.0	B1 > 2^{c}, 3^{c}, 4^{c}, 6^{c}, 7^{c}; B5 > 2^{b}, 3^{c}, 4^{c}, 6^{c}, 7^{c}; B2 > 3^{c}, 4^{c}, 6^{c}, 7^{c}; B3 > 4^{b}, 6^{b}, 7^{b}
No. AHI conditioning sessions	2.9 ± 0.3[%]	0.6 ± 0.5	1.9 ± 1.0	4.8 ± 2.3[>]	0.0 ± 0.0	0.3 ± 0.5	0.0 ± 0.0	B4 > 1^{a}, 2^{c}, 3^{b}, 5^{c}, 6^{c}, 7^{c}; B1 > 2^{c}, 3^{b}, 5^{c}, 6^{c}, 7^{c}; B3 > 2^{b}, 5^{c}, 6^{b}, 7^{c}; B2 > 5^{b}, 6^{a}, 7^{b}; B6 > 5^{a}, 7^{a}
No. SEM conditioning sessions	4.4 ± 0.9[=]	7.1 ± 2.0[♦]	1.7 ± 0.6	1.6 ± 0.6	2.4 ± 0.9	4.2 ± 2.1	4.4 ± 1.9[=]	B2 > 1^{b}, 3^{c}, 4^{c}, 5^{c}, 6^{b}, 7^{b}; B1 > 3^{c}, 4^{c}, 5^{c}; B7 > 3^{b}, 4^{b}, 5^{b}; B6 > 3^{b}, 4^{b}, 5^{a}; B5 > 3^{a}, 4^{a}
No. SEP conditioning sessions	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.9	2.3 ± 1.1[↑]	0.7 ± 0.5	1.4 ± 0.8	B5 > 1^{c}, 2^{c}, 3^{c}, 4^{a}, 6^{b}, 7^{a}; B7 > 1^{c}, 2^{c}, 3^{c}, 6^{a}; B4 > 1^{c}, 2^{b}, 3^{b}, 6^{a}; B6 > 1^{c}, 2^{c}, 3^{c}
Heart Rate Response								
Heart rate exertion (A.U.)	9435.0 ± 2351.7[♣]	6567.3 ± 1829.6	6464.9 ± 1870.4	5915.6 ± 1729.3	5507.4 ± 1749.2	6918.5 ± 906.9	7120.1 ± 1161.7	B1 > 2^{b}, 3^{b}, 4^{b}, 5^{b}, 6^{b}, 7^{b}; B7 & B6 > 4^{a}, 5^{a}
Time >85% HR_{max} (min)	438.1 ± 169.7[Σ]	285.7 ± 130.8	251.4 ± 98.9	228.4 ± 88.5	171.6 ± 67.6	200.7 ± 66.8	211.4 ± 65.9	B1 > 2^{a}, 3^{b}, 4^{b}, 5^{b}, 6^{b}, 7^{b}; B2 > 5^{a}, 6^{a}, 7^{a}; B3 & B4 > 5^{a}
Time >90% HR_{max} (min)	181.1 ± 116.5[•]	96.4 ± 63.7	77.9 ± 44.1	63.6 ± 39.8	45.6 ± 26.1	52.7 ± 38.8	51.1 ± 25.2	B1 > 2^{a}, 3^{a}, 4^{b}, 5^{b}, 6^{b}, 7^{b}; B2 > 5^{a}, 6^{a}, 7^{a}; B3 > 5^{a}, 7^{a}

Abbreviations: EE, extensive endurance; IE, intensive endurance; AHI, aerobic high-intensity; SEM, speed endurance maintenance; SEP, speed endurance production; B1, mesocycle 1; B2, mesocycle 2; B3, mesocycle 3; B4, mesocycle 4; B5, mesocycle 5, B6, mesocycle 6; B7, mesocycle 7. Data presented as means ± standard deviations. [*]Greater than all other blocks (P<0.05). [^]Greater than B4 and 5 (P<0.05). [&]Greater than B2, 5 and 7 (P<0.05). [$]Greater than B1, 3, 6 and 7 (P<0.05). [£]Greater than B3 and 7 (P<0.05). [+]Greater than B1, 3, 4 and 7 (P<0.05). [?]Greater than B3, 5, 6 and 7 (P<0.05). [€]Greater than B3, 6 and 7 (P<0.05).

[>]Greater than B2, 3, 5, 6 and 7 (P<0.05). [@]Greater than B1, 3, 5, 6 and 7 (P<0.05). [%]Greater than B2, 5, 6 and 7 (P<0.05). [~]Greater than B1, 3 and 5 (P<0.05). [§]Greater than B2, 3, 4, 6 and 7 (P<0.05). [=]Greater than B3, 4 and 5 (P<0.05). [♦]Greater than B1, 3, 4, 5, and 7 (P<0.05). [↑]Greater than B1, 2, 3 and 6 (P<0.05). [♣]Greater than B2, 4, 5 and 6 (P<0.05). [Σ]Greater than B5, 6 and 7 (P<0.05). [•]Greater than B6 (P<0.05). [!]Less than B1, 4, 6 and 7 (P<0.05). [#]Less than all other blocks (P<0.05). Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

Table 3.5. Conditioning drills performed within seven six-week mesocycles.

Mesocycle	EE	IE	AHI	SEM	SEP	Effect Size
Block 1	0.0 ± 0.0	3.8 ± 0.6[$]	2.9 ± 0.3[&]	4.4 ± 0.9[$]	0.0 ± 0.0	SEM > EE[c], IE[a], AHI[c], SEP[c]; IE > EE[c], AHI[b], SEP[c]; AHI > EE[c], SEP[c]
Block 2	4.7 ± 1.4[^]	1.7 ± 0.5	0.6 ± 0.5	7.1 ± 2.0[*]	0.0 ± 0.0[#]	SEM > EE[b], IE[c], AHI[c], SEP[c]; EE > IE[c], AHI[c], SEP[c]; IE > AHI[c]; SEP[c]; AHI > SEP[b]
Block 3	3.4 ± 0.9[*]	0.6 ± 0.5	1.9 ± 1.0[£]	1.7 ± 0.6[£]	0.0 ± 0.0[#]	EE > IE[c], AHI[b], SEM[c], SEP[c]; AHI > IE[b], SEP[c]; SEM > IE[b], SEP[c]; IE > SEP[b]
Block 4	6.1 ± 1.5[*]	0.0 ± 0.0[#]	4.8 ± 2.3[+]	1.6 ± 0.6	1.3 ± 0.9	EE > IE[b], AHI[a], SEM[c], SEP[c]; AHI > IE[c], SEM[b], SEP[b]; SEM > IE[c]; SEP > IE[b]
Block 5	2.0 ± 1.2	3.4 ± 1.2[*]	0.0 ± 0.0[#]	2.4 ± 0.9	2.3 ± 1.1	IE > EE[a], AHI[c], SEM[a], SEP[a]; SEM > AHI[c]; SEP > AHI[c]
Block 6	3.1 ± 0.9[^]	0.0 ± 0.0[#]	0.3 ± 0.5	4.2 ± 2.1[^]	0.7 ± 0.5	SEM > EE[a], IE[c], AHI[c], SEP[c]; EE > IE[c], AHI[c], SEP[c]; SEP > IE[c], AHI[a]; AHI > IE[a]
Block 7	3.1 ± 0.9[^]	0.0 ± 0.0	0.0 ± 0.0	4.4 ± 1.9[^]	1.4 ± 0.8[?]	SEM > EE[a], IE[c], AHI[c]; SEP[b]; EE > IE[c], AHI[c], SEP[b]; SEP > IE[c], AHI[c]

Abbreviations: EE, extensive endurance; IE, intensive endurance; AHI, aerobic high-intensity; SEM, speed endurance maintenance; SEP, speed endurance production. Data presented as means ± standard deviations. [$]Greater than EE, AHI and SEP (*P*<0.05). [&]Greater than EE and SEP (*P*<0.05). [*]Greater than all other conditioning sessions (*P*<0.05). [^]Greater than IE, AHI & SEP (*P*<0.05). [£]Greater than IE and SEP (*P*<0.05). [+]Greater IE, SEM and SEP (*P*<0.05). [?]Greater than IE and AHI (*P*<0.05). [#]Less than all other conditioning sessions (*P*<0.05). Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

3.4.3 Microcycles

During typical one game week microcycles (*n*=10) more conditioning drills took place on MD-4 accounting for 49% of all conditioning sessions compared to all other training days ($P<0.01$, ES: 1.3-4.6) with MD-5 the second most prevalent training day accounting for 33% of the weekly conditioning ($P<0.01$, ES: 1.5-4.7; Table 3.6). No conditioning sessions took place on MD-3 (day off) or MD-1. SEM was the second most frequent conditioning drill on MD-5, MD-4 and MD-2 (26-39%) following EE, whilst IE and SEP were only administered on MD-5 (23%) (Table 3.7). Heart rate exertion was greater on MD-5, -4 and -2 compared to MD-1 ($P<0.01$, ES: 2.4-5.5; Table 6). Time >85% HR_{max} was greater on MD-4 and MD-2 compared to MD-1 ($P<0.05$, ES: 2.1-2.2) whilst time >90% HR_{max} was greater on MD-4 compared to MD-1 ($P<0.05$, ES: 1.6).

Table 3.6. Conditioning drills performed across the five days preceding a match during a typical microcycle (*n*=10).

Exposure	**Match Day -5**	**Match Day -4**	**Match Day -3**	**Match Day -2**	**Match Day -1**	**Effect Size**
Training duration (min)	119.0 ± 10.5[£]	136.7 ± 33.6[£]	0.0 ± 0.0[#]	146.1 ± 14.3[^]	73.5 ± 11.8[!]	MD-2 > -5[c], -2[c], -1[c]; MD-4 > -5[a], -2[c], -1[c]; MD-5 > -1[c]
No. conditioning sessions	6.2 ± 1.8[$]	9.3 ± 2.8[*]	0.0 ± 0.0[!]	3.6 ± 1.5	0.0 ± 0.0[!]	MD-4 > -5[b], -2[c], -1[c]; MD-5 > -2[b], -1[c]; MD-2 > -1[c]
No. EE sessions	1.7 ± 0.5[£]	4.6 ± 1.4[*]	0.0 ± 0.0[!]	1.6 ± 0.5[£]	0.0 ± 0.0[!]	MD-4 > -5[c], -2[c], -1[c]; MD-5 > -1[c]; MD-2 > -1[c]
No. IE sessions	0.8 ± 0.4[*]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	MD-5 > -4[c], -2[c], -1[c]
No. AHI sessions	0.7 ± 0.5[£]	1.9 ± 1.0[*]	0.0 ± 0.0[!]	0.6 ± 0.5[£]	0.0 ± 0.0[!]	MD-4 > -5[b], -2[b], -1[c]; MD-5 > -1[c]; MD-2 > -1[b]
No. SEM sessions	1.6 ± 0.6[£]	2.9 ± 1.1[*]	0.0 ± 0.0[!]	1.4 ± 0.7[£]	0.0 ± 0.0[!]	MD-4 > -5[b], -2[b], -1[c]; MD-5 > -1[c]; MD-2 > -1[c]
No. SEP sessions	1.4 ± 0.8[*]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	MD-5 > -4[c], -2[c], -1[c]
Heart rate exertion (A.U.)	363.7 ± 94.5	425.3 ± 98.0	0.0 ± 0.0[#]	457.9 ± 58.9	184.6 ± 33.7[!]	MD-2 & MD-4 > -5[a], -1[c]; MD-5 > -1[c]
Min >85% HR_{max}	10.4 ± 7.1	16.1 ± 7.7[£]	0.0 ± 0.0[#]	15.0 ± 7.6[£]	3.3 ± 1.2	MD-4 > -5[a]; -1[c]; MD-2 > -1[c]; MD-5 > -1[b]
Min >90% HR_{max}	2.4 ± 2.3	4.2 ± 3.1	0.0 ± 0.0[#]	4.4 ± 3.4[£]	0.5 ± 0.3	MD-2 & MD-4 > -5[a], -1[b]; MD-5 > -1[a]

Abbreviations: EE, extensive endurance; IE, intensive endurance; AHI, aerobic high-intensity; SEM, speed endurance maintenance; SEP, speed endurance production; MD-, match day minus. Data presented as means ± standard deviations. [*]Greater than all other days (*P*<0.05). [^]Greater than MD-5, -3 and -1 (*P*<0.05). [$]Greater than MD-3, -2 and -1 (*P*<0.05). [£]Greater than MD-3 and -1 (*P*<0.05). [!]Less than MD-5, -4 and -2 (*P*<0.05). [#]Less than all other days (*P*<0.05). Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

Table 3.7. Conditioning drills performed within the five days preceding a match during a typical microcycle (*n*=10).

Microcycle Day	EE	IE	AHI	SEM	SEP	Effect Size
Match Day -5	1.7 ± 0.5[^]	0.8 ± 0.4	0.7 ± 0.5	1.6 ± 0.6[^]	1.4 ± 0.8	EE > IE[b], EI[c]; SEM > IE[b], EI[b]; SEP > IE[a], EI[a]
Match Day -4	4.6 ± 1.4[*]	0.0 ± 0.0	1.9 ± 1.0[&]	2.9 ± 1.1[&]	0.0 ± 0.0	EE > IE[c], EI[c], SEM[b], SEP[c]; SEM > IE[c], EI[a], SEP[c]; EI > IE[c], SEP[c]
Match Day -3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	
Match Day -2	1.6 ± 0.5[$]	0.0 ± 0.0	0.6 ± 0.5[£]	1.4 ± 0.7[$]	0.0 ± 0.0	EE > IE[c], EI[b], SEP[c]; SEM > IE[c], EI[a], SEP[c]; EI > IE[b]; SEP[b]
Match Day -1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	

Abbreviations: EE, extensive endurance; IE, intensive endurance; AHI, aerobic high-intensity; SEM, speed endurance maintenance; SEP, speed endurance production. Data presented as means ± standard deviations. [*]Greater than all other conditioning sessions (*P*<0.05). [^]Greater than IE and AHI (*P*<0.05). [$]Greater than IE, AHI and SEP (*P*<0.05). [£]Greater than AHI and SEP (*P*<0.05). [&]Greater than IE and SEP (*P*<0.05). Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

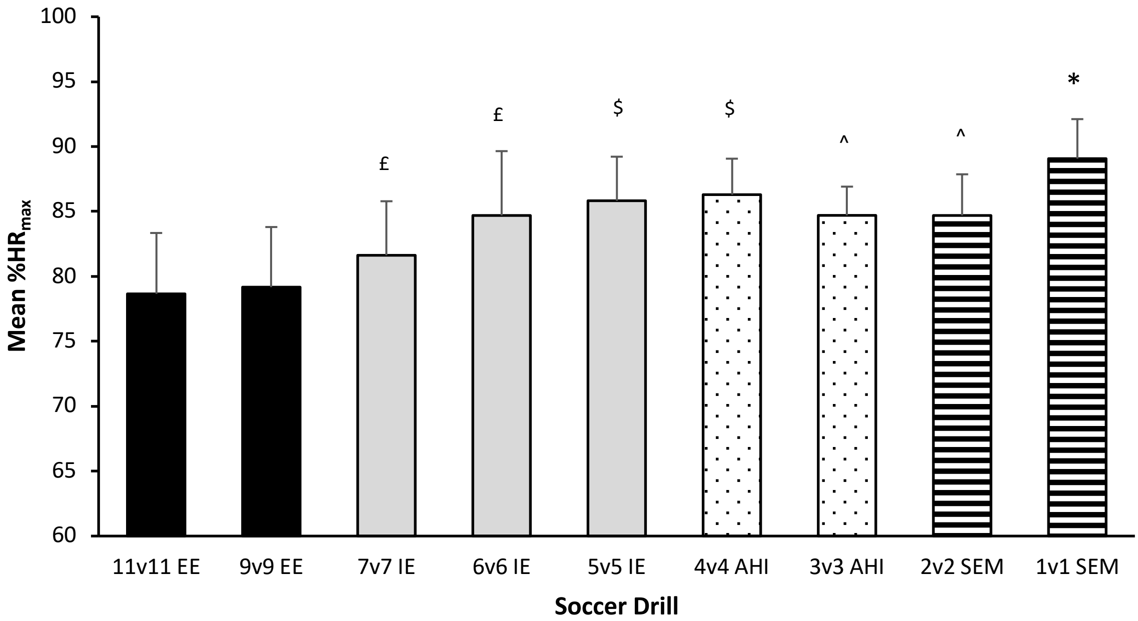


Figure 3.1. Heart rate response during soccer conditioning drills. *Greater than 2v2, 3v3, 4v4, 5v5, 7v7, 9v9 and 11v11 drills (*P*<0.05, ES = 0.9-2.4). $^{\$}$Greater than 7v7, 9v9 and 11v11 drills (*P*<0.01, ES = 1.1-1.8). ^Greater than 9v9 and 11v11 drills (*P*<0.01, ES = 1.3). $^{£}$Greater than 11v11 drill (*P*<0.05, ES = 0.6-1.3). 11v11 EE (7 session, *n*=96); 9v9 EE (2 sessions, *n*=29); 7v7 IE (3 sessions, *n*=32); 6v6 IE (1 session, *n*=13); 5v5 IE (3 sessions, *n*=29); 4v4 AHI (3 sessions, *n*=27), 3v3 AHI (1 session, *n*=10); 2v2 SEM (1 session, *n*=13); 1v1 SEM (2 sessions, *n*=28). EE, extensive endurance; IE, intensive endurance; AHI, aerobic high-intensity; SEM; speed endurance maintenance. Values are mean ± SD.

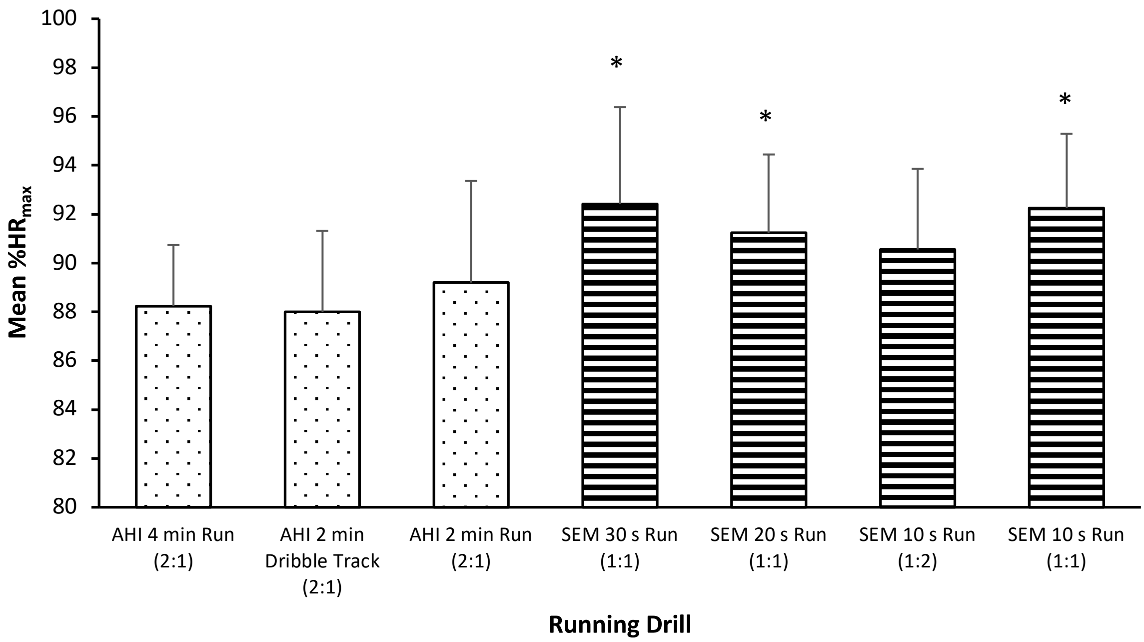


Figure 3.2. Heart rate response during running conditioning drills. *Mean HR$_{max}$ greater than AHI 4 min run (P<0.05, ES = 1.0-1.4). AHI 4 min Run (3 sessions, n=26); AHI 2 min Dribble Track (1 session, n=5); AHI 2 min Run (1 session, n=10); SEM 30 s Run (1 session, n=12); SEM 20 s Run (2 sessions, n=25); SEM 10 s Run (1:2) (4 session, n=38); SEM 10 s Run (1:1) (2 sessions, n=24). AHI, aerobic high-intensity; SEM, speed endurance maintenance. Numbers in parenthesis of drill description indicate exercise to rest ratio. Values are mean ± SD.

3.5 DISCUSSION

The present study was the first to quantify drill exposure in elite youth soccer players throughout a competitive season. The main findings were that players were predominantly exposed to SEM and EE conditioning over the 42-week season. The least frequent conditioning drill performed was SEP, however both SEP and SEM displayed the most equal distribution between soccer and running drills. The greater exposure to EE soccer conditioning drills over the season is not surprising as large-sided games best replicates the decision-making processes during a match, enabling the coach to develop tactical skills which are positively related to elite soccer performance (Kannekens, Elferink-Gemser & Visscher, 2009). Nonetheless, the most frequently performed conditioning session across the season was SEM training closely followed by EE training. The time efficient manner of SEM training is appealing as running or soccer drills only require a minimal dose of 4 or 12 min total time respectively, thus allowing the coaches more time to work on technical and tactical skills. SE soccer drills were often prescribed in the form of 1v1 / 2v2 SSG's or possessions using mini goals early in the session whilst goalkeepers performed specific work in isolation.

The higher exposure to SEM running drills compared to soccer drills may have been due to the shorter minimal dose duration or the ability to provide a physiological stimulus whilst concurrently unloading explosive actions such as kicking, jumping and changes of direction that place high mechanical stress on the neuromuscular system (Nedelec et al., 2012; Mohr et al., 2016; Devrnja & Matković, 2018). This concept was employed during the preseason period (B1) in an effort to avoid soft tissue injuries known to be prevalent at the beginning of the season (Walden, Hagglund & Ekstrand, 2005). Further reasons for administering running drills instead of soccer drills include challenging the players mentality by prescribing something they do not enjoy, whilst identifying those who are lacking fitness as players can pace themselves during SSG's (Los Arcos et al., 2015; Lacombe et al., 2018). Nonetheless, SEM running drills have been found to enhance repeated sprint and high-intensity intermittent running performance in elite male soccer players (Thomassen et al., 2010; Ingebrigtsen et al., 2013; Iaia et al., 2015). It would be of interest to establish whether SEM 1v1 and 2v2 SSG's are able to provide the same physiological response and improvements in physical performance as the running drills in the literature, as such drills would ensure player motivation whilst concurrently training soccer specific movement patterns and technical skills under fatigue (Hill-Haas et al., 2011).

The limited mean heart rate data collected during the conditioning drills indicate SEM SSG's resulted in a greater heart rate response than IE and EE soccer drills and are similar to SSG's interventions shown to improve physical performance (Bujalance-Moreno et al., 2019). Based on recommendations in the literature, such drills may therefore be appropriate to improve aerobic and anaerobic performance when administered twice a week, prescribing 4 to 8 repetitions that accumulate a work duration longer than 12 min for a minimum period of four weeks (Bujalance-Moreno et al., 2019). Similarly, mean heart rate during SEM running drills were higher than AHI running drills but also slightly higher than the SEM SSG's. However, future research should compare SEM modes using matched protocols with the same sample size. Additionally, an investigation comparing the blood lactate concentration, RPE, time-motion characteristics and reproducibility of each SEM mode would provide further information on the appropriateness of SEM SSG's.

In contrast, SEP training was the least frequent training stimulus across the season with no exposure until B5. The relative distribution of running and SSG SEP sessions was almost equal but as with the SEM drill, the running mode requires less time for a minimal dose (3 vs 10 min). Without a detailed understanding of the physiological responses associated to SEP SSG's, it is difficult to justify prescribing such drills with a short exercise duration and relatively long recovery period when training time is limited and the emphasis is on developing technical skill not only physical performance in elite youth soccer players (Simmon, 2004; Vaeyens et al., 2008; Morley et al., 2014). Training interventions that administered SEP as all out running drills have been shown to improve sprint, submaximal and high-intensity intermittent running performance in moderately trained runners (Iaia et al., 2008; Bangsbo et al., 2009; Iaia et al., 2009a). However, to date the appropriateness of SSG's as SEP drills is yet to be investigated. An in-depth analysis into the physiological response, time-motion characteristics and reproducibility of SEP SSG's compared to SEM SSG's and respective running drills would be advantageous to indicate whether they warrant further inclusion in an already comprehensive soccer training programme.

Analysis of the season in seven six-week mesocycles revealed there was a greater exposure to conditioning sessions during the first half of the season whilst the relative exposure to SEM and SEP drills increased at the end of the season. These findings are consistent with recommendations to develop fitness early in the competitive season before reducing training volume towards the end of the season to maintain fitness and minimise chronic fatigue (Reilly, 2007; Thomassen et al., 2010; Mujika et al., 2018). These data in addition to the fact both SEM and SEP soccer drills were prescribed irrespective of the number of players available to train indicate adherence to a periodisation model. A clear periodisation model was evident for conditioning exposure during 'typical' seven-day microcycles with sessions predominantly delivered on MD-4 with an appropriate taper before the match in an effort to allow fatigue induced by the physical stimulus to dissipate and enable supercompensation (Turner, 2011; Mujika et al., 2018). The data in the present study is in agreement with analysis of external and internal training load of the first team squad at the same professional soccer club that reported greater total distance, high speed running and sprinting distances, acceleration and deceleration distances and time spent over 90% HR_{max} on MD-4 (Akenhead et al., 2016). However, the low occurrence of 'typical' seven-day microcycles (*n*=10) in the present study indicates there is a need for an adaptable training programme which supports individual player development and fits around the dynamic nature of soccer training (Kiely, 2012, 2017).

Unsurprisingly, internal load quantified using heart rate analysis within mesocycles does not appear to be related to conditioning drill exposure alone. Instead, heart rate exertion may be related to the number of training sessions and matches evident in B1, B6 and B7. In contrast, the internal load during the typical microcycle would appear to be consistent with conditioning drill exposure. However, the reader should be aware of the limitations of the current study. The heart rate exertion method used did not alter the weighting for each zone based on individual lactate curves. Therefore, the internal load quantification method may have been inappropriate for some players (Akubat et al., 2012). Furthermore, the study was retrospective using secondary data to categorise on-pitch conditioning drills based on specific training parameters. Heart rate monitors were worn but drills were only analysed for time spent above 85% and 90% HR_{max} in line with club protocol. Ideally, the study would have monitored the time spent in individualised heart rate zones and RPE to gain a greater understanding of internal load. Furthermore, only occasional drills were split to investigate the players mean heart rate response at the request of the coach. Although an original study would have enabled a more comprehensive analysis of cardiovascular load and subjective measures associated to the conditioning drills, the retrospective design was necessary to prevent researcher bias so not to influence training prescription due to employment as a member of the coaching staff. Nonetheless, based on the findings of the present study, future research should examine whether SSG's provide the same physiological response and physical demands as matched running drills. Such drills would ensure player motivation whilst concurrently training soccer specific movement patterns and technical skills under fatigue.

3.6 CONCLUSION

The main findings were that players were predominantly exposed to SEM and EE conditioning over the 42-week season. EE was the most frequent soccer conditioning drill followed by SEM, whilst SEM was the most frequent running drill followed by AHI. A greater number of conditioning sessions were performed during the first half of the season during B1-4, while there was an increase in SEP training during B5-7 with a concomitant reduction in AHI training. Finally, conditioning exposure was greatest on MD-4 during a ‘typical’ one game week microcycle.

3.7 PERSPECTIVE

A very high proportion of the conditioning programme delivered to elite youth soccer players consisted of SEM training, however exposure to SEP training was limited. Due to the prevalence of SEM drills, it is necessary to examine differences in modes to allow practitioners to make informed decisions when devising training sessions. Heart rate response to SEM SSG’s is comparable to SEM running drills, however further research is needed evaluating the physiological response, time-motion characteristics and reproducibility of matched duration protocols. This information would also be welcomed for SEP SSG’s to evaluate whether such drills are appropriate to develop anaerobic capacity whilst concurrently exposing players to soccer specific movement patterns, technical skills and decision making under fatigue.

CHAPTER FOUR

THE PHYSIOLOGICAL RESPONSE, TIME-MOTION CHARACTERISTICS AND REPRODUCIBILITY OF VARIOUS SPEED ENDURANCE DRILLS IN ELITE YOUTH SOCCER PLAYERS: SMALL-SIDED GAMES VS GENERIC RUNNING

THE PHYSIOLOGICAL RESPONSE, TIME-MOTION CHARACTERISTICS AND REPRODUCIBILITY OF VARIOUS SPEED ENDURANCE DRILLS IN ELITE YOUTH SOCCER PLAYERS: SMALL-SIDED GAMES VS GENERIC RUNNING

4.1 ABSTRACT

Purpose: To quantify the physiological responses, time-motion characteristics and reproducibility of various speed endurance production (SEP) and maintenance (SEM) drills. **Methods:** Twenty-one elite male youth soccer players completed four drills: (1) SEP 1v1 small-sided games (SSG's), (2) SEP running drill, (3) SEM 2v2 SSG, (4) SEM running drill. Heart rate response, blood lactate concentration, subjective ratings of perceived exertion (RPE) and time-motion characteristics were recorded for each drill. **Results:** The SEP and SEM running drills elicited greater (P<0.05) heart rate responses, blood lactate concentrations and RPE than the respective SSG's (ES: 1.1-1.4 & 1.0-3.2). Players covered less (P<0.01) total distance and high-intensity distance in the SEP and SEM SSG's compared to the respective running drills (ES: 6.0-22.1 & 3.0-18.4). Greater distances (P<0.01) were covered in high-maximum acceleration/deceleration bands during the SEP and SEM SSG's compared to the respective running drills (ES: 2.6-4.6 & 2.3-4.8). The SEP SSG and generic running protocols produced greater (P<0.05) blood lactate concentrations than the respective SEM protocols (ES: 1.2-1.7). Small-moderate test-retest variability was observed for heart rate response (CV: 0.9-1.9%), RPE (CV: 2.9-5.7%) and blood lactate concentration (CV: 9.9-14.4%). Moderate-large test-retest variability was observed for high-intensity running parameters (CV: >11.3%) and the majority of accelerations/deceleration distances (CV: >9.8%) for each drill. **Conclusions:** The data demonstrate the potential to tax the anaerobic energy system to different extents using speed endurance SSG's and identify SSG's elicit greater acceleration/deceleration load compared to generic running drills

4.2 INTRODUCTION

Soccer is an intermittent sport which encompasses brief bouts of high-intensity running and longer periods of low-intensity exercise (Rampinini et al., 2007b). Although aerobic energy production dominates energy provision in soccer, elite players perform up to 250 brief high-intensity actions during a match producing peak blood lactate concentrations of 10-14 $mmol \cdot L^{-1}$ (Krustrup et al., 2006). This indicates the high anaerobic demands during intense periods of play (Bangsbo, 1994). To enable players to cope with these demands, high-intensity aerobic and anaerobic training is prescribed (Iaia et al., 2009b). Speed endurance (SE) training is a form of high-intensity anaerobic training which can be categorised as speed endurance production (SEP) or speed endurance maintenance (SEM) (Iaia & Bangsbo, 2010). The term SE may be misleading when associated to soccer as the aim is not to train at maximum or near maximum velocity but to overload the anaerobic system to improve performance of match related high-intensity activities consisting of frequent changes of direction and consequently speed. The energy contribution from creatine phosphate, anaerobic glycolysis, and aerobic metabolism is dependent on the bout duration and work to rest ratio (Iaia & Bangsbo, 2010). Training guidelines recommends SEP encompasses exercise bouts with a short duration (20-40 s) and extensive recovery period (≥5 times exercise duration) to train the anaerobic glycolytic system. In contrast, SEM training incorporates exercise bouts with a varied duration (10-90 s) with reduced rest periods (1-3 times exercise duration) to train both the anaerobic glycolytic and oxidation systems (Bangsbo, 1994; Bangsbo, 2015). Research recommends SEP training to improve the players' ability to perform maximal high-intensity activities for a relatively short period while SEM training is recommended to enhance the players' capacity to sustain high-intensity activities and recover from intense periods (Iaia & Bangsbo, 2010). Research demonstrates that SEP and SEM training can enhance repeated sprint ability, intense intermittent running capacity, anaerobic power and running economy during sub-maximal running (Thomassen et al., 2010;

Gunnarsson et al., 2012; Wells et al., 2014; Iaia et al., 2015). Studies have typically employed intermittent high-intensity running and/or sprint training modalities to develop SE performance. At the time of writing this study, there was limited available information on the appropriateness of various small-sided games (SSG's) to develop SE capabilities despite elite youth soccer players regularly participating in SEM SSG's throughout a competitive season (Chapter 3).

It has been suggested that anaerobic capacity could be developed with 2v2 SSG's using 60 s exercise bouts with an exercise to rest ratio of 1:1, but no physiological response or reproducibility data were provided (Reilly & Bangsbo, 1998). Although research has investigated the physiological response of 2v2 SSG's, the repetition duration is outside the recommended range (>90 s) to be considered a SE drill with protocols encompassing various durations from 2-24 min (Little & Williams, 2006, 2007; Dellal et al., 2008; Hill-Haas et al., 2009; Koklu et al., 2011; Brandes et al. 2012; Dellal et al., 2012; Koklu, 2012). There is scant research relating to the physiological response and time-motion characteristics of SSG's that have adhered to specific SE recommendations. For instance, authors have quantified the physiological response of SEM 1v1 and 2v2 SSG's using 60-90 s exercise bouts with an exercise to rest ratio of 1:1-1:2 across 3-6 repetitions on various pitch dimensions (Aroso et al., 2004; Dellal et al., 2008; Koklu et al., 2011). However, the number of repetitions prescribed are lower than recommended SE protocols (Mohr et al., 2007; Iaia et al., 2009a), most of the pitch dimensions are considered small (Little 2009) and the 90 s repetition duration is approaching the upper end of the SE range (Bangsbo, 1994; Iaia & Bangsbo, 2010). An in-depth examination of the physiological responses elicited through various speed-endurance drills could provide insight into the differential response of SEP and SEM SSGs for taxing various energy systems and thus provide information on optimal training prescription.

4.3 METHODS

4.3.1 Participants

Sixteen elite male soccer players that represented an English Premier League youth team were used in this study (mean ± SD; age 17 ± 1yr, height 1.80 ± 0.06 m and body mass 75.3 ± 8.5 kg). This sample included players from various playing positions (centre backs *n*=4, fullbacks *n*=4, central midfielders *n*=4, wide midfielders *n*=5 and forwards *n*=4). All players and parents were fully informed of the experimental procedures and associated risks before giving informed consent and the study was approved by the appropriate University Research Ethics Committee. The subjects were free to withdraw from the study at any time without the need to give a reason.

4.3.2 Experimental Design

Players completed four drills: (1) SEP 1v1 SSG, (2) SEP running drill, (3) SEM 2v2 SSG and (4) SEM running drill. The SEP drills consisted of eight bouts of 30 s with 120 s recovery (1:4 exercise to rest ratio) whilst SEM drills encompassed eight bouts of 60 s with 60 s recovery (1:1 exercise to rest ratio). The 30 and 60 s exercise periods were designed to fall within the original range for SEP and SEM training recommendations (Bangsbo, 1994). Although the SEP exercise to rest ratio is below the recommended guidelines, it was the maximum time allocated by the coaching staff and was considerably greater than the exercise to rest ratio for the SEM drill. A repeated measures design incorporating a one-week period between testing sessions was used to establish the physiological response, time-motion characteristics and reproducibility of the SEP and SEM drills. Between groups differences in physiological response and time-motion characteristics during the SSG and generic running drill modalities were established using the same respective subjects for each variable. Additionally, between groups differences in physiological response and time-motion characteristics during the SEP and SEM protocols were established using the same respective subjects for each variable. The sample size for the analysis of drills differed due to player and equipment availability. Physiological response and time-motion characteristic data from the subject's initial test was used to analyse between groups differences. Testing sessions were conducted between March-May and preceded by a standardised 15-min warm-up. Testing took place at the same time of day, in the same order, with verbal encouragement throughout. All players were familiarised with the experimental procedures and drills prior to the study.

4.3.2.1 Speed Endurance Drills

The SEP and SEM running drills involved eight repetitions of continuous running across the length of a pitch (105 x 68 m) for 30 and 60 s interspersed by 120 and 60 s recovery, respectively. Players were instructed to cover as much distance as possible during the allocated time for each running drill. The SEP and SEM soccer drills involved 1v1 and 2v2 SSG's consisting of eight games of 30 and 60 s separated by 120 and 60 s recovery, respectively (Reilly & Bangsbo, 1998). In accordance with previous research, all drills were played on pitch dimensions of 27 × 18 m with unattended mini goals (Aroso et al., 2004; Sampaio et al., 2007). The player/team that scored a goal retained possession but had to return to their half to receive the next ball from the coach. To ensure a high tempo the coach fed balls into the players as soon as a goal was scored or a ball went out of play. Players were required to start each repetition on their goal line and enter the opposition's half to score. Each player started four repetitions in possession of the ball with the coach alternating the service. Players were matched according to their physical capacity (Yo-Yo intermittent recovery test level 1 performance) and skill level (opinion of the coaching staff).

4.3.3 Experimental Measures

4.3.3.1 Physiological and Perceptual Response

Heart rate was recorded continuously in 5 s intervals throughout the drills using radio telemetry (Polar Team System, Oy, Kempele, Finland) and the mean and peak heart rate quantified. Player HR_{max} was determined prior to the study using peak values attained during the Yo-Yo intermittent recovery test level 1. Capillary blood samples were collected from a finger at rest and on completion of the eighth repetition for each drill. The sample at rest verified players had acceptable blood lactate concentrations before each drill to be included in the analysis, while samples collected after the eighth repetition were used to test within drill differences. Blood was analysed immediately for lactate concentration using an automated analyser (Lactate Pro, Arkray, Kyoto, Japan). Manufacturer calibration strips were inserted into the lactate analysers before each test to calibrate the analysers automatically. Lactate Pro analysers display good reliability (intra-TE = 0.5 $mmol \cdot L^{-1}$, inter-TE = 0.4 $mmol \cdot L^{-1}$), accuracy (r = 0.91) and limits of agreement (<2.1 $mmol \cdot L^{-1}$) compared to laboratory-based Yellow Springs Instruments (Medbø et al., 2000; Tanner, Fuller & Ross, 2010). Subjective ratings of perceived exertion (RPE) were recorded after each repetition using the 6-20 scale (Borg, 1998).

4.3.3.2 Time-motion Characteristics

Time-motion characteristics were quantified using microelectromechanical system (MEMS) devices (Catapult MinimaxX S4, Catapult Innovations, Scoresby, VIC, Australia) harnessed between the shoulder blades and anchored using an undergarment to restrict movement artefact. MEMS devices containing a global positioning system (GPS) processor with a sample frequency of 10 Hz have previously been shown to provide a valid and reliable measure of instantaneous velocity during acceleration, deceleration and constant motion (Varley et al, 2012b; Scott et al., 2016). Motion characteristics were quantified as total distance covered (m), high-speed running distance (m) (14.4-19.7 $km \cdot h^{-1}$), very high-speed running distance (m) (19.8-25.2 $km \cdot h^{-1}$), sprint distance (>25.2 $km \cdot h^{-1}$), high (2-3 ms^{-2}) and maximum (>3 ms^{-2}) acceleration distance (m), and high (-2--3 ms^{-2}) and maximum (<-3 ms^{-2}) deceleration distance (m). Cumulative high-speed running, very high-speed running and sprinting is referred to as high-intensity running and the velocity thresholds were selected to be consistent with the literature (Varley & Aughey, 2013). Data were analysed using proprietary software (Logan Plus v5, Catapult Innovations, Canberra, ACT, Australia). Data sets were verified for satellite signal (mean = >11) and horizontal dilution of precision (HDOP); (mean = <1.0) before being included in the analysis.

4.3.4 Statistical Analysis

All analyses were conducted using statistical software (SPSS, Chicago, USA). Descriptive statistics were calculated using z scores to verify data normality. Repeated measures ANOVA tests were used to evaluate differences between the SSG's and running drills for both the SEP and SEM formats. If appropriate, Bonferroni post-hoc tests were applied to identify any localised effects and statistical significance was set at $P<0.05$. Effect sizes (ES) were calculated and the magnitude of the effect classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0), and very large (>2.0-4.0) (Batterham & Hopkins, 2006). Reproducibility was determined using the coefficient of variation (CV) for each participant across all time points in each variable (Atkinson & Nevill, 1998). Values are presented as mean and standard deviations unless otherwise stated.

4.4 RESULTS

4.4.1 Physiological and Perceptual Response

The SEP and SEM running drills elicited greater mean heart rate responses, blood lactate concentrations and RPE than the respective SSG (Table 4.1). The SEP SSG's produced similar heart rate responses but greater blood lactate concentrations and RPE than the SEM protocol. Higher heart rate responses but lower blood lactate concentrations were evident for SEM running drill compared to the SEP protocol (Table 4.2).

Table 4.1. Physiological and perceptual responses to speed endurance drills (SSG vs. Run).

Physiological and perceptual variable	Production				Maintenance			
	n	1v1 SSG	Run	ES	*n*	2v2 SSG	Run	ES
Mean $\%HR_{max}$	12	82 ± 1.9 (81.2-83.7)	84 ± 1.5$^{\#}$ (83.3-85.2)	1.1	14	84 ± 2.6 (82.4-85.3)	87 ± 2.9$^{\#}$ (85.1-88.5)	1.0
Peak $\%HR_{max}$	12	89 ± 2.1 (87.9-90.6)	90 ± 1.6 (89.3-91.4)	0.5	14	91 ± 2.3 (89.7-92.3)	92 ± 2.5 (90.5-93.4)	0.3
Blood Lactate ($mmol \cdot L^{-1}$)	12	10.2 ± 1.9 (9.1-11.4)	13.1 ± 2.4$^{\#}$ (11.9-14.4)	1.3	9	6.3 ± 1.5 (5.5-7.3)	11.1 ± 2.8$^{\#}$ (9.1-13.1)	2.0
Ratings of perceived exertion (6-20)	12	14.9 ± 1.0 (14.5-15.5)	16.6 ± 1.7$^{\#}$ (15.7-17.8)	1.4	14	14.0 ± 1.4 (13.4-15.0)	17.5 ± 0.6$^{\#}$ (17.2-17.8)	3.2

Abbreviations: SSG, small-sided game; ES, effect size; $\%HR_{max}$, percentage of heart rate maximum. Data presented as means ± standard deviations (95% confidence interval). Effect size (ES) were classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) and very large (>2.0-4.0) (Batterham & Hopkin, 2006). *Greater than respective running drill (*P*<0.05). $^{\#}$Greater than respective SSG (*P*<0.05).

Table 4.2. Physiological and perceptual responses to speed endurance drills (SEP vs. SEM).

Physiological and perceptual variable	SSG				Run			
	n	SEP 1v1	SEM 2v2	ES	*n*	SEP	SEM	ES
Mean $\%HR_{max}$	13	82 ± 1.8 (81.3-83.6)	84 ± 2.3 (82.4-85.2)	0.6	13	84 ± 2.1 (83.1-85.8)	87 ± 3.1# (85.0-88.7)	0.9
Peak $\%HR_{max}$	13	89 ± 2.2 (88.1-90.8)	91 ± 2.0 (89.9-92.2)	0.7	13	90 ± 2.1 (89.1-91.7)	92 ± 2.5# (90.5-93.5)	0.6
Blood Lactate ($mmol{\cdot}L^{-1}$)	11	10.1 ± 1.8* (8.9-11.3)	6.8 ± 1.9 (5.5-8.1)	1.7	11	13.2 ± 1.8* (12.1-14.5)	10.5 ± 2.7 (8.7-12.3)	1.2
Ratings of perceived exertion (6-20)	12	14.9 ± 1.0* (14.5-15.5)	13.9 ± 1.4 (13.3-15.1)	0.7	13	16.7 ± 1.7 (15.7-17.8)	17.5 ± 0.6 (17.5-17.8)	0.6

Abbreviations: SSG, small-sided game; ES, effect size; $\%HR_{max}$, percentage of heart rate maximum; SEP, speed endurance production; SEM, speed endurance maintenance. Data presented as means ± standard deviations (95% confidence interval). Effect size (ES) were classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) and very large (>2.0-4.0) (Batterham & Hopkin, 2006). *Greater than respective SEM protocol (P<0.05). #Greater than respective SEP protocol (P<0.05).

4.4.2 Time-motion Characteristics

Players covered more total, very high-speed running, and sprint distance during the SEP running drill compared to the respective SSG. Greater distances were covered in total, at high-, very high-speed running and sprinting during the SEM running drill versus the SSG equivalent. Players covered more high acceleration and high-maximum deceleration distance during the SEP SSG compared to the respective running drill. Greater high-maximum acceleration and deceleration distance was covered during the SEM SSG compared to the respective running drill (Table 4.3). Players covered more total distance but less high-speed running in the SEM 2v2 versus the SEP 1v1 SSG. Greater total and high-speed running distances but less sprint distance was covered in the SEM compared to the SEP running drill. Players covered greater maximum acceleration and high deceleration distance in the SEM

2v2 SSG compared to the SEP 1v1 SSG. More high acceleration and maximum deceleration distance was covered in the SEP compared to the SEM running drill (Table 4.4).

Table 4.3. Time-motion responses to speed endurance drills (SSG vs. Run), m.

	Production				Maintenance			
Time-motion variable	***n***	**1v1 SSG**	**Run**	**ES**	***n***	**2v2 SSG**	**Run**	**ES**
Total distance	11	84.5 ± 3.7 (82.0-87.0)	176.4 ± 4.9# (173.1-179.8)	22.1	11	130.9 ± 12.5 (122.5-139.4)	281.7 ± 11.0# (274.3-289.1)	11.5
Total HSR distance at 14.5-19.7 $km \cdot h^{-1}$	11	25.6 ± 3.0 (23.6-27.6)	30.2 ± 8.4 (24.5-35.8)	1.1	11	20.2 ± 5.5 (16.5-23.9)	168.5 ± 13.9# (159.2-177.8)	18.4
Total VHSR distance at 19.7-25.2 $km \cdot h^{-1}$	11	5.6 ± 1.9 (4.4-6.9)	88.1 ± 9.0# (82.1-94.2)	12.8	11	3.9 ± 2.2 (2.4-5.4)	73.2 ± 25.4# (56.2-90.3)	6.4
Total SPR distance at >25.2 $km \cdot h^{-1}$	11	0.2 ± 0.5 (-0.1-0.6)	48.7 ± 10.9# (41.4-56)	6.0	11	0.1 ± 0.3 (-0.1-0.3)	6.6 ± 2.9# (4.6-8.6)	3.0
HI acceleration distance at >3 $m \cdot s^{-2}$	10	3.3 ± 0.5 (3.0-3.7)	2.5 ± 0.9 (1.9-3.2)	1.0	11	4.5 ± 1.3* (3.6-5.4)	1.1 ± 1.5 (0.1-2.2)	2.3
MI acceleration distance at 2-3 $m \cdot s^{-2}$	10	4.8 ± 0.6* (4.4-5.3)	3.2 ± 0.5□ (2.8-3.6)	2.6	11	4.9 ± 0.7* (4.4-5.4)	1.7 ± 1.5 (0.7-2.7)	2.6
HI deceleration distance at <-3 $m \cdot s^{-2}$	10	3.0 ± 0.5* (2.7-3.4)	1.3 ± 0.7€ (0.8-1.8)	2.7	11	3.6 ± 0.4 * (3.4-3.9)	0.9 ± 0.8 (0.3-1.4)	4.2
MI deceleration distance at -2--3 $m \cdot s^{-2}$	10	3.3 ± 0.5* (2.9-3.6)	1.1 ± 0.4† (0.8-1.4)	4.6	11	3.4 ± 0.8* (2.9-4.0)	0.2 ± 0.4 (-0.1-0.5)	4.8

Abbreviations: SSG, small-sided game; ES, effect size; HSR, high speed running; VHSR, very high speed running; SPR, sprint; HI, high-intensity; MI, moderate-intensity. Data presented as means ± standard deviations (95% confidence interval). Effect size (ES) were classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) and very large (>2.0-4.0) (Batterham & Hopkin, 2006). *Greater than respective running drill (P<0.01). #Greater than respective SSG (P<0.01).

Table 4.4. Time-motion responses to speed endurance drills (SEP vs. SEM), m.

	SSG				Run			
Time-motion variable	*n*	SEP 1v1	SEM 2v2	ES	*n*	SEP	SEM	ES
Total distance	12	85.9 ± 5.0 (82.7-89.1)	132.7 ± 13.2# (124.3-141.1)	4.5	11	174.7 ± 4.3 (171.8-177.5)	284.3 ± 10.7# (277.1-291.5)	12.9
Total HSR distance at 14.5-19.7 $km \cdot h^{-1}$	12	26.3 ± 3.5 (24.1-28.6)	22.2 ± 6.7# (17.9-26.4)	0.7	11	31.5 ± 8.4 (25.9-37.1)	165.5 ± 12.7# (157.0-174.0)	12.0
Total VHSR distance at 19.7-25.2 $km \cdot h^{-1}$	12	5.5 ± 1.8 (4.4-6.7)	4.0 ± 2.3 (2.5-5.5)	0.7	11	89.4 ± 10.8 (82.1-96.6)	80.4 ± 21.4 (66.1-94.8)	0.5
Total SPR distance at >25.2 $km \cdot h^{-1}$	12	0.2 ± 0.5 (-0.1-0.5)	0.1 ± 0.3 (-0.1-0.2)	0.3	11	44.6 ± 12.7* (36.0-53.1)	6.6 ± 3.0 (4.7-8.8)	3.9
HI acceleration distance at >3 $m \cdot s^{-2}$	12	3.4 ± 0.6 (3.1-3.8)	4.6 ± 1.2# (3.8-5.3)	1.2	10	4.0 ± 5.0 (0.5-7.6)	1.0 ± 1.6 (-0.1-2.2)	0.8
MI acceleration distance at 2-3 $m \cdot s^{-2}$	12	4.9 ± 0.5 (4.6-5.3)	5.1 ± 0.8 (4.6-5.7)	0.3	10	3.2 ± 0.5* (2.8-3.5)	1.7 ± 1.6 (0.6-2.9)	1.2
HI deceleration distance at <-3 $m \cdot s^{-2}$	12	3.1 ± 0.5 (2.8-3.5)	3.8 ± 0.5# (3.4-4.1)	1.1	10	1.4 ± 0.8 (0.8-1.9)	0.9 ± 0.9 (0.3-1.5)	0.5
MI deceleration distance at -2--3 $m \cdot s^{-2}$	12	3.2 ± 0.5 (2.9-3.5)	3.5 ± 0.9 (2.9-4.1)	0.4	10	1.0 ± 0.4* (0.8-1.3)	0.2 ± 0.5 (-0.1-0.5)	1.8

Abbreviations: SSG, small-sided game; ES, effect size; HSR, high speed running; VHSR, very high speed running; SPR, sprint; HI, high-intensity; MI, moderate-intensity. Data presented as means ± standard deviations (95% confidence interval). Effect size (ES) were classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) and very large (>2.0-4.0) (Batterham & Hopkin, 2006). *Greater than respective SEM protocol (*P*<0.05). #Greater than respective SEP protocol (*P*<0.05).

4.4.2 Reproducibility

Table 4.5 displays the physiological response test-retest reproducibility of the SE drills. Minimal test-retest variation was observed for heart rate responses and RPE across all SE drills. Blood lactate concentrations displayed moderate-large test-retest variability during the running drills and the respective SSG's. Table 4.6 displays the time-motion test-retest reproducibility of the SE drills. Low-moderate test-retest variability was observed for total distance covered, however large test-retest variability was evident for high-, very high-speed running and sprinting during all SE drills. Large test-retest variability was also evident for most acceleration/deceleration categories for all SE drills. Acceleration/deceleration distance reported greater reproducibility than quantifying the number of acceleration/deceleration efforts for 94% of the thresholds measured during all SE drills.

Table 4.5. Physiological and perceptual reproducibility of speed endurance drills.

	Production				Maintenance			
	1v1 SSG		Run		2v2 SSG		Run	
Physiological and perceptual variable	***n***	**CV**	**n**	**CV**	***n***	**CV**	**n**	**CV**
Mean $\%HR_{max}$	8	1.3%	8	0.9%	13	1.9%	11	1.9%
Peak $\%HR_{max}$	8	1.1%	8	1.0%	13	1.0%	11	1.0%
Blood Lactate ($mmol \cdot L^{-1}$)	9	9.9%	8	10.2%	10	8.5%	9	14.4%
Ratings of perceived exertion (6-20)	9	4.9%	8	4.0%	12	5.7%	11	2.9%

Abbreviations: SSG, small-sided game; $\%HR_{max}$, percentage of heart rate maximum. Reproducibility is expressed as a coefficient of variation (CV).

Table 4.6. Time-motion reproducibility of speed endurance drills.

	Production				Maintenance			
	1v1 SSG		Run		2v2 SSG		Run	
Variable	***n***	**CV**	***n***	**CV**	***n***	**CV**	***n***	**CV**
Total distance (m)	9	7.9%	8	3.1%	10	6.1%	10	2.2%
Total HSR distance 14.5-19.7 $km{\cdot}h^{-1}$ (m)	9	16.6%	8	17.7%	10	13.6%	10	11.3%
Total VHSR distance 19.7-25.2 $km{\cdot}h^{-1}$ (m)	9	37.2%	8	16.9%	10	61.9%	10	32.5%
Total sprint distance at >25.2 $km{\cdot}h^{-1}$ (m)	9	141.4%*	8	21.6%	10	141.4%*	10	106.7%
HI acceleration distance at >3 $m{\cdot}s^{-2}$	9	12.4%	7	25.4%	9	23.6%	10	64.2%
MI acceleration distance at 2-3 $m{\cdot}s^{-2}$	9	12.1%	7	10.2%	9	12.1%	10	13.5%
HI deceleration distance at <-3 $m{\cdot}s^{-2}$	9	9.8%	7	25.7%	9	10.7%	10	17.6%
MI deceleration distance at -3--2 $m{\cdot}s^{-2}$	9	12.9%	7	17.3%	9	11.6%	10	102.1%*

Abbreviations: SSG, small-sided game; HSR, high speed running; VHSR, very high speed running. Reproducibility is expressed as a coefficient of variation (CV). *Only one player reached the speed threshold.

4.5 DISCUSSION

The physiological responses were greater in the running drills compared to the respective SSG's. No research has quantified the physiological responses of SEP 1v1 or SEM 2v2 SSG's using the specified exercise to rest ratios used in the present study. Previous research reported greater mean heart rate and similar blood lactate concentrations during SEM 1v1 SSG's using 60 s exercise bouts (1:2 exercise to rest ratio) in comparison to the SEP 1v1 SSG’s used in the present study (Koklu et al., 2011). A greater mean heart rate is to be expected due to the extended bout duration and reduced recovery time resulting in a greater contribution of energy from the oxidation system (Bangsbo, 1994). The data would suggest that 1v1 SSG's can highly tax the anaerobic energy system while ensuring a low training volume with such training methods shown to reduce relative energy expenditure during exercise (Bangsbo et al., 2009; Iaia et al., 2009a).

Mean heart rate response of the SEM 2v2 SSG's is in agreement with previous research investigating 90 s exercise bouts (1:1 exercise to rest ratio) across 3 repetitions, while blood lactate concentration and RPE were also similar to the present study (Aroso et al., 2004). Though the pitch dimensions were initially the same as the present study (27 × 28 m), comparisons are difficult as the authors varied the conditions on each repetition to include man to man marking, a maximum of three consecutive touches and an increased pitch size (50 × 30 m) while conducting five fewer repetitions than the present study. Research examining eight 30 s runs at ~130% of $\dot{V}O_{2max}$ with 90 s rest periods (1:3 exercise to rest ratio) reported identical mean but greater peak heart rate responses and blood lactate concentrations than the SEP running drill in the present study (Mohr et al., 2007). Again, comparisons are difficult as the participants were untrained and had a $\dot{V}O_{2max}$ below that reported in elite male youth soccer players (McMillan et al., 2005).

The SEP 1v1 SSG elicited lower mean and peak heart rate responses but greater blood lactate concentrations and RPE than the SEM 2v2 SSG. These findings agree with previous research (Aroso et al., 2004; Dellal et al., 2008; Koklu et al., 2011) and support the notion that heart rate monitoring as a sole measure of training intensity underestimates the intensity of short duration SSG's and should be used in addition to another monitoring tool such as blood lactate concentration, RPE or time-motion analysis (Little & Williams, 2007). The data would suggest SEM requires a greater contribution from the aerobic energy system than SEP training and is supported by subsequent research examining matched duration SE SSG’s (Castagna et al., 2017). Nonetheless, it is not clear how each training protocol results in performance improvements. Although SEP training interventions in trained individuals have been shown to improve the muscles ability to maintain ion homeostasis, investigations into the effects of SEM training on physiological adaptations are limited (Hostrup & Bangsbo, 2017). The only study to investigate physiological adaptations following SEM training reported no change in $\dot{V}O_{2max}$, $\dot{V}O_2$ kinetics or running economy in elite soccer players (Wells et al., 2014). Nevertheless, the authors reported performance improvements in high-intensity intermittent running capacity and maximal anaerobic running (Wells et al., 2014). Therefore, although SEM may result in a greater heart rate response than SEP, improvements in performance are likely due to physiological adaptations of anaerobic processes within the muscle. The findings of this study demonstrate the potential to train various energy systems using SEP and SEM SSG's and thus could provide information on optimal training prescription, however further research investigating the physiological adaptations following SEM training is warranted.

Unsurprisingly, players covered more distance in high-intensity running parameters during the SEP and SEM running drills compared to the respective SSG's. The small pitch dimensions for the SSG's and the tactical task associated with SSG's limit the space available for players to reach the speed thresholds to register high-intensity running (Hill-Haas et al., 2009; Casamichana & Castellano, 2010). Players in the SEP 1v1 SSG covered less total distance but greater high-intensity running distance than the SEM 2v2 SSG. Previous research supports this finding, whereby the percentage of time spent sprinting was higher in 2v2 compared to 3v3 SSG's using the same pitch dimensions (Aroso et al., 2004). An increase in relative pitch size due to a reduction in players provides more space to reach high-intensity running thresholds and increases the players' number of direct involvements in the SSG's (Rampinini et al., 2007a; Owen et al., 2011; Castagna et al., 2019). The data further supports the notion that SEP 1v1 SSG's can be prescribed to overload and improve anaerobic performance due to the increased high-intensity running profile in comparison to the SEM 2v2 SSG.

Interestingly, players covered greater high-maximum acceleration/deceleration distance during the SEP and SEM SSG's compared to the respective running drills. It has been established that players perform a greater number of maximum accelerations than sprints per match, with 85% of accelerations not reaching the high-intensity running threshold (Varley & Aughey, 2013). Thus, the demand of alternating speeds across short distances needs to be considered given that accelerations are more metabolically demanding than constant velocity movements (di Prampero et al., 2005; Osgnach et al., 2010). Additionally, the deceleration demands of SSG's place more mechanical stress on the body due to eccentric muscle contractions leading to exercise-induced muscle damage (Thompson, Nicholas & Williams, 1999). It is therefore important for sport scientists and fitness coaches to monitor frequent accelerations and decelerations during SSG's due to their high metabolic demand.

Low test-retest variability for heart rate responses is in agreement with previous studies (Little & Williams, 2006, 2007; Rampinini et al., 2007a) and though blood lactate concentrations reported moderate variability, SSG's were more reproducible compared to the respective running drill for both the SEP and SEM protocol. This may be due to the running drills not being individualised to cover a set distance resulting in inconsistent performance over the eight repetitions between the test-retest trials. Future studies should implement running drills designed using individual maximal aerobic speed (Dupont et al., 2004). RPE reported low test-retest variability and the SEM 2v2 SSG was in close agreement with previous research when investigating high-intensity aerobic 2v2 SSG's with an exercise duration of 2 min using the same exercise to rest ratio and pitch dimensions as the present study (Little & Williams, 2006).

Test-retest variance during SSG's was moderate-high for high-intensity running parameters. Higher running speeds produced greater variability in the majority of drills supporting previous research (Hill-Haas et al., 2008). However, it should be noted that GPS units generally report greater variability at higher speed thresholds (Coutts & Duffield, 2010; Scott et al., 2016). The SSG's display very large variance at the very high-speed running and sprinting thresholds, suggesting this aspect of physical load experienced by players during short duration SE SSG's is inconsistent. However, the running drills used in the present study also displayed large-very large variability for distance covered at the very high-speed running and sprinting threshold. Acceleration/deceleration distance during SSG's displayed moderate-large test-retest variability but was lower than the equivalent running drills in the majority of parameters. Similar to the variability for high- and very high-speed running, greater acceleration/deceleration thresholds displayed larger test-retest variability in each drill with the exception of high and maximum deceleration in the SEP running drill. However, it should be noted that GPS units report greater variability at higher acceleration/deceleration thresholds (Varley et al., 2012b). The acceleration/deceleration distance during the SE SSG's was more reproducible than the distance covered at the very high-speed running and sprinting thresholds. The data suggests practitioners can therefore achieve the desired physical load through accelerations/decelerations rather than high-intensity running when prescribing SE SSG's. In summary, practitioners can manipulate the exercise bout duration and exercise to rest ratios of SE SSG's to tax the anaerobic glycolytic energy system. Furthermore, practitioners should quantify the acceleration/deceleration distance covered during SSG's as not to underestimate high-intensity activity.

The reader should be aware of the limitations of the present study. Although stringent guidelines were followed by the authors to standardise procedures, marginal variation would have been present due to the outdoor surfaces and environment. Moreover, the low sample size must also be acknowledged but is an unavoidable drawback given the elite nature of the players. The differences in physiological responses and time-motion characteristics during the SSG’s can only be attributed to the protocols used in the present study. Future research should administer SEP and SEM SSG’s with matched relative pitch space per player and exercise durations. Furthermore, the research area would benefit from direct measurements of the metabolic systems using a portable system to measure oxygen uptake and muscle biopsies to establish muscle ion transport protein activity attributed to SEP and SEM SSG's. Finally, it is recommended that to obtain greater physiological responses during soccer drills with a ball, future research should establish position-specific SE drills based on match time-motion analysis data that incorporate high speed running and frequent changes of direction.

4.5.1 Practical Application

It is suggested that short duration SSG's have the potential to increase anaerobic power and capacity when prescribed as SE training drills. Though the physiological response was greater in the running drills compared to the equivalent SSG's, the ability to overload the anaerobic energy system while concurrently training the technical skill of the soccer players will appeal to both soccer and fitness coaches to ensure specificity of training, economy of time and a reduction in training volume. Practitioners should incorporate a number of methods to monitor load during SE SSG's and not solely rely on heart rate analysis. Sport scientists and fitness coaches should quantify acceleration/deceleration distance during short duration SSG's in addition to distance covered at high-intensity running thresholds due to greater reproducibility.

4.6 CONCLUSION

The data demonstrate that SE SSG's elicit lower physiological responses compared to the equivalent running drills. Although high-intensity running parameters were lower in SSG's versus the equivalent running drills, SSG's illustrated superior acceleration/deceleration profiles. Irrespective of drill modality, SEP elicited lower heart rate responses but higher blood lactate concentrations than SEM. Finally, all drills exhibited low-moderate test-retest variability for physiological responses but moderate-large for high-intensity running and acceleration/deceleration parameters.

4.7 PERSPECTIVE

SSG's used in the present study may be desirable to practitioners wishing to provide a high physiological and neuromuscular stimulus in a time efficient manner whilst limiting very high speed running exposure. However, to achieve greater physiological responses attributed to performance gains following a period of SE training, individual position-specific drills that simultaneously expose players to very high speed running efforts, changes of direction, soccer specific movement patterns and technical skills would be advantageous. Position-specific SE drills should be designed using video analysis of time-motion data to capture the most frequent movement patterns, technical skills and tactical actions associated with very high speed running efforts.

CHAPTER FIVE

HIGH-INTENSITY EFFORTS IN ELITE SOCCER MATCHES AND ASSOCIATED MOVEMENT PATTERNS, TECHNICAL SKILL AND TACTICAL ACTIONS. INFORMATION FOR POSITION-SPECIFIC SPEED ENDURANCE DRILLS

HIGH-INTENSITY EFFORTS IN ELITE SOCCER MATCHES AND ASSOCIATED MOVEMENT PATTERNS, TECHNICAL SKILL AND TACTICAL ACTIONS. INFORMATION FOR POSITION-SPECIFIC SPEED ENDURANCE DRILLS

5.1 ABSTRACT

Purpose: This study aimed to translate movement patterns, technical skills and tactical actions associated with high-intensity efforts into metrics that could be used to construct position-specific speed endurance drills. **Methods:** Twenty individual English Premier League players high-intensity running profiles were observed multiple times (*n*=100) using a computerised tracking system. Data were analysed using a novel High-intensity Movement Programme across five positions (centre back = CB, fullback = FB, central midfielder = CM, wide midfielder = WM and forward= FW). **Results:** High-intensity efforts in contact with the ball and the average speed of efforts were greater in WM than in CB, CM and FW (ES: 0.9-2.1, $P<0.05$). WM produced more repeated high-intensity efforts than CB and CM (ES: 0.6-1.3, $P<0.05$). In possession, WM executed more tricks post effort than CB and CM (ES: 1.2-1.3, $P<0.01$). FB and WM performed more crosses post effort than other positions (ES: 1.1-2.0, $P<0.01$). Out of possession, FW completed more efforts closing down the opposition (ES: 1.4-5.0, $P<0.01$) but less tracking opposition runners than other positions (ES: 1.5-1.8, $P<0.01$). FW performed more arc runs before efforts compared to CB, FB and WM (ES: 0.9-1.4, $P<0.05$), however CB completed more 0-90° turns compared to FB, CM and WM (ES: 0.9-1.1, $P<0.01$). **Conclusions:** The data demonstrate unique high-intensity trends in and out of possession that could assist practitioners when devising position-specific speed endurance drills.

5.2 INTRODUCTION

The physical demands of elite match-play have substantially increased in the last decade (Bradley et al., 2016) and thus the need to optimise a player's physical capacity using running and soccer based drills has received increasing attention (Gunnarsson et al., 2012; Ingebrigtsen et al., 2013; Ade et al., 2014). Small-sided games (SSG's) adhering to speed endurance (SE) parameters have been reported to induce greater acceleration/deceleration demands than matched running drills, however the physiological response and very high speed running exposure was considerably lower (Ade et al., 2014). Consequently, it is proposed soccer drills that incorporate very high speed running efforts in addition to position-specific movement patterns and technical skills could provide similar physiological responses reported in the literature that improve physical performance (Mohr et al., 2007; Gunnarsson et al., 2012; Ingebrigtsen et al., 2013). Despite a plethora of research, only one study has used performance data in the form of the most intense match-play period to configure a soccer-specific aerobic high-intensity training drill (Kelly et al., 2013). The drill not only produced a greater mean heart rate response than SSG's but also showed less inter-player variability. Although the physical stimulus was soccer-specific, no technical and tactical match data were used in the drill construction despite these been discriminatory factors between competitive standards (Bradley et al., 2013, 2016) and thus should be considered when developing highly specific game based drills.

Positional variation in match performance parameters is a robust finding within the research literature. Typically, wide midfielders (WM) cover the most and centre backs (CB) cover the least high-intensity running during a match (Bradley et al., 2009; Di Salvo et al., 2009; Dellal et al., 2010). When data are expressed relative to the total distance covered in a match, fullbacks (FB) cover the greatest proportion of high-intensity running with central midfielders (CM) performing the most frequent efforts with limited recovery (Carling, Le Gall & Dupont, 2012). From a technical perspective, forwards (FW) and CM have more touches per ball possession with CM performing and completing more passes (Taylor, Mellalieu & James, 2004; Redwood-Brown, Bussell & Bharaj, 2012). Although these findings have implications for developing specific training drills that mimic positional characteristics (Bush et al., 2015a), limited research has actually translated the unique technical and physical positional demands into drill construction metrics. Bloomfield et al. (2007) is the only study that has quantified the movement and technical demands of various positions during elite match play using a valid classification system that could be applied to training. For instance, midfielders (MF) performed fewer 0-90° turns and spent less time standing and shuffling than other positions. While defenders (DF) spent less time sprinting than MF and FW but greater time travelling backwards. Although the technical analysis was basic, it highlighted FW performed fewer long passes with MF performing more short passes. This information is translational if separate drills for each position are constructed either as a rehabilitation session or isolated drill (Van Winkel et al., 2013). However, additional information on high-intensity and technical actions in conjunction with pitch location, possession status, combination play, and tactics would be advantageous for SE drill construction. This would allow practitioners to condition a number of positions simultaneously using combination drills incorporating game- and position-specific ball work (Van Winkel et al., 2013). Therefore, the aim of this study was to translate movement patterns, technical skills and tactical actions associated with high-intensity efforts during match play into metrics that could be used to construct position-specific SE drills.

5.3 METHODS

5.3.1 Match Analysis and Player Data

Match performance data were collected from a single English Premier League club across consecutive seasons (2010-11 to 2013-14) using a computerised tracking system (AMISCO Pro®, Sport-Universal Process, Nice, France). Players' activities were captured during matches by cameras positioned at roof level and analysed using proprietary software. The validity of this tracking system has been previously verified (Zubillaga, 2006; Rodriguez et al., 2010) and has been shown to detect performance decrements during a soccer match (Randers et al., 2010) while a similar optical tracking system has reported excellent correlations (r = 0.99) with average speed measured using timing gates (Di Salvo et al., 2006). Ethical approval was obtained from the appropriate institutional ethics committee and permission to publish was granted by the professional club and match provider.

Twenty individual players were observed multiple times and analysed across five positions (CB n=4, observations=20; FB: n=4, observations=20; CM: n=4, observations=20; WM: n=4, observations=20; FW: n=4, observations=20). These observations were obtained from 46 home games (22 wins, 9 draws, 15 defeats with an average ball possession of 52±6%), using only home matches ensured that a camera was always accessible to provide a wide-angle full pitch recording of all players throughout matches. Match data were only included for analysis if: (1) players complete the entire match and remained in the same position, (2) both teams finished matches with 11 players, (3) the score differential was <3 and (4) the team used typical formations (4-4-2 or 4-5-1).

5.3.2 High-intensity Efforts

High-intensity efforts were defined as activities reaching speeds >21 $km \cdot h^{-1}$ for a minimum of 1 s (Dellal et al., 2010; Castellano et al., 2011; Bradley et al., 2014). The frequency, distance covered, duration and average speed of high-intensity efforts were analysed in addition to the recovery time between efforts. Furthermore, repeated high-intensity efforts defined as a minimum of two efforts separated by a maximum of 20 s were reported (Gabbett, Wiig & Spencer, 2013).

5.3.3 High-intensity Movement Programme (HIMP)

Movements associated with each high-intensity effort were analysed using video recordings provided by AMISCO® and a wide-angle recording of all players throughout matches. Each effort was linked to a recording that could be viewed at 0.5 × normal speed. To aid position-specific drill design, a High-intensity Movement Programme (HIMP) was devised. Similar to previous work, the HIMP reported turning angles and ball-based high-intensity activities (Bloomfield, Polman & O'Donoghue, 2004). However, unlike other research, activities were quantified in and out of ball possession and were broken down into pre, during and post efforts. The HIMP consisted of five major categories: (1) Movement Patterns, (2) Pitch Location, (3) Technical Skill, (4) Tactical Actions and (5) Combination Play. The categories are summarised in Table 5.1. with the exception of pitch location.

TABLE 5.1. High-intensity movement programme (HIMP).

HIMP categories	Description
Movement Pattern	
Turn 0-90°	Player turns ≤ ¼ circle
Turn 90-180°	Player turns ≥ ¼ circle but ≤ ½ circle
Swerve	Player changes direction at speed without rotating the body
Arc Run	Player (often leaning to one side) moving in a semi-circular direction
Technical Skill	
Long Pass	Player attempts to pass the ball to a teammate over a distance greater than 30 yards
Trick	Player performs ball skill before, during or after dribbling / running with the ball
Cross	Player attempts to cross the ball into the opposition penalty box from either flank in the attacking third of pitch
Shot	Player attempts to kick the ball into the opposition goal
Header	Player makes contact with the soccer ball using the head
Tackle	Player dispossess the soccer ball from the opponent
Tactical Outcome (In Possession)	
Break into the opposition penalty box	Player enters the opposition penalty box
Run with the ball	Player moves with the ball either dribbling with small touches or running with the ball with bigger touches
Overlapping Run	On the external channel, player runs from behind to in front of, or parallel to the player on the ball
Push up the pitch	Player moves up the pitch to support the play or play offside (defensive and middle third of the pitch only)
Drive through the middle of the pitch	Player runs with or without the ball through the middle of the pitch
Drive inside the pitch	Player runs from external flank with or without the ball into the central area
Run the channel of the pitch	Player runs with or without the ball down one of the external areas of the pitch
Run in behind the opposition defence	Player aims to beat the opposition offside trap to run through onto the opposition goal
Tactical Outcome (Out of Possession)	
Close down opposition player	Player runs directly towards opposition player on the ball
Interception of opposition pass	Player cuts out pass from opposition player
Covering	Player moves to cover space or a player on the pitch whilst remaining goal side
Track runner	Player runs alongside opposition player with or without the ball
Ball passed over the top of player	Opposition plays a long pass over the defence through the centre of the pitch
Ball passed down the side of pitch	Opposition plays a ball over the top or down the side of the flank
Recovery run	Player runs back towards own goal when out of position to be goal side

5.3.3.1 HIMP Coding

The pitch location of a player before and after each effort was calculated using a grid generated from the AMISCO® software. Pitch length was divided into thirds to establish defensive, middle and attacking zones while central areas of the pitch were equal to the width of the penalty box with the remaining areas considered wide. A similar technology used by Prozone called MatchViewer has been found to be reliable and valid when reporting pitch location of technical events with a mean absolute error 3.6 m (Bradley et al., 2007). Player location was established using the time period and exact duration of the effort provided by the AMISCO® software. In contrast, movement patterns, technical skills, combination play, and tactical actions were coded using the video recordings allowing an additional 3 s before and after each effort.

5.3.3.2 HIMP Reliability

Inter-reliability was assessed by two observers coding one player for each position (n=5) from randomly selected games (n=5). Two familiarisation sessions were conducted to understand the coding process and discuss the HIMP descriptions. The observers had access to the HIMP descriptions throughout the process (Table 5.1). Intra-reliability assessment was conducted by one observer coding a randomly selected match and player five times. A minimum of seven days separated each observation. All data analyses were conducted independently in a quiet office for a maximum period of 2 h with breaks every 30 min to ensure optimal concentration levels (Atencio, 1996; Bloomfield et al., 2007). All five major categories of the HIMP were analysed as a complete data set and reported excellent inter- and intra-observer agreement (k>0.8 and >0.9, respectively) whilst individual HIMP categories revealed moderate to almost perfect agreement (K=0.62-1.00, Table 5.2).

Table 5.2. HIMP reliability kappa statistic data.

	Inter-Rater Reliability		Intra-Rater Reliability	
HIMP	**Value of *k***	**Agreement**	**Value of *k***	**Agreement**
Location	0.99	Almost Perfect	1.00	Almost Perfect
Combination	0.70	Moderate	1.00	Almost Perfect
Movement	0.62	Moderate	0.69	Moderate
Technical	0.86	Strong	1.00	Almost Perfect
Tactical	0.84	Strong	0.92	Almost Perfect
Overall	0.85	Strong	0.91	Almost Perfect

Levels of agreement defined as follows: 0-0.20 = none, 0.21-0.39 = minimal, 0.40-0.59 = weak, 0.60-0.79 = moderate, 0.80-0.90 = strong, >0.90 almost perfect (McHugh, 2012).

5.3.4 Statistical Analysis

Data analyses were conducted using software (SPSS, Chicago, IL, USA) and z-scores were calculated to verify normality. One-way ANOVA's explored positional differences and Bonferroni post hoc tests identified localised effects. Statistical significance was set at $P<0.05$. Effect sizes (ES) were calculated to determine meaningful differences with magnitudes classed as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0), and very large (>2.0-4.0; Batterham & Hopkins, 2006). Intra-positional match-to-match variability was examined using the coefficient of variation (CV) for each variable. Values are presented as mean and standard deviations unless otherwise state

5.4 RESULTS

5.4.1 High-intensity Efforts

CB performed less high-intensity efforts and had longer recoveries between efforts than other positions (ES: 1.1-1.6, $P<0.05$; Table 5.3). FB and WM covered greater distance during efforts compared to CB (ES: 0.7-1.1, $P<0.01$). The number of efforts in contact with the ball and the average speed of efforts were greater in WM than in CB, CM and FW (ES: 0.9-2.1, $P<0.05$). WM produced more repeated efforts than CB and CM (ES: 0.6-1.3, $P<0.05$). Moderate mean intra-positional variation (CV=10.0%) was reported for the number of efforts in contact with the ball. Very large intra-positional variation was evident for the number of high-intensity efforts, the recovery time between efforts, and number of repeated high-intensity efforts (CV > 30.0%, 24.7%, 55.8%, respectively).

5.4.2 Movement Patterns

In possession, FB completed a lower percentage of arc runs before high-intensity efforts compared to CM (ES: 1.1, $P<0.01$, Table 5.4). Out of possession, FW performed more arc runs before efforts compared to CB, FB and WM (ES: 0.9-1.4, $P<0.05$), however CB completed more 0-90° turns before efforts compared to FB, CM and WM (ES: 0.9-1.1, $P<0.01$). FB executed a greater percentage of 90-180° turns before efforts compared to all other positions (ES: 0.8-2.2, $P<0.05$). Out of possession, FW completed a greater proportion of arc runs than CB and FB (ES: 0.8, $P<0.05$) with FW also executing more arc runs post effort than CB, CM and WM (ES: 0.9-1.4, $P<0.01$). CB completed a greater proportion of 0-90° turns after efforts than FB (ES: 1.4, $P<0.05$). Large to very large intra-positional variation was reported for all movement patterns performed in and out of possession (CV >11.1%).

Table 5.3. Physical data for high-intensity efforts and repeated high-intensity bouts across positions.

Physical	Centre back	Fullback	Central Midfielder	Wide Midfielder	Forward	
HI Effort Data						
No. Efforts	20.3 ± 6.5	30.6 ± 10.2	29.4 ± 9.3	38.7 ± 14.4	33.6 ± 10.0	WM > CB*, FB$^{\alpha}$, CM$^{\alpha}$; FW > CB*; FB > CB$^{\alpha}$; CM > CB$^{\alpha}$
Distance (m)	16.6 ± 3.0	20.2 ± 2.6	18.5 ± 2.8	20.3 ± 3.5	17.8 ± 2.2	WM > CB$^{\alpha}$, FW$^{\alpha}$; FB > CB*, CM$^{\alpha}$, FW$^{\alpha}$; CM > CB$^{\alpha}$
Duration (s)	2.6 ± 0.4	3.1 ± 0.4	2.9 ± 0.4	3.1 ± 0.5	2.8 ± 0.3	FB > CB*, FW$^{\alpha}$; WM > CB$^{\alpha}$, FW$^{\alpha}$; CM > CB$^{\alpha}$
Recovery Time (s)	271.4 ± 93.7	183.9 ± 65.8	192.7 ± 47.5	154.5 ± 49.5	175.4 ± 62.7	CB > FB$^{\alpha}$, CM$^{\alpha}$, WM*, FW$^{\alpha}$; CM > WM$^{\alpha}$
Average Speed ($km \cdot h^{-1}$)	23.1 ± 0.4	23.1 ± 0.5	22.9 ± 0.4	23.5 ± 0.5	23.1 ± 0.5	WM > CB$^{\alpha}$, FB$^{\alpha}$, CM*, FW$^{\alpha}$
No. HI Efforts with Ball Contact	4.8 ± 2.6	10.4 ± 4.3	7.9 ± 3.4	13.6 ± 5.2	9.0 ± 4.0	WM > CB$^{\#}$, FB$^{\alpha}$, CM*, FW$^{\alpha}$; FB > CB*, CM$^{\alpha}$, FW > CB*; CM > CB$^{\alpha}$
HI Efforts with Ball Contact (%)	23.4 ± 10.8	33.2 ± 9.2	27.1 ± 9.9	39.1 ± 18.2	26.8 ± 9.0	WM > CB$^{\alpha}$, CM$^{\alpha}$, FW$^{\alpha}$; FB > CB$^{\alpha}$, FB$^{\alpha}$, FW$^{\alpha}$
In Possession (IP)						
No. HI Efforts	3.3 ± 3.5	12.3 ± 5.7	9.5 ± 6.3	22.0 ± 7.3	23.3 ± 8.4	FW > CB$^{\#}$, FB*, CM*; WM > CB$^{\#}$, FB*, CM*; FB > CB*; CM > CB$^{\alpha}$
Percentage of Total HI Efforts	14.1 ± 13.5	38.4 ± 9.9	31.7 ± 14.6	59.3 ± 15.6	68.4 ± 11.6	FW > CB$^{\#}$, FB$^{\#}$, CM$^{\#}$, WM$^{\alpha}$; WM > CB$^{\#}$, FB*, CM*; CM > CB*; FB > CB$^{\#}$
No. HI Efforts with Ball Contact	1.9 ± 2.0	7.0 ± 4.0	4.9 ± 3.0	11.7 ± 4.6	8.8 ± 3.9	WM > CB$^{\#}$, FB$^{\alpha}$, CM*, FW$^{\alpha}$; FW > CB$^{\#}$; FB > CB*
HI Efforts IP with Ball Contact (%)	57.6 ± 36.0	56.1 ± 20.1	54.8 ± 21.8	55.7 ± 20.1	38.2 ± 11.8	CB > FW$^{\alpha}$; FB > FW$^{\alpha}$; WM > FW$^{\alpha}$; CM > FW$^{\alpha}$
Out of Possession (OP)						
No. HI Efforts	17.0 ± 5.0	19.1 ± 6.2	20.3 ± 7.5	16.9 ± 10.8	10.4 ± 4.3	CM > FW*; FB > FW*; CB > FW*; WM > FW$^{\alpha}$
Percentage of Total HI Efforts	85.7 ± 14.0	61.6 ± 9.9	68.5 ± 14.7	40.7 ± 15.6	31.6 ± 11.6	CB > FB*, CM$^{\alpha}$, WM$^{\#}$, FW$^{\#}$; CM > WM*, FW$^{\#}$; FB > WM*, FW$^{\#}$; WM > FW$^{\alpha}$
No. HI Efforts with Ball Contact	3.0 ± 1.9	3.4 ± 1.6	3.0 ± 1.9	1.9 ± 2.1	0.2 ± 0.4	FB > FW$^{\#}$, WM$^{\alpha}$; CB > FW*; CM > FW*; WM > FW$^{\alpha}$
HI Efforts OP with Ball Contact (%)	17.4 ± 10.3	18.2 ± 7.0	14.7 ± 10.0	14.3 ± 22.0	1.4 ± 3.0	FB > FW$^{\#}$; CB > FW$^{\#}$; CM > FW*; WM > FW$^{\alpha}$
Repeated HI Bout Data >2						
No. RHIE Efforts	1.7 ± 1.4	3.6 ± 2.6	2.9 ± 1.6	5.2 ± 3.4	3.4 ± 2.1	WM > CB*, CM$^{\alpha}$, FW$^{\alpha}$; FB > CB$^{\alpha}$; FW > CB$^{\alpha}$; CM > CB$^{\alpha}$
RHIE Distance (m)	14.7 ± 4.5	17.8 ± 3.5	17.4 ± 5.0	18.6 ± 6.0	15.7 ± 3.3	WM > CB$^{\alpha}$; FB > CB$^{\alpha}$
RHIE Duration (s)	2.3 ± 0.7	2.8 ± 0.5	2.7 ± 0.8	2.8 ± 0.8	2.4 ± 0.5	WM > CB$^{\alpha}$; FB > CB$^{\alpha}$; CM > CB$^{\alpha}$
RHIE Recovery time (s)	8.1 ± 4.8	7.5 ± 3.7	7.0 ± 3.8	6.7 ± 3.5	6.7 ± 3.3	
Max No. RHIE Efforts	2.1 ± 0.5	2.5 ± 0.6	2.2 ± 0.4	2.5 ± 0.7	2.4 ± 0.5	

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; IP, in possession; OP, out of possession; HI, high-intensity; RHIE, repeated high-intensity effort. Values presented as means ± standard deviations. Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

Table 5.4. Movement patterns performed pre-, mid and post high-intensity effort in and out of possession across positions.

Movement Pattern	Centre Back	Fullback	Central Midfielder	Wide Midfielder	Forward	Effect Size
In Possession (%)						
Pre HI Effort: Arc Run	9.3 ± 14.9	4.9 ± 7.1	17.1 ± 14.3	11.0 ± 6.6	12.3 ± 9.2	CM > FB$^{\alpha}$; FW > FB$^{\alpha}$; WM > FB$^{\alpha}$
Pre HI Effort: 0-90° Turn	45.9 ± 37.1	33.0 ± 17.9	32.6 ± 18.2	32.3 ± 10.9	36.5 ± 11.4	
Pre HI Effort: 90-180° Turn	6.7 ± 14.6	8.0 ± 10.0	15.4 ± 15.9	10.9 ± 8.4	17.6 ± 10.3	FW > CB$^{\alpha}$, FB$^{\alpha}$, WM$^{\alpha}$
Mid HI Effort: Arc Run	24.6 ± 27.4	23.5 ± 17.3	15.9 ± 12.6	15.2 ± 7.4	17.6 ± 7.9	FB > WM$^{\alpha}$
Mid HI Effort: Swerve	44.0 ± 51.9	35.0 ± 20.2	33.7 ± 17.5	37.1 ± 16.6	41.2 ± 12.1	
Post HI Effort: Arc Run	7.3 ± 12.5	9.1 ± 10.0	14.8 ± 11.8	12.5 ± 9.0	16.1 ± 9.0	FW > CB$^{\alpha}$, FB$^{\alpha}$; CM > CB$^{\alpha}$
Post HI Effort: 0-90° Turn	29.5 ± 32.7	27.5 ± 13.9	31.1 ± 19.8	37.0 ± 11.4	34.5 ± 10.6	WM > FB$^{\alpha}$
Post HI Effort: 90-180° Turn	30.4 ± 39.4	19.0 ± 17.3	13.9 ± 15.1	11.7 ± 6.6	17.7 ± 9.0	CB > WM$^{\alpha}$; FW > WM$^{\alpha}$
Out Possession (%)						
Pre HI Effort: Arc Run	8.9 ± 7.7	4.3 ± 6.1	12.1 ± 9.3	7.8 ± 6.3	19.0 ± 13.6	FW > CB$^{\alpha}$, FB*, WM$^{\alpha}$; CM > FB$^{\alpha}$; CB > FB$^{\alpha}$
Pre HI Effort: 0-90° Turn	40.2 ± 14.5	24.4 ± 12.5	27.8 ± 11.0	25.4 ± 13.1	30.4 ± 14.9	CB > FB$^{\alpha}$, CM$^{\alpha}$, WM$^{\alpha}$, FW$^{\alpha}$
Pre HI Effort: 90-180° Turn	21.7 ± 12.2	32.4 ± 11.9	17.2 ± 9.1	21.3 ± 15.9	10.3 ± 7.3	FB > CB$^{\alpha}$, CM*, WM$^{\alpha}$, FW$^{\#}$; CB > FW$^{\alpha}$; WM > FW$^{\alpha}$; CM > FW$^{\alpha}$
Mid HI Effort: Arc Run	11.5 ± 8.8	11.1 ± 6.9	17.7 ± 12.4	15.1 ± 9.9	23.0 ± 18.4	FW > CB$^{\alpha}$, FB$^{\alpha}$; CM > FB$^{\alpha}$
Mid HI Effort: Swerve	40.9 ± 20.9	35.6 ± 14.5	40.7 ± 14.6	41.6 ± 20.8	34.1 ± 13.5	
Post HI Effort: Arc Run	18.3 ± 11.9	10.8 ± 9.3	13.9 ± 8.1	16.2 ± 10.3	31.7 ± 17.9	FW > CB$^{\alpha}$, FB*, CM*, WM$^{\alpha}$; CB > FB$^{\alpha}$
Post HI Effort: 0-90° Turn	39.4 ± 11.2	21.6 ± 13.5	28.3 ± 17.1	32.5 ± 18.0	31.5 ± 17.3	CB > FB*, CM$^{\alpha}$; WM > FB$^{\alpha}$; FW > FB$^{\alpha}$
Post HI Effort: 90-180° Turn	25.1 ± 10.3	22.5 ± 15.3	14.5 ± 12.0	17.2 ± 11.9	18.1 ± 16.1	CB > CM$^{\alpha}$, WM$^{\alpha}$

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; IP, HI, high-intensity. Values presented as means ± standard deviations. Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

5.4.3 Pitch Location

Inter-positional differences are presented in Table 5.5. In possession, all positions started the majority of efforts in the middle third of the pitch in central locations, though FB finished almost equal efforts in wide areas. CB and CM finished most efforts in the middle third of the pitch while FB, WM and FW finished most efforts in the attacking third. CB, CM and FW finished most efforts in central locations. FB finished most efforts in wide locations while WM finished an almost equal number of efforts in central and wide areas. Out of possession, all positions started most efforts in the middle third of the pitch and in central locations. CB and FB finished most efforts in the defensive third of the pitch, WM and FW finished most efforts in the middle third of the pitch while CM finished an equal number in the defensive and middle thirds. Moderate to very large intra-positional variation was reported for the start and end location of high-intensity efforts (CV >8.9%).

5.4.4 Technical Skills

In possession, CB performed a greater proportion of long passes post high-intensity effort than WM and FW (ES: 0.7, $P<0.05$, Table 5.6). WM executed more tricks post effort than CB and CM (ES: 1.2-1.3, $P<0.01$). FB and WM performed more crosses post effort than other positions (ES: 1.1-2.0, $P<0.01$). Out of possession, FW performed less tackles post effort than FB, CM and WM (ES: 1.1-1.8, $P<0.05$). Very large intra-positional variation was reported for technical skills performed before and after high-intensity efforts (CV >59.9%).

Table 5.5. Pitch location of high-intensity efforts in and out of possession across positions.

Pitch Location	Centre Back	Fullback	Central Midfielder	Wide Midfielder	Forward	Effect Size
In Possession (%)						
Pre HI Effort: Defensive 1/3	37.5 ± 32.8	18.6 ± 13.7	25.1 ± 18.9	9.8 ± 8.6	5.5 ± 5.2	CB > FB; FW*, WM$^{\alpha}$; FB > WM$^{\alpha}$, FW*; CM > WM$^{\alpha,}$ FW*; WM > FW$^{\alpha}$
Pre HI Effort: Middle 1/3	43.5 ± 37.3	68.2 ± 13.5	61.8 ± 18.3	64.5 ± 9.8	58.3 ± 14.9	FB > CB$^{\alpha}$, WM$^{\alpha}$, FW$^{\alpha}$; WM > CB$^{\alpha}$; CM > CB$^{\alpha}$
Pre HI Effort: Attacking 1/3	19.0 ± 27.4	13.2 ± 11.5	13.1 ± 11.3	25.6 ± 11.0	36.2 ± 15.6	FW > FB*, CB$^{\alpha}$, CM*; WM > FB$^{\alpha}$, CM$^{\alpha}$
Pre HI Effort: Central	80.9 ± 35.7	51.0 ± 17.4	87.8 ± 11.5	58.3 ± 15.9	86.3 ± 8.4	CM > FB$^{\#}$, WM$^{\#}$; FW > FB$^{\#}$, WM$^{\#}$; CB > FB$^{\alpha}$, WM$^{\alpha}$
Pre HI Effort: Wide	19.1 ± 35.7	49.0 ± 17.4	12.2 ± 11.5	41.7 ± 15.9	13.7 ± 8.4	FB > CB$^{\alpha}$, CM$^{\#}$, FW$^{\#}$; WM > CB$^{\alpha}$, CM$^{\#}$, FW$^{\#}$
Post HI Effort: Defensive 1/3	33.0 ± 32.0	7.1 ± 9.5	13.0 ± 17.2	3.5 ± 5.2	1.5 ± 2.9	CB > FB$^{\alpha}$, CM$^{\alpha}$, WM*, FW*; CM > WM$^{\alpha}$, FW$^{\alpha}$; FB > FW$^{\alpha}$
Post HI Effort: Middle 1/3	39.2 ± 35.4	44.7 ± 12.3	48.7 ± 12.6	32.1 ± 11.4	25.0 ± 12.9	FB > WM$^{\alpha}$, FW*; CM > WM*, FW*
Post HI Effort: Attacking 1/3	27.8 ± 27.8	48.2 ± 14.9	38.3 ± 19.5	64.3 ± 12.9	73.5 ± 13.8	FW > CB$^{\#}$, FB*, CM*, WM$^{\alpha}$; WM > FB$^{\alpha}$, CB*, CM*; FB > CB$^{\alpha}$
Post HI Effort: Central	73.5 ± 30.5	24.4 ± 13.0	73.2 ± 16.9	50.1 ± 18.6	79.7 ± 11.3	FW > FB$^{\#}$, WM*; CB > FB$^{\#}$, WM$^{\alpha}$; CM > FB$^{\#}$, WM*; WM > FB*
Post HI Effort: Wide	26.5 ± 30.5	75.6 ± 13.0	26.8 ± 16.9	49.1 ± 17.9	20.3 ± 11.3	FB > CB$^{\#}$, CM$^{\#}$, WM*, FW$^{\#}$; WM > CB$^{\alpha}$, CM*, FW*
Out Possession (%)						
Pre HI Effort: Defensive 1/3	39.4 ± 14.2	34.5 ± 13.2	16.8 ± 9.9	15.0 ± 11.0	5.0 ± 6.7	CB > CM*, WM*, FW$^{\#}$; FB > CM*, WM*, FW$^{\#}$; CM > FW*; WM > FW$^{\alpha}$
Pre HI Effort: Middle 1/3	49.8 ± 6.8	55.4 ± 14.9	73.1 ± 10.9	58.4 ± 13.7	62.5 ± 17.5	CM > CB$^{\#}$, FB*, WM$^{\alpha}$, FW$^{\alpha}$; FW > CB$^{\alpha}$; WM > CB$^{\alpha}$
Pre HI Effort: Attacking 1/3	10.8 ± 11.3	9.8 ± 11.9	10.0 ± 9.2	26.6 ± 14.5	32.5 ± 15.3	FW > CB*, FB*, CM*; WM > CB$^{\alpha}$, FB*, CM*
Pre HI Effort: Central	92.4 ± 6.1	60.6 ± 11.7	90.0 ± 5.1	69.7 ± 18.4	89.9 ± 11.8	CB > FB$^{\#}$, WM*, CM > FB$^{\#}$, WM*; FW > FB$^{\#}$, WM*
Pre HI Effort: Wide	7.4 ± 5.8	39.1 ± 12.0	9.8 ± 5.0	30.3 ± 18.4	10.1 ± 11.8	FB > CB$^{\#}$, CM$^{\#}$, FW$^{\#}$; WM > CB*, CM*, FW*
Post HI Effort: Defensive 1/3	74.3 ± 16.7	66.9 ± 21.1	47.3 ± 11.0	39.1±16.9	3.3 ± 6.7	CB > CM*, WM*, FW$^{\#}$; FB > CM$^{\alpha}$, WM*, FW$^{\#}$; CM > FW$^{\#}$, WM > FW$^{\#}$
Post HI Effort: Middle 1/3	21.4 ± 14.6	29.8 ± 18.7	47.3 ± 9.7	49.2 ± 13.0	58.4 ± 16.9	FW > CB$^{\#}$, FB*; CM$^{\alpha}$, WM > CB*, FB$^{\alpha}$; CM > FB$^{\alpha}$, CB*
Post HI Effort: Attacking 1/3	4.3 ± 5.9	3.0 ± 4.8	5.2 ± 6.3	10.8 ± 11.1	38.4 ± 16.8	FW > CB$^{\#}$, FB$^{\#}$, CM$^{\#}$, WM*; WM > CB$^{\alpha}$, FB$^{\alpha}$, CM$^{\alpha}$
Post HI Effort: Central	72.8 ± 14.5	59.3 ± 11.3	78.1 ± 12.4	46.2 ± 18.1	74.1 ± 16.9	CM > FB*; WM*; FW > FB$^{\alpha}$, WM*; CB > FB$^{\alpha}$, WM*; FB > WM$^{\alpha}$
Post HI Effort: Wide	27.2 ± 14.5	40.4 ± 11.8	21.8 ± 12.4	53.0 ± 17.0	25.9 ± 16.9	WM > CB*, FB$^{\alpha}$, CM$^{\#}$, FW*; FB > CB$^{\alpha}$, CM*, FW$^{\alpha}$

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; HI, high-intensity. Values presented as means ± standard deviations. Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

Table 5.6. Technical skills performed pre- and post high-intensity effort in and out of possession across positions.

Technical Skill	Centre Back	Fullback	Central Midfielder	Wide Midfielder	Forward	Effect Size
In Possession (%)						
Pre HI Effort: Long Pass	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 1.1	0.0 ± 0.0	0.0 ± 0.0	
Pre HI Effort: Trick	$2.1 \pm 8.3^{\$}$	0.4 ± 1.7	$2.8 \pm 6.1^{\$}$	$4.1 \pm 6.8^{\$}$	0.8 ± 2.2	WM > FB$^{\alpha}$, FW$^{\alpha}$
Pre HI Effort: Tackle	$2.1 \pm 8.3^{\$}$	$1.0 \pm 4.5^{\beta}$	1.0 ± 4.5	0.9 ± 3.1	0.7 ± 2.3	
Pre HI Effort: Header	0.0 ± 0.0	$1.6 \pm 5.8^{\$}$	0.5 ± 2.2	1.4 ± 3.6	$1.5 \pm 2.3^{\$}$	FW > CB$^{\alpha}$
Pre HI Effort: Cross	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 2.5	0.0 ± 0.0	0.0 ± 0.0	
Post HI Effort: Long Pass	$8.1 \pm 16.1^{\$}$	2.5 ± 5.5	3.0 ± 6.4	0.2 ± 1.0	0.2 ± 0.7	CB > WM$^{\alpha}$, FW$^{\alpha}$; CM > FW$^{\alpha}$
Post HI Effort: Trick	0.0 ± 0.0	2.0 ± 5.9	0.0 ± 0.0	5.6 ± 6.1	2.0 ± 3.4	WM > CB*, CM*, FW$^{\alpha}$; FW > CB$^{\alpha}$, CM$^{\alpha}$
Post HI Effort: Header	$6.8 \pm 25.0^{\beta}$	0.4 ± 1.7	0.0 ± 0.0	0.6 ± 1.9	$5.5 \pm 6.8^{\beta}$	FW > FB$^{\alpha}$, CM$^{\alpha}$, WM$^{\alpha}$
Post HI Effort: Cross	0.0 ± 0.0	$12.5 \pm 10.0^{\$}$	2.4 ± 4.6	$10.9 \pm 7.2^{\$}$	3.4 ± 4.7	FB > CB*, CM*, FW$^{\alpha}$; WM > CB*, CM*, FW*; FW > CB$^{\alpha}$; CM > CB$^{\alpha}$
Post HI Effort: Shot	0.8 ± 3.1	2.6 ± 5.0	$4.3 \pm 8.8^{\$}$	2.7 ± 4.5	$4.6 \pm 5.3^{\beta}$	FW > CB$^{\alpha}$
Out Possession (%)						
Pre HI Effort: Tackle	0.3 ± 1.1	1.2 ± 3.8	0.8 ± 2.1	0.0 ± 0.0	0.0 ± 0.0	
Pre HI Effort: Header	0.9 ± 2.2	0.6 ± 1.4	0.4 ± 1.7	0.0 ± 0.0	0.0 ± 0.0	
Post HI Effort: Tackle	5.9 ± 6.8	9.3 ± 5.7	8.6 ± 8.3	7.0 ± 7.2	1.1 ± 2.8	FB > FW*; CM > FW; WM > FW; CB > FW$^{\alpha}$
Post HI Effort: Header	2.5 ± 5.0	3.1 ± 4.2	1.3 ± 3.2	0.3 ± 1.3	0.0 ± 0.0	FB > WM$^{\alpha}$, FW$^{\alpha}$; CB > FW$^{\alpha}$

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; HI, high-intensity. Values presented as means ± standard deviations. Effect sizes were classified as ^{a}moderate (>0.6-1.2), ^{b}large (>1.2-2.0) and ^{c}very large (>2.0-4.0) (Batterham & Hopkin, 2006). Mean standardised difference (MSD): $^{\beta}$moderate MSD, $^{\$}$large MSD.

5.4.5 Tactical Actions

In possession, FW performed a greater percentage of high-intensity efforts breaking into the box than other positions (ES: 0.7-1.1, $P<0.05$) but ran with the ball less compared to FB and WM (ES: 1.3, $P<0.05$, Table 5.7). FB produced more overlapping runs than all positions (ES: 0.8-1.9, $P<0.01$). Out of possession, FW completed more efforts closing down the opposition (ES: 1.4-5.0, $P<0.01$) but less tracking opposition runners than other positions (ES: 1.5-1.8, $P<0.01$). WM and FW had fewer efforts covering the opposition than other positions (ES: 1.4-1.8, $P<0.01$) WM performed more recovery runs than other positions (ES: 0.9-2.4, $P<0.01$). Very large intra-positional variation was reported for tactical actions in and out of possession (CV >31.8%).

5.4.6 Combination Play

WM received a greater percentage of passes from CM pre high-intensity effort than CB (ES: 0.8, $P<0.05$, Table 5.8) and more passes from FW than CB and FB (ES: 0.9-1.0, $P<0.01$). WM performed a greater percentage of passes to FB pre effort than other positions (ES: 0.8-1.1, $P<0.01$). CB received more passes from CM (ES: 0.7, $P<0.05$) and performed more passes to the goalkeeper than CM, WM and FW post effort (ES: 0.7, $P<0.05$). Very large intra-positional variation was reported for combination play pre and post high-intensity effort (CV >77.5%).

Table 5.7. Tactical actions associated with high-intensity effort in and out of possession across positions.

Tactical Action	Centre Back	Fullback	Central Midfielder	Wide Midfielder	Forward	Effect Size
In Possession (%)						
Break into the box	13.1 ± 26.2	3.6 ± 9.0	6.2 ± 8.8	13.6 ± 8.8	28.4 ± 17.0	FW > CB$^{\alpha}$, FB*, CM*, WM$^{\alpha}$; WM > FB$^{\alpha}$, CM$^{\alpha}$
Run with the ball	22.2 ± 28.8$^{\beta}$	30.8 ± 17.6	23.2 ± 21.9	30.9 ± 17.3$^{\beta}$	11.1 ± 11.9	WM > FW*; FB > FW*; CM > FW$^{\alpha}$
Overlap	7.0 ± 15.6	18.6 ± 12.8	1.7 ± 3.9	4.2 ± 4.7	1.0 ± 2.1	FB > CB$^{\alpha}$, CM*, WM*, FW*; WM > FW$^{\alpha}$
Push up the pitch	38.1 ± 37.1$^{\$}$	20.5 ± 11.6	29.4 ± 21.1$^{\beta}$	24.7 ± 16.2	10.5 ± 8.2	CB > FB$^{\alpha}$, FW$^{\alpha}$; CM > FW$^{\alpha}$; WM > FW$^{\alpha}$; FB > FW$^{\alpha}$
Drive through the middle	18.9 ± 31.2	15.1 ± 15.1	45.8 ± 23.6$^{\$}$	30.8 ± 15.1$^{\beta}$	58.7 ± 17.8^	FW > CB*, FB$^{\#}$, CM$^{\alpha}$, WM*; CM > CB$^{\alpha}$, FB*, WM$^{\alpha}$; WM > FB$^{\alpha}$
Drive inside	0.0 ± 0.0	5.2 ± 8.6	3.6 ± 7.5	13.2 ± 14.1	7.7 ± 5.0	WM > CB*, FB$^{\alpha}$, CM$^{\alpha}$; FW > CB*, CM$^{\alpha}$; FB > CB$^{\alpha}$; CM > CB$^{\alpha}$
Run the channel	7.6 ± 15.5	64.0 ± 17.8^	12.0 ± 12.1	38.8 ± 16.3$^{\$}$	15.8 ± 10.0	FB > CB$^{\#}$, CM$^{\#}$, WM*, FW$^{\#}$; WM > CB*, CM*, FW*; FW > CB$^{\alpha}$
Run in behind	1.8 ± 5.0	4.1 ± 6.6	1.5 ± 4.7	6.1 ± 6.0	31.6 ± 12.7	FW > CB$^{\#}$, FB$^{\#}$, CM$^{\#}$, WM$^{\#}$; WM > CB$^{\alpha}$, CM$^{\alpha}$
Out Possession (%)						
Close down	13.6 ± 9.9	23.2 ± 10.8	36.6 ± 14.2	54.0 ± 21.0$^{\beta}$	81.5 ± 16.1^	FW > CB$^{\#}$, FB$^{\#}$, CM$^{\#}$, WM*; WM > CB$^{\#}$, FB*, CM$^{\alpha}$; CM > FB$^{\alpha}$, CB*; FB > CB$^{\alpha}$
Interception	8.1 ± 6.3	8.7 ± 5.9	6.0 ± 5.7	2.7 ± 4.9	0.3 ± 1.3	FB > WM$^{\alpha}$, FW*; CB > WM$^{\alpha}$, FW*; CM > WM$^{\alpha}$, FW*; WM > FW$^{\alpha}$
Covering	74.1 ± 15.9^	69.7 ± 13.2$^{\$}$	72.9 ± 9.7$^{\$}$	46.5 ± 18.5$^{\beta}$	36.7 ± 28.6	CB > WM*, FW*; CM > WM*, FW*; FB > WM*, FW*
Track runner	37.0 ± 15.4	35.9 ± 15.5	30.9 ± 11.2	35.2 ± 18.1	12.1 ± 11.8	CB > FW*; FB > FW*; WM > FW*, CM > FW*
Ball over the top	19.9 ± 10.0	8.8 ± 7.9	5.3 ± 4.8	0.5 ± 1.7	0.0 ± 0.0	CB > CM*, WM$^{\#}$, FW$^{\#}$; FB > WM*, FW*; CM > WM*, FW*
Ball down the side	29.5 ± 12.6	12.3 ± 9.6	4.0 ± 4.8	0.6 ± 2.5	0.0 ± 0.0	CB > FB*, CM$^{\#}$, WM$^{\#}$, FW$^{\#}$; FB > CM$^{\alpha}$, WM*, FW*; CM > WM$^{\alpha}$, FW$^{\alpha}$
Recovery run	24.1 ± 14.7	32.2 ± 16.8	31.7 ± 11.7	49.1 ± 20.0$^{\beta}$	8.0 ± 12.4	WM > CB*, FB$^{\alpha}$, CM$^{\alpha}$, FW$^{\#}$; FB > FW*; CM > FW*; CB > FW$^{\alpha}$
Challenge CB	0.0 ± 0.0	0.2 ± 0.9	2.6 ± 4.9	0.6 ± 2.0	45.2 ± 26.4$^{\$}$	FW > CB$^{\#}$, FB$^{\#}$, CM$^{\#}$, WM$^{\#}$; CM > CB$^{\alpha}$, FB$^{\alpha}$
Challenge FB	1.8 ± 3.0	5.9 ± 5.3	3.9 ± 7.7	34.2 ± 18.3$^{\$}$	14.3 ± 13.1	WM > CB$^{\#}$, FB$^{\#}$, CM$^{\#}$, FW*; FW > CB*, FB$^{\alpha}$, CM$^{\alpha}$; FB > CB$^{\alpha}$
Challenge CM	1.8 ± 3.5	3.8 ± 4.3	33.3 ± 11.1$^{\$}$	13.2 ± 11.3	15.6 ± 14.6	CM > CB$^{\#}$, FB$^{\#}$, WM*, FW*; FW > CB*, FB$^{\alpha}$; WM > CB*, FB$^{\alpha}$
Challenge WM	13.5 ± 9.1	32.6 ± 14.6$^{\$}$	13.5 ± 9.2	25.6 ± 22.4$^{\beta}$	2.4 ± 6.8	FB > CB*, CM*, FW$^{\#}$; WM > CB$^{\alpha}$, CM$^{\alpha}$, FW*; CB > FW*; CM > FW*
Challenge FW	31.1 ± 13.7$^{\$}$	7.8 ± 7.4	7.0 ± 6.5	3.8 ± 6.7	0.0 ± 0.0	CB > FB$^{\#}$, CM$^{\#}$, WM$^{\#}$, FW$^{\#}$; FB > FW*; CM > FW*; WM > FW$^{\alpha}$

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; HI, high-intensity. Values presented as means ± standard deviations. Effect sizes were classified as ^{a}moderate (>0.6-1.2), ^{b}large (>1.2-2.0) and ^{c}very large (>2.0-4.0) (Batterham & Hopkin, 2006). Mean standardised difference (MSD): $^{\beta}$moderate MSD, $^{\$}$large MSD, ^very large MSD.

Table 5.8. In possession, combination plays pre-and post high-intensity effort across positions.

Combination Play	Centre Back	Fullback	Central Midfielder	Wide Midfielder	Forward	Effect Size
Pre Effort						
Receives pass from GK	6.3 ± 25.0$^{\$}$	3.4 ± 5.1	1.0 ± 2.7	0.2 ± 0.9	0.2 ± 0.8	FB > WM$^{\alpha}$, FW$^{\alpha}$
Receives pass from CB	4.9 ± 9.4$^{\beta}$	3.7 ± 4.9	4.3 ± 6.9	3.3 ± 4.3	2.3 ± 3.7	
Receives pass from FB	2.6 ± 6.0	0.0 ± 0.0	9.2 ± 12.1$^{\$}$	8.7 ± 6.3$^{\beta}$	3.0 ± 4.2	CM > CB$^{\alpha}$, FB$^{\alpha}$, FW$^{\alpha}$; WM > CB$^{\alpha}$, FB*, FW$^{\alpha}$; FW > FB$^{\alpha}$; CB > FB$^{\alpha}$
Receives pass from CM	3.3 ± 8.7	9.4 ± 9.2$^{\$}$	8.0 ± 11.2$^{\beta}$	12.6 ± 12.8$^{\$}$	5.4 ± 4.7$^{\$}$	WM > CB$^{\alpha}$, FW$^{\alpha}$; FB > CB$^{\alpha}$
Receives pass from WM	0.8 ± 3.1	3.4 ± 5.7	2.8 ± 6.3	1.1 ± 2.5	2.4 ± 3.6	
Receives pass from FW	0.0 ± 0.0	0.7 ± 2.1	3.8 ± 7.2	5.4 ± 6.9	1.3 ± 2.6	WM > CB$^{\alpha}$, FB$^{\alpha}$, FW$^{\alpha}$; CM > CB$^{\alpha}$; FW > CB$^{\alpha}$
Passes ball to GK	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	
Passes ball to CB	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 4.5	0.5 ± 1.6	0.0 ± 0.0	
Passes ball to FB	0.0 ± 00	0.0 ± 0.0	0.8 ± 2.2	3.5 ± 4.2$^{\beta}$	0.7 ± 1.9	WM > CB$^{\alpha}$, FB$^{\alpha}$, CM$^{\alpha}$, FW$^{\alpha}$
Passes ball to CM	2.7 ± 8.5	0.4 ± 1.7	1.9 ± 4.4	2.6 ± 3.7	2.7 ± 4.3$^{\beta}$	FW > FB$^{\alpha}$; WM > FB$^{\alpha}$
Passes ball to WM	7.1 ± 17.1$^{\$}$	9.0 ± 11.2^	6.0 ± 9.2$^{\$}$	0.2 ± 1.0	3.2 ± 3.9$^{\$}$	FB > WM$^{\alpha}$, FW$^{\alpha}$; CM > WM$^{\alpha}$; FW > WM$^{\alpha}$
Passes ball to FW	2.1 ± 8.3	0.3 ± 1.2	2.8 ± 7.1	4.4 ± 5.6$^{\$}$	0.7 ± 1.4	WM > FB$^{\alpha}$, FW$^{\alpha}$
Post Effort						
Receives pass from GK	4.9 ± 13.1	0.7 ± 2.1	0.0 ± 0.0	0.4 ± 1.2	1.8 ± 4.8	
Receives pass from CB	0.0 ± 0.0	1.6 ± 4.2	1.7 ± 4.1	0.9 ± 2.4	1.6 ± 3.1	FW > CB$^{\alpha}$
Receives pass from FB	3.5 ± 8.9	0.0 ± 0.0	3.4 ± 5.2$^{\beta}$	3.4 ± 4.8$^{\beta}$	2.2 ± 3.3	CM > FB$^{\alpha}$; WM > FB$^{\alpha}$; FW > FB$^{\alpha}$
Receives pass from CM	19.5 ± 34.6$^{\$}$	9.7 ± 12.7$^{\$}$	2.1 ± 4.0	6.3 ± 5.3$^{\$}$	4.8 ± 4.8$^{\$}$	CB > CM$^{\alpha}$, FW$^{\alpha}$; FB > CM$^{\alpha}$; WM > CM$^{\alpha}$
Receives pass from WM	3.1 ± 12.5	10.4 ± 8.5$^{\$}$	4.1 ± 7.2$^{\$}$	1.3 ± 3.6	5.1 ± 5.0$^{\$}$	FB > CB$^{\alpha}$, CM$^{\alpha}$, WM*, FW$^{\alpha}$; FW > WM$^{\alpha}$
Receives pass from FW	2.1 ± 8.3	2.4 ± 3.9	2.5 ± 4.7	4.5 ± 4.4$^{\beta}$	1.6 ± 2.7	WM > FW$^{\alpha}$
Passes ball to GK	9.1 ± 18.1	2.3 ± 7.0	0.0 ± 0.0	0.2 ± 0.8	0.0 ± 0.0	
Passes ball to CB	7.7 ± 17.0	1.1 ± 3.4	5.0 ± 10.5	0.5 ± 1.6	0.0 ± 0.0	
Passes ball to FB	5.6 ± 14.1	0.4 ± 1.7	4.9 ± 8.4	5.3 ± 4.6$^{\beta}$	1.1 ± 2.3	WM > FB*
Passes ball to CM	7.9 ± 15.4	1.8 ± 4.8	4.6 ± 10.2	6.1 ± 5.3$^{\beta}$	3.4 ± 3.6$^{\beta}$	
Passes ball to WM	16.1 ± 33.8$^{\$}$	11.3 ± 10.8$^{\$}$	8.6 ± 9.3$^{\$}$	1.6 ± 2.7	3.5 ± 4.6$^{\$}$	FB > WM*
Passes ball to FW	5.7 ± 10.0	4.7 ± 6.4	6.1 ± 8.6	6.1 ± 5.1$^{\beta}$	1.6 ± 3.1	

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; HI, high-intensity. Values presented as means ± standard deviations. Effect sizes were classified as ^{a}moderate (>0.6-1.2), ^{b}large (>1.2-2.0) and ^{c}very large (>2.0-4.0) (Batterham & Hopkin, 2006). Mean standardised difference (MSD): $^{\beta}$moderate MSD, $^{\$}$large MSD.

5.5 DISCUSSION

The present study revealed position-specific trends for high-intensity efforts with special reference to movement patterns, pitch location, technical skills, tactical actions and combination play. Similar to previous research indicating match-to-match variability of physical and technical metrics are high to very high (Gregson et al., 2011; Bush et al., 2015b; Carling et al., 2016), the HIMP displayed moderate to very high intra-positional match-to-match variability. Nonetheless, the objective data provides additional information for practitioners wishing to design position-specific drills. Various permutations of this data could allow this information to be translational. For instance, applied scientists could potentially create SE combination drills in which all positions are worked in unison with game- and position-specific ball work present (Van Winkel et al., 2013). A starting point for SE drill development is to quantify position-specific trends in high-intensity metrics and the present data demonstrated that CB had the longest recoveries between consecutive high-intensity efforts, which concurs with previous research (Carling et al., 2012). The disparity in recovery times between studies (271 vs 195 s) is probably related to the differing high-intensity speed thresholds used (>21 vs 19.7 $km \cdot h^{-1}$). Moreover, WM produced more repeated high-intensity efforts compared to CB, CM and FW and these efforts were longer in distance and duration. Although some literature exists for comparative purposes, evaluating trends is problematic due to variations in the methods adopted across studies (Carling et al., 2012; Gabbett et al., 2013; Barbero-Alvarez et al., 2014). Despite this, the duration and distance of efforts across positions are valuable prescription metrics when constructing combination drills, particularly when considered relative to one another. However, practitioners should be aware that the data reported in the present study are means and if overload is desired then players need to be conditioned to 'worst case scenarios' such as those reported during intense match-play periods (Di Mascio & Bradley,

2013) or using predefined work-rest ratio from the literature (Iaia et al., 2009b; Iaia & Bangsbo, 2010).

Positional differences in pitch location during high-intensity efforts are expected due to distinct tactical roles (Wilson, 2008). The data demonstrates that in possession WM drive inside the pitch at high-intensity more than CB, FB and CM, performing an equal percentage of efforts in central and wide locations, which agrees with the most recent tactics outlined by the Football Association (FA) (Bate & Peacock, 2010). Supported by previous findings (Van Lingen, 1997; Hughes et al., 2012), FB and WM performed more crosses after runs than other positions due to efforts finishing in wide attacking pitch areas. Typically, WM perform efforts with the ball, which aligns with recommendations by the FA for WM to attack with the ball in 1 vs 1 situations (Bate & Peacock, 2010). FW finished more efforts in the attacking third of the pitch while driving through the middle, running in behind or breaking into the opposition box. Such tactics are required to exploit space in order to score and create space for teammates (Bangsbo & Peitersen, 2004).

Out of possession, all positions begin most efforts in the central and middle third of the pitch. All positions finished the majority of efforts in central locations with the exception of WM that finished in wide areas possibly due to tracking back with the opposition FB. The location of efforts across positions when out of possession is consistent with the coaching literature that suggest players should remain narrow and compact to limit space for the opposition (Hughes, 1994; Bangsbo & Peitersen, 2002). For effective SE drill design on a full-sized pitch, the start and end location of efforts could be replicated to enhance the ecological validity of drills. Thus, duplicating position-specific in and out of possession scenarios but with overload. For example, the FB starts an effort in the defensive third before overlapping the WM, to receive a pass in the wide attacking third to perform a cross. Simultaneously the FW breaks into the box to score while being tracked by the CB both having started in the middle third of the pitch. The CM drives through the middle of the pitch performing an arc run to support the attack ending with a possible shot on goal.

Movement patterns associated with efforts during possession highlight CM and WM perform more arc runs before efforts compared to FB. This may be due to the fact FB start more efforts in wide areas of the pitch compared to midfielders that are in more congested central locations (Tipping, 2007; Bush et al., 2015a). However, FB did perform more arc runs during efforts in possession than WM, possibly due to overlapping runs. FW performed more arc runs after efforts compared to CB and FB possibly to remain onside when trying to run in behind the opposition or recovering position during a misplaced pass. Although no positional differences were evident for 0-90° turns preceding efforts in possession, this is an important drill design metric due to its prevalence (>32%). When supporting play, discrete changes of direction are required to evade an opposition player or to find space to receive a pass (Bate & Jeffereys, 2014). Another movement to consider in drills after efforts in possession would be 0-90° turns for WM (37%) and FW (35%). This is possibly related to reacting to a second phase of the attack or to evade an opposition player to receive a pass or create space to shoot (Bate & Peacock, 2010). CB performed more 90-180° turns when recovering back into position. Furthermore, a swerve occurs in >33% of efforts across all positions and should therefore be considered when designing in and out of possession position-specific conditioning drills. Swerves are often referred to as slaloms when performed as part of a conditioning drill and are necessary to evade players or simply to advance up the pitch in congested areas (Bate & Jeffereys, 2014).

Out of possession, FW performed more arc runs than CB and FB before, during and after efforts. This could be due to channelling an opponent with the ball one way while closing them down in order to delay their attack and enable teammates to support the press (Michels, 2001). However, only post effort occurrence was >30% and it should also be acknowledged that FW only perform 32% of efforts out of possession. Nonetheless, this information is supported by recent research reporting the angle of sprints performed across positions was lowest for FB and highest for FW compared to all other positions (Fitzpatrick et al., 2019a). The present study also found CB performed more 0-90° turns pre and post efforts out of possession compared to FB and CM and due to its occurrence (>39%) should be considered when designing positional drills. Most efforts performed by CB out of possession are anticipated with players already on a half turn as sudden directional changes are necessary to react to opposition movement (Bangsbo & Peitersen, 2002). FB performed more 90-180° turns pre efforts compared to others with an occurrence of 32% often transitioning from attack into defence in order to perform a recovery run. Previous research examining positional demands of Premier League soccer matches reported no differences performing arc runs across playing positions but did report midfield players performed less 0-90° turns and swerves than defenders and forwards (Bloomfield et al., 2007). However, direct comparisons to the present study are not possible as the data was from 15-min of general play rather than isolated efforts over a full match and it did not account for whether players were in or out of possession.

In possession, CB performed more long passes after efforts than WM and FW, supporting previous research (Van Lingen, 1997). Although the percentage of efforts performed before a long pass is low (8%) the intra-position mean standardised difference was large compared to other technical skills (>1.2 SD). Direct comparisons are not possible, but research supports these findings as defenders and midfielders performed more long passes than forwards during matches (Bloomfield et al., 2007). In the present study, WM performed more tricks than FB and FW pre effort and CB, CM and FW post effort. Although overall percentage of efforts was again low pre and post effort (4 and 6%, respectively), intra-position differences pre effort were large (>1.2 SD). Tricks are required to beat an opponent in 1 vs 1 play and should be demonstrated by WM to create goal-scoring opportunities (Wiemeyer, 2003; Hughes et al., 2012). When employing intra-position mean standardised differences (>0.6 SD) as criteria to identify key components during drill design, FW and CM should perform a shot on goal, FW and CB should execute a header, while FB and WM should deliver a cross post high-intensity effort. All of the above mentioned technical skills are identified as key attributes for the relevant positions within the coaching literature (Hughes, 1994; Van Lingen, 1997; Wiemeyer, 2003; Bangsbo & Peitersen, 2004; Bate & Peacock, 2010; Hughes et al., 2012). Out of possession, FB performed more tackles and headers post effort, which are key defensive indicators (Hughes et al., 2012) despite being infrequent (3 and 9%, respectively). In contrast, Mohr et al. (2003) reported in a sample of Italian and Danish players that FB performed less tackles and headers than other positions. The discrepancies between findings may be due to quantifying general match play rather than isolated efforts, different playing styles between the leagues and failure to quantify skills in or out of possession.

Although the overall percentage of combination play between positions pre and post efforts was generally low (<13 and <20%, respectively) intra-position mean standardised differences could be used to prescribe the most likely scenario when designing drills to incorporate passing sequences. Though not interlinked, the data details that pre effort, CB received more passes from the goalkeeper and completed the greatest percent of passes to WM, while post effort, CB received more passes from CM and completed the greatest percent of passes to WM. The combination play reported for CB is supported by large intra-position differences relative to all other positions. This process can be implemented for each position in which all combination plays are supported by intra-position mean standardised differences considered at least moderate (>0.6 SD). This data allows practitioners to easily prescribe individual positional drills, however, position-specific combination drills require both objective data and the art of coaching.

The reader should be aware of the present study's limitations. Due to the high match-to-match variability practitioners should apply the HIMP on their own data due to unique individual physical profiles and team's style of play, which can impact match performances (Bradley et al., 2011; Fernandez-Navarro et al., 2018; Memmert et al., 2019). Moreover, using distances covered during high-intensity efforts is one-dimensional when attempting to determine the demands of match-play as it does not quantify metabolically taxing activities such as acceleration and decelerations (Varley & Aughey, 2013). Furthermore, drill design would be enhanced had the HIMP quantified combination play mid effort rather than just before and after.

The information provided in the present study is not intended to dictate the methods of the soccer coach but to help practitioners condition players in the absence of a coach led training session. The implications of a hypothetico-deductive method is acknowledged where the complexities and unpredictability of soccer is oversimplified (Mackenzie & Cushion, 2013), however such information can transfer to drill construction during the rehabilitation process when it is necessary to increase physiological load using controlled drills incorporating soccer specific movement patterns and skills (Van Winkel et al., 2013). As the player progresses through the rehabilitation process the drills should become more reactive in nature to better simulate the complex nature of the sport in preparation to train with the squad (Adams et al., 2012; Gleason, Kramer & Stone, 2015; Taberner, Allen & Cohen, 2019). That said, soccer players perform training drills during pitch based recovery sessions working on patterns of play which are predictable, however as with the proposed conditioning drills, the execution of technical skills require players to be reactive and engage in some form of decision making (Delgado-Bordonau & Mendez-Villanueva, 2012).

If the philosophy of the practitioner is to overload one component of fitness as in supra-maximal training using high-intensity running, the data in the present study could be advantageous. Should SE drills be designed on the information in this paper, the work to rest ratio and method of recovery between efforts can be manipulated to target different physiological energy systems (Iaia & Bangsbo, 2010; Buchheit & Laursen, 2013b; Ade et al., 2014). The data from the present paper is not meant to act as a prescriptive recipe but to help inform fitness staff of the most common soccer actions associated to high speed running. Therefore, the present data can be implemented into individual player position-specific drills during rehabilitation or additional conditioning. However, the skill of the practitioner is to design combination drills to train a number of positions simultaneously while ensuring variation for motivation and decision making to represent the game. Future research should aim to quantify mechanical loading during intense match play to provide guidelines for appropriate training methods.

5.6 CONCLUSION

The data demonstrate unique physical, technical and tactical position-specific trends in and out of possession during elite soccer matches. The novel HIMP method displayed excellent reliability however the high math-to-match variability needs to be acknowledged. Nonetheless, information from the present study should help practitioners devise positional drills and thus help to bridge the gap between scientific research and practical application.

5.7 PERSPECTIVE

Players perform unique movement patterns and technical skills due to tactical requirements associated with running at very high speed. Future research should use the data from the present study to configure both combination drills in which multiple positions are trained simultaneously, and individual player drills necessary during end stage rehabilitation or when additional conditioning is required. Once drills have been designed, the physiological response and time-motion characteristics of different protocols should be investigated to provide information on optimal training prescription.

CHAPTER SIX

PHYSIOLOGICAL CHARACTERISTICS AND ACUTE FATIGUE ASSOCIATED WITH INDIVIDUAL POSITION-SPECIFIC SPEED ENDURANCE DRILLS: PRODUCTION VS MAINTENANCE TRAINING

PHYSIOLOGICAL CHARACTERISTICS AND ACUTE FATIGUE ASSOCIATED WITH INDIVIDUAL POSITION-SPECIFIC SPEED ENDURANCE DRILLS: PRODUCTION VS MAINTENANCE TRAINING

6.1 ABSTRACT

Purpose: To compare the physiological characteristics and acute fatigue associated with position-specific speed endurance production (SEP) and maintenance (SEM) soccer drills. **Methods:** Ten elite and ten sub-elite male soccer players participated in the study (mean ± SD, age 21±4 yr; height 1.79±0.05 m; body mass 74.2±9.5 kg). The SEP protocol included 8 exercise bouts lasting ~30 s interspersed by 150 s of passive recovery, the SEM protocol was matched but used a reduced recovery period of 60 s. The sub-elite sample of players (*n*=10) also completed neuromuscular and subjective assessments of recovery pre, immediately after and 24 h post drill. **Results:** Players covered greater total (5%), high speed (12%), very high speed (49%) and sprint (218%) running distances in the SEP vs SEM protocol (P<0.05, ES: 0.51-0.80). Additionally, the SEP protocol resulted in greater peak (7%) and average (10%) running speeds (P<0.01, ES: 0.70-0.93). Mean and peak heart rate responses were greater in the SEM vs SEP protocol (4-10%, P<0.01, ES: 0.97–1.84) whilst blood lactate concentrations were higher following the SEP protocol (6%, P<0.05, ES: 0.42). Reductions in vertical countermovement jump height were more pronounced immediately after the SEP drill (2%, P<0.05, ES: 0.36) but 24 h post SEM drill (4%, P<0.05, ES: 0.52). Horizontal countermovement jump performance was reduced immediately post SEP and SEM protocols (3-5%, P<0.01, ES: 0.22-0.38) and 24 h post SEM protocol (4%, >1.5 × TE, ES: 0.32). No differences in vertical countermovement jump flight time contraction time ratio, isometric hamstring strength or subjective ratings of perceived recovery were evident between protocols over time**.** **Conclusions:** The data demonstrate that position-specific SEP and SEM drills overload different physiological indices and induce small impairments in some neuromuscular measures.

6.2 INTRODUCTION

High-intensity actions during matches have increased exponentially in recent years (Barnes et al., 2014). Thus, optimizing the physical performances of players using various training modes has received increasing attention (Fransson et al., 2017; Garcia-Ramos et al., 2018). Recently, speed endurance (SE) training has received greater attention with the performance benefits of such interventions becoming more evident along with the underlying adaptive mechanisms (Hostrup & Bangsbo, 2017). SE training is a prominent part of the annual training programme delivered to an elite youth soccer team (Chapter 3) whilst studies employing production (SEP) or maintenance (SEM) training demonstrate improvements in intense intermittent running capacity, short duration repeated sprint ability and submaximal running economy (Thomassen et al., 2010; Gunnarsson et al., 2012; Iaia et al., 2015).

Some cross-over is evident in the performance improvements after a period of SEM or SEP training. Although, the magnitude of these responses and adaptations are dependent on the training mode performed (Ade et al., 2014; Mohr & Krustrup, 2016; Castagna et al., 2017). For instance, individual SEP soccer drills reflecting game situations induce superior performance effects compared to SEM 2v2 small-sided games (SSG's) whilst reporting to elicit greater peak running speeds and heart rate responses (Mohr & Krustrup, 2016). In contrast, research comparing SEP & SEM 1v1 SSG's with matched exercise duration did not reveal any differences in high-intensity running distances but found greater mean heart rates during the SEM protocol (Castagna et al., 2017). Given these inconsistencies, further research comparing matched SEP versus SEM soccer drills reflecting game situations is warranted.

Most SE interventions administer 'all out' running drills, sometimes with 180° directional changes whilst others report 'all out' efforts with ball contacts (Gunnarsson et al., 2012; Iaia et al., 2015; Vitale et al., 2018). However, none provide drill information on movement patterns or technical skills. To ensure specificity, soccer based SE drills may be advantageous. A player's tactical role is a major determinant of their match physical exertion, so it could be advantageous to incorporate a positional conditioning stimulus within the SE drills (Martin-Garcia et al., 2018a). Position-specific SE drills that incorporate high-speed running and frequent changes of direction may achieve the necessary physiological and mechanical loading required to improve physical performance. Research in Chapter 5 identified unique position-specific movement patterns, technical skills and tactical actions associated with intense running efforts in elite matches (Ade et al., 2016). Thus, designing position-specific SE drills using such trends to overload supra-maximal running alongside relevant technical skills and necessary movement patterns would greatly contribute to the SE literature. Pilot work of a position-specific SE combination drill, designed using the data in Chapter 5, revealed physiological responses were lower (~9-31%) than the SEM running drills investigated in Chapter 4, whilst also displaying greater between player variability (Chapter 8). Therefore, this study will investigate individual position-specific SE drills to ensure a greater control of exercise intensity and more uniformed response.

An area of SE research so far overlooked is the acute fatigue associated with different protocols. Intense training aims to provide a stimulus to promote adaptation and enhance performance but as a result this will induce a period of fatigue that must dissipate to enable supercompensation (Issurin, 2010). If another intense stimulus is administered while the body has not adequately recovered, physical performance will decrease while the likelihood of injury could increase (Small et al., 2009; Dupont et al., 2010). Acute fatigue has been quantified following soccer matches (Nedelec et al., 2012; Silva et al., 2018), however understanding the recovery time-course associated with intense training drills would enable practitioners to prescribe SE protocols within a training micro-cycle more effectively (Buchheit et al., 2018; Martin-Garcia et al., 2018b). Therefore, the aim of this study is to compare the physiological characteristics and acute fatigue associated with novel SEP and SEM position-specific drills.

6.3 METHODS

6.3.1 Participants

Ten elite and ten sub-elite male soccer players took part in this study. The elite sample (*n*=10) represented an English Premier League youth team (mean ± SD; age 18 ± 1 yr; height 1.79 ± 0.05 m; body mass 70.2 ± 8.8 kg) and completed the drills as part of their scheduled training. The sub-elite sample (*n*=10) consisted of semi-professionals (age 23 ± 3 yr; height 1.80 ± 0.04 m; body mass 78.7 ± 8.6 kg) that volunteered to participate in the study. The elite and sub-elite samples consisted of the same number of players in each position (centre backs *n*=4, fullbacks *n*=4, central midfielders *n*=4, wide midfielders *n*=4, and forwards *n*=4). The physiological characteristics of the drills were analysed in both samples (*n*=20) but it was only possible to assess acute fatigue associated with the drills in the sub-elite sample (*n*=10) as the activity patterns of the elite players could not be standardised 24 h post drill. Training status of the sub-elite players is provided in Table 6.1. Players were informed of the procedures and associated risks before giving informed consent, and the study was approved by the appropriate ethics committee.

Table 6.1. Fitness data for comparison between elite and sub-elite groups

Test	Elite Youth (*n*=10)	Sub-elite Adult (*n*=10)	Difference (%)
Isometric Hamstring Strength (N)	671.5 ± 70.6	655.3 ± 103.7	-2.4
Countermovement Jump Height (cm)	39.8 ± 4.5	38.3 ± 8.4	-3.8
Reactive Strength Index	3.12 ± 0.52	3.04 ± 0.43	-2.6
Bi-lateral Horizontal Jump (cm)	204.3 ± 13.7	201.2 ± 25.0	-1.5
Endurance Test - Final Stage Time (s)	89.4 ± 9.8	95.4 ± 6.6	6.3
Sub-maximal run (%HR_{max})	88.2 ± 2.3	89.8 ± 2.5	1.8

Abbreviations: %HR_{max}, percentage of maximum heart rate.

6.3.2 Experimental Design

Elite players performed the position-specific drills throughout the season as the final part of their scheduled end stage rehabilitation programme. In line with regular protocol, it was deemed safer to prescribe the SEM before the SEP protocol based on proposed intensities to build chronic high speed running loads (Morrison, Ward & duManoir, 2017; Taberner et al., 2019). Prior to completing the SEM drill in the present study, all players completed a minimum of twelve pitch based conditioning sessions of which at least two were SE protocols (pre SEM drill 14 day external loadings: mean ± SD; total distance 38992±8782 m; very high-intensity >19.7 $km \cdot h^{-1}$ distance 2000±61 m; sprint >25.2 $km \cdot h^{-1}$ distance 245±144 m). This experimental design was replicated by the sub-elite players who supplemented their habitual schedule consisting of 2-3 training sessions and 1-2 matches a week. SEM and SEP drills took place outside on a full-size pitch separated by 5-7 days in an ambient temperature of 8-12˚C. To minimize learning effects, players were familiarized with the drills and neuromuscular assessments prior to the commencement of the study (Figure 6.1). All tests were performed at the same of time of day for each player to account for circadian variation. Players were asked to consume a standardized meal 2 h before testing and refrain from any strenuous exercise prior to testing. The sub-elite sample also refrained from strenuous exercise for 24 h following both drills.

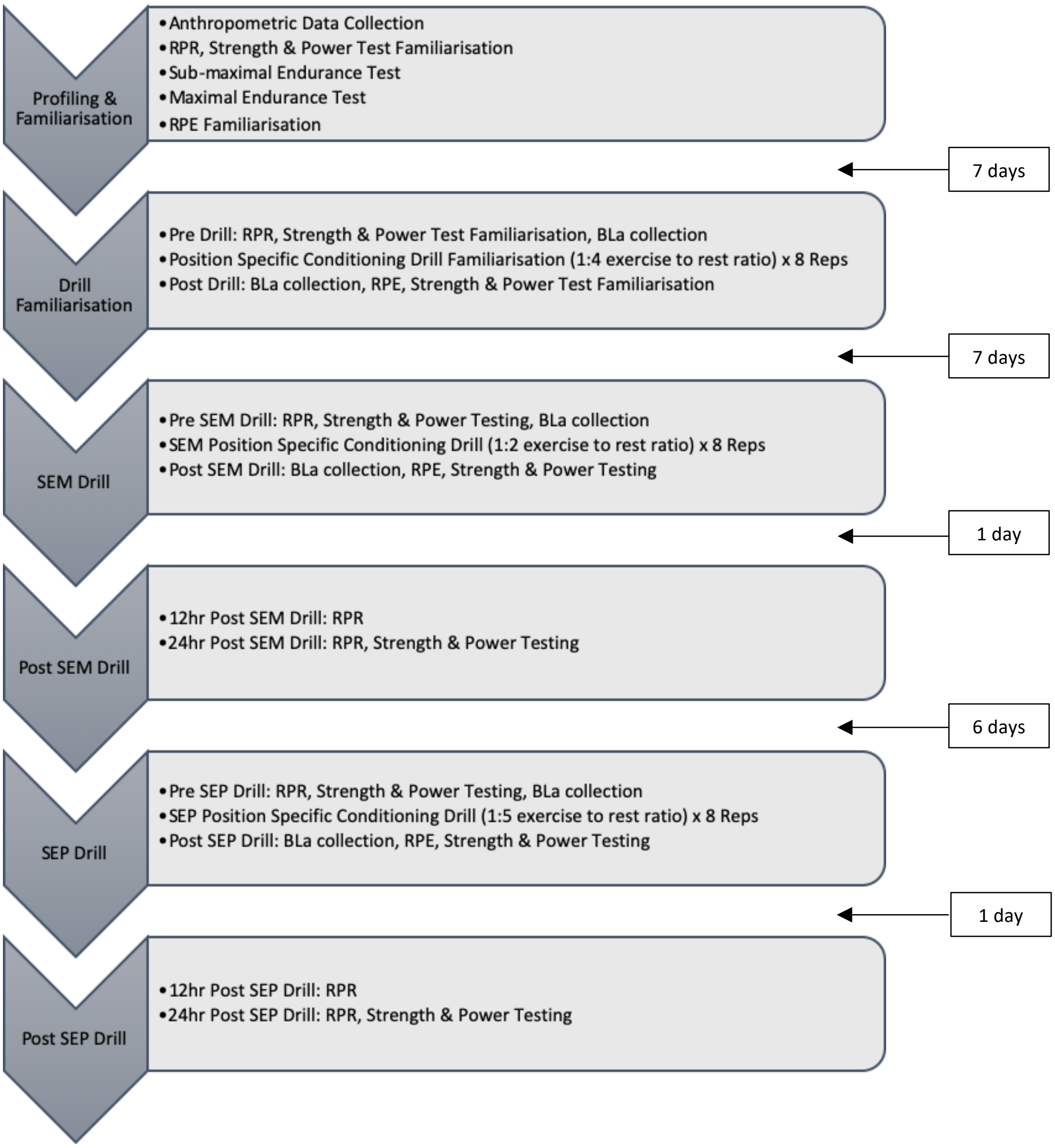
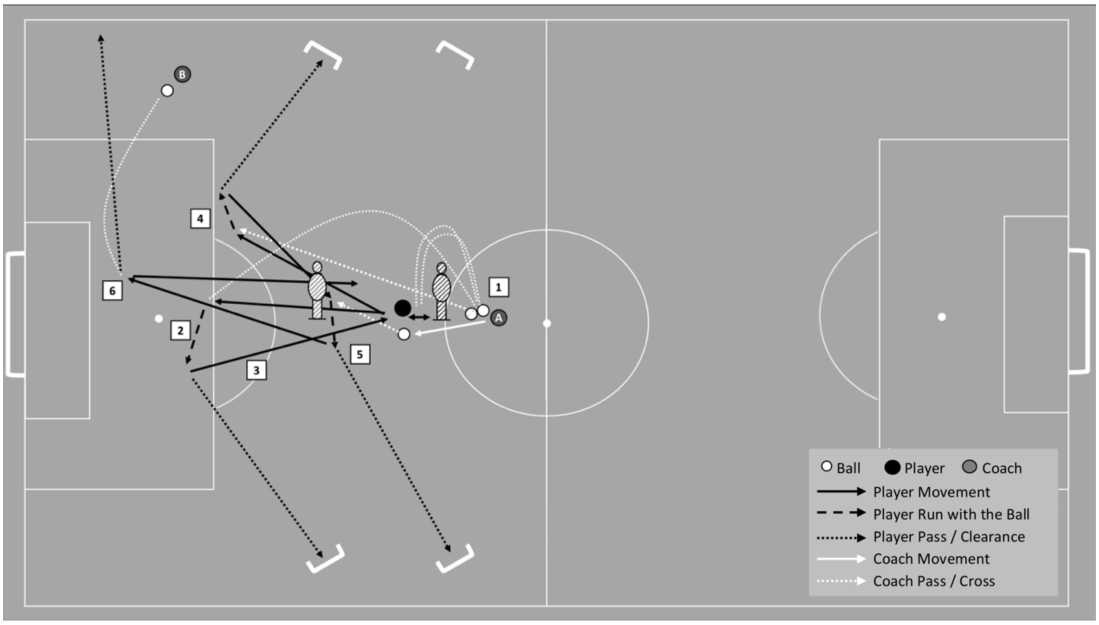


Figure 6.1. Flow diagram of the testing schedule administered over six sessions to the non-elite players. Abbreviations: RPR, rating of perceived recovery; RPE, rating of perceived exertion; BLa, blood lactate; Reps, repetitions; SEM, speed endurance maintenance; SEP speed endurance production.

6.3.3 Position-specific Drills

Drills were performed in isolation with each designed using position-specific match data that quantified pitch location, movement patterns, technical skills, combination play and tactical actions during high-intensity efforts reported in Chapter 5 (Ade et al., 2016). In order for these to be included in the drill, they had to adhere to one of the following criteria: (1) it occurred in >33% of efforts, (2) there was at least a small effect size difference (>0.2, Batterham & Hopkins, 2006) compared to a minimum of two other positions, (3) in categories with a large number of sub-variables (>3), there was a moderate standardized difference (>0.6) compared to the mean of the other variables. The third criteria permitted actions that may not occur in a high percentage of efforts, but relative to other variables are the most prominent and should therefore be included. The majority of high-intensity efforts do not include any ball contact (60-75%), however for player enjoyment, technical skill development under fatigue, ball contact was included (Ade et al., 2016). Drill configurations can be found in Figure 6.2. The SEP protocol included 8 exercise bouts lasting ~30 s interspersed by 150 s of passive recovery (1:5 exercise to rest ratio), while the SEM protocol used the same exercise bout duration with a reduced recovery of 60 s (1:2). Verbal encouragement was provided throughout the drills and players were instructed to exert maximum effort across all repetitions.

A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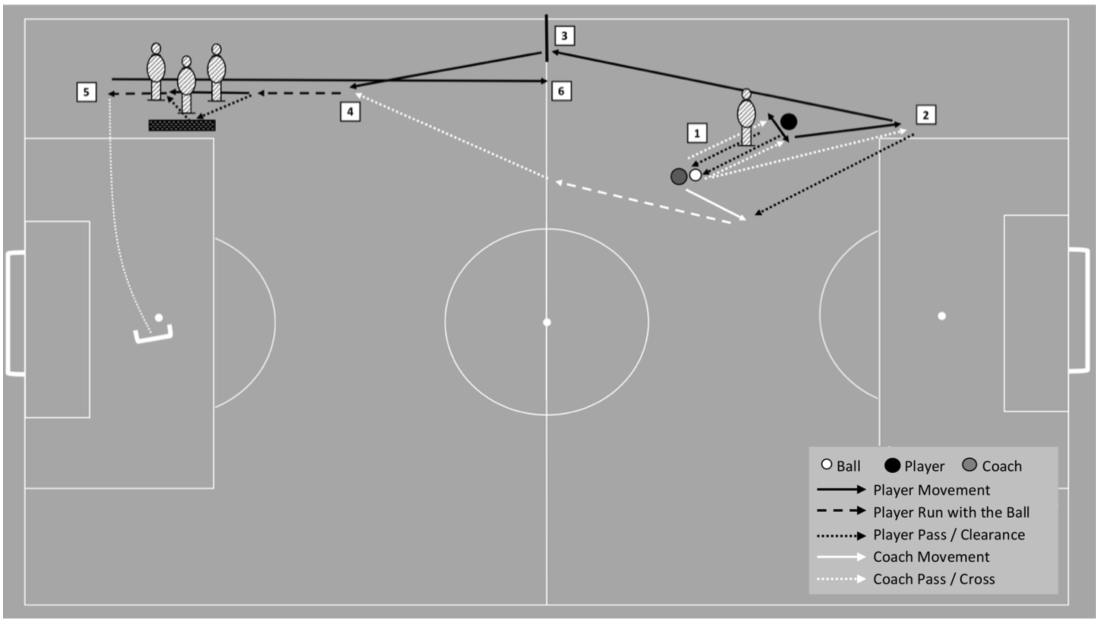
Coach
Player Movement
Player Run with the Ball
Player Pass / Clearance
Coach Movement
Coach Pass / Cross

B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Player Pass / Clearance
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Coach Pass / Cross

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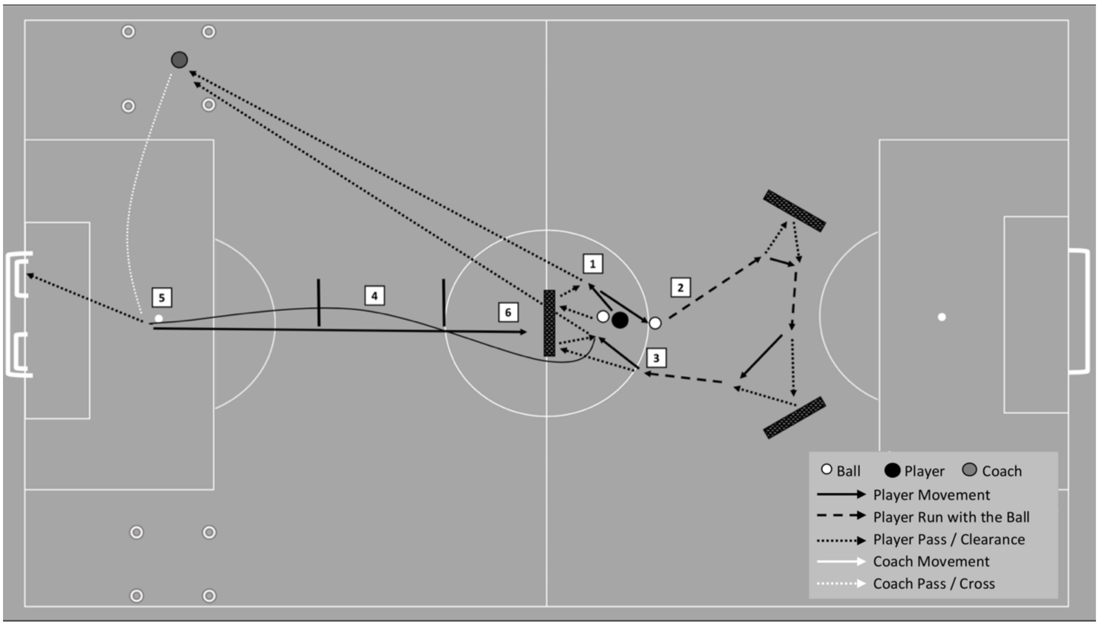
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Player Pass / Clearance
Coach Movement
Coach Pass / Cross

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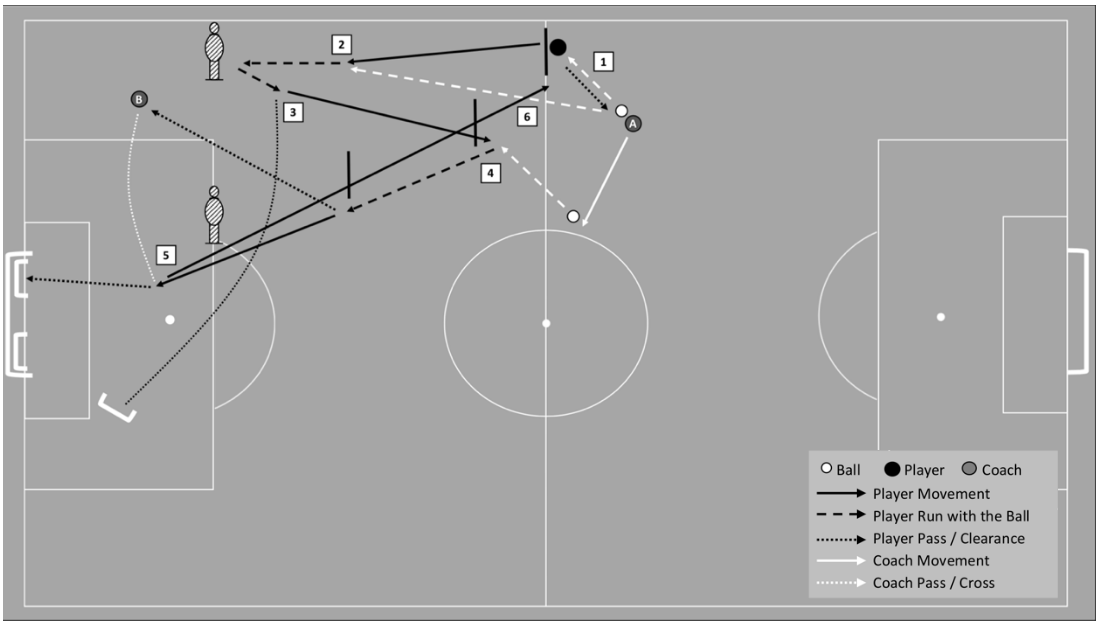
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Player Movement
Player Run with the Ball
Player Pass / Clearance
Coach Movement
Coach Pass / Cross

E

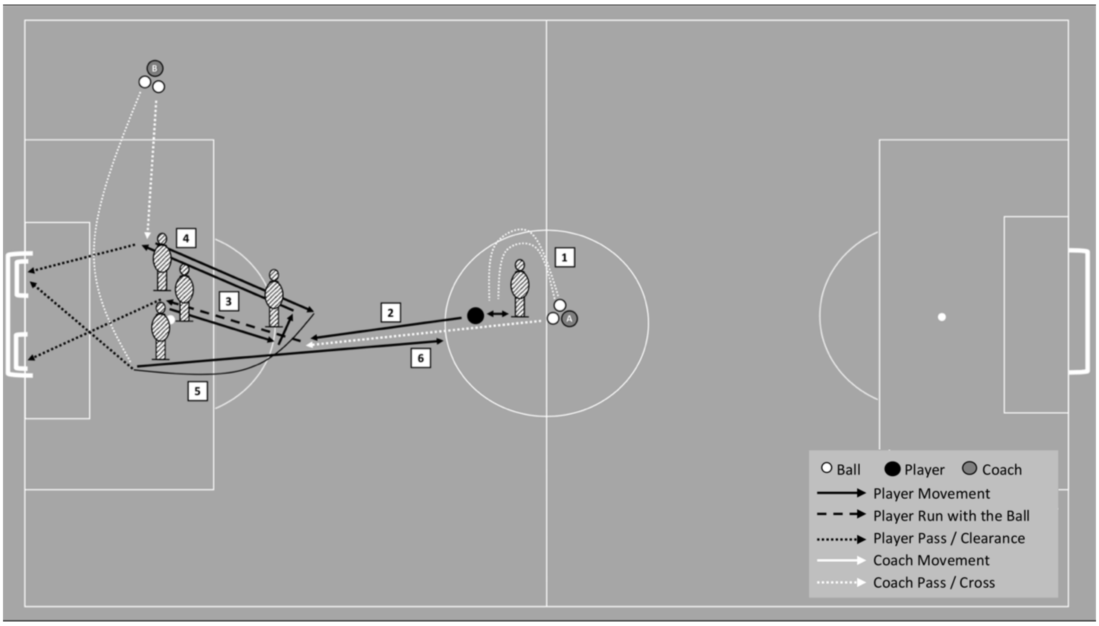


Figure 6.2. Position-specific drills. **(A) Centre back**, (1) press mannequin and perform two headers back to coach. (2) recover ball over the top from coach A, take a touch to the side or play first time pass into a mini goal. (3) push up the pitch to press the mannequin. (4) recover second ball over the top from coach A, take a touch to the side or play first time pass into a mini goal. (5) push up pitch and intercept pass from coach A in front of the mannequin and pass into mini goal. (6) recover into box to defend cross from coach B before pushing up the pitch. **(B) Fullback**, (1) move either side of the mannequin to play first time pass back to coach (x 2/3). (2) perform recovery run to retrieve coaches pass behind defence, turn and pass back to coach inside the pitch (CM). (3) perform overlapping run down the channel. (4) receive ball from coach (CM) and run with ball (option to play off bounce board or beat mannequins). (5) cross ball into mini goal. (6) perform recovery run to halfway line. **(C) Central midfielder**, (1) play bounce pass off the board before playing long pass out wide to coach. (2) run to ball on edge of centre circle and play bounce passes off the two deeper boards. (3) play bounce pass off board on centre circle and perform another long pass to the

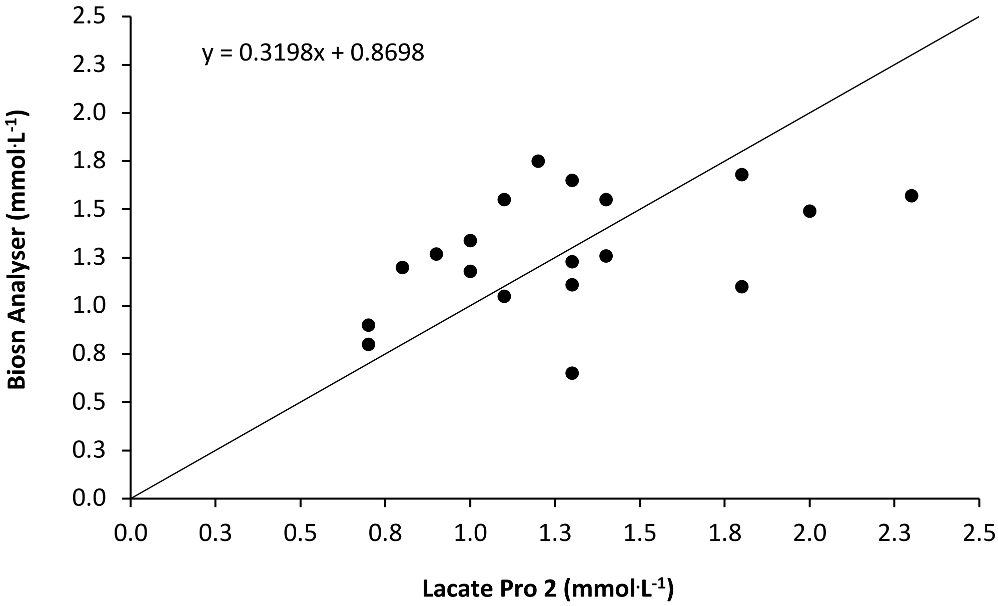
coach. (4) drive through the middle performing a swerve through the poles. (5) arrive in box to receive a cross from the coach to shoot at goal. (6) perform recovery run to halfway line. **(D) Wide midfielder**, (1) play bounce pass with coach A and make a run down the channel. (2) receive pass from coach A, run with the ball, perform a trick in front of mannequin. (3). execute in-swinging cross into mini goal, then perform recovery run. (4) receive another pass from coach A, perform a trick and run with the ball driving inside the pitch before passing the ball wide to coach B. (5) sprint into box to receive cross form coach B and finish into mini goal. (6) perform recovery run back to original start position on halfway line. (**E) Forward**, (1) press mannequin and perform two headers back to coach. (2) turn and run onto through ball from coach. (3) drive into the box with the ball and shoot on goal. (4) recover around mannequin on outside of 18yd box and attack the near post to finish cross from coach. (5) recover back around mannequin on edge of 18yd box again to attack another cross from the coach at the back post. (6) perform recovery run to front of centre circle.

6.3.4 Experimental Measures

6.3.4.1 Physiological and Perceptual Response

Heart rates were recorded in 5 s intervals throughout the drills using radio telemetry (Polar H1, Oy, Kempele, Finland). Mean and peak heart rates in addition to the time spent >85 and >90% of their maximal values (HR_{max}) were quantified. Player HR_{max} was determined before the study using peak values attained during an intermittent endurance test regularly performed by the elite players. The endurance test consisted of six submaximal runs (320 m / 4 x 80 m with three 180° changes of direction in 70 s) interspersed by 70 s passive rest periods. Following the sixth submaximal run, the participants rested for 30 s before running a set distance (480 m / 6 x 80 m with five 180° changes of direction) as fast as possible. In-house analysis revealed similar maximum heart rate responses (average -1.2 ± 3.5 bpm) as an incremental exercise test to exhaustion consisting of ~5 min running bouts at progressive running speeds known to be valid at obtaining peak physiological measurements (Bentley, Newell & Bishop, 2007). The players also completed an intermittent sub-maximal running protocol shown to have excellent reproducibility (CV = 2.6%, SEM = 2.2%) in elite youth soccer players (Orme et al., 2016). The time taken to complete the final stage of the progressive endurance test and the $\%HR_{max}$ achieved during the sub-maximal run indicate the training status between both groups of players are comparable (Table 6.1). The subjective ratings of perceived exertion (RPE) for the drill was recorded after the final repetition using the 6-20 scale (Borg, 1998). Capillary blood samples were collected from a finger at rest and on completion of the final repetition of each drill. Blood was analysed immediately for lactate concentration using an automated analyser (Lactate Pro 2, Arkray, Kyoto, Japan). This analyser is highly accurate for concentrations >15 $mmol{\cdot}L^{-1}$ when compared to a criterion analyser (Model ABL90, Radiometer, Copenhagen, Denmark), reporting a bias of ~2 $mmol{\cdot}L^{-1}$ (Bonaventura et al., 2015). To further assess the validity of the Lactate Pro 2 analyser, some methodological work was conducted by quantifying the blood lactate concentration of sub-elite players during their familiarization sessions using both a portable and a valid benchtop analyser (Biosen C-Line, EKF Diagnostic, Ebendorfer Chaussee 3, Germany; Davison et al., 2000). The portable Lactate Pro 2 analyser systematically produced higher lactate concentrations post exercise than the Biosen analyser (n=28, 18.9 ± 2.9 vs 15.8 ± 2.5 $mmol{\cdot}L^{-1}$) but similar resting values (n=19, 1.3 ± 0.4 vs 1.3 ± 0.3 $mmol{\cdot}L^{-1}$; Figure 6.3).

A



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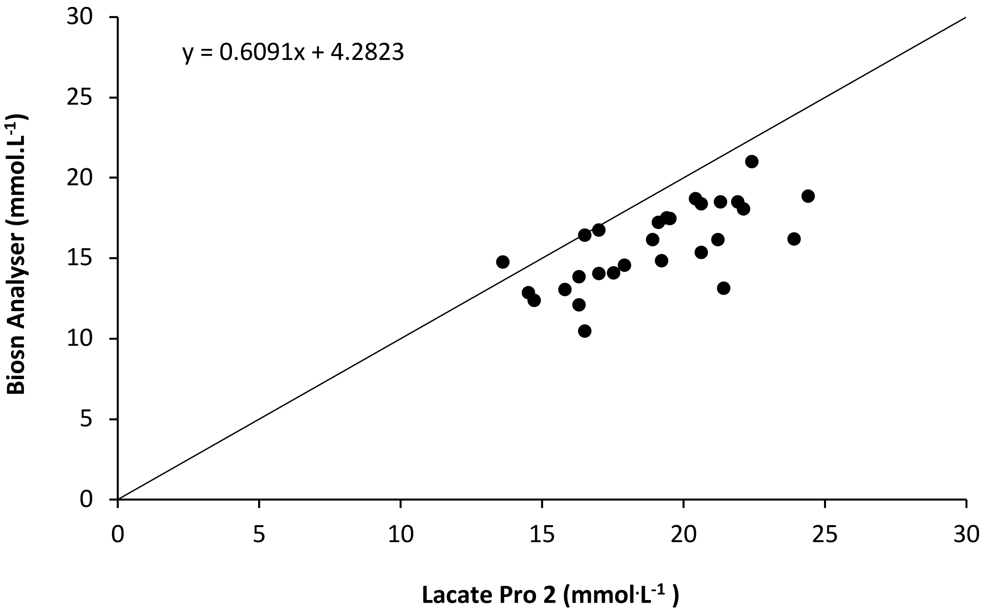


Figure 6.3. The relationship between the Lactate Pro 2 portable analyser and the Biosen analyser **(A)** Before drill (n=19, r=0.452, P>0.05; r^2=0.205). **(B)** Immediately after drill (n=28, r=0.694, P<0.01; r^2=0.481).

6.3.4.2 Time-motion Characteristics

The time-motion characteristics of drills were quantified using a micro-electro-mechanical device (STATSports Apex, Ireland) harnessed between the shoulders and anchored using an undergarment. This device contained a global positioning system (GPS) processor sampling at 10 Hz and has been found to provide a valid and reliable measure of instantaneous velocity during accelerations, decelerations and constant motion (Scott et al., 2016; Beato et al., 2018). Variables included total distance covered, high-speed running (>14.4 $km \cdot h^{-1}$), very high-speed running (>19.7 $km \cdot h^{-1}$) and sprinting (>25.2 $km \cdot h^{-1}$). The total number of accelerations (>0.5 $m \cdot s^{-2}$), decelerations (<-0.5 $m \cdot s^{-2}$) and high-intensity accelerations (≥3 $m \cdot s^{-2}$) and decelerations (≤-3 $m \cdot s^{-2}$) were quantified using a minimum dwell time of 0.5 s. The thresholds selected are consistent with the research literature (Varley & Aughey, 2013). Additionally, total and dynamic stress load were calculated using a tri-axial accelerometer within the device that sampled at 100 Hz. Total loading is the total magnitude of force scaled by 1000, whilst dynamic stress load is a training impulse (TRIMP) measurement that weights magnitudes >2 g using a dwelling time of 0.1 s. Accelerometers have acceptable interunit reliability during sport-specific movements and tasks requiring peak accelerations (Boyd, Ball & Aughey, 2011; Varley et al., 2012b). Data sets verified satellite signal (mean >14) and horizontal dilution of precision (mean <1.0) before being included in the analysis.

6.3.4.3 Neuromuscular Function

Neuromuscular performance was assessed via bilateral vertical countermovement jump (VCMJ), vertical drop jump (VDJ) and horizontal countermovement jump (HCMJ) performance. The VCMJ and VDJ were performed on a portable force platform sampling at 1000 Hz (ForceDecks FD4000, London, UK). Jump height for the VCMJ was recorded using the vertical reaction force impulse during take-off (Linthorne, 2001) whilst flight time contraction time ratio (FT:CT) was calculated from the peak VCMJ height to monitor changes in movement strategies (Cormack et al., 2008). Players were instructed to jump with maximum effort with arms akimbo. Downward phase depth during the VCMJ and HCMJ was self-selected (Cormack et al. 2008). Three maximal efforts were performed for all jumps with the best score used for analysis. The VDJ was performed from a 30 cm box to assess reactive strength index (RSI) which was calculated for each jump (flight time/contact time) permitting ground contact time was <0.25 ms (Flanagan & Comyns, 2008). Assessment of HCMJ performance required players to stand with feet shoulder width and their toes behind a marked line on the floor. They were asked to jump maximally in a horizontal direction with the distance recorded at the heel of the backmost foot (Thomas et al, 2017). Isometric knee flexor strength (ISO) was measured in a prone position using a NordBord. The lower front thighs and extended knees were placed on a padded board with a hip and knee angle equal to 0˚ while the players elbows were placed on an airex pad directly below the ipsilateral shoulder. Maximal contractions were performed against individual ankle braces, placed 1.5 inches superior to the lateral malleolus, attached to custom data collection system and uniaxial load cells (Vald Performance, Brisbane, Australia; Opar et al., 2013; Buchheit et al., 2016; Macdonald, 2017). Players performed three maximal contractions maintaining a neutral hip position throughout each effort. Verbal encouragement was provided throughout all contractions, each held for 3 s interspaced by 30 s recovery. Peak force was captured using the manufactures software (Vald Performance, Brisbane, Australia).

6.3.4.4 Subjective Ratings of Recovery

Subjective ratings of recovery were assessed pre drill, 12 and 24 h post drill using a perceived recovery scale (PRS) using a 0-10 scale with 0 and 10 representing 'very poorly recovered / extremely tired' and 'very well recovered / highly energetic', respectively (Laurent et al., 2011). The PRS has been shown to be a reproducible tool for monitoring perceptions of recovery in trained youth soccer players and sensitive to time-course changes relating to a match (Paul, Tomazoli & Nassis, 2019).

6.3.5 Statistical Analysis

Data are expressed as mean ± SD with 95% confidence intervals. All analyses were conducted using statistical software (SPSS, Chicago, USA). Descriptive statistics were calculated and z scores used to verify data normality. A two-way repeated-measures analysis of variance test was used to evaluate differences in time-motion analysis, physiological responses between SE formats, in addition to neuromuscular function at selected times. If sphericity was violated, the Greenhouse-Geisser correction was used. Bonferroni post-hoc tests were used to identify any localised effects. Statistical significance was set at $P<0.05$. The coefficient of variation (CV) was assessed across repetitions in both SE protocols to compare intra-drill variation. Effect sizes (ES) were calculated with the magnitude of the effect classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0), and very large (>2.0-4.0) (Batterham & Hopkins, 2006). Test re-test analysis of pre drill neuromuscular and subjective scores were used to calculate the coefficient of variation derived from the typical error for each test to establish usefulness. Magnitudes of change >1.5 times the typical error and the smallest worthwhile change were considered meaningful (SWC; 0.2 × between-subject standard deviation; Table 6.2) (Hopkin, 2000; Sawczuk et al., 2018).

Table 6.2. Reliability and Sensitivity of Fatigue Assessments (*n*=10)

Fatigue Assessment	Mean ± SD	CV%	SWC%	TE x 1.5	Usefulness
VCMJ Height (cm)	38.3 ± 8.7	2.9	5.0	1.7	Good
VCMJ FT:CT	0.8 ± 0.1	8.2	2.7	0.1	Marginal
DJ30cm Reactive Strength Index	3.0 ± 0.4	8.4	3.1	0.4	Marginal
HCMJ Distance (cm)	201.2 ± 25.7	2.6	2.7	7.9	Good
Isometric Hamstring Force (N)	655.3 ± 105.8	6.1	3.5	59.5	Marginal
Rating of Perceived Recovery	6.8 ± 1.2	18.2	4.5	1.9	Marginal

Abbreviations: CV, coefficient of variation; SWC, smallest worthwhile change; TE, typical error; VCMJ, vertical countermovement jump; FT:CT, flight time contraction time ratio; DJ30cm, 30cm drop jump; HCM, horizontal countermovement jump. Usefulness of test: Good = CV < SWC%, Marginal = CV > SWC% (Hopkins, 2000; Sawczuk et al., 2018).

6.4 RESULTS

6.4.1 Time-motion Characteristics

Players covered 5-12% more distance in total and running at high speed in the SEP compared to the SEM drill ($P<0.01$, ES: 0.51-0.56; Table 6.3). The SEP drill resulted in 49-218% more distance covered at very high speed and sprinting than SEM ($P<0.05$, ES: 0.66-0.80). Peak and average speed was 7% and 10% greater in SEP compared to SEM drill, respectively ($P<0.01$, ES: 0.70-0.93). The SEP drill also resulted in 13-27% greater total loading and the dynamic stress load compared to the SEM drill ($P<0.05$, ES: 0.61-0.79). No differences existed between protocols for acceleration and deceleration demands. Greater CV's were evident in the SEM drill across all speeds with the lowest CV's evident for total distance (SEM: 6.9, SEP: 5.2%) and highest CV's for sprinting (SEM: 205.2, SEP: 122.4%, Figure 6.4).

6.4.2 Physiological and Perceptual Response

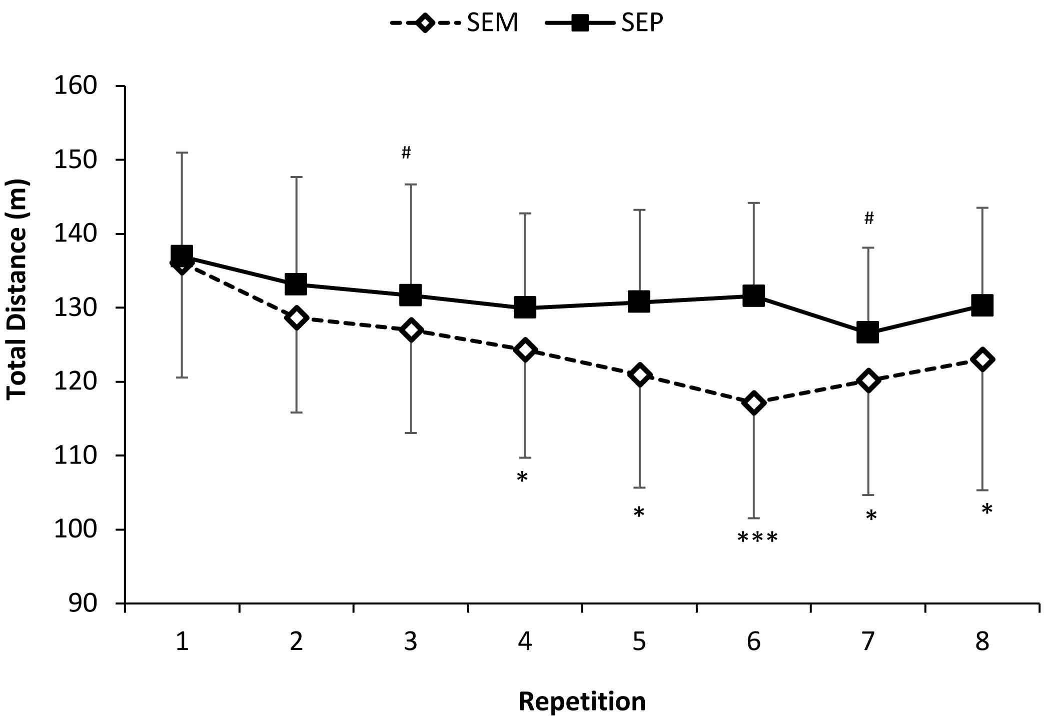
Mean and peak heart rates were 4-10% greater in the SEM drill compared to the SEP ($P<0.01$, ES: 0.97-1.84; Table 6.3). RPE was 4% higher in the SEM than in the SEP drill ($P<0.05$, ES: 0.47). Blood lactate concentrations were 6% higher following the SEP drill however the magnitude of difference was small (*P*<0.05, ES: 0.42). Though not the main aim of the study, it is still of interest to observe positional variation in external and internal load metrics within the SEM and SEP drill (Table 6.4 & 6.5). However, data should be treated with caution due to the small sample size and high intra-positional variation for sprint distance, intense accelerations/decelerations, and time spent >85 and 90% of HR_{max} across repetitions.

Table 6.3. Physical and physiological response to speed endurance maintenance and production position-specific drills (*n*=20).

Variable	Maintenance (*n*=20)	Production (*n*=20)	Mean Diff (95% CI)	Effect Size (95% CI)
External Load				
Total Distance (m)	124.7 ± 13.7	131.3 ± 11.8***	-6.7 (-9.7, -3.7)	-0.52 (-1.14, 0.12)
High Speed Running Distance (m)	93.0 ± 20.3	103.9 ± 17.9***	-10.9 (-14.5, -7.4)	-0.56 (-1.19, 0.07)
Very High Speed Running Distance (m)	38.0 ± 21.7	56.5 ± 23.5***	-18.5 (-22.1, -14.8)	-0.80 (-1.45, -0.16)
Sprint Distance (m)	2.2 ± 3.0	7.0 ± 11.1*	-4.8 (-8.8, -0.9)	-0.58 (-1.22, 0.05)
Maximum Speed ($m\cdot s^{-1}$)	6.7 ± 0.4	7.1 ± 0.5***	-0.45 (-0.58, -0.33)	-0.93 (-1.58, -0.28)
Average Speed ($m\cdot s^{-1}$)	4.1 ± 0.5	4.5 ± 0.7**	-0.41 (-0.72, -0.12)	-0.70 (-1.34, -0.06)
No. Total Accelerations (>0.5 $m\cdot s^{-2}$)	6.5 ± 1.3	6.6 ± 1.4	-0.11 (-0.74, 0.64)	-0.08 (-0.70, 0.54)
No. High-intensity Accelerations (>3 $m\cdot s^{-2}$)	2.2 ± 1.0	2.1 ± 1.3	0.13 (-0.44, 0.74)	0.10 (-0.52, 0.72)
No. Total Decelerations (<-0.5 $m\cdot s^{-2}$)	5.7 ± 1.5	5.7 ± 1.6	0.01 (-0.69, 0.29)	0.01 (-0.61, -0.63)
No. High-intensity Decelerations (<-3 $m\cdot s^{-2}$)	2.2 ± 1.0	2.1 ± 1.5	0.15 (-0.52, 0.82)	0.12 (-0.50, 0.74)
Total Loading Score	2.0 ± 0.3	2.3 ± 0.4***	-0.25 (-0.37, -0.13)	-0.79 (-1.43, -0.14)
Dynamic Stress Load	6.8 ± 2.0	8.7 ± 3.7*	-1.85(-3.36, -0.34)	-0.61 (-1.25, 0.02)
Internal Load				
Mean $\%HR_{max}$	85.0 ± 2.8***	77.9 ± 4.6	7.13 (5.39, 8.88)	1.84 (1.10, 2.58)
Peak $\%HR_{max}$	91.2 ± 2.7***	87.7 ± 4.2	3.52 (2.28, 4.78)	0.97 (0.31, 1.63)
Exercise Time >85% HR_{max} (min)	00:18 ± 00:06***	00:07 ± 00:05	00:11 (00:08, 00:13)	1.99 (1.23, 2.75)
Exercise & Rest Time >85% HR_{max} (min)	07:45 ± 02:07***	04:32 ± 2:17	03:13 (02:15, 04:12)	1.44 (0.74, 2.13)
Exercise Time >90% HR_{max} (min)	00:06 ± 00:05**	00:02 ± 00:02	00:04 (00:02, 00:06)	1.02 (0.36, 1.68)
Exercise & Rest Time >90% HR_{max} (min)	02:53 ± 02:13***	01:09 ± 01:16	01:44 (01:00, 02:28)	0.94 (0.29, 1.60)
Blood Lactate Post Drill ($mmol\cdot L^{-1}$)	17.7 ± 2.5	18.7 ± 2.5*	-1.07 (-2.10, -0.04)	-0.42 (-1.04, 0.21)
Rating of Perceived Exertion (6-20 scale)	17.9 ± 1.3*	17.2 ± 1.6	0.70 (0.09, 1.31)	0.47 (-0.16, 1.10)

Abbreviations: CI, confidence intervals; HR_{max}, heart rate maximum. Values presented as means ± standard deviations. *P<0.05, **P<0.01, ***P<0.001.

A


SEM
SEP
160
150
140
130
120
110
100
90
Total Distance (m)
#
#
*
*
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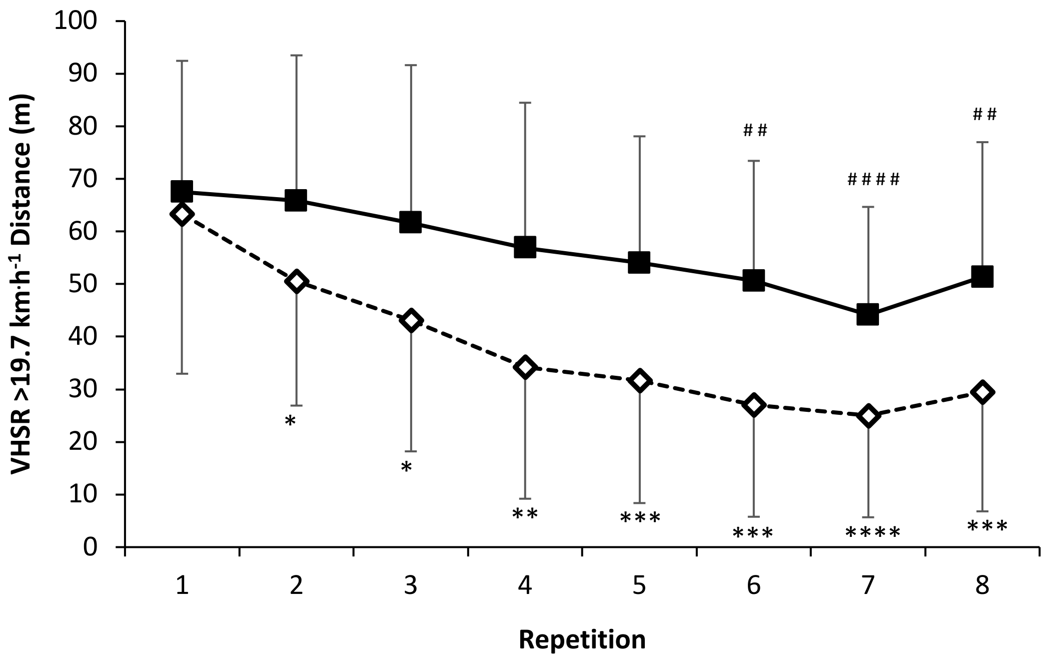
*
*
1
2
3
4
5
6
7
8
Repetition

B


100
90
80
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60
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40
30
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0
VHSR >19.7 km·h-1 Distance (m)
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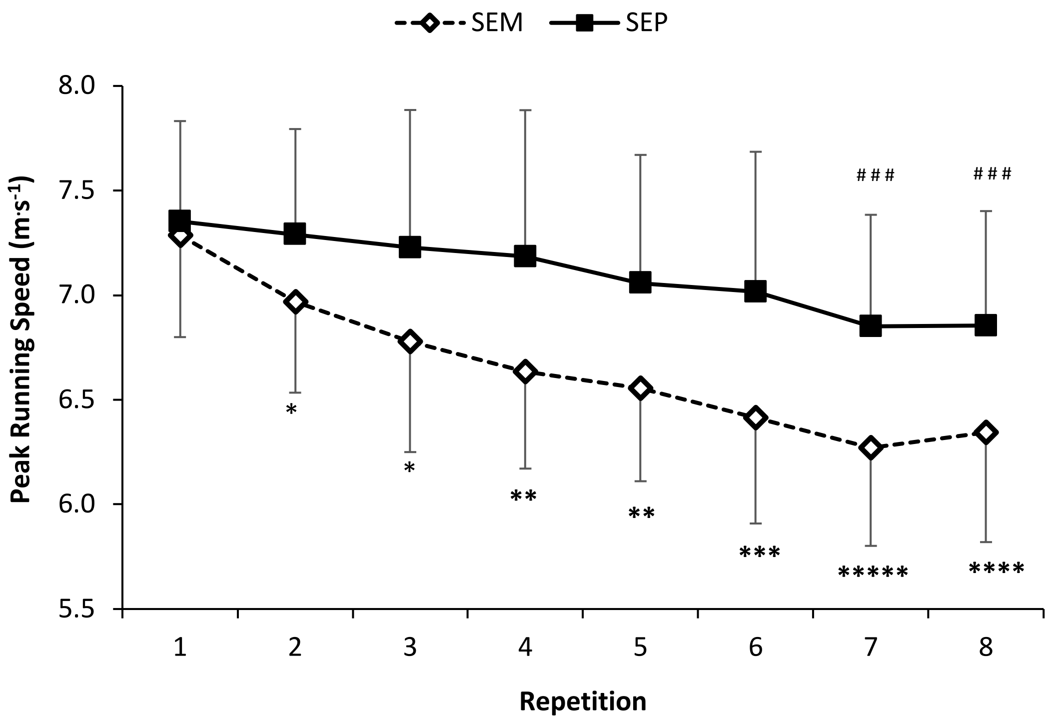
Repetition

C


SEM
SEP
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7.5
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Peak Running Speed (m·s-1)
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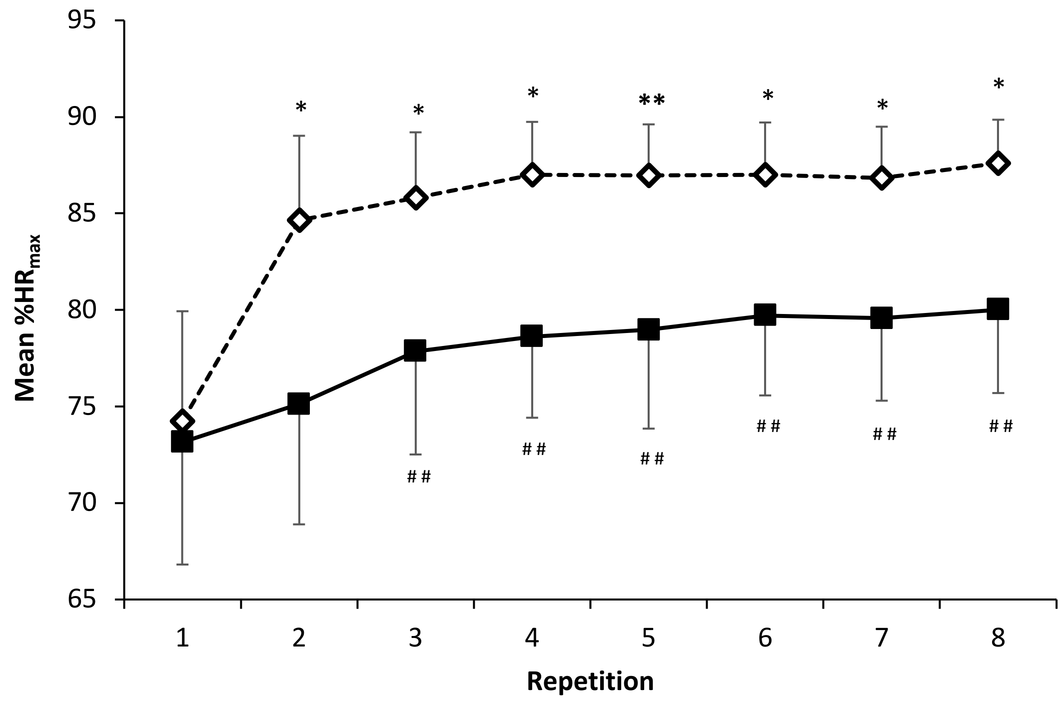
D


95
90
85
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75
70
65
Mean %HRmax
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Repetition
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Figure 6.4. Speed endurance drill responses and variability across repetitions (*n*=20). Abbreviations: SEM, speed endurance maintenance; SEP, speed endurance production; VHSR, very high speed running; $\%HR_{max}$, percentage heart rate maximum; CV, coefficient of variation. **(A) Total distance covered.** Interaction effect of protocol on repetition *P*<0.01, *significantly lower than other SEM repetitions denoted by the number of symbols, #significantly lower than other SEP repetitions denoted by the number of symbols, (*P*<0.05, CV: SEM = 6.9%, SEP = 5.2%). **(B) Very high speed running distance.** Interaction effect of protocol on repetition *P*<0.01, *significantly lower than other SEM repetitions denoted by the number of symbols, #significantly lower than other SEP repetitions denoted by the number of symbols, (*P*<0.05, CV: SEM = 53.5%, SEP = 24.2%). **(C) Peak speed.** Interaction effect of protocol on repetition *P*<0.01, *significantly lower than other SEM repetitions denoted by the number of symbols, #significantly lower than other SEP repetitions denoted by the number of symbols, (*P*<0.05, CV: SEM = 6.0%, SEP = 4.8%). **(D) Mean heart rate (%max)**. Interaction effect of protocol on repetition *P*<0.05, *significantly higher than other SEM repetitions denoted by the number of symbols, #significantly higher than other SEP repetitions denoted by the number of symbols, (*P*<0.05, CV: SEM = 5.6%, SEP = 4.1%).

Table 6.4. Positional physical and physiological response to speed endurance maintenance position-specific drills (each position n=4).

Variable	Centre Back	Fullback	Central Midfielder	Wide Midfielder	Forward	Effect Size Differences
External Load						
Total Distance (m)	107.5 ± 6.4	130.1 ± 2.8	126.0 ± 3.5	143.0 ± 11.5	116.6 ± 5.5	WM > CB[c], FB[b], CM[b], FW[c]; FB > CB[c], CM[a], FW[c]; CM > CB[c], FW[b]; FW > CB[b]
High Speed Running Distance (m)	68.1 ± 9.6	104.0 ± 1.5	92.6 ± 3.7	120.3 ± 15.8	79.9 ± 6.4	WM > CB[c], FB[b], CM[c], FW[c]; FB > CB[c], CM[c], FW[c]; CM > CB[c], FW[c]; FW > CB[b]
Very High Speed Running Distance (m)	15.7 ± 2.0	59.6 ± 12.4	28.4 ± 20.0	56.0 ± 22.0	30.3 ± 4.8	FB > CB[c], CM[b], FW[c]; WM > CB[c], CM[a], FW[b]; FW > CB[c]; CM > CB[a]
Sprint Distance (m)	0.6 ± 0.5	4.5 ± 5.7	0.4 ± 0.8	3.0 ± 2.0	2.3 ± 2.3	FB > CB[a], CM[a]; WM > CBb, CM[b]; FW > CB[a], CM[a]
Maximum Speed ($m{\cdot}s^{-1}$)	6.4 ± 0.2	6.9 ± 0.3	6.2 ± 0.5	7.0 ± 0.2	6.8 ± 0.3	WM > CB[c], CM[b]; FB > CB[b], CM[b]; FW > CB[b], CM[b]
Average Speed ($m{\cdot}s^{-1}$)	3.5 ± 0.2	4.4 ± 0.1	4.1 ± 0.2	4.7 ± 0.3	3.8 ± 1.2	WM > CB[c], FB[b], CM[c], FW[c]; FB > CB[c], CM[b], FW[c]; CM > CB[c], FW[b]; FW > CB[b]
No. Total Accelerations (>0.5 $m{\cdot}s^{-2}$)	7.4 ± 0.3	5.7 ± 0.6	7.2 ± 1.8	4.9 ± 0.6	7.5 ± 0.1	FW > FB[c], WM[c]; CB > FB[c], WM[c]; CM > FB[a], WM[b]
No. High-intensity Accelerations (>3 $m{\cdot}s^{-2}$)	2.7 ± 1.1	3.2 ± 1.1	1.3 ± 0.9	1.8 ± 0.3	2.1 ± 0.7	FB > CM[b], WM[b], FW[a]; CB > CM[b], WM[a]; FW > CM[a]; WM > CM[a]
No. Total Decelerations (<-0.5 $m{\cdot}s^{-2}$)	6.7 ± 0.5	5.4 ± 1.2	5.8 ± 0.8	3.7 ± 0.5	7.2 ± 1.2	FW > FB[b], CM[c], WM[c]; CB > FB[b], CM[a], WM[c]; CM > WM[c]; FB > WM[b]
No. High-intensity Decelerations (<-3 $m{\cdot}s^{-2}$)	3.2 ± 0.9	2.8 ± 0.5	1.3 ± 1.4	1.6 ± 0.1	2.2 ± 0.7	CB > CM[b], WM[c], FW[a]; FB > CM[b], WM[c], FW[a]; FW > CM[a], WM[a];
Total Loading Score	1.9 ± 0.4	2.1 ± 0.2	2.0 ± 0.1	2.2 ± 0.4	2.1 ± 0.1	WM > CB[a], CM[a]; CF > CM[a]
Dynamic Stress Load	7.2 ± 3.3	6.2 ± 2.1	7.3 ± 2.2	6.6 ± 1.7	6.7 ± 0.5	
Internal Load						
Mean $\%HR_{max}$	86.1 ± 2.4	84.9 ± 3.9	85.5 ± 3.0	84.4 ± 3.1	84.2 ± 2.4	CB > FW[a]
Peak $\%HR_{max}$	92.1 ± 2.6	91.2 ± 4.6	90.6 ± 3.8	91.3 ± 1.6	91.0 ± 1.3	
Exercise Time >85% $\%HR_{max}$ (min)	00:20 ± 00:06	00:17 ± 00:07	00:18 ± 00:07	00:18 ± 00:06	00:17 ± 00:05	
Exercise & Rest Time >85% $\%HR_{max}$ (min)	07:44 ± 02:45	07:53 ± 02:17	07:52 ± 02:08	07:05 ± 02:24	08:13 ± 02:03	
Exercise Time >90% $\%HR_{max}$ (min)	00:07 ± 00:06	00:05 ± 0:05	00:07 ± 00:07	00:05 ± 00:06	00:05 ± 00:04	
Exercise & Rest Time >90% $\%HR_{max}$ (min)	01:46 ± 01:24	01:01 ± 01:15	01:21 ± 01:44	02:05 ± 01:59	01:32 ± 01:15	
Blood Lactate Post Drill ($mmol{\cdot}L^{-1}$)	17.5 ± 1.8	16.1 ± 1.5	19.3 ± 3.3	17.9 ± 3.8	17.7 ± 1.3	CM > FB[a]; FW > FB[a]; CB > FB[a]
Rating of Perceived Exertion (6-20 scale)	18.3 ± 1.5	17.8 ± 1.0	17.3 ± 2.1	18.0 ± 1.2	18.0 ± 0.8	

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, Forward; HR_{max}, heart rate maximum. Values presented as means ± standard deviations. Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

Table 6.5. Positional physical and physiological response to speed endurance production position-specific drills (each position *n*=4).

Variable	Centre Back	Fullback	Central Midfielder	Wide Midfielder	Forward	Effect Size Differences
External Load						
Total Distance (m)	118.9 ± 5.6	136.5 ± 6.7	130.4 ± 2.7	148.5 ± 6.3	122.3 ± 2.4	WM > CB[c], FB[b], CM[c], FW[c]; FB > CB[c], CM[a], FW[c]; CM > CB[c], FW[c]; FW > CB[a]
High Speed Running Distance (m)	84.2 ± 8.8	112.3 ± 9.3	102.2 ± 2.6	130.3 ± 8.1	90.6 ± 3.3	WM > CB[c], FB[b], CM[c], FW[c]; FB > CB[c], CM[b], FW[c]; CM > CB[c], FW[c]; FW > CB[a]
Very High Speed Running Distance (m)	28.8 ± 5.1	81.5 ± 12.3	48.7 ± 12.8	80.4 ± 13.6	43.1 ± 5.2	FB > CB[c], CM[c], FW[c]; WM > CB[c], CM[c], FW[c]; CM > CB[b]; FW > CB[c]
Sprint Distance (m)	0.6 ± 0.8	17.8 ± 22.0	1.7 ± 2.6	7.4 ± 5.6	7.6 ± 3.3	FB > CB[a], CM[a]; FW > CB[c], CM[b]; WM > CB[b], CM[a]
Maximum Speed ($m \cdot s^{-1}$)	6.6 ± 0.3	7.4 ± 0.6	6.7 ± 0.3	7.4 ± 0.4	7.4 ± 0.3	FB > CB[b], CM[b]; FW > CB[c], CM[c]; WM > CB[b], CM[b]
Average Speed ($m \cdot s^{-1}$)	4.5 ± 1.4	4.7 ± 0.3	4.4 ± 0.2	4.9 ± 0.2	4.0 ± 0.1	WM > FB[a], CM[c], FW[c]; FB > CM[b], FW[c]; CM > FW[c]
No. Total Accelerations (>0.5 $m \cdot s^{-2}$)	8.4 ± 1.5	5.4 ± 0.3	6.5 ± 0.6	5.4 ± 0.7	7.5 ± 0.3	CB > FB[c], CM[b], WM[c], FW[a]; FW > FB[c], CM[b], WM[c]; CM > FB[c], WM[b]
No. High-intensity Accelerations (>3 $m \cdot s^{-2}$)	2.6 ± 1.9	1.9 ± 1.5	1.3 ± 1.1	1.5 ± 0.8	3.1 ± 0.3	FW > FB[a], CM[b], WM[c]; CB > CM[a], WM[a]
No. Total Decelerations (<-0.5 $m \cdot s^{-2}$)	7.3 ± 1.8	4.7 ± 0.8	5.6 ± 1.4	4.3 ± 0.7	6.8 ± 0.6	CB > FB[b], CM[b], WM[b]; FW > FB[c], CM[a], WM[c]; CM > FB[a], WM[a]
No. High-intensity Decelerations (<-3 $m \cdot s^{-2}$)	2.3 ± 1.8	2.0 ± 1.2	1.2 ± 1.5	1.2 ± 0.8	3.6 ± 0.8	FW > CB[a], FB[b], CM[b], WM[c]; CB > WM[a]; FB > WM[a]
Total Loading Score	2.3 ± 0.5	2.3 ± 0.3	2.1 ± 0.1	2.4 ± 0.2	2.3 ± 0.5	WM > CM[b]; FB > CM[a]; CF > CM[a]
Dynamic Stress Load	12.4 ± 4.8	7.0 ± 2.6	6.4 ± 2.7	8.9 ± 3.8	8.5 ± 2.5	CB > FB[b], CM[b], WM[a], CF[a]; WM > CM[a]; CF > CM[a]
Internal Load						
Mean $\%HR_{max}$	79.9 ± 2.0	78.5 ± 2.2	77.6 ± 9.2	75.1 ± 4.4	78.2 ± 1.9	CB > WM[b], FW[a]; FB > WM[a]; FW > WM[a]
Peak $\%HR_{max}$	90.1 ± 3.1	87.1 ± 5.2	85.6 ± 7.4	87.1 ± 1.9	88.6 ± 1.6	CB > FB[a], CM[a], WM[a]; FW > WM[a]
Exercise Time >85% $\%HR_{max}$ (min)	00:09 ± 00:04	00:05 ± 00:05	00:08 ± 00:10	00:05 ± 00:02	00:08 ± 00:03	CB > FB[a], WM[b]; FW > FB[a], WM[b]
Exercise & Rest Time >85% $\%HR_{max}$ (min)	04:45 ± 01:59	04:15 ± 01:47	04:50 ± 04:34	03:30 ± 01:03	05:21 ± 01:11	FW > FB[a], WM[b]; CB > WM[a]
Exercise Time >90% $\%HR_{max}$ (min)	00:03 ± 00:03	00:01 ± 00:02	00:03 ± 00:03	00:00 ± 00:00	00:02 ± 00:01	CB > FB[b], WM[b], FW[a]; CM > WM[a]; FW > WM[b]
Exercise & Rest Time >90% $\%HR_{max}$ (min)	01:46 ± 01:24	01:01 ± 01:15	01:21 ± 01:44	00:05 ± 00:06	01:32 ± 01:15	CB > WM[b]; FW > WM[b]; CM > WM[a]; FB > WM[a]
Blood Lactate Post Drill ($mmol \cdot L^{-1}$)	19.9 ± 1.9	17.9 ± 3.1	19.3 ± 2.9	18.6 ± 3.4	17.8 ± 1.2	CB > FB[a], FW[a]
Rating of Perceived Exertion (6-20 scale)	17.5 ± 1.3	18.3 ± 0.5	16.3 ± 2.6	17.0 ± 1.4	16.8 ± 1.7	FB > CB[a], CM[a], WM[a], FW[a]

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, Forward; HR_{max}, heart rate maximum. Values presented as means ± standard deviations. Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

6.4.3 Neuromuscular Function (sub elite players *n*=10)

Reductions in VCMJ height were more pronounced immediately post SEP (1.9%, $P<0.05$, ES: 0.36) but 24 h post SEM drill (3.5%, $P<0.05$, ES: 0.52, Table 5). HCMJ performance was reduced immediately post SEP (4.6%, >1.5 × TE & SWC, $P<0.01$, ES: 0.38) and SEM (3.0%, $P<0.01$, ES: 0.22) while meaningful changes were also evident 24 h post SEM protocol (-4.2%, >1.5 × TE & SWC, ES: 0.32). There were no differences in FT:CT or ISO across protocols or over time. RSI was reduced immediately post SEP and SEM (5.5-6.0%, $P<0.05$, ES: 0.41) however the change was less than the noise of the test (CV=8.4%).

6.4.4 Subjective Rating of Recovery (sub elite players *n*=10)

Subjective ratings of recovery using the PRS was significantly reduced immediately post and 24 h post SEP compared to the SEM protocol (14.7-16.2%, $P<0.05$, ES: 0.50-0.67) however again the change was less than the noise of the test (CV=18.2%).

Table 6.6. Neuromuscular function and perceptual responses to position-specific speed endurance drills (sub elite players *n*=10).

	Mean ± SD			Pre – Post Drill		Pre – 24h Post Drill	
Fatigue Assessment	**Pre**	**Post**	**24h Post**	**Mean Diff (95% CI)**	**Effect Size (95% CI)**	**Mean Diff (95% CI)**	**Effect Size (95% CI)**
SE Maintenance							
VCMJ Height (cm)#	38.7 ± 8.5	38.0 ± 8.5	37.4 ± 7.9	-0.65 (-2.36, 1.06)	-0.07 (-0.95, 0.80)	-1.26 (-3.40, 0.88)^	-0.15 (-1.02, 0.73)
VCMJ FT:CT	0.81 ± 0.10	0.84 ± 0.10	0.84 ± 0.11	0.03 (-0.03, 0.08)	0.26 (-0.62, 1.14)	0.03 (-0.08, 0.14)	0.25 (-0.63, 1.13)
VDJ30cm (Reactive Strength Index)	3.10 ± 0.41	2.94 ± 0.38*	2.93 ± 0.38	-0.17 (-0.34, -0.00)	-0.41 (-1.29, 0.48)	-0.18 (-0.48, 0.13)	-0.42 (-1.31, 0.46)
HCMJ Distance (cm)	201.8 ± 27.2	195.7 ± 26.6**	193.4 ± 23.7	-6.10 (-13.16, 0.96)^	-0.22 (-1.10, 0.66)	-8.40 (-17.08, 0.28)^^	-0.32 (-1.20, 0.57)
Isometric Hamstring Peak Force (N)	645.7 ± 98.5	612.4 ± 88.6	655.1 ± 107.7	-33.30 (-61.4, -5.2)	-0.34 (-1.22, 0.54)	9.40 (-31.6, 50.4)	0.09 (-0.79, 0.96)
Perceived Recovery Scale (0-10)	6.9 ± 1.0	7.4 ± 1.0	7.5 ± 1.4	0.50 (-0.90, 1.90)	0.49 (-0.40, 1.38)	0.60 (-1.11, 2.31)	0.47 (-0.42, 1.35)
SE Production							
VCMJ Height (cm)#	38.0 ± 8.8	36.6 ± 8.1	38.1 ± 7.2	-1.38 (-3.24, 0.48)^	-0.16 (-1.03, 0.72)	0.06 (-2.30, 2.42)	0.01 (-0.87, 0.88)
VCMJ FT:CT	0.88 ± 0.10	0.81 ± 0.11	0.84 ± 0.12	-0.06 (-0.12, -0.01)	-0.59 (-1.49, 0.31)	-0.04 (-0.12, 0.04)	-0.36 (-1.25, 0.52)
VDJ40cm (Reactive Strength Index)	2.99 ± 0.46	2.80 ± 0.38*	2.83 ± 0.38	-0.18 (-0.41, 0.04)	-0.41 (-1.30, 0.47)	-0.16 (-0.31, -0.01)	-0.35 (-1.24, 0.53)
HCMJ Distance (cm)	200.6 ± 24.1	191.4 ± 22.4**	197.6 ± 17.3	-9.20 (-16.17, -2.23)^^	-0.38 (-1.26, 0.51)	-3.00 (-13.08, 7.08)	-0.14 (-1.01, 0.74)
Isometric Hamstring Peak Force (N)	664.8 ± 113.0	646.4 ± 108.1	649.2 ± 129.5	-18.40 (-76.53, 39.73)	-0.16 (-1.04, 0.72)	-15.60 (-87.00, 55.80)	-0.12 (-1.00, 0.75)
Perceived Recovery Scale (0-10)	6.7 ± 1.5	6.1 ± 1.6	6.3 ± 2.0	-0.60 (-2.13, 0.93)	-0.37 (-1.26, 0.51)	-0.40 (-2.27, 1.47)	-0.22 (-1.10, 0.66)

Abbreviations: Diff, difference; CI, confidence intervals; VCMJ, vertical countermovement jump; FT:CT, flight time contraction time ratio; VDJ30cm, vertical 30cm drop jump; HCMJ, horizontal countermovement jump. #Cross-over interaction between protocols over time (P<0.05). Main effects of time *P<0.05, **P<0.01. ^Δ >coefficient of variation; ^^Δ >meaningful change (1.5 x typical error).

6.5 DISCUSSION

This was the first study to compare the physiological characteristics and acute fatigue associated with novel SEP and SEM positional drills. Findings revealed that external loading was greater in the SEP drill whilst internal loading was higher in the SEM drill. Furthermore, sub-elite players experienced small decrements in VCMJ post drill performance which was dependent on the protocol performed, whilst HCMJ performances were reduced immediately after both protocols and 24 h following the SEM drill.

Higher external load during the SEP versus SEM protocols is consistent with research comparing SSG's with equivalent running drills in Chapter 4 (Ade et al, 2014). However direct comparisons are difficult as the exercise duration in the above study were not standardized. In contrast, comparisons of SEP and SEM SSG's and running drills using matched exercise durations revealed no differences in external load between protocols (Castagna et al., 2017). This discrepancy could be attributed to the authors only prescribing 4 rather than the 8 repetitions in the present study. For instance, the high external load in the SEP drill was maintained across the 8 repetitions compared to the SEM drill due to a greater recovery time between bouts (Figure 6.4), thus performing 4 repetitions may not be sufficient to induce significant differences between protocols. Furthermore, the higher external load evident in the SEP drill of the present study is in agreement with research reporting higher peak and mean running speeds after 8-10 repetitions of individual SEP soccer drills reflecting game situations vs SEM SSG's (Mohr & Krustrup, 2016). However, due to the variation in SE modes and exercise durations it is again difficult to make direct comparisons.

Although no differences were evident in the number of accelerations and decelerations between protocols, the SEP protocol resulted in greater inertial loads. It is somewhat surprising the number of intense accelerations and decelerations did not differ between SE protocols. This could be related to the diminished accuracy of the GPS units when quantifying changes in velocities of greater magnitude (Akenhead et al., 2014), while it is also possible that a pacing strategy was employed during the SEP drill in which players performed arced turns in favour of cutting manoeuvres due to the higher mechanical demands associated with changing direction at greater running speeds (Waldron & Highton, 2014; Dos Santos et al., 2016; Ferraz et al., 2018). Furthermore, the drills were based on high-intensity running profiles during match play, had they been designed using training data or acceleration/deceleration profiles there may have been greater variability (Hodgson et al., 2014. Abbott, Brickley & Smeeton, 2018; Vigh-Larsen, Dalgas & Andersen 2018).

The greater heart rate responses in the SEM vs the SEP protocol is in agreement with the finding in Chapter 4 and previous research (Ade et al., 2014; Castagna et al., 2017). In contrast, a higher mean heart rate has been reported during individual SEP soccer drills compared to SEM 2v2 SSG's (Mohr & Krustrup, 2016). However, this is probably due to the difference in exercise modes as heart rates during individual SEP drills were far greater than SEP SSG's (91 vs 82-84% HR_{max}) reported in previous research (Ade et al., 2014; Castagna et al., 2017). This is not surprising given the greater control of exercise intensity during individual player positional soccer drills compared to the unstructured nature of SSG's involving other players. Heart rates during the present study were close to peaking on the fourth repetition during the SEM protocol and remained elevated throughout the drill while heart rates during the SEP protocol steadily increased across repetitions. This information may aid practitioners in their prescription of sets and repetitions to achieve the desired cardiovascular response.

Blood lactate concentrations were greater immediately after the SEP than SEM protocol, although the difference was small. Such findings are consistent with other research investigating SE soccer drills (Ade et al., 2014; Castagna et al., 2017). Concentrations in previous studies were much lower than in the current study (SEP = ~10 vs. 18; SEM = 8 vs. 17 $mmol \cdot L^{-1}$) but similar blood lactate concentrations were reported following 8 × 30 s all out running (1:3 exercise to rest ratio; ~17 $mmol \cdot L^{-1}$) using gold standard techniques (Mohr et al., 2007). It should be acknowledged methodological work revealed post drill blood lactate concentrations in the present study were systematically higher than the criterion measure (3-5 $mmol \cdot L^{-1}$; Figure 6.3) and this bias was similar to previous research investigating the accuracy of similar portable analysers (Tanner et al., 2010; Bonaventura et al., 2015). The higher concentrations in the present study are likely due to the more controlled nature of the drills in which a single player exercises in isolation (Mohr & Krustrup, 2016). Additionally, the concurrent exposure to very high speed running and metabolically taxing changes of direction may contribute to the elevated blood lactate response (Akenhead et al., 2015). The high metabolic and cardiovascular response to the position-specific SEM drill may therefore result in greater physiological adaptations and physical performance improvements than previously reported in the literature (Iaia & Bangsbo, 2010; Hostrup & Bangsbo, 2017). This would appeal to coaches and practitioners given the more time efficient manner of implementing a lower exercise to rest ratio (Iaia & Bangsbo, 2010; Bangsbo, 2015).

Although interpreting positional trends from a low sample size requires caution, it is worth noting wide midfielders and fullbacks covered the greatest high speed running distances across both protocols whilst forwards covered more sprint distance during the SEP protocol. This is in agreement with the data in Chapter 5 and the majority of match analysis literature (Barnes et al., 2014; Sarmento et al., 2014; Ade et al., 2016). Furthermore, centre backs and forwards covered the lowest total distance but performed the most accelerations and decelerations across both protocols. The position-specific SE drills utilized in the present study were designed using research on high-intensity running efforts and expert knowledge from a UEFA Pro License soccer coach (Ade et al., 2016). Acceleration and deceleration load would have no doubt been different had the position-specific drills been designed using match profiles reported in new emerging literature (Abbott et al., 2018b; Baptista et al., 2018; Vigh-Larsen et al., 2018). Minimal positional differences for internal load were evident during the SEM protocol, however centre backs generally produced greater heart rate and blood lactate responses during the SEP protocol compared to other positions which is not surprising given they typically have lower physical demands during training and match play (Akenhead, Harley & Tweddle, 2016; Martin-Garcia et al., 2018a; 2018b).

The sub-elite players experienced a more pronounced reduction in VCMJ and HCMJ performances immediately after the SEP protocol and 24 h following the SEM protocol, however, only changes in HCMJ performance were considered meaningful. As HCMJ performance relates to acceleration and sprint performance, it is not surprising that drills exposing players to high running velocities with rapid changes of direction effect power in a horizontal more than the vertical plane due to greater activation of the hamstrings (Jones et al., 2003; Dobbs et al., 2015; Morin et al., 2015). The decrements in HCMJ performance after the SEP protocol could be due to the higher running velocities inducing greater acute neural fatigue in fast twitch motor units thereby compromising subsequent explosive actions (Ross, Leveritt & Riek, 2001). The reduced HCMJ performance 24 h following the SEM protocol is surprising as one would expect the greater high speed running distances and mechanical load during the SEP drill to induce longer lasting fatigue due to the high neural and eccentric neuromuscular demands (Ross et al., 2001; Howatson & Milak, 2009). However, it is possible the density of high-intensity stretch-shortening cycle actions performed during the SEM protocol, with a shorter recovery time between repetitions, induced low-frequency fatigue (Jones, 1996; Keeton & Binder-Macleod, 2006; Calderon, Bolanos & Caputo, 2014).

The lack of a meaningful change in VCMJ is consistent with research monitoring elite players performance following regular training sessions throughout a microcycle (Malone et al., 2015a; Thorpe et al., 2015; Buchheit et al., 2018) but not competitive matches (Silva et al., 2018) or aerobic high-intensity SSG’s which have been shown to compromise neuromuscular function (Sparkes et al., 2018). The reduction in HCMJ performance following SE drills is below that reported following a simulated soccer match (Thomas et al., 2017) whilst the lack of changes in FT:CT, RSI or ISO performance is in conflict with literature investigating neuromuscular function of elite players following match play (Nedelec et al., 2014; McCall et al., 2015; Silva et al., 2018). The active exercise duration of the SE drills is far lower than a 90 min match while the noise of the FT:CT, RSI and ISO tests were greater than the VCMJ and HCMJ suggesting these measures may lack sensitivity to detect a true change. In agreement, these data are consistent with recent investigations into a moderate volume of sprinting bouts with or without changes of direction that found no significant decrements in neuromuscular function or changes in muscle damage-related variables in well-trained athletes (Grazioli et al., 2019). Furthermore, it is not surprising that decrements in explosive assessments were present in the absence of any change in maximal voluntary contraction of the knee flexors as rate of force development has been reported to be better associated with athletic performance (Tillin, Pain, Folland, 2013). These data support the notion that neuromuscular assessments that incorporate stretch-shortening cycle actions are more sensitive to fatigue following high-intensity intermittent exercise than assessment of maximal voluntary contractions (Buckthorpe, Pain & Folland, 2014).

The positional SE drills may affect physical performance of sub-elite players in subsequent drills within a training session, indicated by reduced horizontal power, however it is not possible to determine whether running mechanics would be altered due to fatigue. Changes in running mechanics under fatigue increase the risk of injury due to inefficient loading patterns and compromised intra-muscular co-ordination (Small et al., 2009; Cowley & Gates, 2017). Ultimately, it is for the practitioner to decide what magnitude of change is of practical importance based on the training status and physical profile of each individual player. For instance, a decrement in HCMJ performance of 4% may be considered meaningful for a player returning from a recent hamstring injury. Nonetheless, practitioners need to ensure players are adequately prepared for the large exposure to very high speed running and sprinting demands of the drills to avoid an acute spike in load which may increase the risk of injury (Gabbett, 2016).

The reader should be aware of the limitations of the present study. The drills were performed with elite player during end stage rehabilitation due to the dynamic nature of soccer training and challenges of implementing new practices in the applied environment (Morgans et al., 2014; Walker & Hawkins, 2017; Favero & White, 2018). A paired t-test analysis revealed no significant differences in neuromuscular function between pre-drill assessments (P>0.05) however future research should use a randomised crossover experimental design with players regularly participating in training and games. Additionally, although speed thresholds were set in agreement with the majority of literature in soccer match play, future research should individualise thresholds based on physical profiles to provide a more accurate comparison of the very high speed running and sprinting demands between drills (Hunter et al., 2015; Abbott et al., 2018a). Furthermore, the small changes in neuromuscular function is related to the SE drills when performed in isolation. In reality such drills will be performed in conjunction with other drills during end stage rehabilitation or following a team training session which may have a greater effect on neuromuscular function. Moreover, neuromuscular function was only assessed in the sub-elite players so it is not known whether these data would be consistent in elite players, although differences in neuromuscular strength and power were small (2-4%).

No between protocol differences were found for subjective ratings of recovery however this may be due to the poor test re-test reproducibility of the PRS in the present study. This is consistent with other research investigating subjective wellness questionnaires (Fitzpatrick et al., 2019b) however is at odds with recent research reporting the PRS to be reproducible in trained soccer players (Paul et al., 2019a). It is likely the structured five day training programme performed by the trained soccer players prior to both tests was more consistent than that of the sub-elite players in the present study. Future research should investigate changes in PRS following SE drills in elite soccer players whilst changes in neuromuscular function may have been more pronounced had eccentric and concentric force during the VCMJ been monitored in favour of jump height (de Hoyo et al., 2016). Furthermore, assessment of ISO using hip and knee angles more specific to foot strike during running may be more sensitive to detect changes in MVC of the hamstring muscles (Novacheck, 1998; Wollin, Thorborg & Pizzari, 2017). Finally, practitioners may which to consider monitoring performance changes of individual players due to unique physical and physiological profiles resulting in responders and non-responders for a given stimulus (Rabbani, Kargarfard & Twist, 2018; Ward et al., 2018).

6.5.1 Practical Applications

The findings suggest position-specific SEP drills should be prescribed to achieve a greater anaerobic stimulus and expose players to high running speeds whilst the SEM protocol should be administered when a greater cardiovascular load is desirable with a concomitant reduction in high speed running. Furthermore, practitioners should prescribe position-specific SE drills at the end of a training session as performance in subsequent drills may be compromised unless there is a desire to train under fatigue. Due to the very high speed running demands of the SEP protocol and reduction in HCMJ 24 h following the SEM protocol, it is suggested position-specific SE drills should be prescribed earlier in the weekly microcycle. Such drills can also be prescribed as an additional stimulus before a day off or during the end stage rehabilitation process.

6.6 CONCLUSION

This was the first study to compare the physiological characteristics and acute fatigue associated with novel SEP and SEM position-specific soccer drills. External loading was greater in the SEP drill whilst internal loading was higher in the SEM drill. Small effects of acute fatigue were evident in HCMJ performance immediately post SEP protocol and 24 h post SEM protocol in sub-elite players. These drills offer a positional SE training stimulus to tax the anaerobic energy system whilst ensuring specificity of training.

6.7 PERSECTIVE

Individual position-specific SE soccer drills provide an appropriate alternative to generic running drills with the added advantageous of simultaneously training soccer specific movement patterns and technical skills under fatigue. Future research investigating position-specific conditioning drills should consider including acceleration and deceleration demands. Furthermore, it would be of interest to compare position-specific drills consisting of multiple shorter duration repeated sprints / high-intensity activities interspaced by low intensity recovery periods with the longer duration more continuous nature of SE drills. Physiological response data investigating the activity of muscle enzymes and ion transport proteins of the positional drills would be advantageous, whilst further investigations into the effect of such drills on neuromuscular function would be beneficial to inform training prescription.

CHAPTER SEVEN

SYNTHESIS OF FINDINGS

7.1 SYNTHESIS

The purpose of the following chapter is to consider the current findings in relation to the original aim and objectives of the research programme. Practical recommendations to optimise speed endurance training in elite youth soccer players will be discussed based on a synthesis of the major findings. The limitations of the research studies will be acknowledged before making recommendations for future research based on the current findings and the evolution of soccer training methods and technologies in recent years.

7.2 ACHIEVEMENT OF AIMS AND OBJECTIVES

The main aim of this research programme was to understand and develop speed endurance practice in elite youth soccer players. This was met through the completion of four separate studies (Chapter 3, 4, 5 and 6) investigating the following objectives:

Objective One: To determine speed endurance exposure in elite youth soccer players over a season relative to all on-pitch conditioning drills.

In order to develop speed endurance (SE) practices, it was necessary to understand the exposure over a season relative to all other on-pitch conditioning drills. This objective was met within Chapter 3. The investigation identified speed endurance maintenance (SEM) exposure was greater than all other conditioning drills whilst speed endurance production (SEP) was the least frequent. Nevertheless, the proportion of SE drills performed as running drills relative to small-sided games (SSG's) was almost equal for both protocols. This investigation highlighted that SE training is a prominent part of an elite youth soccer player's training programme and indicates SSG's may provide an appropriate training stimulus as they elicited a similar heart rate response as the aerobic high-intensity drills. However, more research was warranted to investigate the anaerobic response, locomotive demands and reproducibility of SE SSG's.

Objective Two: To establish the physiological response, time-motion characteristics and reproducibility of speed endurance small-sided games and running drills.

Based on the findings from Chapter 3, an in-depth analysis of the physiological response, time-motion characteristics and reproducibility of SE SSG's was necessary to further understand SE practice. This objective was clearly met in Chapter 4. Elite youth soccer players completed four SE drills: (1) SEP 1v1 SSG, (2) SEP running drill, (3) SEM 2v2 SSG, (4) SEM running drill. The running drills elicited greater physiological and perceptual responses than respective SSG's. Players covered less total distance and high-intensity distance in the SSG's, but greater high-intensity acceleration/deceleration distance in the respective running drills. Additionally, the SEP drills produced greater blood lactate concentrations and greater high speed running demands than the respective SEM protocols. These findings suggest SE SSG's could be used to train the anaerobic energy system, however the physiological response was lower than the respective running drills whilst also exhibiting greater time-motion variability. It is therefore suggested position-specific SE drills should be designed based on high speed running profiles. Such drills that incorporate the ball may elicit greater physiological responses than SSG's whilst also ensuring greater acceleration/deceleration demands than the running drills.

Objective Three: To quantify the position-specific movement patterns, technical skills and tactical actions associated with high speed running efforts during elite match play to aid speed endurance drill design.

Considering the outcomes of Chapter 4, a time-motion analysis study was conducted to quantifying the most frequent movement patterns, technical skills and tactical actions associated to high-intensity running efforts across playing positions to develop SE practice. This objective was met in Chapter 5. Twenty individual English Premier League players high-intensity running profiles were observed multiple times using a computerised tracking system. Data were analysed using a novel High-intensity Movement Programme across five positions (centre back = CB, fullback = FB, central midfielder = CM, wide midfielder = WM, forward = FW) and revealed position-specific trends in and out of possession. These findings demonstrate playing positions perform unique movement patterns, technical skills and tactical actions when performing high-intensity running efforts in and out of possession. This information could be used to develop position-specific SE conditioning drills.

Objective Four: To investigate the physiological characteristics, physical demands and subsequent effect on neuromuscular function of position-specific speed endurance soccer drills.

This objective was met in Chapter 6. Information gathered in Chapter 5 was used to construct five different position-specific drills. Ten elite and ten sub-elite male soccer players performed a position-specific SEP and SEM conditioning drill. The sub-elite sample of players also completed neuromuscular and subjective assessments of recovery pre, immediately after and 24 h post drill. Players covered greater distances across all speed thresholds attaining greater peak and average running speeds during the SEP protocol compared to SEM drill. Mean and peak heart rate responses were greater in the SEM protocol whilst blood lactate concentrations were higher following the SEP protocol. Minimal differences in neuromuscular function and subjective ratings of recovery were evident following both protocols up to 24 h post drill. The findings suggest position-specific SEP drills should be prescribed to achieve a greater anaerobic stimulus and expose players to high running speeds whilst the SEM protocol should be administered when a greater cardiovascular load is desirable with a concomitant reduction in high speed running.

7.3 GENERAL DISCUSSION

This research programme investigated the physical and physiological cost of various SE drills in elite youth soccer players to develop soccer SE practice. The main findings were that the physiological responses and time-motion characteristics attributed to SE drills were protocol and mode dependent. Furthermore, this was the first research project to translate physical match data into metrics that could be used to design position-specific SE conditioning drills. This should be considered a major landmark within this area given that the first match demands paper was published four decades ago (Reilly & Thomas, 1976). Subsequent analysis indicated for the first time that individual position-specific SE soccer drills provide an appropriate alternative to generic running drills with the added advantageous of simultaneously training soccer specific movement patterns and technical skills under fatigue.

Although SEM training was found to be a prominent part of an elite youth soccer players training programme, information on the acute physiological response to SE SSG's was limited (Aroso et al., 2004; Little, 2009). The greater anaerobic demands of the SEP and cardiovascular demands of the SEM protocol reported for the SSG's and running drills in Chapter 4 were consistent with the individual position-specific drills in Chapter 6 and the majority of findings within the SE literature (Iaia & Bangsbo, 2010; Hostrup & Bangsbo, 2017). Limitations of the investigation included not using matched exercise durations, playing numbers or relative pitch space between protocols known to effect exercise intensity (Joo et al., 2016; Castagna et al., 2019). However, subsequent research accounting for these limitations were in agreement that SEM elicits a greater heart rate response whilst SEP SSG's result in greater blood lactate concentrations (Castagna et al., 2017). Additionally, high speed running demands were greater for the SEP compared to the SEM protocol for all drills in the research project evidenced in Chapter 4 and 6. This is not consistent with an investigation into SEP and SEM 1v1 SSG's, however discrepancies are likely due to the low number of repetitions compared to the studies in the present thesis (Castagna et al., 2017). These findings confirm practitioners can manipulate the exercise to rest ratio of SE drills to target different physiological and metabolic responses and induce different high speed running demands which is in line with the theoretical concept of SE training guidelines to develop and sustain high intensity actions (Iaia & Bangsbo, 2010; Bangsbo, 2015).

Interestingly, although the blood lactate response was higher for the individual position-specific SEP drill, the blood lactate response was also very high for the SEM protocol. This may indicate the drill is able to stimulate the anaerobic energy system to a greater extent than SEM drills investigated previously in the literature (Mohr et al., 2007; Ade et al., 2014; Castagna et al., 2017). If this were possible, the SEM drill may induce greater performance improvements closer to those witnessed following a period of SEP training. This would appeal to coaches and practitioners given the more time efficient manner of implementing a lower exercise to rest ratio (Iaia & Bangsbo, 2010; Bangsbo, 2015). A finding of the first investigation in Chapter 3 was that SEM training was far more prominent than SEP with a possible explanation suggested to be the lower overall drill duration as the soccer training programme of an elite youth player must cover numerous components of the game (Simmon, 2004; Vaeyens et al., 2008; Morley et al., 2014). However, the physiological and metabolic response to SE SSG's and position specific drills is currently limited to blood lactate concentration and heart rate. Investigations into enzyme and ion transport protein activity would provide additional insight into the metabolic stress different SE soccer drills place on the body, whilst the effect of such drills on the nervous system, endocrine system, immune function, respiration and lymphatic systems are yet to be explored. Although GPS technology provides some indirect information on the external load experienced by the musculo-skeletal system, an understanding of the biomechanical load and its effects on muscle and tendon adaptation would be of value. Future research should endeavour to investigate the potential of novel technologies in an attempt to better understand the overall physiological, metabolic and physical cost of SE soccer drills in order to aid training prescription.

Comparisons on training modes revealed SSG's resulted in a lower physiological response than the respective running drills, possibly due to the reduced high speed running exposure. The predefined area for SSG's and greater density of players is likely to have limited the opportunity to accelerate over distances necessary to reach high speed running thresholds whilst the tactical requirements of the game should also be considered a contributing factor. In contrast, the reduced playing space, greater player density and tactical requirements increased the acceleration and deceleration demands when performing soccer specific movement patterns than in the respective running drills. Nonetheless, the physiological responses evident following the SEP SSG's indicate they may be suitable to train the anaerobic energy system (~10 $mmol \cdot L^{-1}$). However, the 2v2 SSG's elicited a blood lactate concentration considerably lower than the running drills (~40% lower) signifying this format is unlikely to achieve the same physiological adaptations. It is suggested a greater exercise intensity may have been achieved by reducing the number of players participating in SEM SSG's. Research investigating SEM 1v1 SSG's revealed blood lactate concentrations of ~8 $mmol \cdot L^{-1}$ which was only ~15% lower than the respective running drill (Castagna et al., 2017). Nonetheless, if the ultimate aim of the SE drill is to elicit a high physiological response than running drills should be considered appropriate (Ade et al., 2014; Castagna et al., 2017). Furthermore, in reality it is difficult to perform multiple SEM 1v1 SSG's within a squad training session consisting of twenty players. A SEM protocol using an exercise to rest ratio of 1:2 would require 3-4 individual pitches, 6-8 mini goals and numerous soccer coaches and balls to ensure the drill is played at maximum intensity. SEM 1v1 SSG's with a 1:1 exercise to rest ratio would require 5 individual pitches, 10 mini goals and even more soccer coaches and balls. Therefore, SE SSG's should be considered when training fewer players at the end of a session for additional conditioning, the day following a match or during end stage rehabilitation sessions. In contrast, although the concept of SE drills that incorporate soccer movements and technical skills is appealing, the practical constraints and greater control of external load variables suggest running drills may be a more suitable option when training large numbers of players or administering post match conditioning when equipment and time is limited (Buchheit & Laursen, 2013a, 2013b; García-Ramos et al., 2018). Furthermore, practitioners may wish to prescribe running drills during a period of fixture congestion or high training density to provide a physiological stimulus whilst concurrently unloading explosive soccer actions such as kicking, jumping and changes of direction that place high mechanical stress on the neuromuscular system (Nedelec et al., 2012; Mohr et al., 2016; Devrnja & Matković, 2018).

Although SSG's incorporate soccer specific movement patterns, technical skills and decision-making processes, these are not always position-specific. For instance, the locomotive demands of 1v1 and 2v2 SSG's are similar between positions, however during a match a WM is often required to cover double the high speed running distance of a CB (Bradley et al., 2009; Di Salvo et al., 2009; Sarmento et al., 2018). Furthermore, unlike a WM, a CB will not typically perform many 1v1 duels attacking an opponent in possession of the ball (Hughes et al., 2012; Ade et al., 2016). Although constraints can be placed on the practice whereby the CB plays the ball back to the coach having regained possession from the opponent to remain as a defender (DF), this is now a positional drill instead of a SSG's practice. Positional training is a key component of a soccer programme as it is well established in the literature playing positions have unique physical, technical and tactical demands during a match (Mohr et al., 2003; Bloomfield et al., 2007; Fitzpatrick et al., 2019a). In agreement, information from the third investigation revealed distinct position-specific requirements when performing very high speed running efforts in and out of possession. It is the first time-motion analysis study to provide contextual information as to why and how different playing positions perform high-intensity running efforts by revealing the associated tactical purpose, technical skills and movement patterns. As with all time-motion analysis studies, the high match-to-match and intra-positional variability needs to be considered when interpreting the data (Bush et al., 2015b; Carling et al, 2016). Nonetheless, this investigation provided novel information for position-specific drill design and it is hoped it may generate further research and technological innovation in attempting to contextualise match performance (Bradley & Ade, 2018).

Pilot work of a SEM combination drill based on the findings of Chapter 5 revealed mean heart rate and post drill blood lactate concentration below that of the running drills administered in Chapter 4. In contrast, individual position-specific SEM drills investigated in Chapter 6 elicited a similar heart rate response and greater blood lactate concentrations than the running drills in Chapter 4. Additionally, the individual drills exhibited similar high speed running demands as the running drills and greater high-intensity acceleration / deceleration demands than the 2v2 SSG's (Figure 7.1). These data are in agreement with research reporting a greater heart rate response and peak running speeds during individual SE drills to reflect game situations compared to SE 2v2 SSG's (Mohr & Krustrup, 2016). Furthermore, these findings indicate individual position-specific drills may be a suitable alternative to the running drills often prescribed during SE research interventions (Iaia et al., 2015; Fransson et al., 2018; Vitale et al., 2018). Although the number of players in each position was small, differences in the external load was consistent with the majority of match analysis research (Di Salvo et al., 2009; Varley & Aughey, 2013; Ade et al., 2016). These data further support the inclusion of such drills into an elite youth soccer players and evidence match analysis data can be translated to effective training practices.

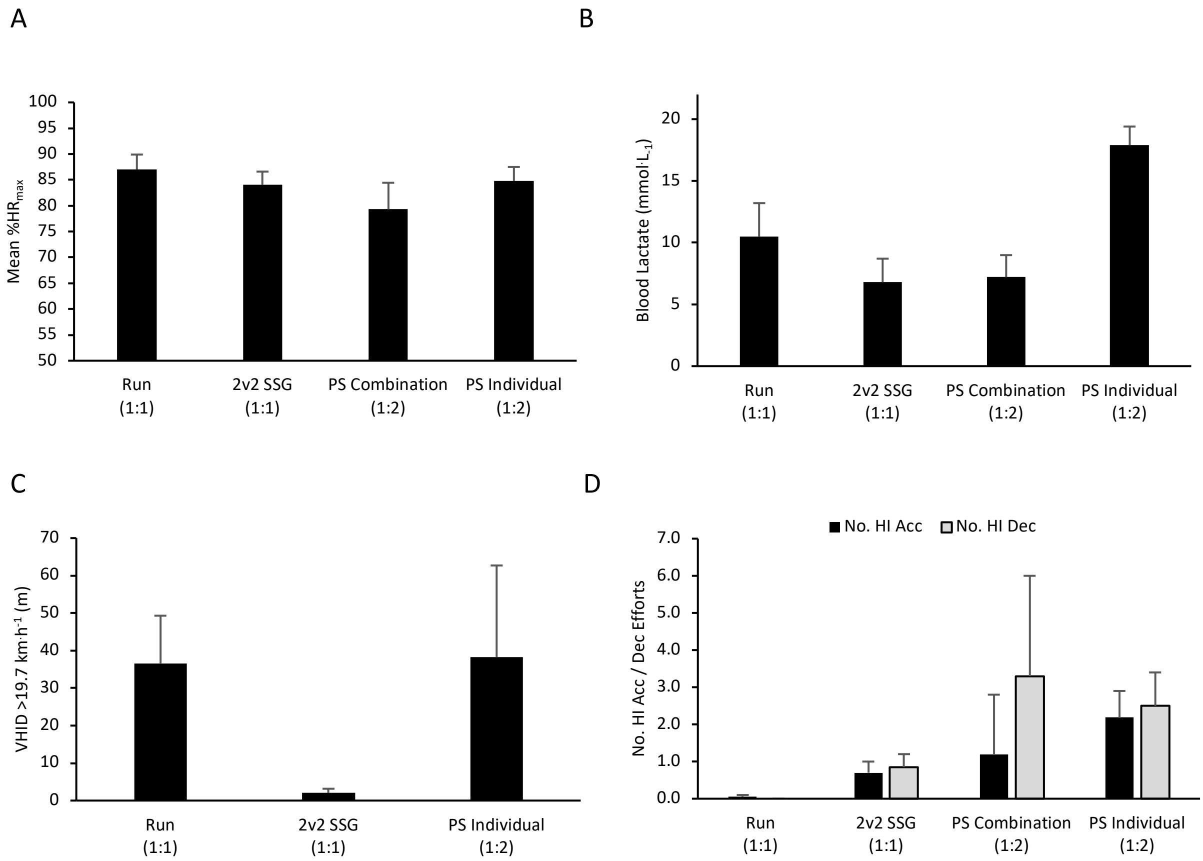


Figure 7.1. Comparison of physiological and perceptual responses and time-motion characteristics between different speed endurance maintenance drills across Chapters 2, 4 and 8. **(A)** Mean heart rate response. **(B)** Blood lactate concentration. **(C)** Very high-intensity distance (m). **(D)** Number of high-intensity accelerations >3 $m \cdot s^{-2}$ & decelerations <-3 $m \cdot s^{-2}$. Abbreviations: SEM, speed endurance maintenance; PS, position-specific; HR_{max}, percentage of heart rate maximum; VHID, very high-intensity distance; No., number; Acc, accelerations; Dec, decelerations. Numbers in parenthesis of drill description indicate exercise to rest ratio. Data for Run (1:1) and 2v2 SSG (1:1) is relative to 30 s duration. Data for PS Individual (1:2) is from elite youth players only (*n*=10). Values are mean ± SD. N.B. Time-motion data for Run (1:1) and 2v2 SSG (1:1) is relative to position-specific drills.

The concept of developing a position specific SE combination drill that simultaneously trains five positions is attractive to ensure efficient use of training time. However, the role of the practitioner is to prescribe physical work that supports the philosophy, playing style and training methods of the coach. Thus, practitioners would be well served to investigate the internal and external load associated to intermittent high-intensity soccer drills the coach regularly prescribes during training in an attempt to develop and guide current practices rather than introduce new drills which may be met with resistance. It is suggested practitioners should use the findings of this research programme to advice the soccer coach on appropriate exercise to rest ratios, player numbers and relative pitch space to achieve the desired physiological response and physical demands. Nonetheless, in the absence of a coach led session, individual position-specific SE drills could be administered when working with a player that requires additional conditioning if not selected for a match or is in the end stage of rehabilitation. Therefore, based on the main findings of this thesis, the training programme of an elite youth soccer player should incorporate a combination of SE running drills, SSG's and individual position-specific drills depending on the desired internal and external loads and practical constraints.

This research programme was the first to investigate the effects of SE training on neuromuscular function and subjective ratings of recovery. Such information is of paramount importance to practitioners working in elite soccer to understand when best to schedule drills within a training microcycle. Minimal effects were reported immediately post and 24 h post SEM and SEP drills in sub-elite soccer players. However, although monitoring neuromuscular function to indicate training status is commonplace in elite soccer clubs (Malone et al., 2015a; Thorpe et al., 2017), it is not known how decrements in jump performance or isometric strength relates to subsequent soccer performance (Carling et al., 2018). It could be suggested assessments of repeat sprint performance or high intensity intermittent running capacity would be more valid assessments of fatigue associated to high intensity training drills. However, it is very unlikely an elite soccer team would agree to perform a maximal fitness test during the competitive season as it will disrupt the training schedule and potentially increase the risk of injury. Submaximal runs may be a plausible alternative from which physiological response data is analysed in addition to tri-axial loading from accelerometers that may indicate changes in movement strategies associated with fatigue (Buchheit et al., 2018; Fitzpatrick et al., 2019b). However, although submaximal running is closer to the locomotor patterns during a match than performing a jump, it is not representative of the uncontrolled intermittent nature of the game.

Unfortunately, this research project was unable to investigate chronic adaptations to any of the drills presented in the chapters. An intervention investigating the effects of different periodisation strategies when administering SE drills was attempted with an U16's age group over an eight-week period, however regrettably the number of players available for post intervention testing was too low due to a large number being released by the Club. Although it may have been possible to perform a training intervention with sub-elite players, it is not known whether those results would be applicable to elite players with a greater level of fitness. Furthermore, as already discussed the opportunity to perform a training intervention in-season with elite soccer players is extremely limited. This somewhat questions the validity of training interventions reported in the literature that administer SE drills two or three times a week for a period of six weeks if they cannot then be replicated in the elite environment. Future research may consider investigating individual player case studies returning from injury, not involved in regular match play or lacking fitness (Mujika et al., 2007; Anderson et al., 2019). If drills are to be used sporadically due to inconsistent training schedules, as evidenced in Chapter 3 with less than a quarter of training weeks adhering to a typical seven day microcycle, than information on the physiological response to specific drills should be considered very useful to practitioners.

Finally, the concept of SE training is based on achieving a high metabolic response which when exposed to numerous times during an intervention results in physiological adaptations to delay fatigue and ultimately enhance physical performance (Iaia & Bangsbo, 2010; Skovgaard et al., 2014; Fiorenza et al., 2018). Much of the early scientific research into soccer training focused on the metabolic response (Bangsbo et al., 2006; Krustrup et al., 2006). However, with the recent emergence of GPS technology there has been a shift towards research examining the external locomotor activity patterns and biomechanical load using accelerometers (Akenhead et al., 2016; Vanrenterghem et al., 2017). Consequently, many elite soccer teams periodise the training week using external loadings rather than specific energy system development (Malone et al., 2015b; Akenhead et al., 2016; Martin-Garcia et al., 2018b). Therefore, it is suggested the external load associated to SE training drills needs to be further investigated alongside physiological response data to remain applicable to current training methodologies. It is hoped the novel findings relating to the intense acceleration and decelerations demands of different SE drills revealed in this research programme may provide some additional insight.

7.4 CONCLUSIONS

Analysis of an elite youth soccer players training programme revealed SEM training to be a prominent form of conditioning whilst SEP was the least frequent. The proportion of SE drills performed as running drills relative to SSG's was almost equal for both SEM and SEP protocols. Physiological responses and time-motion characteristics were mode and protocol dependent. Regardless of mode, SEP elicited a greater blood lactate concentration and resulted in greater high speed running demands whilst SEM required a greater contribution of energy from the cardiovascular system. A lower physiological response was evident during SSG's compared to respective running drills, possibly due to the reduced high speed running exposure, however in contrast, the acceleration and deceleration demands where greater in the SSG's. A novel High Intensity Movement Programme with good to excellent reliability was devised and revealed playing positions performed unique physical, technical and tactical actions associated to high speed running efforts. A method to design a position-specific combination drill and individual position-specific SE drills was established to translate the match analysis data into key metrics. Individual position-specific SE drills displayed physiological responses and high speed running demands similar to the generic running drills in Chapter 4 whilst the high-intensity acceleration / deceleration demands were greater than the SSG's. Furthermore, the variation in positional external load was similar to match analysis research indicating individual position-specific drills may be a suitable alternative to the running drills often prescribed during SE research interventions. The drills displayed minimal effects on neuromuscular function and subjective ratings of recovery however this area of research requires further investigation. It is hoped the data from this research project can aid practitioners in their drill prescription and the information from the match analysis study can be used to generate further research attempting to contextualise match analysis data.

7.5 PROJECT LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This research project has investigated the physiological response and time-motion characteristics for various SE drills and developed a novel High Intensity Movement Programme to understand the position-specific technical and tactical requirements when performing high speed running efforts during match play to aid drill design. Whilst achieving the aim to understand and develop SE practices in soccer, some limitations have been identified from which recommendations for future research are suggested.

The SE drills investigated in Chapter 4 were limited to SSG's and generic running drills. Future research should consider investigating the physiological response, time-motion characteristics and reproducibility of other high-intensity intermittent drills regularly performed within the coaching programme such as smaller combination drills using lower playing numbers, counter-attacking drills or crossing and finishing drills. Such information would allow practitioners to support the coach by making suggestions to adjust the drills to achieve the desired physiological and physical load without having to implement new practices. Additionally, it would be of interest to investigate the difference in response to more intermittent position-specific drills that consist of short duration repeated high-intensity actions interspaced by active recovery. This method would be more specific to the intermittent nature of soccer however it is not known whether these drills would elicit the same physiological response.

The chronic adaptations to the drills in this research project are unknown. Future research should perform a training intervention comparing the effect of SE 1v1 SSG's, running drills and individual position-specific drills on physical performance and soccer skills under fatigue. Furthermore, the research project would have benefited from performing muscle biopsies to gain a greater understanding of the acute physiological response to the SE drills in conjunction with pre vs post physiological tests. It would be of interest to know how the different modes and protocols effect enzyme activity and the expression of ion transport proteins thought to be integral to the delay of neuromuscular fatigue (Hostrup & Bangsbo, 2017). Due to the difficulties performing a training intervention in elite soccer, future research should consider investigating individual player case studies of those returning from injury, not involved in regular match play or lacking fitness (Mujika et al., 2007; Anderson et al., 2019).

The High Intensity Movement Programme devised in Chapter 5 provided novel information on positional trends of physical, technical and tactical actions associated to high speed running efforts, however the data quantified in isolation and does not account for sequences of events. Such information would enhance drill development and future research should use artificial intelligence and machine learning to provide contextualised match analysis data. The research area would benefit further by comparing positions within positions across a number of formations. Finally, the technical and tactical actions could be quantified during peak periods of physical match play incorporating both high speed running and high-intensity accelerations and decelerations using GPS technology.

Minimal effects on neuromuscular performance were evident following the individual position-specific SE drills in sub-elite soccer players. A limitation of this investigation was that the drill was performed in isolation. It is not known whether performing additional soccer drills within a session would result in greater changes in neuromuscular function. Future research should consider testing neuromuscular function throughout a control training week and then a subsequent training week when SE drills are performed in place of another high-intensity drill or in addition to the training programme. It would be of interest to examine the effect of numerous SE drills such as 1v1 SSG's whilst the research should endeavour to recruit a large sample size to monitor individual responders and whether these are influenced by genetics, muscular strength, high-intensity running capacity or muscle fibre type.

It was not possible to standardise the portable blood lactate analysers across studies as the Lactate Pro used in Chapter 4 was discontinued, however a strong linear relationship has been reported with the Lactate Pro 2 used in Chapter 6 (r=0.976, P<0.01; Rowe & Whyte, 2016; Arratibel-Imaz, Calleja-González & Terrados, 2017). Finally, due to a change of employer, it was an unavoidable drawback that the GPS units in Chapter 4 and 6 were not made by the same manufacturer. No research to date has directly compared measurements between the GPS units, however sampling rates were consistent and are considered optimal (Scott et al., 2016).

7.6 PRACTICAL RECOMMENDATIONS FROM THE PRESENT THESIS

It is hoped the information in this research project will provide practitioners with a greater understanding of the physiological and physical cost of various SE practices in soccer to aid drill prescription. The practical recommendations from the present thesis are as follows:

1. SE running drills should be prescribed when working with large numbers of players, limited equipment or during a period of fixture congestion or high training density to achieve a high physiological response and unload explosive actions such as kicking, jumping and changes of direction that place high mechanical stress on the neuromuscular system (Nedelec et al., 2012; Devrnja & Matković, 2018).
2. The limited high speed running exposure in addition to the high acceleration and deceleration demands associated to the SEP 1v1 SSG's suggest it could be prescribed early in the microcycle when administering an 'intensive' training day aiming to overload the neuromuscular system (Delgado-Bordonau & Mendez-Villanueva, 2012; Verheijen, 2014). This drill is also suggested to developing anaerobic power due to the high blood lactate response (Iaia & Bangsbo, 2010).
3. Individual position-specific SE conditioning drills could be performed on match day minus 4 or 3 during the microcycle on an 'extensive' training day due to the very high speed running demands (Delgado-Bordonau & Mendez-Villanueva, 2012; Verheijen, 2014; Martin-Garcia et al., 2018b).
4. The individual position-specific SE drills could be administered during a typical training microcycle to ensure greater positional variation in external load representative of match demands which is not evident in some (Malone et al., 2015b; Akenhead et al., 2016) but not all investigations into training practices (Martin-Garcia et al., 2018b).

5. Additionally, it is proposed these drills should be administered to players that are not regular match starters so that they receive the necessary training stimulus to ensure they are prepared for future selection and the demands of the game (Anderson et al., 2016; Los Arcos et al., 2017).
6. Finally, these drills should be considered appropriate during the final stages of end stage rehabilitation to expose players to a very high metabolic and mechanical load whilst performing technical and tactical actions needed on their return to training (Morrison et al., 2017; Taberner et al., 2019).

CHAPTER EIGHT

APPENDICES

8.1 DEVELOPMENT OF A POSITION-SPECIFIC SPEED ENDURANCE COMBINATION DRILL – A PILOT STUDY

8.1.1 Aim

To investigate the physiological response and time-motion characteristics of a position-specific speed endurance (SE) combination drill based on objective match data. The aim of the drill is to expose players to high speed running and produce a high physiological response whilst simultaneously performing position-specific movement patterns and technical skills to provide a high acceleration/deceleration demand. The between position internal and external load data should be representative of typical differences in elite match play.

8.1.2 Method

8.1.2.1 Participants

Fifteen elite male soccer players that represented an English Premier League youth team completed the drill (mean ± SD; age 17 ± 1yr, height 1.79.6 ± 0.06 m and body mass 74.7 ± 6.0 kg) representing five positions: centre back (CB) *n*=3, fullback (FB) *n*=3, central midfielder *n*=3, wide midfielder (WM) *n*=3 and forward (FW) *n*=3.

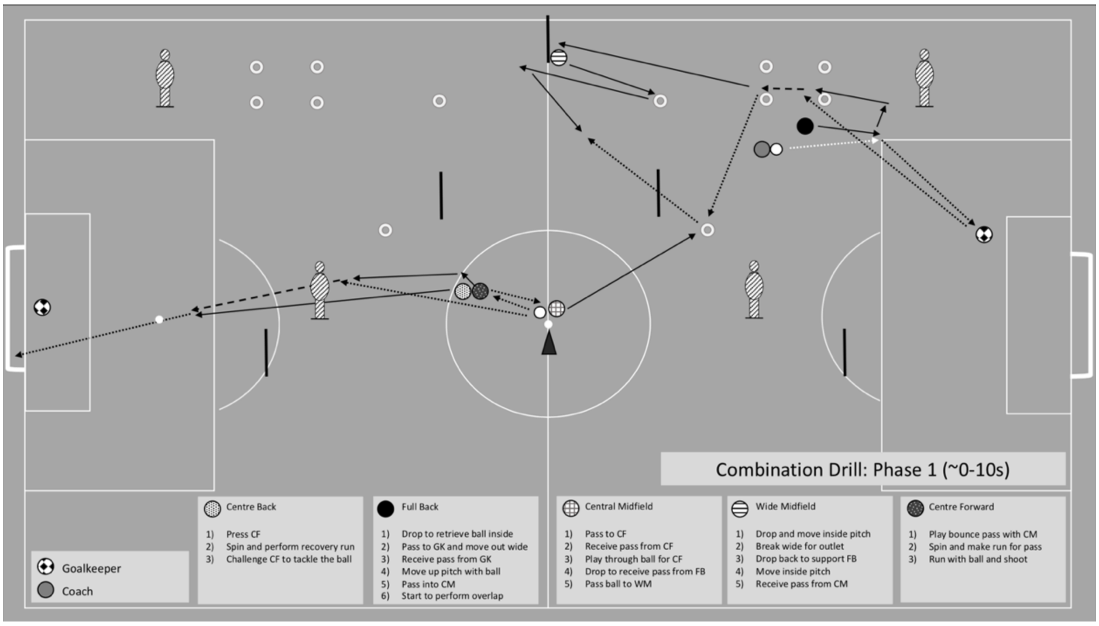
8.1.2.2 Combination Drill Protocol

The combination drill used a SE maintenance (SEM) protocol consisting of eight bouts of ~30 s exercise followed by 60 s passive recovery (1:2 exercise to rest ratio). The drill was performed in September once players were fully conditioned for the season. Verbal encouragement was provided throughout, and players were instructed to exert maximal effort. All players were familiarised with the experimental procedures and completed the drill twice prior to the pilot study.

8.1.2.3 Drill Configuration

A position-specific SE combination drill was designed in collaboration with a UEFA Pro Licence soccer coach based on the time-motion analysis match data presented in Chapter 5 (Ade et al., 2016). The drill was designed to train five different playing positions simultaneously. The FB, CM, WM and FW performed the drill in possession of the ball whilst the CB was out of possession (Figure 8.1.1). The movement patterns, technical skills, combination play and tactical actions were based on position-specific match data associated to high-intensity running efforts. A limitation of the High-intensity Movement Programme (HIMP) is that it does not quantify series of actions collectively, but rather actions in isolation. This is especially problematic when analysing combination play, as although a player may pass to and receive a pass from specific playing positions more frequently, it may not necessarily occur during the same phase of play, so to prescribe such combinations would be false. Thus, combination play information from the HIMP was occasionally overlooked in favour of typical positional interplay expected by the UEFA Pro Licence coach. As mentioned in the discussion of Chapter 5, the information from the HIMP was not intended to be used as a recipe but merely provide practitioners with the most frequently occurring scenarios from which drills can be designed. For instance, according to the HIMP study the FB passed to the WM before the vast majority of high-intensity running efforts, however to cinque all the other demands across positions in unison, the combination drill in the present study requires the FB to pass inside the pitch to the CM before embarking on an overlapping run (Figure 8.1.1). In order for actions to be included in the drill, they had to adhere to one of the following criteria: (1) it occurred in >33% of efforts, (2) there was at least a small effect size difference (>0.2, Batterham & Hopkins, 2006) compared to a minimum of two other positions, (3) in categories with a large number of sub-variables (>3: combination play technical skills in possession; tactical actions), there was a moderate standardized difference (>0.6) compared to the mean. The third criteria permitted actions that may not occur in a high percentage of efforts, but relative to other variables are the most prominent and should therefore be included. Sometimes technical actions were not justified before high-intensity running efforts, however the total exposure warranted the inclusion to enhance the flow of the drill and to expose players to the technical actions they perform regularly. For instance, CM played a through ball to initiate the start of the drill for the CB and FW. Additionally, though not justified using the set criteria, the CB was required to perform a recovery run at the beginning of the combination drill to compliment the overall flow of the drill and demands of the FW running in behind. Moreover, the recovery run complimented other positional demands of the CB such as covering, tracking a runner and challenging the FW whilst the tactical action was representative of approximately a quarter of high-intensity running efforts out of possession during match play. The majority of high-intensity efforts do not include any ball contact (60-75%), however for player enjoyment and technical skill development under fatigue, ball contact was included (Ade et al., 2016). The justification for each positions role within the combination drill is presented in Tables 8.1.1-8.1.5.

A



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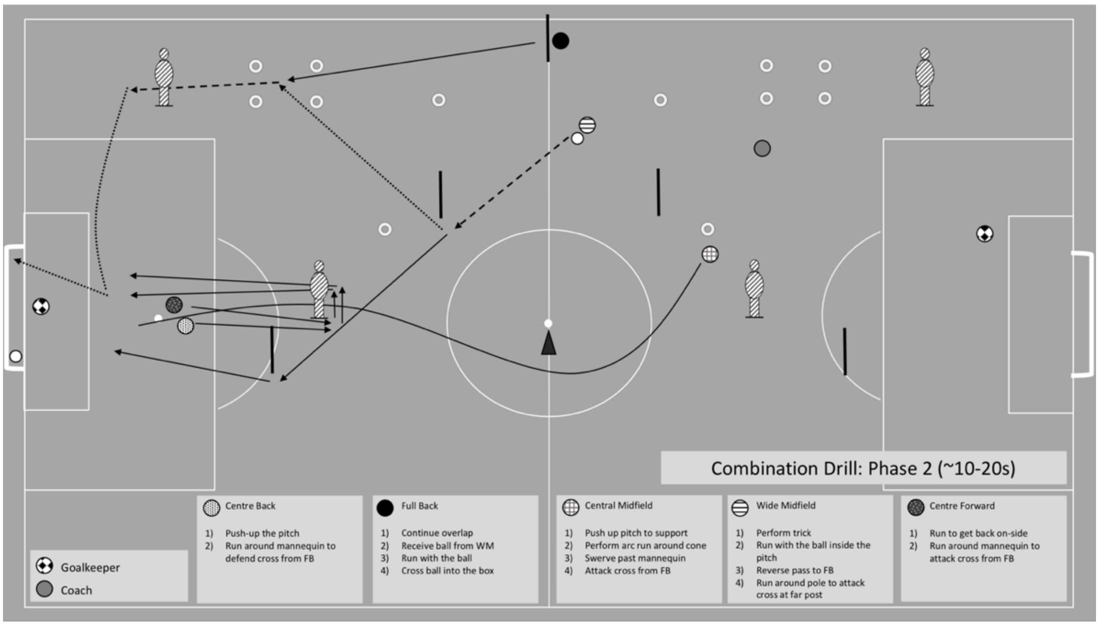

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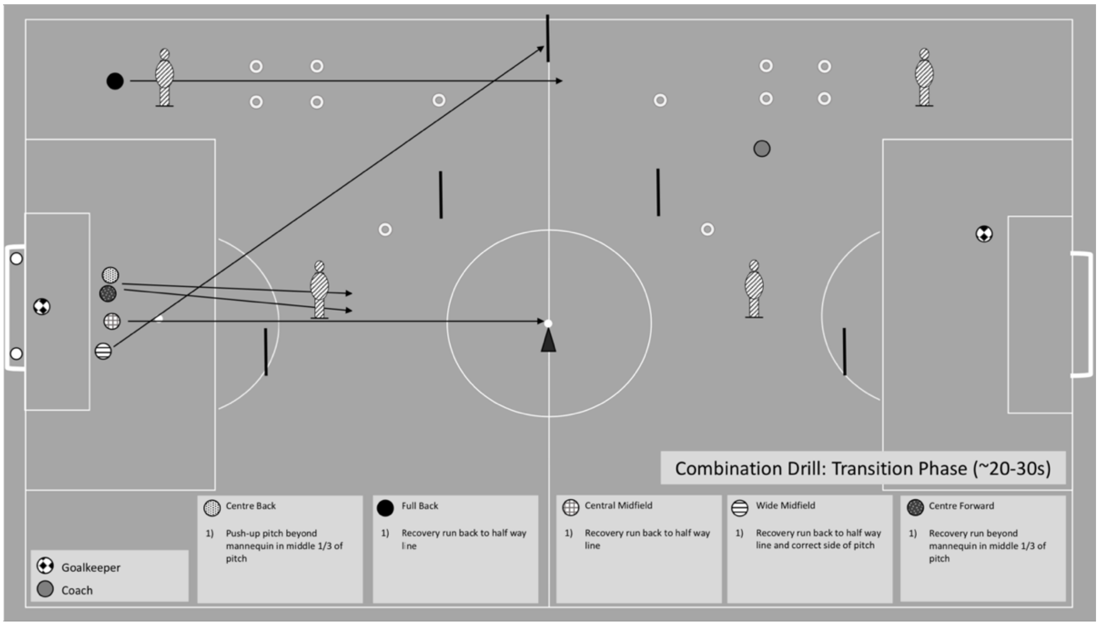

Figure 8.1.1. Position-specific Speed Endurance Combination Drill. **(A)** Phase 1: Coach plays ball inside FB to recover and play back to GK, at the same time the CM plays a bounce pass with FW before playing a ball over the top for the FW and CB to run on to contest. At the

same time the WM drops to support the play but then pushes up and wide for an outlet for the GK. The FB then moves wide to receive the ball from the GK, CM drops to support the FB. The FB plays to the CM, the WM drops and moves inside the pitch to support the play. The CM passes to the WM whilst the FB performs an overlapping run. At the same time the FW and CB challenge for the ball over the top in a 1v1 situation resulting in the either the FW shooting on goal or the CB performing a clearance. **(B)** second sequence of drill: FB continues to perform overlapping run, CB pushes up the pitch whilst the FW performs a recovery run. The WM performs a trick upon receiving the ball from the CM, runs with the ball inside the pitch before playing a reverse pass out wide to the FB. The CM performs an arced run before driving through the middle of the pitch. The WM continues to run through the middle of the pitch. The CB and FW turn around the mannequin and start to accelerate into the box. The CM continues to drive through the middle of the pitch performing a swerve inside the mannequin. The FB runs with the ball and crosses into the box. The FW and CB run into the box to attack the ball whilst the CM and WM attack the front of the box and back post, respectively. **(C)** final sequence of drill: All players perform recovery runs back to set positions. See text above for description of drill.

Table 8.1.1. Justification of combination drill configuration for centre back.

Category	Variable	Frequency	Positional Effect Size Difference
Before (OP)			
Location	Middle 1/3	49.8%	
Location	Central	92.4%	>FB^{d}, CMa, WM^{c}, FW^{a}
Movement	0-90° turn	40.2%	>FB^{b}, CM^{b}, WM^{b}, FW^{b}
Movement	90-180° turn	21.7%	>CM^{a}, FW^{b}
Movement	Backwards	11.3%	>FB^{a}, CM^{b}, WM^{c}, FW^{c}
Movement	Lateral	25.6%	>FB^{b}, CM^{c}, WM^{c}, FWc
Tactical	Ball Over Top	19.9%	>FB^{b}, CM^{c}, WM^{d}, FW^{d}
During Phase 1 (OP)			
Tactical	Recovery Run$^{\#}$	24.1%	
Movement	Swerve	40.9%	>FB^{a}, FW^{a}
Tactical	Challenge FW	31.1%**	>FB^{d}, CM^{d}, WM^{d}, FW^{d}
After Phase 1 (IP)			
Tactical	Push up the pitch	38.1%**	>FB^{b}, CM^{a}, WM^{a}, FW^{b}
During Phase 2 (OP)			
Tactical	Ball Down Side	29.5%	>FB^{c}, CM^{d}, WM^{d}, FW^{d}
Tactical	Track Runner	37.0%	>CM^{a}, FW^{c}
Tactical	Covering	74.1%***	>FB^{a}, WM^{c}, FW^{c}
Tactical	Interception	8.1%	>CM^{a}, WM^{b}, FW^{c}
Technical	Header	2.5%	>CM^{a}, WM^{a}, FW^{b}
Tactical	Challenge FW	31.1%**	>FB^{d}, CM^{d}, WM^{d}, FW^{d}
After Phase 2			
Location	Defensive 1/3	74.3%	>FB^{a}, CM^{c}, WM^{c}, FW^{d}
Location	Central	72.8%	>FB^{b}, WM^{c}
Movement	0-90° turn	39.4%	>FB^{c}, CM^{b}, WM^{a}, FW^{a}
Movement	90-180° turn	25.1%	>CM^{b}, WM^{b}, FW^{a}
Transition Phase (IP)			
End Location	Middle 1/3	39.2%	>WM^{a}, FW^{a}
End Location	Central	73.5%	>FB^{d}, WM^{b}
Tactical	Push up the pitch	38.1%**	>FB^{b}, CM^{a}, WM^{a}, FW^{b}

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; IP, in possession; OP, out of possession. Effect sizes were classified as ^{a}small (>0.2-0.6), ^{b}moderate (>0.6-1.2), ^{c}large (>1.2-2.0) and ^{d}very large (>2.0-4.0) (Batterham and Hopkin, 2006). *Moderate within position standardised difference (>0.6 SD), **Large within position standardised difference (>1.2 SD), *** Very large within position standardised difference (>2.0 SD). $^{\#}$Not justified.

Table 8.1.2. Justification of combination drill configuration for fullback.

Category	Variable	Frequency	Positional Effect Size Difference
Before (Transition)			
Location (OP)	Defensive 1/3	34.5%	>CM[c], WM[c], FW[d]
Location (OP)	Wide	39.1%	>CB[d], CM[d], WM[a], FW[d]
Tactical (OP)	Ball down the side	12.3%	>CM[b], WM[b], FW[b]
Movement (OP)	0-90° turn	33.0%	
Tactical (OP)	Recovery run	32.2%	>CB[a], FW[c]
Combination	Receive ball from OPP	8.2%*	>FW[a]
Combination	Pass ball to GK#	0%	
Movement (IP)	Backward	5.9%	>CB[a], CM[b]
Movement (IP)	Lateral	5.9%	>CB[a], CM[a], WM[a]
During Phase 1 (IP)			
Location	Defensive 1/3	18.6%	>WM[b], FW[c]
Location	Wide	49.0%	>CB[b], CM[d], WM[a], FW[d]
Tactical	Push up the pitch	20.5%***	>CB[b], FW[b]
Combination	Receive ball from GK	3.4%	>CM[a], WM[b], FW[b]
Tactical	Run with the ball	30.8%	>CB[a], CM[a], FW[c]
Combination	Pass ball to CM#	0.4%	
Tactical	Run the channel	64.0%***	>CB[d], CM[d], WM[c], FW[d]
During Phase 2 (IP)			
Movement	Arc	23.5%	>CM[a], WM[a], FW[a]
Tactical	Overlap	18.6%	>CB[b], CM[c], WM[c], FW[c]
Movement	Swerves	35.0%	
Combination	Receive ball from WM	10.4%**	>CB[c], CM[b], WM[c], FW[b]
Combination	Receive ball from CM	9.7%**	>CM[b], WM[a], FW[a]
Tactical	Run w/ Ball	30.8%	>CB[a], CM[a], FW[c]
Technical	Cross	12.5%***	>CB[c], CM[b], FW[b]
After Phase 2			
Location	Attacking 1/3	48.2%	>CB[b], WM[a]
Location	Wide	75.6%	>CB[d], CM[d], WM[c], FW[d]
Movement	90-180° turn	19.0%	>CM[a], WM[a]
Transition Phase (OP)			
End Location	Middle 1/3#	29.8%	>CB[a]
End Location	Wide	40.4%	
Tactical	Recovery run	32.2%	>CB[a], FW[c]

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; IP, in possession; OP, out of possession. Effect sizes were classified as [a]small (>0.2-0.6), [b]moderate (>0.6-1.2), [c]large (>1.2-2.0) and [d]very large (>2.0-4.0) (Batterham and Hopkin, 2006). *Moderate within position standardised difference (>0.6 SD), **Large within position standardised difference (>1.2 SD), *** Very large within position standardised difference (>2.0 SD). #Not justified.

Table 8.1.3. Justification of combination drill configuration for central midfielder

Category	Variable	Frequency	Positional Effect Size Difference
Before (IP)			
Location	Middle 1/3	61.8%	
Location	Central	87.8%	>CB[a], FB[d], WM[d]
Combination	Pass ball to FW	2.8%	>FB[a], FW[a]
Combination	Receive ball from FW	3.8%	>CB[b], FB[a], FW[a]
Technical	Through ball	0.2%	>CB[a], FB[a], FW[a]
During Phase 1 (IP)			
Movement	90-180° turn	15.4%	>CB[a], FB[a], WM[a]
Tactical	Come short	10.7%	>CB[a], FB[b], WM[b], FW[b]
Combination	Receive ball from FB	9.2%**	>CB[b], FB[b], FW[b]
Movement	0-90° turn[#]	32.6%	
Combination	Pass to WM	6.0%**	>WM[b], FW[a]
During Phase 2 (IP)			
Movement	90-180° turn	15.4%	>CB[a], FB[a], WM[a]
Movement	Arc	17.1%	>CB[a], FB[b], WM[a], FW[a]
Tactical	Drive through middle	45.8%**	>CB[b], FB[c], WM[b]
Movement	Swerve	33.7%	
Technical	Shot	4.3%**	>CB[a]
After Phase 2 (IP)			
Location	Attacking 1/3	38.3%	>CB[a]
Location	Central	73.2%	>FB[d], WM[b]
Movement	90-180° turn[#]	13.9%	
Transition Phase (OP)			
End Location	Middle 1/3	47.3%	>CB[c], FB[b]
End Location	Central	78.1%	>CB[a], FB[c], WM[c], FW[a]
Tactical	Recovery run	31.7%	>CB[a], FW[c]

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; IP, in possession; OP, out of possession. Effect sizes were classified as [a]small (>0.2-0.6), [b]moderate (>0.6-1.2), [c]large (>1.2-2.0) and [d]very large (>2.0-4.0) (Batterham and Hopkin, 2006). *Moderate within position standardised difference (>0.6 SD), **Large within position standardised difference (>1.2 SD), *** Very large within position standardised difference (>2.0 SD). [#]Not justified.

Table 8.1.4. Justification of combination drill configuration for wide midfielder

Category	Variable	Frequency	Positional Effect Size Difference
Before (OP)			
Location	Middle 1/3	58.4%	>CB^{b}
Location	Wide	30.3%	>CB^{c}, CM^{c}, FW^{c}
Tactical	Recovery Run	49.1%*	>CB^{c}, FB^{b}, CM^{b}, FW^{d}
During Phase 1 (IP)			
Location	Middle 1/3	64.5%	>CB^{b}, FW^{a}
Location	Wide	41.7%	>CB^{b}, CM^{d}, FW^{d}
Movement	90-180° turn	10.9%	>CB^{a}, FB^{a}
Tactical	Run the channel	38.8%**	>CB^{c}, CM^{c}, FW^{c}
Tactical	Drive inside the pitch	13.2%	>CB^{b}, FB^{b}, CM^{b}, FW^{a}
Combination	Receive pass from CM	12.6%**	>CB^{b}, FB^{a}, CM^{a}, FWb
During Phase 2 (IP)			
Movement	90-180° turn	10.9%	>CB^{a}, FB^{a}
Technical	Trick	4.1%**	>CB^{a}, FB^{b}, FW^{b}
Tactical	Run with the ball	30.9%*	>CB^{a}, CM^{a}, FW^{c}
Tactical	Drive inside the pitch	13.2%	>CB^{b}, FB^{b}, CM^{b}, FW^{a}
Combination	Pass ball to FB	3.5%*	>CB^{b}, FB^{b}, CM^{b}, FW^{b}
Tactical	Drive through middle	30.8%*	>CB^{a}, FB^{b}
Movement	Swerve	37.1%	
Tactical	Break into box	13.6%	>FB^{b}, CM^{b}
After Phase 2 (IP)			
Location	Attacking 1/3	64.3%	>CB^{c}, FB^{b}, CM^{c}
Location	Central	50.1%	>FB^{c}
Movement	0-90° turn	37.0%	>CB^{a}, FB^{b}, CM^{a}
Transition Phase (OP)			
End Location	Middle 1/3	49.2%	>CB^{c}, FB^{b}
End Location	Wide	53.0%	>CB^{c}, FB^{b}, CM^{d}, FW^{c}
Tactical	Recovery Run	49.1%*	>CB^{c}, FB^{b}, CM^{b}, FW^{d}

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; IP, in possession; OP, out of possession. Effect sizes were classified as ^{a}small (>0.2-0.6), ^{b}moderate (>0.6-1.2), ^{c}large (>1.2-2.0) and ^{d}very large (>2.0-4.0) (Batterham and Hopkin, 2006). *Moderate within position standardised difference (>0.6 SD), **Large within position standardised difference (>1.2 SD), *** Very large within position standardised difference (>2.0 SD).

Table 8.1.5. Justification of combination drill configuration for forward

Category	Variable	Frequency	Positional Effect Size Difference
Before (IP)			
Location	Middle 1/3	58.3%	>CB[a]
Location	Central	86.3%	>FB[d], WM[d]
Combination	Receive pass from CM	5.4%**	>CB[a]
Combination	Pass to CM	2.7%*	>FB[b]
Movement	Lateral	6.9%	>CB[b], CM[a], WMa
Movement	Backward	7.0%	>CB[a], CM[b], WM[a]
Movement	90-180° turn	17.6%	>CB[b], FB[b], WM[b]
During Phase 1 (IP)			
Tactical	Run in behind	31.6%	>CB[d], FB[d], CM[d], WM[d]
Tactical	Drive through middle	58.7%***	>CB[c], FB[d], CM[a], WM[c]
Movement	Swerve	41.2%	>FB[a], CM[a], WM[a]
Tactical	Break into the box	28.4%	>CB[b], FB[c], CM[c], WM[b]
Technical	Shot	4.6%*	>CB[b], FB[a], WM[a]
Movement	90-180° turn (Post)	17.7%	>CM[a], WM[b]
After Phase 1 (OP)			
Tactical	Recovery run[#]	8.0%	
Tactical	Covering	36.7%*	
During Phase 2 (IP)			
Movement	90-180° turn	17.6%	>CB[b], FB[b], WM[b]
Tactical	Drive through middle	58.7%***	>CB[c], FB[d], CM[a], WM[c]
Movement	Swerve	41.2%	>FB[a], CM[a], WM[a]
Tactical	Break into the box	28.4%	>CB[b], FB[c], CM[c], WM[b]
Technical	Shot	4.6%*	>CB[b], FB[a], WM[a]
Technical	Header	5.5%**	>FB[b], CM[b], WM[b]
After Phase 2 (IP)			
Location	Attacking 1/3	73.5%	>CB[d], FB[c], CM[c], WM[b]
Location	Central	79.7%	>CB[a], FB[d], CM[a], WM[c]
Movement	90-180° turn (Post)	17.7%	>CM[a], WM[b]
Movement	Arc (Post)	16.1%	>CB[b], FB[b], WM[a]
Transition Phase (OP)			
End Location	Middle 1/3	58.4%	>CB[d], FB[c], CM[b], WM[a]
End Location	Central	74.1%	>FB[b], WM[c]
Tactical	Recovery run[#]	8.0%	
Tactical	Covering	36.7%*	

Abbreviations: CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward; IP, in possession; OP, out of possession. Effect sizes were classified as [a]small (>0.2-0.6), [b]moderate (>0.6-1.2), [c]large (>1.2-2.0) and [d]very large (>2.0-4.0) (Batterham & Hopkin, 2006). *Moderate within position standardised difference (>0.6 SD), **Large within position standardised difference (>1.2 SD), *** Very large within position standardised difference (>2.0 SD). [#]Not justified.

8.1.2.4 Physiological & Perceptual Responses

Heart rate was recorded continuously in 5 s intervals throughout the drills using radio telemetry (Polar Team System, Oy, Kempele, Finland) and the mean and peak heart rate quantified. Player maximum heart rate (HR_{max}) was determined prior to the study using peak values attained during the Yo-Yo intermittent recovery test level 1. Capillary blood samples were collected from a finger at rest and on completion of the eighth repetition for each drill. The sample at rest verified players had acceptable blood lactate levels before each drill to be included in the analysis, while samples collected after the eighth repetition were used to test post drill responses. Blood was analysed immediately for lactate concentration using an automated analyser (Lactate Pro, Arkray, Kyoto, Japan). Subjective ratings of perceived exertion (RPE) were recorded after each repetition using the 6-20 scale (Borg, 1998).

8.1.2.5 Time-motion Characteristics

Time-motion characteristics were quantified using microelectromechanical system (MEMS) devices (Catapult MinimaxX S4, Catapult Innovations, Scoresby, VIC, Australia) harnessed between the shoulder blades and anchored using an undergarment to restrict movement artefact. MEMS devices containing a global positioning system (GPS) processor with a sample frequency of 10 Hz have previously been shown to provide a valid and reliable measure of instantaneous velocity during acceleration, deceleration and constant motion (Varley et al., 2012b; Scott et al., 2016). Motion characteristics were quantified as total distance covered (m), very high-speed running distance (m) (>21.0 $km \cdot h^{-1}$) and sprint distance (>24.0 $km \cdot h^{-1}$). These speeds are in line with Club protocol and are consistent with those reported in the literature (Dellal et al., 2010). The distance covered and number of maximum accelerations (>3 ms^{-2}) and maximum decelerations (<-3 ms^{-2}) were recorded in addition to tri-axial accelerometer 'PlayerLoad' data (Barrett, Midgley & Lovell, 2014). Data were analysed using proprietary software (Logan Plus v5, Catapult Innovations, Canberra, ACT, Australia). Data sets were verified for satellite signal (mean = >12) and horizontal dilution of precision (HDOP); (mean = <1.0) before being included in the analysis.

8.1.2.6 Statistical Analysis

Effect sizes (ES) were calculated to establish inter-positional differences in internal and external load with the magnitude of the effect classified as trivial (<0.2), small (>0.2–0.6), moderate (>0.6–1.2), large (>1.2– 2.0), and very large (>2.0–4.0) (Batterham & Hopkins, 2006). Values are presented as means and standard deviations unless otherwise stated.

8.1.3 Results

The GPS signal dropped out for one player whilst the heart rate trace was very poor for a further four players. Therefore, the number of players included in the final analysis was variable dependent (Blood lactate concentration and RPE *n*=15, GPS: *n*=14, HR: *n*=10). Mean repetition data for all positions combined was as follows: Mean $\%HR_{max}$ = 79.3 ± 5.1%; peak $\%HR_{max}$ = 92.4 ± 3.7%; blood lactate concentration = 7.2 ± 1.8 $mmol \cdot L^{-1}$; RPE = 18.7 ± 1.0; total distance = 129.0 ± 10.5 m; very high-intensity distance >21 $km \cdot h^{-1}$ = 56.4 ± 20.9 m; sprint distance >24 $km \cdot h^{-1}$ = 29.8 ± 12.8 m; peak running speed = 28.1 ± 1.2 $km \cdot h^{-1}$; number of high-intensity accelerations >3 $m \cdot s^{-2}$ = 1.2 ± 1.6; number of high-intensity decelerations <-3 $m \cdot s^{-2}$ = 3.3 ± 2.7; high-intensity acceleration distance >3 $m \cdot s^{-2}$ = 1.0 ± 0.8 m; high-intensity deceleration distance <-3 $m \cdot s^{-2}$ = 1.4 ± 1.2 m; player load = 14.6 ± 1.4 A.U. Positional differences in internal and external load are presented in Table 8.1.6.

Table 8.1.6. Positional Physical and physiological response to speed endurance maintenance position-specific combination drill.

Variable	Centre Back (*n*=2)	Fullback (*n*=3)	Central Midfielder (*n*=3)	Wide Midfielder (*n*=3)	Forward (*n*=3)	Effect Size Differences
External Load						
Total Distance (m)	125.7 ± 3.1	136.1 ± 5.0	123.4 ± 12.0	139.4 ± 3.8	119.2 ± 9.3	WM > CB[c], CM[b], FW[c]; FB > CB[b], CM[a], FW[b]
VHID >21.0 $km{\cdot}h^{-1}$ (m)	37.6 ± 2.5	77.0 ± 7.2	59.8 ± 15.5	71.1 ± 7.5	30.5 ± 11.6	FB & WM > CB[c], CM[a], FW[c]; CM > CB[b], FW[b]
SPD >24.0 $km{\cdot}h^{-1}$ (m)	16.9 ± 0.4	45.0 ± 7.0	23.2 ± 9.0	39.8 ± 2.4	19.5 ± 6.9	FB > CB[c], CM[c], WM[a], FW[a]; WM > CB[c], CM[b], FW[c]; CM > CB[a]
Peak Speed ($km{\cdot}h^{-1}$)	28.3 ± 0.8	28.8 ± 0.6	26.9 ± 1.0	27.7 ± 1.3	28.7 ± 1.3	FB > CM[b], WM[a]; FW > CM[b]; CB > CM[a]
No. HI Acc (>3 $m{\cdot}s^{-2}$)	0.8 ± 0.4	0.3 ± 0.1	1.5 ± 0.8	0.5 ± 0.3	0.8 ± 0.4	CM > CB[a], FB[b], WM[b], FW[a]; CB > FB[a], WM[a], FW > FB[b], WM[a]
No. HI Dec (<-3 $m{\cdot}s^{-2}$)	1.3 ± 0.4	0.8 ± 0.8	0.8 ± 0.5	0.1 ± 0.1	1.5 ± 0.3	FW > FB[a], CM[b], WM[c]; CB > CM[a], WM[c]; CM > WM[b]; FB > WM[a]
Player Load (A.U.)	13.4 ± 1.1	14.4 ± 2.0	14.3 ± 0.9	15.4 ± 0.8	15.2 ± 1.9	WM > CB[b], CM[a]; CM & FW > CB[a],
Internal Load						
Mean $\%HR_{max}$	76.1 ± 4.6	79.8 ± 2.3*	83.0 ± 6.1*	81.1 ± 2.2	75.6 ± 10.2*	CM & WM > CB[a]
Peak $\%HR_{max}$	91.4 ± 1.3	93.1 ± 2.7*	94.0 ± 2.7*	94.2 ± 4.7	88.7 ± 5.4*	CM > CB[a], FW[a]; WM > FW[a]
Blood Lactate ($mmol{\cdot}L^{-1}$)	6.9 ± 1.6	6.1 ± 2.3	6.0 ± 0.2	8.1 ± 2.5	8.6 ± 0.3	FW > FB[a], CM[c]; WM & CB > CM[a]
RPE (6-20 scale)	19.0 ± 0.0	19.3 ± 1.2	18.3 ± 0.6	18.3 ± 1.5	19.0 ± 1.0	CB, FB & FW > CM[a]

Abbreviations: VHID, very high-intensity distance; SPD, sprint distance; No., number; A.U., arbitrary unit; $\%HR_{max}$, percentage heart rate maximum; RPE, ratings of perceived exertion. CB, centre back; FB, fullback; CM, central midfielder; WM, wide midfielder; FW, forward. Values presented as means ± SD. *n=2. Effect sizes were classified as [a]moderate (>0.6-1.2), [b]large (>1.2-2.0) and [c]very large (>2.0-4.0) (Batterham & Hopkin, 2006).

8.1.4 Discussion

The position-specific combination drill was unable to achieve the same heart rate and blood lactate response as the SEM running drill investigated in Chapter 4. In contrast the position-specific combination drill did achieve similar peak running speeds and triaxial accelerometer player load as the running drills.

The combination drill requires all technical aspects to be successful to ensure work rate is maximal across all positions for the entire drill. Observations of video footage suggests poor technical proficiency has a negative effect on the intensity of the drill as players slow down to be the right area on the pitch or have to delay play whilst in possession of the ball for other players to be in the correct position. For instance, the CB and FW react off a through ball pass from the CM to initiate their first high speed run. A poor pass from the CM during the first phase will result in the one versus one situation finishing early in which case the FW and CB work sub-maximally into the position for the second phase to contest the cross from the FB. Individual position-specific drills would allow greater control of intensity in which players can work maximally for the desired repetition duration as they are not dependent on the proficiency of other players (Mohr & Krustrup, 2016). Such drills may provide a greater physiological response closer to running drills and require further investigation.

Nonetheless, positional differences were evident across all variables. Positional trends in physiological responses generally agrees with the limited information available in the literature which has reported midfielders (MF) and CB have the highest and lowest heart rate responses during a match, respectively (Ali & Farrally, 1991; Stroyer et al., 2004). Furthermore, MF have been reported to spend a higher percentage of time playing at 85-90% of HR_{max} than CB, FB and FW whilst also spending a greater time playing at 90-95% of HR_{max} compared to CB and FW (Coelho et al., 2011). In agreement with the present study, higher blood lactate concentrations have been reported for FW in elite youth soccer players during match play compared to defenders (DF) though no differences were reported for MF (Aslan et al., 2012).

Some external load variables appear to be consistent with match analysis studies but not all. For instance, wide players (WM & FB) covered greater distance running at very high speed and sprinting compared to central players (CB, CM & FW) which is consistent with general match play and peak 5 min periods (Bradley et al., 2009; Di Mascio & Bradley, 2013) whilst FB have been reported to cover the greatest VHSR and SPR distance during the most intense 3 and 1 min periods of a match (Martin-Garcia et al., 2018a). In contrast, CM covered greater VHSR distance and comparable SPR distance to FW which is at odds with the majority of match analysis studies (Andrezejewski et al., 2015; Ade et al., 2016) though not all (Di Salvo et al., 2009; Dellal et al., 2010). Additionally, central players had greater high-intensity acceleration and deceleration demands than wide players which again is not consistent with positional differences reported during match play (Varley & Aughey, 2013; Tierney et al., 2016; Martin-Garcia et al., 2018a). However, somewhat in agreement with the present study, CM have been reported to cover greater high-intensity acceleration distance compared to FB and FW and greater high-intensity deceleration distance compared to CB and FW during the most intense 5 min period of match play (Martin-Garcia et al., 2018a). Therefore, it would appear the position-specific combination drill does support some positional differences reported in match analysis studies however it should be acknowledged the drills were based on high speed running activity during a match and not acceleration/deceleration demands. It is suggested the WM high-intensity acceleration/deceleration distance would have been greater had they been exposed to an additional specific action at the beginning of the drill based on information from the HIMP in Chapter 5. For instance, a coach could play a pass down the line for the WM to run onto and perform a cross into the box before recovering back to the halfway line to then receive the pass from the CM leading into the rest of the drill. It is therefore suggested individual position-specific drills may provide a greater representation of between position differences in external load reported during match play as activity profiles are not influenced by the need to complement another four positions thereby allowing greater individualisation.

It is suggested quantifying the frequency of specific turning angles pre and post effort is unnecessary as the technical and tactical actions will naturally ensure these specific movement patterns occur. For instance, transitioning into a recovery run will require the specific turning angle. Additionally, quantifying movement patterns was found to be the least reliable of all HIMP categories further supporting the notion that position-specific SE drills should prioritise pitch location, technical and tactical actions.

8.1.5 Conclusion

The position-specific SE combination drill was insufficient in providing a physiological response comparable to the running drill reported in Chapter 4. Some positional differences in external load were consistent with match analysis data however this could be improved by designing individual position-specific drills.

CHAPTER NINE

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