Quantifying Sprint Demands in Soccer Training: Insights from Individualised Analysis of Soccer-Specific Exercises and Small-Sided Games

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy
in
Sport and Exercise Science

at Massey University, Albany, New Zealand.

Daniel Gordon

Abstract

Training approaches that combine technical, tactical and physical objectives are now commonplace in elite soccer. Determining how teams are able to meet physical training objectives using soccer-specific exercises and small-sided games (SSG) is a key research topic. Sprinting is a fundamental component of physical preparation for elite soccer players, however, the current body of research concerning sprinting during soccer-specific exercises is limited. This is firstly due to the scarcity of studies directly analysing running demands of a sufficient intensity, and secondly due to the use of generic movement analysis variables that do not account for individual differences in maximal sprint speed (MSS). This thesis aimed firstly to describe the individualised sprint demands of typical soccer training and competition, and secondly, to determine which soccer-specific exercises or prescriptive variables are able to elicit sprint demands in line with recommendations for the enhancement of sprint ability and reduction of injury risk. The four studies presented in this thesis combine observational data with global positioning system (GPS) movement analysis, collected in situ from both elite amateur and professional academy players. The cross-sectional data presented in Chapter 4 demonstrate that SSG do not typically elicit maximal (>95% MSS) sprint efforts, while peak running speeds reaching 85-95% of MSS can be achieved when the relative playing area is increased in proportion to competition. Chapter 5, using a diverse sample of SSG data, further demonstrates that relative playing area may be the central factor in determining the peak sprinting speed achieved, while other prescriptive variables such as game objective (goals vs. possession), duration, and limited touch rules also have significant effects. Chapter 6 establishes that non-continuous soccer-specific exercises, such as unopposed and finishing exercises generally elicit a low level of sprint demands, however multi-phase, counter-attacking exercises where player positioning can be tightly constrained were a significant outlier and warrant further investigation. Chapter 7 presents data showing that competitive matches elicit individualised sprint demands greater than those reported in training. The inclusion of isolated sprinting in the physical preparation of elite soccer players is therefore strongly recommended, even when implementing an otherwise fully integrated training approach.

Table of Contents

List of Tables and Figures

Abbreviations

BLa:	Blood lactate concentration.
CI:	Confidence intervals.
FP:	The absence of 1T or 2T constraints during soccer exercises.
GCT:	Ground contact time.
GPS:	Global positioning system.
HR:	Heart rate.
HR$_{max}$:	Maximum heart rate.
LPS:	Local positioning system
MSS:	Maximal sprint speed.
PSS:	Peak sprint speed.
RPE:	Rating of perceived exertion.
RSA:	Repeat sprint ability.
SSG:	Small-sided games.
1T:	Constraint on play during small-sided soccer games limiting players to one touch of the ball.
2T:	Constraint on play during soccer exercises limiting players to two touches of the ball.

Acknowledgements

Firstly, I would like to thank my supervisors, Dr Andrew Foskett and Dr Ajmol Ali. Your guidance since I first began undergraduate study many years ago has had a great impact on my academic and professional journey to this point. Your trust and calming advice throughout the long and challenging PhD process will always be appreciated. I am also sincerely thankful to Dr Andrew Simpkin for joining the supervisory team from afar. You provided unique insight into our methods, patiently helped me to develop new skills and understanding that was greatly beneficial to the research.

I would also like to acknowledge the staff and players at both Wellington Phoenix Academy and Auckland City Football Club for their enthusiastic participation in these studies. I am particularly grateful to José, Ivan, and Adria for welcoming me so readily into their coaching team and environment.

I would like to express my appreciation of Owen, Wendy, Kyle, and the many other colleagues who I have shared parts of this journey with. Thanks must also be given to Jana, Chloe, and Saskia for their many suggestions and reminders.

I am deeply grateful to my Mum and Dad for their lifelong encouragement to pursue my academic endeavours as far as possible. Lastly, I would like to thank my wife Hannah for her constant love and support through every challenge and success. This achievement belongs as much to her as it does to me.

Chapter 1: Introduction

This thesis investigates the design and application of small-sided games and other soccer-specific exercises with respect to sprint training objectives in an elite soccer team environment. The aim of this thesis is to determine the extent to which soccer exercises can elicit sprinting, and how this may be modified using prescriptive variables. This will give insight into the practical implementation and viability of this approach to sprint training for soccer.

Firstly, the importance of sprinting with respect to elite male professional soccer is established through a narrative review examining the demands of competition, relationships between sprinting and injury, and the determining factors of sprint performance. Secondly, the rationale behind the use small-sided soccer games in the preparation of teams is examined, alongside a critical review of previous studies to investigate sprinting during these activities.

The thesis then investigates this topic using a series of cross-sectional studies, both through a direct intervention investigating exercises and modifications that represent the best chance of reaching maximal running speeds, and through a broader inductive approach analysing larger samples of SSG and soccer-specific exercises performed by a team throughout the course of normal training.

Background and brief literature review

Soccer is a high-intensity intermittent team sport in which players must perform a wide array of physical and technical demands in dynamic and unpredictable fashion (Ade, Fitzpatrick, & Bradley, 2016; Bradley & Ade, 2018; Stølen, Chamari, Carlo, & Wisløff, 2005; Turner & Stewart, 2014). The range of demands during soccer match-play make it necessary for elite players to attain an optimal level of fitness and performance across a range of measurable physical characteristics (Lacome, Simpson, Cholley, & Buchheit, 2018; Morgans, Orme, Anderson, & Drust, 2014; Turner & Stewart, 2014), including but not limited to aerobic endurance, speed and agility, strength and power, and the ability to repeatedly execute high-intensity actions (Hoff & Helgerud, 2004; Little & Williams, 2006; Stølen et al., 2005; Turner & Stewart, 2014). The design and application of training to optimise each of these characteristics is therefore critical to the successful preparation of an elite soccer team. Of all the physical characteristics required for success in elite soccer, sprinting is arguably one of the most important, and as such this thesis is focused specifically on this aspect.

Role and importance of sprinting in soccer

Several aspects ensure sprinting is a critical element of soccer training, and a key topic in training research. For clarity, this thesis is focused specifically on the maximal speed aspect of sprinting as it relates to soccer training and competition, rather than the acceleration and deceleration components aspects of a straight-line sprint effort. Sprinting has been shown to occur frequently during critical, goalscoring actions in competition (Faude, Koch, & Meyer, 2012), and players routinely perform between 100-400 m of running at speeds over 24-26 $km \cdot h^{-1}$ during matches (Barnes, Archer, Hogg, Bush, & Bradley, 2014; Bradley et al., 2013, 2009; Di Salvo et al., 2010; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Gregson, Drust, Atkinson, & Salvo, 2010). Additionally, sprinting appears to display both positive (Woods et al., 2004) and negative (Colby, Dawson, Heasman, Rogalski, & Gabbett, 2014; Malone et al., 2018; Malone, Roe, Doran, Gabbett, & Collins, 2017) relationships with injury. In combination with the exercise-induced muscle damage (Howatson & Milak, 2009; Moir, Brimmer, Snyder, Connaboy, & Lamont, 2018) and neural fatigue (Byrne, Twist, & Eston, 2004; Howatson & Milak, 2009; Ross, Leveritt, & Riek, 2006) associated with sprinting, these factors demand that coaches include and actively manage sprint training within a soccer training microcycle (Buchheit, Lacome, Cholley, & Simpson, 2018).

Small-sided game training in soccer

Several authors have discussed the concept of concurrent or “integrated” training approaches, in which soccer small-sided games (SSG) are used as the primary training mode to provide physical conditioning and meet physical training objectives (Buchheit et al., 2018; Clemente, Martins, & Mendes, 2014b; Delgado-Bordonau & Mendez-Villanueva, 2012). Small-sided games are modified soccer games, most often using a smaller playing area and reduced number of overall players (Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). The reduced playing area and number of players used in SSG allow coaches to “overload” the frequency of match-specific technical and tactical actions that players experience (Dellal, Owen, et al., 2012; Jones & Drust, 2007; Katis & Kellis, 2009; Owen, Wong, Paul, & Dellal, 2014). Furthermore, SSG allow practice of these skills in a dynamic environment that incorporates perceptual-cognitive skills similarly to competitive matches (Davids, Araújo, Correia, & Vilar, 2013; Gabbett, Jenkins, & Abernethy, 2009; Roca & Ford, 2020; Roca, Ford, McRobert, & Williams, 2013; Williams, Hodges, North, & Barton, 2006), supporting the development of “game awareness” in a highly competition-specific manner (Williams et al., 2006). The movement and physiological demands elicited during SSG are able to closely replicate those of a competitive match (Abbott, Brickley, & Smeeton, 2018a; Casamichana, Castellano, & Castagna, 2012; Gabbett & Mulvey, 2008; Hill-Haas, Dawson, Coutts, & Rowsell, 2009; Hill-Haas et al., 2011; Owen, Twist, & Ford, 2004; Rampinini, Impellizzeri, et al., 2007), therefore adhering closely to the training principle of specificity and again enhancing “transfer” to competition (Gamble, 2006; Turner & Stewart, 2014). Finally, SSG training is also thought to enhance player compliance and motivation, and result in increased time efficiency over traditional approaches performing discrete technical, tactical, and physical training elements (Hill-Haas et al., 2011; Little, 2009).

The efficacy of SSG-based training approaches to meet physical objectives in training is dependent on the precise SSG design. A large volume of previous literature has examined the effect various modifications of prescriptive variables have on physical demands (Clemente, Martins, et al., 2014b; Clemente, Wong, Martins, & Mendes, 2014; Dellal, Chamari, Owen, et al., 2011; Dellal, Drust, & Lago-Peñas, 2012; Hill-Haas, Dawson, et al., 2009; Hill-Haas et al., 2011; Hill-Haas, Rowsell, Dawson, & Coutts, 2009; Impellizzeri et al., 2006; Rampinini, Impellizzeri, et al., 2007), and SSG training programmes have been shown to elicit similar physiological responses (Dellal et al., 2008) and provoke similar training adaptations (Impellizzeri et al., 2006; Owen, Wong, Paul, & Dellal, 2012) to more traditional interval running exercises and training regimes.

However, there are limitations to the physical demands that can be elicited during SSG (Buchheit & Laursen, 2013b) and some authors (Abbott et al., 2018a; Djaoui, Chamari, Owen, & Dellal, 2017; Owen et al., 2014) have questioned the capacity of SSG to elicit maximal speed running in particular. This represents a significant challenge to the feasibility of an SSG-based approach to meeting sprint training objectives.

SSG are able to elicit running speeds in the range of 22-27 km·h^{-1} (Casamichana & Castellano, 2010; Castellano, Casamichana, & Dellal, 2013; Djaoui et al., 2017; Kyprianou et al., 2022). While these speeds are unlikely to represent maximal running efforts, interpretation of *absolute* peak sprint speed values is severely limited by the variation possible in player maximal sprint speed (MSS). Several studies indicate a range between 28-35 km·h^{-1} amongst elite players (Al Haddad, Simpson, Buchheit, Di Salvo, & Mendez-Villanueva, 2015; Djaoui et al., 2017; Kyprianou et al., 2022), while only one study (Djaoui et al., 2017) has reported peak sprint speed during SSG as a percentage of individual player MSS.

Despite the limited peak running speeds reported during SSG, competitive matches elicit greater peak running speeds in the range of 27-29 km·h^{-1} (Castellano et al., 2013; Djaoui et al., 2017; Kyprianou et al., 2022). This could infer that the “ceiling” of peak sprint demands during soccer activities is greater than the aforementioned research suggests when the ideal prescriptive variables and game conditions are present. Previous studies have thus far only investigated the effects of a narrow range of prescriptive variables (playing area, player number, and game objective) amongst those that have been shown to modify physical demands during SSG (Hill-Haas et al., 2011). Future research could benefit from investigation of both a wider array of prescriptive variables, and more purposeful combinations of prescriptive variables designed to elicit maximal sprinting, in accordance with real-world SSG-based training practice (Buchheit et al., 2018).

In summary, given the significant role of sprinting in soccer competition, importance of designing and managing training to elicit sprinting, and possible benefits of performing training using soccer-specific exercises, further research addressing these limitations is warranted to quantify the sprint demands during SSG and other soccer-specific exercises.

Aims, objectives, scope, and hypotheses of the thesis.

The aim of this thesis was to investigate the design and application of small-sided games and specific exercises in soccer to meet sprint training objectives in the team training environment. It is important to convey that training-related enhancement of sprint is not necessarily implied in meeting sprint training objectives, and that the scope of this thesis pertains primarily to the capacity of these exercises to elicit maximal or near-maximal running demands.

There were four main objectives associated with the aim of the thesis:

1. Describe the typical relative sprint demands of small-sided games, overall team training, and competition.
2. Determine to what extent, if any, small-sided games or other soccer-specific exercises are able to elicit maximal sprint efforts.
3. Understand how the relative sprint demands during small-sided games and soccer-specific exercises are modified according to prescriptive variables.
4. Determine the differences in relative sprint demands between playing positions during small-sided games, overall team training, and competition.

It is intended that this thesis will aid in the design of soccer-specific training exercises and enable coaches to realise the potential benefits of this training. It will also give coaches and practitioners a better understanding of the relative sprint demands of different soccer specific exercises and when these efforts are likely to arise. Overall, this information will help to determine if, and how, sprint training objectives are able to be met within integrated, soccer-specific exercise-based training approaches.

Thesis structure and methodological approach

The present thesis comprises 2 literature reviews (Chapters 2 and 3) and 4 experimental chapters (Chapters 4-7), followed by the integrated discussion and conclusion chapter (Chapter 8). The literature review of Chapter 2 firstly explores the sprinting demands of elite soccer competition and training (Section 1), before discussing the importance of why these demands might play a crucial role in performance, physical preparation, and injury prevention (Section 2). Secondly, Chapter 2 defines sprinting as a physical skill, outlines its determinant factors, and summarises perspectives of the training and development of sprint ability with specific respect to elite soccer players (Section 3).

Chapter 3 discusses the background and rationale of small-sided game training exercises in elite soccer and determines how these exercises can be utilised to meet technical, tactical, and physical training objectives in an integrated manner. A critical review exploring the gaps within this body of research as it pertains to sprinting is then included to directly inform the research questions posed in this thesis.

In order to more effectively investigate the application and design of SSG to elicit sprint demands, a series of cross-sectional studies were performed, addressing the literature gaps outlined in the critical review. Firstly, each of the present studies reports *relative* sprint demands, i.e., either the peak percentage of MSS attained, or distance covered above relative sprint speed thresholds. Additionally, the effect of playing position will be explored in each of these studies.

Chapter 4 compares 9 different SSG in a crossover design comprising 3 levels each of two variables. This study directly addresses the limited research reporting the sprint demands of SSG when prescriptive variables are directly “optimised” towards sprinting, namely larger match-specific relative playing areas and combinations of rule modifications derived from previous research (Buchheit et al., 2018).

Chapter 5 and 6 investigate samples of SSG (Study 2) and scenario-based soccer-specific exercises (Study 3) collected *in situ* during the day-to-day training of a competitive team. The inductive approach used in these studies allows the investigation of the effects of a broader assortment of prescriptive variables on peak sprint demands. These studies also provide valuable data as to the extent of the sprint demands during soccer-specific exercises performed in normal team training.

Chapter 7 is a descriptive analysis of the overall sprint demands during training and match-play in a team environment. The purpose of this study to further contextualise the relative sprint demands reported in Chapters 4, 5, and 6.

References

Abbott, W., Brickley, G., & Smeeton, N. J. (2018). An individual approach to monitoring locomotive training load in English Premier League academy soccer players. *International Journal of Sports Science & Coaching*, *13*(3), 421–428.

Ade, J., Fitzpatrick, J., & Bradley, P. S. (2016). High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions. Information for position-specific training drills. *Journal of Sports Sciences*, *34*(24), 2205–2214.

Al Haddad, H., Simpson, B. M., Buchheit, M., Di Salvo, V., & Mendez-Villanueva, A. (2015). Peak match speed and maximal sprinting speed in young soccer players: effect of age and playing position. *International Journal of Sports Physiology and Performance*, *10*(7), 888–896.

Barnes, C., Archer, D. T., Hogg, B., Bush, M., & Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine*, *35*(13), 1095–1100.

Bradley, P. S., & Ade, J. (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.

Bradley, P. S., Carling, C., Gomez Diaz, A., Hood, P., Barnes, C., Ade, J., … 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.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences*, *27*(2), 159–168.

Buchheit, M., Lacome, M., Cholley, Y., & Simpson, B. M. (2018). Neuromuscular responses to conditioned soccer sessions assessed via GPS-Embedded accelerometers: Insights into tactical periodization. *International Journal of Sports Physiology and Performance*, *13*(5), 577–583.

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle. Part II: anaerobic energy, neuromuscular load and practical applications. *Sports Medicine*, *43*(10), 927–954.

Byrne, C., Twist, C., & Eston, R. (2004). Neuromuscular function after exercise-induced muscle damage. *Sports Medicine*, *34*(1), 49–69.

Casamichana, D., & Castellano, J. (2010). Time-motion, heart rate, perceptual and motor behaviour demands in small-sided soccer games: Effects of pitch size. *Journal of Sports Sciences*, *28*(14), 1615–1623.

Casamichana, D., Castellano, J., & Castagna, C. (2012). Comparing the physical demands of friendly matches and small-sided games in semiprofessional soccer players. *Journal of Strength and Conditioning Research*, *26*(3), 837–843.

Castellano, J., Casamichana, D., & Dellal, A. (2013). Influence of game format and number of players on heart rate responses and physical demands in small-sided soccer games.

Journal of Strength and Conditioning Research, *27*(5), 1295–1303.

Clemente, F. M., Martins, F. M. L., & Mendes, R. S. (2014). Periodization based on small-sided soccer games: Theoretical considerations. *Journal of Strength and Conditioning Research*, *36*(5), 34–43.

Clemente, F. M., Wong, D. P., Martins, F. M. L., & Mendes, R. S. (2014). Acute effects of the number of players and scoring method on physiological, physical, and technical performance in small-sided soccer games. *Research in Sports Medicine*, *22*(4), 380–397.

Colby, M. J., Dawson, B. T., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *Journal of Strength and Conditioning Research*, *28*(8), 2244–2252.

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews*, *41*(3), 154–161.

Delgado-Bordonau, J. L., & Mendez-Villanueva, A. (2012). Tactical periodization: Mourinho's best kept secret. *Soccer Journal*, (June), 28–34.

Dellal, A., Chamari, K., Owen, A. L., Wong, D. P., Lago-Peñas, C., & Hill-Haas, S. V. (2011). Influence of technical instructions on the physiological and physical demands of small-sided soccer games. *European Journal of Sport Science*, *11*(5), 341–346.

Dellal, A., Chamari, K., Pintus, A., Girard, O., Cotte, T., & Keller, D. (2008). Heart rate responses during small-sided games and short intermittent running training in elite soccer players: A somparative study. *Journal of Strength and Conditioning Research*, *22*(5), 1449–1457.

Dellal, A., Drust, B., & Lago-Penas, C. (2012). Variation of activity demands in small-sided soccer games. *International Journal of Sports Medicine*, *33*(5), 370–375.

Dellal, A., Owen, A. L., Wong, D. P., Krustrup, P., van Exsel, M., & Mallo, J. (2012). Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. *Human Movement Science*, *31*(4), 957–969.

Di Salvo, V., Baron, R., Gonzalez-Haro, C., Gormasz, C., Pigozzi, F., & Bachl, N. (2010). Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. *Journal of Sports Sciences*, *28*(14), 1489–1494.

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine*, *30*(3), 205–212.

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal sprinting speed of elite soccer players during training and matches. *Journal of Strength and Conditioning Research*, *31*(6), 1507–1517.

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, *30*(7), 625–631.

Gabbett, T. J., Jenkins, D., & Abernethy, B. (2009). Game-based training for improving skill and physical fitness in team sport athletes. *International Journal of Sports Science & Coaching*, *4*(1), 273–283.

Gabbett, T. J., & Mulvey, M. J. (2008). Time-motion analysis of small-sided training games and competition in elite womens soccer players. *Journal of Strength and Conditioning Research*, *22*(2), 543–552.

Gamble, P. (2006). Implications and Applications of Training Specificity for Coaches and Athletes. *Strength and Conditioning Journal*, *28*(3), 54–58.

Gregson, W., Drust, B., Atkinson, G., & Salvo, V. D. (2010). Match-to-match variability of high-speed activities in premier league soccer. *International Journal of Sports Medicine*, *31*(4), 237–242.

Hill-Haas, S. V., Dawson, B. T., Coutts, A. J., & Rowsell, G. J. (2009). Physiological responses and time–motion characteristics of various small-sided soccer games in youth players. *Journal of Sports Sciences*, *27*(1), 1–8.

Hill-Haas, S. V., Dawson, B. T., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in football: A systematic review. *Sports Medicine*, *41*(3), 199–220.

Hill-Haas, S. V., Rowsell, G. J., Dawson, B. T., & Coutts, A. J. (2009). Acute physiological responses and time-motion characteristics of two small-sided training regimes in youth soccer players. *Journal of Strength and Conditioning Research*, *23*(1), 111–115.

Hoff, J., & Helgerud, J. (2004). Endurance and strength training for soccer players. *Sports Medicine*, *34*(3), 165–180.

Howatson, G., & Milak, A. (2009). Exercise-induced muscle damage following a bout of sport specific repeated sprints. *Journal of Strength and Conditioning Research*, *23*(8), 2419–2424.

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., & Rampinini, E. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine*, *27*(6), 483–492.

Jones, S., & Drust, B. (2007). Physiological and technical demands of 4v4 and 8v8 games in elite youth soccer players. *Kinesiology*, *39*(2), 150–156.

Katis, A., & Kellis, E. (2009). Effects of small-sided games on physical conditioning and performance in young soccer players. *Journal of Sports Science and Medicine*, *8*(3), 374–380.

Kyprianou, E., Di Salvo, V., Lolli, L., Al Haddad, H., Villanueva, A. M., Gregson, W., & Weston, M. (2022). To measure peak velocity in soccer, let the players sprint. *Journal of Strength and Conditioning Research*, 36(1), 273–276.

Lacome, M., Simpson, B. M., Cholley, Y., P, L., & Buchheit, M. (2018). Small-sided games in elite soccer: Does one size fit all? *International Journal of Sports Physiology and Performance*, *13*, 568–576.

Little, T. (2009). Optimizing the use of soccer drills for physiological development. *Strength* *and Conditioning Journal*, *31*(3), 67–74.

Little, T., & Williams, A. G. (2006). Suitability of soccer training drills for endurance training. *Journal of Strength and Conditioning Research*, *20*(2), 316–319.

Malone, S., Owen, A. L., Mendes, B., Hughes, B., Collins, K., & Gabbett, T. J. (2018). High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? *Journal of Science and Medicine in Sport*, *21*(3), 257–262.

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport*, *20*(3), 250–254.

Moir, G. L., Brimmer, S. M., Snyder, B. W., Connaboy, C., & Lamont, H. S. (2018). Mechanical limitations to sprinting and biomechanical solutions. *Strength and Conditioning Journal*, *40*(1), 47–67.

Morgans, R., Orme, P., Anderson, L., & Drust, B. (2014). Principles and practices of training for soccer. *Journal of Sport and Health Science*, *3*(4), 251–257.

Owen, A. L., Twist, C., & Ford, P. (2004). Small-sided games: the physiological and technical effect of altering pitch size and player numbers. *Insight*, *7*(2), 50–53.

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2012). Effects of a periodized small-sided game training intervention on physical performance in elite professional soccer. *Journal of Strength and Conditioning Research*, *26*(10), 2748–2754.

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2014). Physical and technical comparisons between various-sided games within professional soccer. *International Journal of Sports Medicine*, *35*(4), 286–292.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Abt, G., Chamari, K., Sassi, A., & Marcora, S. M. (2007). Factors influencing physiological responses to small-sided soccer games. *Journal of Sports Sciences*, *25*(6), 659–666.

Roca, A., & Ford, P. R. (2020). Decision-making practice during coaching sessions in elite youth football across European countries Decision-making practice during coaching sessions in elite youth football across. *Science and Medicine in Football*, *4*(4), 263–268.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of Sport and Exercise Psychology*, *35*(2), 144–155.

Ross, A., Leveritt, M., & Riek, S. (2001). Neural influences on sprint running. *Sports Medicine*, *31*(6), 409–425.

Stølen, T., Chamari, K., Carlo, C., & Wisløff, U. (2005). Physiology of soccer: An update. *Sports Medicine*, *35*(6), 501–536.

Turner, A. N., & Stewart, P. F. (2014). Strength and conditioning for soccer players. *Strength and Conditioning Journal*, *36*(4), 1–13.

Williams, A. M., Hodges, N. J., North, J. S., & Barton, G. (2006). Perceiving patterns of play in dynamic sport tasks: Investigating the essential information underlying skilled performance. *Perception*, *35*(3), 317–332.

Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., & Hodson, A. (2004). The Football Association Medical Research Programme: an audit of injuries in professional football--analysis of hamstring injuries. *British Journal of Sports Medicine*, *38*(1), 36–41.

Chapter 2: The role of sprinting in elite competitive soccer: A narrative review

Section 1: Match demands of elite competitive soccer

This section will review the existing literature reporting the demands of competitive soccer matches with specific reference to sprinting or high-speed running activity at the elite male competitive level. Comprehensive understanding of the movement demands during competition is important as these demands create key reference points that inform training methods and programmes. The literature search for the present narrative review included combinations of the following keywords: “sprint”, “soccer”, “football”, “competition”, “injury”, and “performance” appropriate to each subsection. Studies involving elite male football players were included in Section 1 pertaining to match demands, while studies involving female and recreational players were excluded. Studies from a broader participant pool were considered in Section 2 relating to sprinting more generally. Studies outside of elite soccer have been included in Section 2 focusing on injury research; primarily these studies examine data in Gaelic football and Australian rules football.

Soccer matches require outfield players to run approximately 10-12 km total distance during a regulation match (Carling, Bloomfield, Nelsen, & Reilly, 2008; Stølen et al., 2005). The majority of this distance is covered whilst walking and jogging (Bradley et al., 2009). However, this low intensity activity is frequently interspersed with more intense physical and technical actions, including jumping, kicking, tackling, “duelling”, changing movement direction via acceleration and deceleration, and high-speed running and sprinting. Modern, player-mounted global-positioning systems (GPS), and automated and semi-automated video-analysis (VA) software are able to collect time-motion data with great ease. As a result, numerous studies report competitive match demands using time or distance within velocity, although, the specific thresholds used to report total distance or frequency of high-intensity and sprint actions are inconsistent across the literature (Dwyer & Gabbett, 2012). With the ease of access of elite soccer clubs to this technology there has also been limited recent research published on the basic demands of elite soccer competition.

Sprint demands of elite competitive soccer

Sprinting is reported to contribute between 1% and 12% of total distance covered during a competitive match (Stølen et al., 2005). A large proportion of the variation in this number appears to be attributable to the varied sprint velocity thresholds employed in each study; the “high”, “very-high”, or “sprinting” speed thresholds used in studies range from 14-26 $km \cdot h^{-1}$. Studies using GPS measurement or video analysis systems with thresholds in the mid-20 $km \cdot h^{-1}$ range more consistently report total sprint distance covered in a match in the low-single digit percentages of total movement (Dellal, Chamari, Wong, et al., 2011).

Distance covered while sprinting

The distance covered above varied sprint speed thresholds in a number of studies is summarised in Table 2.1 below, with most studies reporting between 100-400 m covered at these speeds, with substantial differences between playing positions. Coefficients of variation (CV) for total sprint distance during matches (>25.2 $km \cdot h^{-1}$) are consistently around 30% (Carling, McCall, Le Gall, & Dupont, 2016; Gregson et al., 2010). This limits the use of sprint and other high-speed distances as direct measures of performance; very large magnitude differences would need to be observed to achieve statistical significance. High CV, even within position groups and across large sample sizes, are possibly due to differences in playing style and tactical roles (Gregson et al., 2010).

Table 2.1 Summary of studies reporting the total sprint distance covered above sprint speed thresholds during competition.

Study	Sample	Method	Sprint Speed Threshold (km·h^{-1})	Position	Sprint Distance (m)
Bradley et al., 2009	English Premier League. 2005-2006	VA	25.1	Central defenders	152 ± 50
				Fullbacks	74 ± 23
				Central midfielders	62 ± 19
				Wide midfielders	51 ± 16
				Attackers	73 ± 22
Bradley et al., 2013	English Premier League	VA	25.1	Central defenders	153 ± 64
				Fullbacks	288 ± 109
				Central midfielders	217 ± 93
				Wide midfielders	331 ± 114
				Attackers	312 ± 121
				All players	248 ± 119
	English Championship	VA	25.1	Central defenders	195 ± 64
				Fullbacks	360 ± 124
				Central midfielders	252 ± 83
				Wide midfielders	485 ± 111
				Attackers	335 ± 121
				All players	308 ± 139
	English League One	VA	25.1	Central defenders	245 ± 68
				Fullbacks	394 ± 105
				Central midfielders	339 ± 99
				Wide midfielders	479 ± 106

				Attackers	405 ± 102
				All players	360 ± 123
Gregson et al., 2010	English Premier League, 2003-2006	VA	25.2	Central defenders	145 ± 65
				Wide defenders	253 ± 96
				Central midfielders	198 ± 90
				Wide midfielders	307 ± 109
				Attacker	272 ± 117
Di Salvo et al., 2010	UEFA Champions League and UEFA Cup, 2002-2006	VA	25.2	Central defenders	131 ± 66
				Wide defenders	233 ± 98
				Central midfielders	163 ± 85
				Wide midfielders	285 ± 111
				Attacker	242 ± 106
				All players	205 ± 108
Dellal et al., 2011	Spanish La Liga, 2006-2007	VA	24.1	Central defenders	193.6 ± 64.6
				Full back	248.9 ± 77.4
				Central defensive midfielders	203.3 ± 76.4
				Central attacking midfielders	222.2 ± 66.5
				Wide midfielders	250.8 ± 71.5
				Forwards	260.0 ± 72.6
	English Premier League, 2006-2007	VA	24.1	Central defenders	208.5 ± 69.4
				Wide defenders	263.0 ± 69.9
				Central defensive midfielders	245.8 ± 77.9
				Central attacking midfielders	267.3 ± 64.2
				Wide midfielders	259.2 ± 84.9
				Forwards	278.2 ± 78.0

The distance covered above sprint speed thresholds has also increased dramatically in the previous 20 years in certain elite professional leagues. In a long-term analysis of sprint demands in the English Premier League, Barnes et al. (2014) reported an increase from 232 ± 114 m in the 2006/07 season, to 350 ± 139 m in the 2012/13 season, using a sprint speed threshold of 25.1 km·h^{-1}. Sprint demands during competition can also be markedly different between leagues within different countries. A comparative study by Dellal et al. (2011) showed that players within the English Premier League already covered greater distances above sprint thresholds than those in than La Liga in 2006/07, prior to the longitudinal increases reported by Barnes et al. (2014).

Number and distance of sprint efforts

Determining the typical distances spanned and the number of sprints that comprise these total sprint distances can give greater insight into the sprint demands during competition. However, the number of sprints performed, and the distribution of these efforts across different distances varies greatly across the literature. Video analysis of 10 UEFA Europa League matches with a sprint velocity threshold of >24 km·h^{-1}, showed the average number of sprints performed during a game to be 11.2 ± 5.3, with a mean total sprint distance of 237 ± 123 m, while the majority (~90%) of sprints were below 5 s duration (Andrzejewksi, Chmura, Pluta, Strzelczyk, & Kasprzak, 2013).

Other studies report a greater mean number of sprints performed during matches. Di Salvo et al. (2010) investigated 67 knockout matches in the UEFA Champions League and UEFA Cup competitions from 2002 to 2006 with a sprint threshold of 25.2 km·h^{-1}, finding an average of 17-35 sprints across playing positions. A similar study by Di Salvo et al (2009) using the same video analysis method (Prozone), analysed three seasons of matches in the English Premier League from the 2003/04-2005/06 seasons. Players in this study (Di Salvo et al., 2009) performed 30-35 sprints per game, totalling

167-262 m. Interestingly, despite using a lower sprint threshold of 21 km·h^{-1}, Casamichana et al. (2012) found semi-professional players performed 15.3 ± 6.1 sprint efforts per 60 min of play during friendly matches (equivalent to 22.9 efforts per 90 min), with a maximum duration and distance of a single sprint 5.1 ± 1.7 s and 34.4 ± 12.4, respectively. Again, there is evidence to suggest that match demands have increased significantly in the years subsequent to these studies, at least in certain leagues; Barnes et al. (2014) reported an increase in the number of sprint efforts of 85% in this period (31 ± 14 to 57 ± 20) in the English Premier League between 2006/07 and 2012/13 using a sprint speed threshold of 25.2 km·h^{-1}.

Both studies by Di Salvo et al. (2010, 2009), analysing a large number of matches in the English Premier League and UEFA Champions League/UEFA Cup competitions, respectively, showed that the majority of running efforts exceeded 25.2 km·h^{-1} for only 0-5 m or 5-10 m, with decreasing frequency in subsequent 5-m intervals (Casamichana et al., 2012; Di Salvo et al., 2010, 2009). Taken together, it does appear that, while shorter sprint efforts that exceed the sprint threshold for brief durations predominate competitive activity, longer duration and distance efforts (such as > 5 s, in the 30-40 m range) are performed during matches (Andrzejewksi et al., 2013; Casamichana et al., 2012).

Explosive vs leading sprints

Di Salvo et al (2010, 2009) also explored the type of sprints performed during a match according to the prior movement activity, categorising sprints into “leading sprints” and “explosive sprints”, representing sprint threshold activity occurring either with or without 0.5 s spent in the adjacent “high-intensity” velocity zone (19.8-25.2 km·h^{-1}), respectively. The ratio of these sprints was consistent in both studies; approximately 70% leading and 30% explosive sprints (Di Salvo et al., 2010, 2009).

Individualised sprint distances

Several authors have attempted to rectify the loss of information inherent in a "threshold-based" approach to describing movement demands by individualising high-speed and sprint speed thresholds according to the MSS, and/or maximal aerobic speed of each player (Abbott et al., 2018a; Hunter et al., 2015; Mendez-Villanueva, Buchheit, Simpson, & Bourdon, 2013). The difference between these two values has been termed the "anaerobic speed reserve" (ASR). Mendez-Villanueva et al. (2013) reported match demands across 6 age groups using this method, separating activities into MAS/ASR categories as follows: 0-60% MAS, 61-80% MAS, 81-100% MAS, 101% MAS – 30% ASR, >31% ASR. In the U18 age-group players covered between 100-300 metres above the 30% ASR threshold (Mendez-Villanueva et al., 2013), according to playing position.

Peak sprinting speed

The peak sprinting speed reached during competition can also be an informative analysis method. As shown in Table 2.2, several studies (Bradley et al., 2009; Casamichana et al., 2012; Djaoui et al., 2017; Kyprianou et al., 2022; Mallo, Mena, Nevado, & Paredes, 2015) have reported peak match speeds between 27-29 $km{\cdot}h^{-1}$. As with the distance covered and number of efforts above sprinting thresholds, there is evidence to suggest the peak match running speed also differs between competitive levels, across different countries (Dellal, Chamari, Wong, et al., 2011; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007) and has increased markedly in recent years (Barnes et al., 2014). The peak match running speeds reported by Barnes et al. (2014) across several years in the English Premier League were already greater in the 2006/07 season (32.8 ± 1.5 $km{\cdot}h^{-1}$) compared to those reported in other studies (Bradley et al., 2009; Casamichana et al., 2012; Djaoui et al., 2017; Kyprianou et al., 2022; Mallo et al., 2015) before increasing significantly by the 2012/13 season (34.4 ± 1.4 km·h^{-1}).

Given the variation possible in individual maximum sprint speed (Al Haddad et al., 2015; Djaoui et al., 2017; Kyprianou et al., 2022; Mendez-Villanueva, Buchheit, Kuitunen, et al., 2011), the peak sprint speed reached during competitive matches might be more accurately analysed using a *relative* measure, i.e., the percentage of MSS that players achieve. Interestingly, a limited number of studies have reported sprint demands of competitive matches in relation to players' individual capabilities. Djaoui et al. (2017) examined the peak percentage-MSS from competitive matches in French 1st (professional) and 4th (amateur) division players, finding 91.6 ± 8 % and 92.5 ± 6 % MSS, respectively. All playing positions across both professional and amateur groups showed a peak percentage-MSS of greater than 90%, except amateur central midfielders at 89.3%. While not conducted using adult players, the study by Al Haddad et al. (2015) examined the peak sprint speeds of young players from U13 to U17, finding a pooled peak percentage-MSS of 89.5 ± 5.9%.

Buchheit et al. (2021) investigated the number of sprint efforts exceeding 80%, 85%, and 90% of individual MSS over a large sample (n=1182 player matches) of Ligue 1 (French 1st division) and UEFA Champions League matches. Overall, efforts at near-to-maximal speed were infrequent but clearly present: players did not exceed 90% of max speed in 35% (attackers) to 65% (midfielders) of matches, while reaching at least 90% of max speed 3 or more times in 2% (midfielders) to 11% (attackers) of matches.

Table 2.2 Peak maximal running speed reached during competition.

Study	Sample	Method	Position	MSS (km·h^{1})
Bradley et al., 2009	English Premier League. 2005-2006	VA	Central defenders	26.3 ± 1.1
			Fullbacks	27.9 ± 0.9
			Central midfielders	27.1 ± 1.2
			Wide midfielders	28.5 ± 1.1
			Attackers	27.9 ± 1.0
Mallo et al., 2015	Spanish La Liga, 2010-2012	GPS	Central defenders	27.7 ± 1.7
			Fullbacks	29.2 ± 2.7
			Central midfielders	26 ± 2.1
			Wide midfielders	29.3 ± 2.3
			Forwards	29.3 ± 2.0
Djaoui et al., 2017	French 4th Division (amateur)	GPS	Central defenders	29 ± 2.5
			Wide defenders	30.7 ± 2.0
			Central midfielders	28.1 ± 2.2
			Wide midfielders	29.4 ± 3.0
			Forwards	29.3 ± 1.8
			All players	29.1 ± 2.5
	French 1st Division (professional)	GPS	Central defenders	28 ± 4.0
			Wide defenders	29.1 ± 2.2
			Central midfielders	28.2 ± 2.6
			Wide midfielders	30.1 ± 1.6
			Forwards	30.2 ± 1.9
			All players	28.6 ± 2.9
Kyprianou et al., 2019	Elite academy players	GPS	All players	31.5 ± 1.4
Casamichana et al., 2012	Spanish 3rd Division (semi-professional)	GPS	All players	27 ± 1.8

GPS: global position system, MSS: maximal sprint speed, VA: video analysis.

Positional differences in sprint demands

When analysing competitive match demands, it is clear that each playing position differs in terms of the intensity, volume and frequency of the sprinting performed. Several studies have reported position-specific differences in the distance covered above sprint thresholds and total number of sprints (Ade et al., 2016; Bradley et al., 2013, 2009; Bush, Barnes, Archer, Hogg, & Bradley, 2015; Di Salvo et al., 2010, 2009; Mallo et al., 2015; Rampinini, Coutts, et al., 2007). Studies show consistent differences in the total distance covered above sprint thresholds between positions, with wide midfielders, attackers, and wide defenders covering the greatest total distance above sprint speed thresholds and greatest number of sprint efforts, while central midfielders and central defenders cover the least. Interestingly, despite differences in the number of sprint efforts, both studies by Di Salvo et al. (2010, 2009) report no difference between playing positions in the ratio of “explosive” to “leading” sprint efforts (approximately 30% “explosive” efforts). Similar position-specific differences have been reported with regard to both absolute (Al Haddad et al., 2015; Bush et al., 2015; Djaoui et al., 2017; Mallo et al., 2015; Oliva-Lozano, Fortes, Krustrup, & Muyor, 2020; Rampinini, Coutts, et al., 2007) and relative peak sprinting speed (Al Haddad et al., 2015; Buchheit et al., 2021; Djaoui et al., 2017).

These differences in sprint demands are thought to be the result of variation in tactical roles between playing positions (Al Haddad et al., 2015; Di Salvo et al., 2010, 2009; Djaoui et al., 2017; McCall et al., 2015; Mendez-Villanueva, Buchheit, Kuitunen, et al., 2011; Rampinini, Coutts, et al., 2007), which give rise to differences in movement patterns, tactical, and technical actions (Ade et al., 2016). Positions (e.g., wide midfielders) that have the opportunity for longer sprint efforts likely have the opportunity to reach greater peak sprint speeds, due to the longer acceleration phase possible. (Bradley et al., 2009). Mendez-Villanueva et al. (2011) suggests that certain positions, particularly in the attacking phase (e.g. wide midfielders), are more likely to allow a player the freedom to express their sprint ability maximally. It seems clear from these data that studies examining sprint demands should use at least five position categories (central defenders, wide defenders, central midfielders, wide midfielders, forwards). However, care should be taken when undertaking these comparisons, as even within position categories, tactical roles could be markedly different; for example, a holding central midfielder who refrains from joining the attack in advanced areas of the pitch, versus a "box-to-box" central midfielder who is responsible for defending and attacking both goals repeatedly.

Player MSS

Interestingly, a player's sprint activity during a match may also be affected by their sprinting ability. While not examined in elite adult male players, Mendez-Villanueva et al (2011) found that faster youth players exploited their advantage by reaching higher absolute maximal sprint speeds in matches than slower teammates, independent of position. Additionally, slower wide midfielders did not compensate for their lower MSS by increasing the percentage of MSS used during the game, while slower central defenders did. These findings were also supported in a further study by Al Haddad et al. (2015). This supports the idea that certain playing positions and tactical roles may have a required "threshold" for sprint speed for completion of tactical duties (i.e., central defenders performing defensive actions), while other playing positions may not.

Section 2: Importance of sprinting with respect to injury, team success, and performance

As outlined in Section 1, competitive soccer matches require players to routinely reach high peak running speeds and cover significant cumulative distances at very-high speeds, exhibiting the importance of sprinting within elite soccer training. However, there are several other characteristics that may enhance this importance. For example, several authors suggest sprinting displays relationships with match performance or outcome (Bradley et al., 2013; Di Salvo et al., 2009; Rampinini et al., 2009), injury (in both protective and injurious directions) (Eirale et al., 2013; Ekstrand et al., 2011), and fatigue that reduces overall training efficacy (Marrier et al., 2017; Nagahara et al., 2016). Each of these factors are discussed in detail in the following section.

Involvement in key actions and relationship between running performance and team success

Associations between sprint performance level or volume of sprinting performed in a competitive match and competitive success would underline the importance of sprinting to elite soccer performance. The popularity of time-motion measurement devices such as satellite-based GPS and camera-based local positioning systems (LPS) over the previous 20 years has led to an increase in the number of published studies describing the movement demands of elite soccer (Carling, 2013). Researchers have attempted to use detailed quantifications of movement demands to link measures of physical activity in competition with team performance or success (Bradley et al., 2013; Di Salvo et al., 2009; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009; Vigne et al., 2013).

Somewhat counter-intuitively, several studies have reported a negative relationship between distance covered during matches at high-speed or sprinting thresholds and the competitive level of a team, both within and between leagues. Di Salvo et al. (2009) showed small-moderate increases in the distance covered at sprint (25.2 km·h^{1}) and high-intensity (19.8-25.2 km·h^{1}) running speeds by teams lower in the competitive table of the English Premier League, with differences between the top 5, middle 10, and bottom 5 positions, while Rampinini et al. (2009) reported similar results between the top and bottom 5 teams in the Italian Serie A. Bradley et al., (2013) reported larger increases in the sprint (above 25.1 km·h^{1}) distance and high-speed (19.8-25.1 km·h^{1}) covered between higher and lower competitive tiers. Players in the English Premier League (1st tier) covered 248 ± 119 m above 25.1 km·h^{1} per match, compared to 308 ± 139 m in the Championship (2nd tier), and 360 ± 123 m in League One (3rd tier). Interestingly, Rampinini et al. (2009) reported players covered greater high-speed distance (14.4-19.8 km·h^{1}), but not very-high speed distance (>19.8 km·h^{1}) when playing a team from the top eight table positions, relative to the teams in lower league positions. This trend of reduced distances at high-speed and sprinting speeds performed by higher-ranked teams across these studies has been attributed to greater technical skill and tactical awareness resulting in greater ball possession (Di Salvo et al., 2009; Rampinini et al., 2009; Vigne et al., 2013). The greater high-speed activity observed in lower-ranked teams would seem to be a consequence of their attempts to regain and perhaps inability to maintain ball possession (Carling, 2013; Di Salvo et al., 2009).

Although the evidence above (Bradley et al., 2013; Di Salvo et al., 2009; Rampinini et al., 2009) suggests that performing greater running distances at sprint and high-speed thresholds is negatively correlated with team success, this interpretation is limited by several factors. Match running performances are influenced by factors such as match score-line (Lago-Peñas, Casais, Dominguez, & Sampaio, 2010), team formation (Bradley et al., 2011; Tierney, Young, Clarke, & Duncan, 2016), physical fitness characteristics (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010), and environmental changes (Trewin, Meylan, Varley, & Cronin, 2017). Competitive leagues in different countries also display varying match running profiles attributed to differences in traditional playing style (Dellal, Chamari, Owen, et al., 2011). Consequently, the rationale behind examining these factors one-dimensionally has been challenged (Carling, 2013; Paul, Bradley, & Nassis, 2015). These issues are exacerbated by the difficulty of detecting changes in match sprint performance given the large match-to-match variation (30.8-37.1% coefficient of variation) typically reported for distance covered above sprint speed thresholds (Carling et al., 2016; Gregson et al., 2010).

Team success in soccer competition is complex. Tactical actions that demand sprinting or high-intensity running are not inherently beneficial or detrimental; a player may need to cover distance quickly to create or exploit an advantage (Di Salvo et al., 2009), but must also do so when out of position or recovering from a mistake. Contrary to the aforementioned studies, a 3-year case-study of a professional team in the Italian Serie A (Vigne et al., 2013) investigated trends in performance data over a successful period during which the team improved league position and total competition points tally consecutively. They found that distance covered in sub-maximal running categories (<19 km·h^{1}) during matches reduced each year while the team maintained their average high-intensity (>19 km·h^{1}) running distance. These changes in sub-maximal running were attributed to increased tactical understanding and organisation of the team due to stability of the coaching and tactical system.

Analysing which tactical actions require players to sprint and allowing coaches and practitioners to determine the importance of these to their own strategy may be more informative. Faude et al. (2012) investigated a single season (2007/08) of goals scored from open play in the German 1st division (highest competitive tier). Straight sprints were defined as a “very high intensity run with maximal or near maximal velocity in a straight direction after a distinct acceleration”. Faude et al. (2012) found 45% of goals in the German 1st division during the 2007/08 season were preceded by a straight sprint by the goal scorer. Similarly, 38% of all assists (passes leading directly to a goal) were preceded by a straight sprint by the assisting player. However, while this study did report sufficient inter- and intra-observer reliability of 87% and 92% agreement, respectively, manual video-analysis cannot determine precisely whether maximal or near-maximal running speeds were achieved. Additionally, the study may be limited in analysing only situations in which goals are scored rather than goal-scoring chances created. However, this study (Faude et al., 2012) does demonstrate that sprinting is one of a group of key high-intensity physical actions performed during goalscoring moments in competition.

Given the demand of sprinting during goalscoring actions (Faude et al., 2012), it could be inferred that a greater maximal sprinting ability confers an individual advantage in certain tactical situations. The concept of a player's utilisation of their individual MSS being contingent on their playing position was investigated in the studies of Mendez-Villanueva et al. (2011) and Al Haddad et al. (2015). Mendez-Villanueva et al. (2011) showed that slower central defenders utilised a greater peak percentage of MSS relative to their faster peers in the same playing position during competitive matches, while the slower wide midfielders did not. In contrast, faster wide midfielders utilised a slightly greater percentage of their MSS compared to slower wide midfielders (90.5 ± 1.2% vs. 88.7 ± 4.9%, ES = 0.5, small). This exacerbated the sprint ability differences between these players and resulted in a large difference (31.0 ± 0.4 km·h^{1} vs. 26.8 ± 1.3 km·h^{1}, ES = 3.9, very large) in absolute peak sprint speed during the match. One possible explanation for this finding is that the central defenders in this study (Mendez-Villanueva, Buchheit, Simpson, et al., 2011) were involved in situations during the match (perhaps defensive situations) that necessitated reaching a certain absolute threshold sprint speed irrespective of the sprint ability of the player, while the wide midfielders were afforded greater freedom to express their physical abilities. Perhaps indicative of the varied nature of tactical demands and their physical expression in competitive matches, these results were not replicated later by Al Haddad et al. (2015). In this study (Al Haddad et al., 2015), slower wide midfielders, central midfielders, and strikers used a higher peak percentage of their MSS during matches than faster peers, while slower central defenders and second strikers did not.

Overall, investigating relationships between straightforward measurements of physical output during a competitive match and team success is perhaps of limited utility. The lack of strong or clear relationships suggests factors other than physical output are most important for success in soccer competition (Carling, 2013). Carling (2013, p. 657) suggests future research should focus more on the interaction between the “athletic, behavioural, tactical, and technical components of performance”. Despite this, it is clear that sprinting is a critical feature of decisive tactical actions within competition (Faude et al., 2012), and faster players are at an unquestionable advantage during these moments. Optimising sprint performance and development should therefore be a key feature of elite physical preparation for soccer, provided this does not contraindicate performance in relation to fatigue and injury.

Sprinting as a fatiguing exercise

An aspect which underscores the importance of monitoring the sprinting performed in training, and sprint demands of training exercises, is the fatiguing nature of sprint exercise and the risk this poses to performance in an elite team sport environment. This is of particular concern given the high frequency of competitive fixtures now common in elite soccer (Carling et al., 2016).

Sprinting is a demanding physical task from an energetic, neurological, and morphological perspective. Short-duration maximal exercise comparable to the sprinting requirements of team sports heavily taxes the anaerobic metabolic pathways; one study of a 6-s cycle sprint estimates the ATP energy contribution of the anaerobic glycolytic and phosphocreatine to be 44% and 50%, respectively (Gaitanos, Williams, Boobis, & Brooks, 1993). Additionally, sprinting also necessitates high levels of neural activation (Ross et al., 2001). These levels of neural activation are due to the large muscular forces transmitted through several muscle groups at various points in the stride (Mero, Komi, & Gregor, 1992). Several of these muscle groups are required to contract eccentrically, in particular the hamstrings during the late swing phase (Morin et al., 2015).

Sprint exercise consequently results in large fatigue responses in several systems. Howatson and Milak (2009) investigated the time course of fatigue responses to 15 x 30-m repeated sprints with a rapid deceleration phase, reporting perceptual, neurological, and muscle damage changes up to 72 h post-exercise. Serum creatine kinase activity (a marker of muscle damage), and perceived soreness both remained elevated above baseline levels at 72 h post-exercise, while thigh girth (indicative of swelling or oedema) was also increased up to 48 h post-exercise. While the muscle damage and soreness responses in the present study were likely accentuated by the eccentric contractions required in the rapid deceleration phase (Howatson & Milak, 2009), Byrne et al. (2004) suggests that the eccentric forces generated during accelerative or constant speed sprinting phases are also sufficient to provoke exercise-induced muscle damage. Interestingly, the responses reported above (Howatson & Milak, 2009) are similar to those induced by a 90-min shuttle running protocol simulating a soccer match (Thompson, Nicholas, & Williams, 1999).

Longitudinal changes in electromyographical (EMG) activity during sprinting are difficult to assess due to the challenges of ensuring reliable electrode placement (Ross et al., 2001), hence researchers are limited to measuring isometric maximal voluntary contractions or isokinetic force and torque measures to assess neural fatigue. Howatson and Milak (2009) reported the maximal isometric force of the knee extensors was reduced at 24- and 48-hours following 15 x 30-m sprints. Other authors conclude changes in electromyographical activity are possible for up to 7 days' post-exercise following muscle damage (Byrne et al., 2004; Ross et al., 2001).

Both the exercise-induced muscle damage typically observed following eccentric contractions utilised by sprinting, and neural fatigue, are known to impair sport performance. The likely mechanisms of this reduced performance include impaired proprioception, increased perceived exertion, reduced neural drive during subsequent exercise (Ross et al., 2001) and impaired calcium release (Fowles, 2006), that ultimately reduce the power-generating capabilities of the muscle (Fowles, 2006; Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2013; Ross et al., 2001).

However, assessments of fatigue elicited by sprinting alongside or within team sport training are scarce. Marrier et al. (2017) reported changes in sprint mechanical properties (reduction in theoretical maximal velocity) following an intense rugby sevens training session were correlated to the distance covered at high intensity within the session (Marrier et al., 2017), while Nagahara et al. (2016) demonstrated similar changes following soccer match-play. Buchheit et al. (2018) examined the short-term neuromuscular responses to on-field training exercises combining isolated and soccer-specific exercise, with three training sessions targeting “strength”, “endurance”, and “speed” performed amongst regular soccer training. Pre- and post-exercise responses to the combined soccer-specific and isolated sessions were measured using an adductor squeeze test, countermovement jump height, and GPS-accelerometer variables during a standardised running protocol as in Buchheit et al. (2015). The “speed” exercises performed provoked a mixture of fatigue and potentiation effects; small reductions in adductor squeeze strength were reported, along with small increases in vertical stiffness and countermovement jump height (Buchheit et al., 2018). Interestingly, moderate decreases in “propulsion efficiency” (ratio of velocity load to triaxial accelerometer force load) were observed (Buchheit et al., 2018).

To summarise, sprint exercise has the potential to cause short- and long-term fatigue in multiple systems and impair subsequent intermittent exercise performance. In a practical team-sport setting, this fatigue possibly threatens the players’ ability to effectively meet other objectives in training such as technical or tactical, aerobic, or resistance training requirements. Coaches in elite soccer commonly seek to minimise neuromuscular fatigue to prioritise the quality of technical/tactical training (Buchheit et al., 2021; Delgado-Bordonau & Mendez-Villanueva, 2012), while track and field coaches also typically orient the timing and frequency of maximal sprint exercise around the time-course of this fatigue (Byrne et al., 2004; Ross et al., 2001). This underlines the critical nature of quantifying the sprint training demands of different training activities to allow consideration of these factors in the planning and execution of training.

Section 3: The background and determining factors of sprint performance

Definitions and disambiguation of sprinting

Sprinting is a complex and multidimensional skill (Healy, Kenny, & Harrison, 2021; Moir et al., 2018) which is fundamental to team sport performance (Morin, Edouard, & Samozino, 2011; Seitz, Reyes, Tran, de Villareal, & Haff, 2014). This section will more closely examine sprinting as a physical skill, discussing the biomechanics of sprinting, the determining factors underpinning sprint performance, and consider the current literature relating to the measurement and development of sprint ability in elite soccer players.

Sprinting can be defined as “rapid, un-paced cyclic running of 15 s or less in duration at maximum intensity throughout” (Ross et al., 2001, p. 409), though there is currently no broadly accepted definition in of sprinting in team sports (Sweeting et al,. 2017). There are, however, multiple classifications of sprinting or high-intensity movement tasks in soccer. Little & Williams (2005) categorise “high-speed actions” during soccer competition into acceleration, maximal speed, or agility tasks, while Haugen (2014) classifies “soccer-related sprinting skills” as straight-line sprinting, agility, and repeated-sprint ability. The term “agility” typically encompasses change-of-direction ability and is presently defined as “rapid whole-body movement with change of velocity or direction in response to a stimulus” (Sheppard & Young, 2006). Repeated-sprint ability (RSA) is defined as the capacity to perform short (<10 s) sprint exercise with fractional recovery periods of <60 - 300 s (Girard, Mendez-Villanueva, & Bishop, 2011).

This thesis focuses primarily on straight-line sprinting, and the attainment or development of maximal speed as it relates to soccer training and competition. Straight-line sprinting itself comprises acceleration, maximal (or constant) speed, and deceleration phases (Haugen, 2014; Mero et al., 1992), while each stride cycle within a sprint consists of a contact or support phase, and flight or aerial phase.

Determining factors of sprint performance

Sprint performance is determined by a number of biomechanical, morphological, metabolic, and neurological properties, many of which are largely determined by genetics (Ross & Leveritt, 2001). Determinant morphological properties include muscle fibre type composition, size, and contractile speed of the primary agonist muscles of sprinting (hip and knee extensors, knee flexors, and plantar flexors) (Ross & Leveritt, 2001). Metabolic properties determining sprint exercise performance primarily relate to the ability to support short-term adenosine-triphosphate (ATP) availability via anaerobic glycolysis and phosphocreatine degradation (Spencer, Bishop, Dawson, & Goodman, 2005). Aerobic metabolism greatly contributes to ATP resynthesis following sprinting (and therefore repeated-sprint ability) but is not a determining factor for the performance of a single sprint (Spencer et al., 2005). Neurological properties support the requirement to repeatedly and maximally recruit the lower body musculature to contract rapidly and forcefully, including motoneuron excitability, nerve conduction velocity, and reflex input (Ross et al., 2001). Finally, the biomechanical determinants of sprint performance relate mainly to anthropometry and stride kinematics, and the resultant stride length and frequency. Several properties are shared across more than one of the above categories, for example, muscle-tendon stiffness relies upon a combination of neural and morphological characteristics (Douglas, Pearson, Ross, & McGuigan, 2020), as illustrated in Figure 2.1 below.

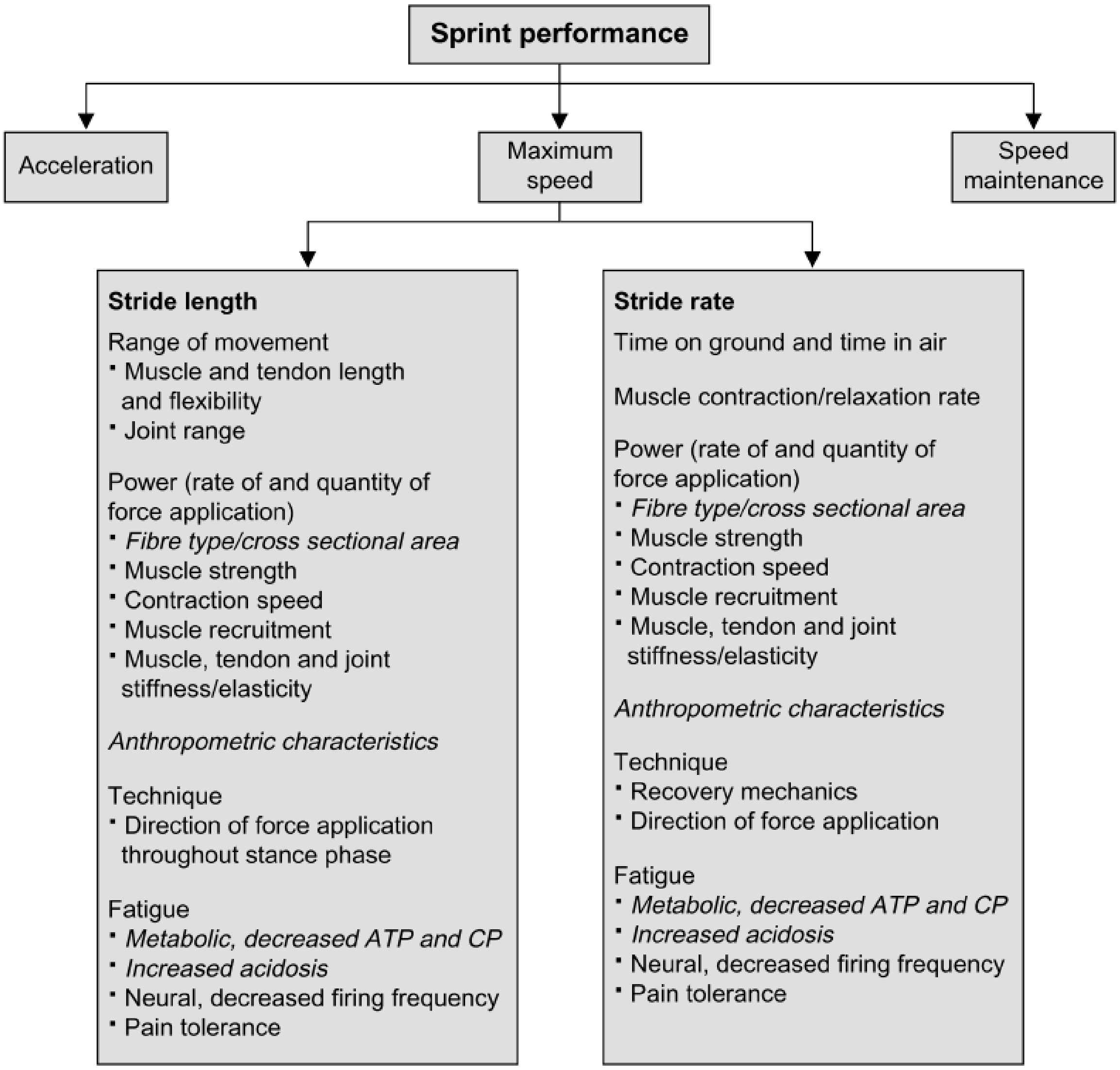


Figure 2.1 Components of sprint performance reproduced from Ross et al. (Ross et al., 2001).

Components in italics are not neurally influenced. ATP = adenosine triphosphate; CP = creatine phosphate.

Sprint performance can be further understood when examining the resultant kinetics of the sprint stride, in which the characteristics above combine to result in the repeated production of considerable force into the ground through the lower body. These forces result in the ground reaction forces (GRF) that propel the athlete (Morin et al., 2011). The overall GRF produced by each ground contact during sprinting is a combination of the mediolateral, anteroposterior, and vertical forces (Moir et al., 2018). The vertical and anteroposterior (horizontal) components of GRF are considered of greatest consequence to sprint performance (Moir et al., 2018; Morin et al., 2011).

The overall vector of the GRF, and relative importance of horizontal and vertical force differs between sprint phases, as key studies by Morin et al. (2011, 2015) and Nagahari et al. (2018) show. The anteroposterior, or horizontal component of the total GRF vector, appears to be of greatest consequence during the acceleration phase. In the anteroposterior plane, a typical support/contact phase consists of an initial braking phase (negative GRF) followed by a propulsive phase (positive GRF) (Morin et al., 2011). Greater net horizontal force/impulse (positive differences between propulsive and braking forces) is strongly associated with improved acceleration performance (Morin et al., 2011), while the ability to sustain a high ratio of horizontal to vertical force over the course of an acceleration phase (effectively, to remain in the acceleration phase for as long as possible) is also a key element of successful short sprint performance (Morin et al., 2011). Faster sprinters, both within categories (e.g., team-sport athletes) and between categories (e.g., team-sport to elite track sprinters) have been shown to produce a greater horizontal component of the overall force vector during the acceleration phase of a sprint (Morin et al., 2015). Interestingly, Morin et al. (Morin et al., 2015) found that reduced braking impulses were not as highly correlated with sprint performance as net horizontal and propulsive impulses, however, it should be noted that this study was performed using a cohort of highly trained sprinters (100 m personal best times ranging from 9.95-10.60 s). Less well-trained sprinters (i.e., team-sport athletes) could possibly enhance their performance by reducing braking impulses during the acceleration phase.

In contrast to the acceleration phase, the vertical component of the GRF vector is thought to be more critical during the maximal or constant speed phase. Higher relative vertical forces, applied over shorter ground contact times, are discriminant between athletes of differing levels of sprint performance at maximal running speeds (Nagahara et al., 2018; Weyand, Sandell, Prime, & Bundle, 2010; Weyand, Sternlight, Bellizzi, & Wright, 2000). The minimum time taken to reposition the swing leg is narrowly constrained in human sprinting (Weyand et al., 2010, 2000), therefore a sufficient vertical impulse to carry the body through the air for this duration is essential. Larger relative vertical forces (and stiffness properties in the lower leg) allow shorter ground contact times (Douglas et al., 2020) and greater stride frequencies without compromising this constraint (and therefore stride length). During all phases, the athlete must also produce sufficient vertical supporting forces (Moir et al., 2018; Morin et al., 2011).

Specificity and relative importance of maximal speed versus acceleration

Many of the biomechanical, morphological, metabolic and neurological properties that determine sprinting ability within each phase (acceleration, maximum speed, deceleration) are broadly related as they concern the effective application of force into the ground through the lower body. However, several studies have found relatively small correlations between tests of acceleration (e.g., 5-m sprint time, 10-m sprint time) and maximal running speed (e.g., flying 20-m time) (Little & Williams, 2005; Mendez-Villanueva, Buchheit, Kuitunen, et al., 2011; Tomáš, František, Lucia, & Jaroslav, 2014). Collectively, the results of these studies infer that acceleration and maximal speed are separate abilities, requiring separate training and testing procedures (Little & Williams, 2005).

In practice, this may raise issues around the organisation or prioritisation of training components. It has been suggested that acceleration ability is of most importance in soccer (Haugen, 2014) due to the predominance of shorter sprint efforts in competitive matches (Vigne, Gaudino, Rogowski, Alloatti, & Hautier, 2010), and the strong predictive relationship acceleration-based mechanical variables (horizontal force) display with overall sprint performance over soccer-specific (25 m) sprint distances (Morin et al., 2015). Indeed, by definition a very high peak sprint speed over a short distance is only attainable after an effective acceleration phase. However, despite their relative scarcity, sprint efforts requiring a very high proportion of MSS do occur in elite competitive matches (Buchheit et al., 2021). A greater MSS is also possibly a competitive advantage that players may exploit during matches (Mendez-Villanueva, Buchheit, Simpson, et al., 2011), and might improve sub-maximal running endurance (Bundle, Hoyt, & Weyand, 2003). Other issues concerning the importance of maximal sprinting are explored in Section 2. Ultimately, elite soccer players must perform, and therefore train to develop, a mixture of both of acceleration and MSS capabilities during competition.

Sprint ability of soccer players

Several methods have been used to measure the sprint abilities of elite adult soccer players. The sprint times of elite soccer players over distances of 20-40 m have been reported in several studies, however, it should be noted that large differences in sprint times are possible according to the timing methods and procedures used (Haugen & Buchheit, 2016). Times reported in the literature ranged from 2.99 – 3.38 s over 20 m (Haugen, Tønnessen, & Seiler, 2013; Hill-Haas, Coutts, et al., 2009; Sporis et al., 2009); and 4.20-4.30 s over 30 m (Cometti et al., 2001; Rebelo et al., 2013). Flying 20 m and 10 m split times (Haugen et al., 2013), and player-mounted GPS (Djaoui et al., 2017; Jastrzebski & Radzimiński, 2015) have also been utilised to report peak or maximal sprinting speed, typically during sprints of 40 m. Mean values in these studies ranged from 29-32 km·h^{-1}, with clear differences between playing positions (Djaoui et al., 2017; Haugen et al., 2013). Differences between elite and amateur players with respect to sprint ability remain unclear (Cometti et al., 2001; Djaoui et al., 2017; Haugen, 2014).

With regard to the varied methods of determining sprint performance, there are several gold-standard options. Fully-automated timing systems (involving the combination of pressure-plate starting block and automated finish photo capture), dual-beam photocells, high frequency (50-100 Hz) continuous radar, and high-speed video are all accurate to a very high standard (Haugen & Buchheit, 2016). Player-mounted GPS is the most practical method to determine sprint ability in a team setting or during team sport activity, however the validity and reliability of GPS measurement method can be reduced according to the sampling rate, running speed, and movement pattern of the athlete (Haugen & Buchheit, 2016; Hoppe et al., 2018). While 1 Hz or 5 Hz GPS units are limited during maximal speed running and change of direction tasks (Scott, Scott, & Kelly, 2016), several studies have determined that 10 Hz GPS units produce acceptable reliability and validity, particularly with respect to maximum velocity determination (Haugen & Buchheit, 2016; Hoppe et al., 2018; Thome et al., 2023; Varley et al., 2012).

There is also evidence to suggest the sprint abilities of elite soccer players has changed over time. Haugen et al. (2013) reports a large number of measurements from 1995-2010, suggesting players became faster throughout this period (Haugen et al., 2013). This improvement in sprinting ability seemingly occurred in parallel with the marked increases in the high-intensity running demands of elite competitive matches (Barnes et al., 2014), though which of these effects is responsible for the other is unclear. Elite soccer players, and indeed, other team sport athletes, although fast, are not at the pinnacle of human sprint performance. Elite sprint athletes are able to achieve speeds in excess of 10 $m \cdot s^{-1}$ (36 $km \cdot h^{-1}$) (Clark & Weyand, 2014), perhaps suggesting soccer players may be able to further improve their sprint performance.

Approaches to sprint training and practical considerations

The biomechanical, morphological, metabolic, and neurological characteristics that determine sprint performance are the natural targets of sprint training interventions or programmes. However, many of these characteristics are primarily determined by genetics (Haugen, 2014; Ross & Leveritt, 2001; Ross et al., 2001). As a result, improvements in sprinting ability following training are relatively small (Haugen, 2014; Haugen, Breitschädel, & Seiler, 2020; Ross & Leveritt, 2001; Ross et al., 2001), though these small improvements (e.g., 0.03 – 0.06 s improvement in 20 m time) can result in practically significant changes over the soccer-specific sprint distances (Haugen & Buchheit, 2016; Hopkins, Marshall, Batterham, & Hanin, 2009). Additionally, given the specificity of characteristics underpinning acceleration and maximum speed abilities, it is recommended that training approaches account for each of the sprint phases (Little & Williams, 2005; Mendez-Villanueva, Buchheit, Kuitunen, et al., 2011; Tomáš et al., 2014).

Typical approaches to sprint training in soccer combine both sprint-based and resistance exercises (Turner & Stewart, 2014). Resistance training to enhance sprint ability focuses on bilateral and unilateral lower-body exercises with the goal of developing hypertrophy, maximal strength, and explosive strength/power ability (Haugen et al., 2020), among other secondary and tertiary objectives (Healy et al., 2021). This is broadly achieved using general gym-based exercises (squat, clean and jerk), more “sprint-specific” gym-based exercises (split squats, single-leg deadlifts, lunges, step ups), and further bodyweight-resisted plyometric exercises (unilateral and bilateral bounding, hopping and jumping) (Haugen et al., 2020), each of which are already recommended elements of resistance training programmes for elite soccer players (Turner & Stewart, 2014). Overall, evidence strongly favours the inclusion of resistance training to enhance sprint performance (Rumpf, Lockie, Cronin, & Jalilvand, 2016; Seitz et al., 2014).

The most specific form of sprint training is to engage directly in sprinting exercises (Moir et al., 2018), and unsurprisingly a meta-analysis by Rumpf et al. (2016) found that training interventions using both free sprinting and specific sprint training (combining free sprinting with resisted and assisted sprinting exercises) were effective in improving sprint performance.

Despite the current evidence, the optimal approach to sprint-based training in soccer is not clear (Turner & Stewart, 2014). Guidelines for the specific volume, intensity, frequency, and organisation of sprint training in an elite soccer training context are scarce, and most training studies recommend only that sprint velocity should be maximal throughout (Haugen, 2014). Limited evidence supports this straightforward guideline. The study by Haugen et al. (2014), investigated soccer players following a 9-week sprint training programme (developed with reference to the training practices of a successful elite sprint coach) consisting of 20-m repeated sprints performed at 90% of MSS. Only trivial differences were reported following the intervention in both the control and training groups, suggesting either the volume or frequency of the sprint training stimulus was insufficient.

It is possible that soccer players might be more responsive to sprint training-related improvements over certain sprint distances. The study by Tønneson et al. (2011) found that young soccer players' maximum speed improved significantly over 20-40 m following a 40-m repeated sprint training intervention. Haugen (2014) suggests that soccer players' frequent exposure to intense accelerations during the course of normal team training leads them to reach their potential over short distances, as compared to maximal sprinting over distances exceeding 20 m.

Sprinting and injury risk

Another factor increasing the importance of measuring, monitoring, and planning the sprint exercise aspects of soccer training is the possible relationship between sprinting and injury risk. The results of several large studies indicate that prevention of injuries is a critical factor of team success in elite soccer (Arnason, Sigurdsson, et al., 2004; Eirale, Tol, Farooq, Smiley, & Chalabi, 2013; Hägglund et al., 2013)

Hågglund et al. (2013) examined the injuries and team performance of 24 teams from nine European leagues over the course of 11 seasons. Lower injury burdens (time-loss per 1000 h of training and match play) and higher match availabilities were significantly associated with higher final league rankings. Similarly, lower injury incidence (injuries per 1000 h of training and match play), lower injury burden and higher match availability were associated with increased points per league match (Hägglund et al., 2013). These results are supported by studies of individual leagues/countries in Iceland (Arnason, Sigurdsson, et al., 2004) and Qatar (Eirale et al., 2013).

Additionally, injuries result in a significant financial burden. For example, data from the English Premier League estimated the salary paid league-wide to injured players totalled £177 million in the 2016/2017 season, a figure which had increased 5 years consecutively, and represented a 55% increase from the £114 million paid in the 2011/2012 season (JLT Specialty Limited, 2017).

There is evidence to suggest sprinting in particular is central to the occurrence of lower-body injuries. High-speed running is the predominant aetiology of hamstring strain injuries (HSI) in soccer, with 57% of hamstring strain injuries occurring during sprinting (Woods et al., 2004). This aetiology is logical; sprinting places a significant demand on the hamstrings muscle group, as it works in a biarticular fashion throughout multiple phases, contracting both eccentrically and concentrically (Moir et al., 2018). However, there remains debate regarding the phase of the stride cycle (late swing phase, or late stance phase) that is most injurious to the hamstrings (Morin et al., 2015).

Hamstring strain injuries are of particular relevance to injury prevention practice given their high frequency in soccer training and match-play. In a large study of 24 elite European teams spanning 9 seasons (2001-2009), Ekstrand et al. (2011) found hamstring strains to be the most frequently occurring injury (12% of all injuries). Eirale et al. (2013) examined all injuries in the highest competitive tier of Qatari club soccer during the 2008/2009 season. Thigh injuries, including anterior (quadriceps), and posterior (hamstrings), were the most common location of injury (39.2%), followed by knee (15.2%) and ankle (12.0%). Of thigh muscle strains, more than half (54.5%) were hamstring strains.

The high incidence of hamstring strain injuries (4-6 per season for a typical 25-player squad), combined with moderate mean severity (mean 14 days return to training, compared to 17 days for quadriceps strain) results in HSI being the single most significant time-loss (burden) injury within elite soccer (Ekstrand et al., 2011). The vast majority of these injuries occur indirectly or through non-contact mechanisms, that is, without intervention of an opposition player (Arnason, Tenga, Engebretsen, & Bahr, 2004; Ekstrand et al., 2011; Ueblacker, Müller-Wohlfahrt, & Ekstrand, 2015)

As outlined in Section 1, sprinting is unavoidable in elite competitive soccer matches. However, research has shown that hamstring strain injury risk is modifiable. There is a large volume of research reporting reduced HSI incidence following eccentric and isometric hamstring resistance-training protocols (Bourne et al., 2018). Importantly, several authors also report that the volume of sprinting performed in team-sport training can modify both general, and hamstring strain injury risk.

In a study of a Portuguese professional soccer team over a single season (Malone et al., 2018), (albeit using a “sprint” threshold of only 19.8 km·h^{1}) higher total weekly sprint distances and higher absolute increases in weekly sprint distance were associated with increased injury incidence overall. However, classifying players according to their chronic load into “high” (3-weekly rolling average above 2584 AU) or “low” (<2584 AU) groups modified these effects. Increases in weekly total sprint volume were associated with large increases in injury incidence in the “low” chronic load group, while the same increases in weekly total sprint volume were associated with decreases in injury incidence in the “high” chronic load group (Malone et al., 2018).

Similar to the overall results of Malone et al. (2018), in a study of elite Australian rules football players Colby et al. (2014) also reported that players performing moderate (864-1453 m >75% MSS) weekly sprint distances were less likely to incur an injury relative to players above and below these thresholds. Further evidence collected in Gaelic football suggests that routine attainment of faster near-MSSs is also associated with reduced injury incidence (Malone et al., 2017). Across a single season of training and match time-motion data, players that had performed at least one sprint over 95% of their individual MSS in a training week were less likely (OR = 0.12, 95% CI, 0.01, 0.92) to become injured in the subsequent week, compared to teammates who had not exceeded 85% MSS (Malone et al., 2017). Again, the effects of near-maximal sprint “exposures” were modified by the long-term training load of the player. Players that completed “low” chronic training loads (4-weekly rolling averages of session-rating of perceived exertion <4750 AU) incurred injuries at a significantly greater rate having performed more than 15 sprint efforts above 95% MSS in the preceding week (OR = 3.38, 95% CI 1.60, 6.75) (Malone et al., 2017).

Using longer-term time-motion data, Duhig et al. (2016) produced the only study to directly examine HSI and sprinting volume. This study examined the sprint (>24 km·h^{1}) training loads of elite Australian Rules footballers, finding HSI risk increased when players exceeded their long-term (2 years) mean training session sprint distances (>24km·h^{1}) in the 1-4 weeks preceding the injury.

The overall interpretation of these studies is difficult. Primarily, it appears very-high sprinting volumes and large increases in sprint volume are associated with increased injury incidence. There is also possibly a U-shaped relationship with injury incidence centred on moderate sprinting volumes (Colby et al., 2014; Malone et al., 2018, 2017). Additionally, when combined with large chronic training load, even “high” volumes of sprinting may be protective against injury. However, precise determination of what constitutes low, moderate, or high volumes of sprinting, increases or decreases in sprinting volume, or general chronic training load is not clear. Several authors (including Malone et al. (2018) above) have attempted to use a ratio calculation to better interpret the relationship between the chronic and acute load performed by athlete with respect to injury risk (Hulin, Gabbett, Lawson, Caputi, & Sampson, 2016), however this method has since been shown to be invalid due to an improper mathematical coupling (Impellizzeri, McCall, Ward, Bornn, & Coutts, 2020). Indeed, some authors have argued that “no strong evidence supports the quantitative use of training load data to manipulate future training for the purpose of preventing injury” (Impellizzeri, Menaspà, Coutts, Kalkhoven, & Menaspà, 2020, p. 885).

There are plausible mechanisms supporting the notion of sprinting providing a protective effect against hamstring injury. Increases in hamstring (biceps femoris long head) fascicle length and increased eccentric peak torque are thought to be the major changes governing reduced hamstring injury risk (Petersen, Thorborg, Nielsen, Budtz-Jørgensen, & Hölmich, 2011) following well-studied eccentric training programmes (Timmins, Bourne, et al., 2016; Timmins, Ruddy, et al., 2016). A recent study by Mendiguchia et al. (2020) reported that a 6-week, 12-session, programme of sprint training including short accelerations, maximal velocity running, heavy resisted-sprinting, and plyometric exercises resulted in greater changes to fascicle length than a matched eccentric-based (Nordic hamstring exercise) programme, while simultaneously “improving” sprinting technique.

There are methodological concerns with reducing injury risk to a limited number of variables. Injuries are inherently complex and multifactorial. Aspects such as previous injury, mood, sleep and psychological stressors all influence injury risk (Halson, 2014). Logically, a player with poor/injurious sprinting biomechanics would not benefit from increased volumes of sprinting. Larger studies incorporating changes in muscle architecture and long-term sprint training load measures would be useful to confirm these findings, but clearly these studies are logistically challenging and subject to limitations such as player movement between teams, changes in coaching staff, or differences in resistance training practices and compliance.

In conclusion, it is unsurprising that while sprinting is the leading cause of hamstring strain injuries in soccer, application of training programmes to enhance sprinting mechanics and coordination, strengthen and condition sprinting-specific musculature, and systematically exposing players to maximal or near-maximal speeds can plausibly reduce this risk. Overall, the available literature underlines the crucial nature of monitoring sprinting demands in soccer, and determining how these might be modified during soccer-specific training exercises.

Conclusion

In conclusion, sprinting is a key facet of the demands of elite competitive soccer, and these demands vary according to factors such as playing position, tactical approach of the team, and player MSS. Only a small number of studies have reported individual data that reflect differences in individual maximum sprint speed. Sprinting appears to be a key variable of training with respect to injury. It is the most common mechanism of injury, and the injury most frequently associated with sprinting (HSI) results in the greatest injury burden. However, sprinting regularly in training and supporting this with appropriate resistance and neuromuscular training regimes are also proposed to reduce the incidence of muscle injuries.

References

Abbott, W., Brickley, G., & Smeeton, N. J. (2018). An individual approach to monitoring locomotive training load in English Premier League academy soccer players. *International Journal of Sports Science & Coaching*, *13*(3), 421–428.

Ade, J., Fitzpatrick, J., & Bradley, P. S. (2016). High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions. Information for position-specific training drills. *Journal of Sports Sciences*, *34*(24), 2205–2214.

Al Haddad, H., Simpson, B. M., Buchheit, M., Di Salvo, V., & Mendez-Villanueva, A. (2015). Peak match speed and maximal sprinting speed in young soccer players: effect of age and playing position. *International Journal of Sports Physiology and Performance*, *10*(7), 888–896.

Andrzejewksi, M., Chmura, J., Pluta, B., Strzelczyk, R., & Kasprzak, A. (2013). Analysis of sprinting activities of professional soccer players. *Journal of Strength and Conditioning Research*, *27*(8), 2134–2140.

Arnason, A., Sigurdsson, S. B., Gudmundsson, A., Holme, I., Engebretsen, L., & Bahr, R. (2004). Physical fitness, injuries, and team performance in soccer. *Medicine and Science in Sports and Exercise*, *36*(2), 278–285.

Arnason, A., Tenga, A., Engebretsen, L., & Bahr, R. (2004). A prospective video-based analysis of injury situations in elite male football: Football incident analysis. *American Journal of Sports Medicine*, *32*(6), 1459–1465.

Barnes, C., Archer, D. T., Hogg, B., Bush, M., & Bradley, P. S. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine*, *35*(13), 1095–1100.

Bourne, M. N., Timmins, R. G., Opar, D. A., Pizzari, T., Ruddy, J. D., Sims, Casey, … Shield, A. J. (2018). An evidence-based framework for strengthening exercises to prevent hamstring injury key points. *Sports Medicine*, *48*, 251–267.

Bradley, P. S., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., … Krustrup, P. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences*, *29*(8), 821–830.

Bradley, P. S., Carling, C., Gomez Diaz, A., Hood, P., Barnes, C., Ade, J., … 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.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences*, *27*(2), 159–168.

Buchheit, M., Gray, A., & Morin, J. B. (2015). Assessing stride variables and vertical stiffness with GPS-embedded accelerometers: Preliminary insights for the monitoring of neuromuscular fatigue on the field. *Journal of Sports Science and Medicine*, *14*(April), 698–701.

Buchheit, M., Lacome, M., Cholley, Y., & Simpson, B. M. (2018). Neuromuscular responses to conditioned soccer sessions assessed via GPS-embedded accelerometers: Insights into tactical periodization. *International Journal of Sports Physiology and Performance*, *13*(5), 577–583.

Buchheit, M., Mendez-Villanueva, A., Simpson, B. M., & Bourdon, P. C. (2010). Match running performance and fitness in youth soccer. *International Journal of Sports Medicine*, *31*(11), 818–825.

Buchheit, M., Simpson, B. M., Hader, K., Lacome, M., Buchheit, M., Simpson, B. M., … Lacome, M. (2021). Occurrences of near-to-maximal speed-running bouts in elite soccer: Insights for training prescription and injury mitigation. *Science and Medicine in Football*, *5*(2), 105–110.

Bundle, M. W., Hoyt, R. W., & Weyand, P. G. (2003). High-speed running performance: a new approach to assessment and prediction. *Journal of Applied Physiology*, *95*(5), 1955–1962.

Bush, M., Barnes, C., Archer, D. T., Hogg, B., & Bradley, P. S. (2015). Evolution of match performance parameters for various playing positions in the English Premier League. *Human Movement Science*, *39*, 1–11.

Byrne, C., Twist, C., & Eston, R. (2004). Neuromuscular function after exercise-induced muscle damage. *Sports Medicine*, *34*(1), 49–69.

Carling, Chris, Bloomfield, J., Nelsen, L., & Reilly, T. (2008). The role of motion analysis in elite soccer. *Sports Medicine*, *38*(10), 839–862.

Carling, Chris, McCall, A., Le Gall, F., & Dupont, G. (2016). The impact of short periods of match congestion on injury risk and patterns in an elite football club. *British Journal of Sports Medicine*, *50*(12), 764–768.

Carling, Christopher. (2013). Interpreting physical performance in professional soccer match-play: Should we be more pragmatic in our approach? *Sports Medicine*, *43*(8), 655–663.

Casamichana, D., Castellano, J., & Castagna, C. (2012). Comparing the physical demands of friendly matches and small-sided games in semiprofessional soccer players. *Journal of Strength and Conditioning Research*, *26*(3), 837–843.

Clark, K. P., & Weyand, P. G. (2014). Are running speeds maximized with simple-spring stance mechanics? *Journal of Applied Physiology*, *117*(6), 604–615.

Colby, M. J., Dawson, B. T., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *Journal of Strength and Conditioning Research*, *28*(8), 2244–2252.

Cometti, G., Maffiuletti, N. A., Pousson, M., Chatard, J. C., & Maffulli, N. (2001). Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *International Journal of Sports Medicine*, *22*(1), 45–51.

Delgado-Bordonau, J. L., & Mendez-Villanueva, A. (2012). Tactical periodization: Mourinho's best kept secret. *Soccer Journal*, (June), 28–34.

Dellal, A., Chamari, K., Owen, A. L., Wong, D. P., Lago-Peñas, C., & Hill-Haas, S. V. (2011). Influence of technical instructions on the physiological and physical demands of small-sided soccer games. *European Journal of Sport Science*, *11*(5), 341–346.

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., … Carling, C. (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *European Journal of Sport Science*, *11*(1), 51–59.

Di Salvo, V., Baron, R., Gonzalez-Haro, C., Gormasz, C., Pigozzi, F., & Bachl, N. (2010). Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches. *Journal of Sports Sciences*, *28*(14), 1489–1494.

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine*, *30*(3), 205–212.

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal sprinting speed of elite soccer players during training and matches. *Journal of Strength and Conditioning Research*, *31*(6), 1507–1517.

Douglas, J., Pearson, S., Ross, A., & McGuigan, M. (2020). Reactive and eccentric strength contribute to stiffness regulation during maximum velocity sprinting in team sport athletes and highly trained sprinters. *Journal of Sports Sciences*, *38*(1), 29–37.

Duhig, S., Shield, A. J., Opar, D., Gabbett, T. J., Ferguson, C., & Williams, M. (2016). Effect of high-speed running on hamstring strain injury risk. *British Journal of Sports Medicine*, *50*(24), 1536–1540.

Dwyer, D. B., & Gabbett, T. J. (2012). Global positioning system data analysis: Velocity ranges and a new definition of sprinting for team sport athletes. *Journal of Strength and Conditioning Research*, *26*(3), 818–824.

Eirale, C., Tol, J. L., Farooq, A., Smiley, F., & Chalabi, H. (2013). Low injury rate strongly correlates with team success in Qatari professional football. *British Journal of Sports Medicine*, *47*(12), 807–808.

Ekstrand, J., Hägglund, M., & Waldén, M. (2011). Epidemiology of muscle injuries in professional football (soccer). *American Journal of Sports Medicine*, *39*(6), 1226–1232.

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, *30*(7), 625–631.

Fowles, J. R. (2006). Technical issues in quantifying low-frequency fatigue in athletes. *International Journal of Sports Physiology and Performance*, *1*(2), 169–171.

Gaitanos, G. C., Williams, C., Boobis, L. H., & Brooks, S. (1993). Human muscle metabolism during intermittent maximal exercise. *Journal of Applied Physiology*, *75*(2), 712–719.

Girard, O., Mendez-Villanueva, A., & Bishop, D. (2011). Repeated-sprint ability: Factors contributing to fatigue. *Sports Medicine*, *41*(8), 673–694.

Gregson, W., Drust, B., Atkinson, G., & Salvo, V. D. (2010). Match-to-match variability of high-speed activities in premier league soccer. *International Journal of Sports Medicine*, *31*(4), 237–242.

Hägglund, M., Waldén, M., Magnusson, H., Kristenson, K., Bengtsson, H., & Ekstrand, J. (2013). Injuries affect team performance negatively in professional football: An 11-year follow-up of the UEFA Champions League injury study. *British Journal of Sports Medicine*, *47*(12), 738–742.

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine*, *44 Suppl 2*, S139-47.

Haugen, T. (2014). *The Role and Development of Sprinting Speed in Soccer*. University of Agder.

Haugen, T., Breitschädel, F., & Seiler, S. (2020). Sprint mechanical properties in soccer players according to playing standard, position, age and sex. *Journal of Sports Sciences*, *38*(9), 1070–1076.

Haugen, T., & Buchheit, M. (2016). Sprint running performance monitoring: Methodological and practical considerations. *Sports Medicine*, *46*(5), 641–656.

Haugen, T., Tønnessen, E., Leirstein, S., Hem, E., & Seiler, S. (2014). Not quite so fast: effect of training at 90% sprint speed on maximal and repeated-sprint ability in soccer players. *Journal of Sports Sciences*, *32*(20), 1979–1986.

Haugen, T., Tønnessen, E., & Seiler, S. (2013). Anaerobic performance testing of professional soccer players 1995–2010. *International Journal of Sports Physiology and Performance*, *8*(2), 148–156.

Healy, R., Kenny, I. C., & Harrison, A. J. (2021). Resistance training practices of sprint coaches. *Journal of Strength and Conditioning Research*, *35*(7), 1939–1948.

Hill-Haas, S. V., Coutts, A. J., Rowsell, G. J., & Dawson, B. T. (2009). Generic versus small-sided game training in soccer. *International Journal of Sports Medicine*, *30*(9), 636–642.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12.

Hoppe, M. W., Baumgart, C., Polglaze, T., & Freiwald, J. (2018). Validity and reliability of GPS and LPS for measuring distances covered and sprint mechanical properties in team sports. *PloS one*, 13(2), e0192708.

Howatson, G., & Milak, A. (2009). Exercise-induced muscle damage following a bout of sport specific repeated sprints. *Journal of Strength and Conditioning Research*, *23*(8), 2419–2424.

Hulin, B. T., Gabbett, T. J., Lawson, D. W., Caputi, P., & Sampson, J. A. (2016). The acute: chronic workload ratio predicts injury: High chronic workload may decrease injury risk in elite rugby league players. *British Journal of Sports Medicine*, *50*(4), 231–236.

Hunter, F., Towlson, C., Lovell, R., Barrett, S., Bray, J., Abt, G., … Smith, M. (2015). Individualisation of time-motion analysis: A Method Comparison and Case Report Series. *International Journal of Sports Medicine*, *36*(01), 41–48.

Impellizzeri, F. M., McCall, A., Ward, P., Bornn, L., & Coutts, A. J. (2020). Training load and its role in injury prevention, part 2: Conceptual and methodologic pitfalls. *Journal of Athletic Training*, *55*(9), 893–901.

Impellizzeri, F. M., Menaspà, P., Coutts, A. J., Kalkhoven, J., & Menaspà, M. J. (2020). Training load and its role in injury prevention, Part I: Back to the future. *Journal of Athletic Training*, *55*(9), 885–892.

Jastrzębski, Z., & Radzimiński, L. (2015). Individual vs general time-motion analysis and physiological responses in 4 vs 4 and 5 vs 5 small-sided soccer games. *International Journal of Performance Analysis in Sport*, *15*, 397–410.

JLT Specialty Limited. (2017). *JLT Sports Injury Index: English Premier League 2016/2017 Review*. Retrieved from https://www.jlt.com/-/media/Files/Sites/Specialty/Insights-Sport/jlt_sp_sportsinjuryindex_2017.ashx?la=en-GB&hash=0EFDB6DCDCE959B70AC0EDA1AB3422D930DD5481

Kyprianou, E., Di Salvo, V., Lolli, L., Al Haddad, H., Villanueva, A. M., Gregson, W., & Weston, M. (2022). To measure peak velocity in soccer, let the players sprint. *Journal of Strength and Conditioning Research*, 36(1), 273–276.

Lago, C., Casais, L., Dominguez, E., & Sampaio, J. (2010). The effects of situational variables on distance covered at various speeds in elite soccer. *European Journal of Sport Science*, *10*(2), 103–109.

Little, T., & Williams, A. G. (2005). Specificity of acceleration, maximum speed, and agility in profesisonal soccer players. *Journal of Strength and Conditioning Research*, *19*(1), 76–78.

Mallo, J., Mena, E., Nevado, F., & Paredes, V. (2015). Physical demands of top-class soccer friendly matches in relation to a playing position using global positioning system technology. *Journal of Human Kinetics*, *47*(1), 179–188.

Malone, S., Owen, A. L., Mendes, B., Hughes, B., Collins, K., & Gabbett, T. J. (2018). High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? *Journal of Science and Medicine in Sport*, *21*(3), 257–262.

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport*, *20*(3), 250–254.

Marrier, B., Le Meur, Y., Robineau, J., Lacome, M., Couderc, A., Hausswirth, C., … Morin, J. B. (2017). Quantifying neuromuscular fatigue induced by an intense training session in rugby sevens. *International Journal of Sports Physiology and Performance*, *12*(2), 218–223.

McCall, A., Nédélec, M., Carling, C., Le Gall, F., Berthoin, S., & Dupont, G. (2015). Reliability and sensitivity of a simple isometric posterior lower limb muscle test in professional football players. *Journal of Sports Sciences*, *33*(12), 1298–1304.

Mendez-Villanueva, A., Buchheit, M., Kuitunen, S., Douglas, A., Peltola, E., & Bourdon, P. (2011). Age-related differences in acceleration, maximum running speed, and repeated-sprint performance in young soccer players. *Journal of Sports Sciences*, *29*(5), 477–484.

Mendez-Villanueva, A., Buchheit, M., Simpson, B. M., & Bourdon, P. C. (2013). Match play intensity distribution in youth soccer. *International Journal of Sports Medicine*, *34*, 101–110.

Mendez-Villanueva, A., Buchheit, M., Simpson, B. M., Peltola, E., & Bourdon, P. (2011). Does on-field sprinting performance in young soccer players depend on how fast they can run or how fast they do run? *Journal of Strength and Conditioning Research*, *25*(9), 2634–2638.

Mendiguchia, J., Conceição, F., Edouard, P., Fonseca, M., Pereira, R., Lopes, H., … Jiménez-Reyes, P. (2020). Sprint versus isolated eccentric training: Comparative effects on hamstring architecture and performance in soccer players. *PLoS ONE*, *15*(2), e0228283.

Mero, A., Komi, P. V., & Gregor, R. J. (1992). Biomechanics of sprint running. *Sports Medicine*, *13*(6), 376–392.

Moir, G. L., Brimmer, S. M., Snyder, B. W., Connaboy, C., & Lamont, H. S. (2018). Mechanical limitations to sprinting and biomechanical solutions. *Strength and Conditioning Journal*, *40*(1), 47–67.

Mooney, M. G., Cormack, S. J., O’Brien, B. J., Morgan, W. M., & McGuigan, M. (2013). Impact of neuromuscular fatigue on match exercise intensity and performance in elite australian rules football. *Journal of Strength and Conditioning Research*, *27*(1), 166–173.

Morin, J. B., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine & Science in Sports & Exercise*, *43*(9), 1680–1688.

Morin, J. B., Gimenez, P., Edouard, P., Arnal, P., Jimenez-Reyes, P., Samozino, P., … Mendiguchia, J. (2015). Sprint acceleration mechanics: The major role of hamstrings in horizontal force production. *Frontiers in Physiology*, *6*, 404.

Nagahara, R., Mizutani, M., Matsuo, A., Kanehisa, H., & Fukunaga, T. (2018). Association of sprint performance with ground reaction forces during acceleration and maximal speed phases in a single sprint. *Journal of Applied Biomechanics*, *34*(2), 104–110.

Nagahara, R., Morin, J. B., & Koido, M. (2016). Impairment of sprint mechanical properties in an actual soccer match: A pilot study. *International Journal of Sports Physiology and Performance*, *11*(7), 893–898.

Oliva-Lozano, J. M., Fortes, V., Krustrup, P., & Muyor, J. M. (2020). Acceleration and sprint profiles of professional male football players in relation to playing position. *PLoS ONE*, *15*(8), e0236959.

Paul, D., Bradley, P. S., & Nassis, G. P. (2015). Factors impacting match running performances of elite soccer players: Shedding some light on the complexity. *International Journal of Sports Physiology and Performance*, *10*(4), 516–519.

Petersen, J., Thorborg, K., Nielsen, M. B., Budtz-Jørgensen, E., & Hölmich, P. (2011). Preventive effect of eccentric training on acute hamstring injuries in Men's soccer: A cluster-randomized controlled trial. *American Journal of Sports Medicine*, *39*(11), 2296–2303.

Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007). Variation in top level soccer match performance. *International Journal of Sports Medicine*, *28*(12), 1018–1024.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisløff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level. *Journal of Science and Medicine in Sport*, *12*(1), 227–233.

Rebelo, A., Brito, J., Maia, J., Coelho-e-Silva, M. J., Figueiredo, A. J., Bangsbo, J., … Seabra, A. (2013). Anthropometric characteristics, physical fitness and technical performance of under-19 soccer players by competitive level and field position. *International Journal of Sports Medicine*, *34*(4), 312–317.

Ross, A., & Leveritt, M. (2001). Long-term metabolic and skeletal muscle adaptations to short-sprint training: Implications for sprint training and taperng. *Sports Medicine*, *31*(15), 1063–1082.

Ross, A., Leveritt, M., & Riek, S. (2006). Neural influences on sprint running. *Sports Medicine*, *31*(6), 409–425.

Rumpf, M. C., Lockie, R. G., Cronin, J., & Jalilvand, F. (2016). Effect of different sprint training methods on sprint performance over various distances: A brief review. *Journal of Strength and Conditioning Research*, *30*(6), 1767–1785.

Scott, M. T., Scott, T. J., & Kelly, V. G. (2016). The validity and reliability of global positioning systems in team sport: a brief review. *The Journal of Strength & Conditioning Research*, 30(5), 1470-1490.

Seitz, L. B., Reyes, A., Tran, T. T., de Villarreal, E. S., & Haff, G. G. (2014). Increases in lower-body strength transfer positively to sprint performance: a systematic review with Meta-Analysis. *Sports Medicine*, *44*(12), 1693–1702.

Sheppard, J. M., & Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of Sports Sciences*, *24*(9), 919–932.

Spencer, M., Bishop, D., Dawson, B. T., & Goodman, C. (2005). Physiological and metabolic responses of repeat-sprint activities. *Sports Medicine*, *35*(12), 1025–1044.

Sporis, G., Jukic, I., Ostojic, S. M., & Milanovic, D. (2009). Fitness profiling in soccer: Physical and physiologic characteristics of elite players. *Journal of Strength and Conditioning Research*, *23*(7), 1947–1953.

Stølen, T., Chamari, K., Carlo, C., & Wisløff, U. (2005). Physiology of soccer: An update. *Sports Medicine*, *35*(6), 501–536.

Sweeting, A. J., Cormack, S. J., Morgan, S., & Aughey, R. J. (2017). When is a sprint a sprint? A review of the analysis of team-sport athlete activity profile. Frontiers in physiology, 8, 256116.

Thome, M., Thorpe, R. T., Jordan, M. J., & Nimphius, S. (2023). Validity of global positioning system technology to measure maximum velocity sprinting in elite sprinters. *The Journal of Strength & Conditioning Research*, *37*(12), 2438-2442.

Thompson, D., Nicholas, C. W., & Williams, C. (1999). Muscular soreness following prolonged intermittent high-intensity shuttle running. *Journal of Sports Sciences*, *17*(5), 387–395.

Tierney, P. J., Young, A., Clarke, N. D., & Duncan, M. J. (2016). Match play demands of 11 versus 11 professional football using global positioning system tracking: Variations across common playing formations. *Human Movement Science*, *49*, 1–8.

Timmins, R. G., Bourne, M. N., Shield, A. J., Williams, M. D., Lorenzen, C., & Opar, D. A. (2016). Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): A prospective cohort study. *British Journal of Sports Medicine*, *50*(24), 1524–1535.

Timmins, R. G., Ruddy, J. D., Presland, J., Maniar, N., Shield, A. J., Williams, M. D., & Opar, D. A. (2016). Architectural changes of the biceps femoris long head after concentric or eccentric training. *Medicine and Science in Sports and Exercise*, *48*(3), 499–508.

Tomáš, M., František, Z., Lucia, M., & Jaroslav, T. (2014). Profile, correlation and structure of speed in youth elite soccer players. *Journal of Human Kinetics*, *40*(1), 149–159.

Tønnessen, E., Shalfawi, S. A. I., Haugen, T., & Enoksen, E. (2011). The effect of 40-m repeated sprint training on maximum sprinting speed, repeated sprint speed endurance, vertical jump and aerobic capacity in young elite male soccer players. *The Journal of Strength & Conditioning Research*, *25*(9), 2364–2370.

Trewin, J., Meylan, C., Varley, M. C., & Cronin, J. (2017). The influence of situational and environmental factors on match-running in soccer: a systematic review. *Science and Medicine in Football*, *1*(2), 183–194.

Turner, A. N., & Stewart, P. F. (2014). Strength and conditioning for soccer players. *Strength and Conditioning Journal*, *36*(4), 1–13.

Ueblacker, P., Müller-Wohlfahrt, H. W., & Ekstrand, J. (2015). Epidemiological and clinical outcome comparison of indirect ('strain’) versus direct ('contusion’) anterior and posterior thigh muscle injuries in male elite football players: UEFA Elite League study of 2287 thigh injuries (2001-2013). *British Journal of Sports Medicine*, *49*(22), 1461–1465.

Varley, M. C., Fairweather, I. H., & Aughey1, 2, R. J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *Journal of Sports Sciences*, *30*(2), 121-127.

Vigne, G., Dellal, A., Gaudino, C., Chamari, K., Rogowski, I., Alloatti, G., … Hautier, C. (2013). Physical outcome in a successful italian serie A soccer team over three consecutive seasons. *Journal of Strength and Conditioning Research*, *27*(5), 1400–1406.

Vigne, G., Gaudino, C., Rogowski, I., Alloatti, G., & Hautier, C. (2010). Activity profile in elite Italian soccer team. *International Journal of Sports Medicine*, *31*(5), 304–310.

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of*

Applied Physiology, *89*(5), 1991–1999.

Weyand, Peter G., Sandell, R. F., Prime, D. N. L., & Bundle, M. W. (2010). The biological limits to running speed are imposed from the ground up. *Journal of Applied Physiology*, *108*(4), 950–961.

Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., & Hodson, A. (2004). The Football Association Medical Research Programme: an audit of injuries in professional football--analysis of hamstring injuries. *British Journal of Sports Medicine*, *38*(1), 36–41.

Chapter 3: Small-sided games in soccer Training: A narrative and critical review with respect to sprinting

Part 1: How and why small-sided games are used in general soccer training

This part of the review will examine the use of small-sided games in soccer training, discuss the purported benefits of SSG-based training, the rationale of manipulating SSG physical demands through prescriptive variables, and critically review previous studies reporting sprint demands during SSG. The literature search for the present review included combinations of the following keywords: “sprint”, “soccer”, “football”, and “small-sided games”. Studies involving elite male football participants were included in Section 1 pertaining to match demands, while studies involving female and recreational participants were excluded.

Small-sided games definitions and history

Small-sided games (SSG) are modified (soccer) games, used in a training context (Clemente, Couceiro, Martins, & Mendes, 2012). SSG have also been referred to as, or intersect terminologically with, skill-based conditioning (Gabbett, 2006), or game-based training (Gabbett et al., 2009). SSG typically take place on pitches of reduced length and width, and with reduced player numbers (Hill-Haas et al., 2011), though for the purposes of this review, the term SSG refers to any continuous soccer game using either fewer than 11 players per side, or less than standard-pitch size. Some authors (Owen et al., 2014), have used the additional terms “large-sided” and “medium-sided” games alongside SSG, but for clarity these terms will not be used within this review.

Origins and popularity

Some authors have suggested that SSG appear to have evolved from unstructured, informal formats of soccer e.g., street or beach soccer (Clemente, Martins, et al., 2014b; Hill-Haas et al., 2011). SSG are often characterised as increasing in popularity (Clemente, Martins, et al., 2014b), however this has not necessarily been supported with more than anecdotal evidence. There has certainly been a substantial increase in SSG research in recent years; searching the keywords “small-sided game” and “soccer” in Web of Science returns 0 results prior to the year 2000, as compared to 13 from 2001-2010 and 134 from 2011-2019. An increase in the prevalence of SSG may be reflective of shifting coaching practices. Roca et al. (2020), in a large study examining the nature of training exercises performed by elite soccer teams, notes consecutive increases in the number of exercises requiring “active decision-making” by players from previous studies in 2010, 2013, and 2020 (Roca & Ford, 2020). Several national sports organisations such as the Dutch Royal Football Association and Football Federation Australia have at times employed coach and player development programmes in which SSG make up a large portion of the syllabus (Hill-Haas et al., 2011). Furthermore, several scientific articles discuss or make reference to “integrated” soccer training methodologies that rely on varied forms of SSG as the primary training exercise to develop all or most elements of team performance (Clemente et al., 2012; Delgado-Bordonau & Mendez-Villanueva, 2012; Lacome et al., 2018).

There are several aspects that may have contributed to the popularity of SSG, desire of coaches to meet training objectives using SSG when possible, and subsequently SSG becoming a key topic of applied research. In a systematic review, Hill-Haas et al. (2011) present four key benefits of small-sided game training:1) increased compliance and motivation of players; 2) increased time efficiency over non-integrated approaches; 3) facilitation of technical and tactical skill improvement; and 4) replication of match specific movement, physiological, and technical demands. Each of these aspects will be discussed in the following section.

Player compliance/motivation and time efficiency

It has been stated that SSG use in training increases player compliance and motivation (Hill-Haas et al., 2011; Owen et al., 2012; Young & Rogers, 2014) however, evidence of this appears to be largely anecdotal. Several authors (Hill-Haas et al., 2011; Hoff & Helgerud, 2004) attribute the apparent improved motivation to the perceived sport specificity of SSG (e.g., involvement of the ball, opposition, etc.) in comparison to traditional, generic physical conditioning exercises.

Utilising SSG-based training exercises is thought to improve time efficiency of training, resulting from the opportunity to train all aspects of competition concurrently (Little, 2009). Training time is a finite resource, and congested playing schedules are frequently cited as a major concern in elite soccer competition (Carling, McCall, Le Gall, & Dupont, 2015; Owen et al., 2012).

This advantage of SSG-based training is largely inarguable provided that SSG are effective in meeting their respective training objectives. The variability possible in the physiological responses and movement demands during SSG (Hill-Haas et al., 2011), and possible issues in eliciting these responses in very highly trained players (Buchheit & Laursen, 2013a) can possibly jeopardise the achievement of certain physical training objectives and could therefore thwart the overall time efficiency of this approach.

Facilitation of technical and tactical improvement

A key benefit of SSG-based training is the opportunities provided for improvement of technical and tactical skills, and enhanced transfer of these skills to competition. This enhanced transfer is a result of SSG allowing practice of these skills in a dynamic environment that incorporates perceptual-cognitive skills similar to competitive matches (Gabbett et al., 2009; Roca & Ford, 2020; Roca et al., 2013; Williams et al., 2006).

Theories of ecological dynamics have been suggested to offer a suitable framework for analysing a complex team sport such as soccer (Davids et al., 2013; Travassos, Vilar, Araújo, & McGarry, 2014). When applying these theories to soccer training, technical skills (at an individual player level) and tactical actions (at the collective team level) are viewed as goal-directed behaviours, which emerge co-adaptively under the imposed individual, task, and environmental constraints (Davids et al., 2013). Small-sided games provide several well-supported features of an ideal practice environment for goal-directed behaviours under this framework.

Firstly, the dynamic, open-play nature of SSG result in constantly changing task and environmental constraints on successful performance. Players must therefore perform technical and tactical actions in a widely variable manner. Authors suggest variability is a key feature of skilled performance practice (Tan, Chow, & Davids, 2012) and training in a variable environment enhances the flexibility of the player to execute these skills in the complex and dynamic competitive setting (Gabbett et al., 2009; Tan et al., 2012).

The flexibility to extensively modify the task and environmental constraints of the SSG using different design variables is also a critical feature of SSG-based training (Davids et al., 2013). This allows coaches to alter which technical or tactical actions are promoted, incentivised or disincentivised according to their training objectives, and offers further opportunity for variability in the task constraints. For example, employing unequal team sizes, or using neutral or “floater” players during SSG has been shown to alter tactical behaviour, increasing the horizontal and longitudinal space occupied and affording greater opportunities for the advantaged team to maintain possession (Bach Padilha, Guilherme, Serra-Olivares, Roca, & Teoldo, 2017; Travassos et al., 2014; Vilar et al., 2014).

Secondly, SSG are thought to maintain the “coupling” of players’ perception with corresponding technical or tactical actions (Davids et al., 2013). During soccer matches and games, players continuously regulate their actions/behaviour according to their perception of several information sources (Roca et al., 2013; Williams et al., 2006). These information sources typically include the position of teammates, opposition, the ball, their own position within the field of play, and body language or other communication. SSG provide numerous opportunities for players to attune their perception to action-relevant information from these sources, in situations which closely reflect the typical spatiotemporal (player-teammate and player-opponent distance, relative speed, and timing) parameters of a competitive match (Davids et al., 2013). This supports the players to develop “game awareness” in a highly competition-specific manner (Williams et al., 2006).

The benefits of the performance variability and sustained information-perception coupling of SSG-based training are particularly emphasised in comparison with traditional, part-task training and adaptive instructional exercises (Davids et al., 2013). Part-task training involves “task decomposition” (Davids, Kingsbury, Bennett, & Handford, 2001), the breakdown and practice of a sport task in subcomponents prior to performance of the task itself. This training is often performed without opposition, or with passive opposition, simplifying decision making during repetitive drills, and the difficulty increased as each step is “mastered”. While these exercises can provide a useful step, particularly for beginners (Davids et al., 2001), it is argued that they may not be as effective in developing performance in the dynamic, unpredictable competition setting.

However, long-term studies directly comparing the technical or tactical development of players following SSG-based training with development following traditional training are scarce (Gabbett et al., 2009). This is unsurprising given the long-term and non-linear nature of player development encompassing training with multiple coaches and within multiple environments. In a survey examining the training history of elite performers in Australian rules football (Gabbett et al., 2009), players who were classified by coaches as “expert decision-makers” had participated in a larger number of structured and unstructured “invasion” sports in their developmental years. Studies by Turner and Martinek (1999) and Chatzopoulos et al. (2006) found game-based training sessions resulted in greater improvements in decision-making and tactical behaviours over the short-term in field-hockey and soccer players, respectively. Miller et al. (2017) found a 9-week game-centred learning approach in community youth netball resulted in an increased proportion of positive decision-making and supporting movement behaviours.

While research demonstrating technical skill development following SSG training is scarce, it is clear that SSG, as miniaturised or adapted versions of competition, provide opportunity for the performance of technical soccer tasks/actions such as passing, shooting, tackling, and intercepting (Owen et al., 2014). Coaches are able to modify the design and constraints of SSG, and these changes can alter the frequency with which different technical actions emerge (Owen et al., 2014). It is useful to briefly summarise the literature relating to changes in frequency and performance of technical skills according to SSG design.

Owen et al. (2014) investigated technical actions (including passes, pass receptions, turns, dribbles, headers, blocks, tackles, interceptions, and shots) during SSG variations using player numbers from 4 vs. 4 up to 11 vs. 11 players, on pitches ranging in relative area (the total playing area expressed in square metres, divided by the total number of players) from 94-336 m^2. The frequency of passes and pass receptions, dribbles, and shots were all significantly greater in the small (4 vs. 4, 94 m^2 per player) games relative to medium (5 vs. 5 – 8 vs. 8, 184-188 m^2 per player) and large (9 vs. 9 – 11 vs. 11, 218-336 m^2 per player) games. These results are in agreement with several studies reporting increased frequency of short passes, tackles, shots, and dribbles (Katis & Kellis, 2009) ball contacts (Jones & Drust, 2007) and opponent duels (Dellal, Owen, et al., 2012) in smaller relative pitch area compared to larger relative pitch area SSG. The increased frequency of these actions has been attributed directly to the reduced pitch area/area per player – the reduced area increases opponent pressure on the player in possession, forcing more ball movement and direct interactions with the opposing players.

The effects of SSG duration on technical actions have been analysed by Casamichana & Castellano (2010), reporting the frequency of multiple technical actions across 5 vs. 5 SSG played on three relative pitch areas (273 m^2, 175 m^2, and 73.6 m^2). Distinctively, these authors considered the association between each technical variable and “effective playing time” (the total time the ball was in play) in each SSG variation, despite identical timed durations. Congruent with the above studies, the smaller pitch areas resulted in increased frequencies of interceptions, ball controls, dribbles, shots, clearances, and entering the ball into play. However, the smaller playing areas also resulted in shorter effective playing times, due to the increase in balls lost out of play and subsequent inactive time, a finding also reported in other studies (Dellal, Hill-Haas, Lago-Peñas, & Chamari, 2011; Dellal, Owen, et al., 2012). The authors suggest effective playing time may also mediate or partly mediate the differences in physical demands observed in SSG of differing pitch area as well.

Studies by Dellal et al. (2011; Dellal, Owen, et al., 2012) and Owen et al. also demonstrate how design variables other than pitch size can alter the technical actions performed during SSG, and in particular the difficulty of these actions. Restricting the number of ball touches per player from free-play, to 2- and 1-touch during 75 m^2 per player SSG resulted in significantly more misplaced passes and reduced the number of opponent duels. Importantly, in the study by Dellal et al. (Dellal, Hill-Haas, et al., 2011) these constraints resulted in different frequencies of mistakes in amateur vs. professional players –professional players did not experience the same increase in mistakes from free-play to 2-touch games as did the amateur players. This suggests modifications to SSG design to alter the difficulty should be tailored to the skill or competitive level of the team/players.

In summary, SSG are able to replicate the perceptual-cognitive environment that players experience during competition. This is thought to enhance the acquisition of critical competition decision-making skills. Secondly, SSG are able to elicit an array of technical actions. The frequency and nature of these actions is able to be modified by way of the coach employing different prescriptive variables and task constraints.

Specificity of physical demands

It is widely accepted as a central principle of training that adaptation or "transfer" is greatest when the training stimulus is closest to the competitive demands (Gabbett et al., 2009; Gamble, 2006; Turner & Stewart, 2014). Therefore, as with technical and tactical demands, the replication of match-specific movement demands and physiological strain is believed to be a key benefit of SSG (Hill-Haas et al., 2011).

Several studies have shown SSG are able to elicit movement demands (Abbott, Brickley, & Smeeton, 2018b; Casamichana et al., 2012; Gabbett & Mulvey, 2008; Hill-Haas, Dawson, et al., 2009) similar to that of competitive matches. In a detailed analysis, Abbott et al. (2018b) compared the movement demands of a large number of SSG to those of competitive matches, using both the average values per minute and highest 1-min values across several variables. In general, the varied SSG were able to elicit average values per minute comparable to competition across all categories (total distance covered, very-high speed and sprinting distance, moderate intensity “explosive” distance, and high intensity “explosive” distance). Comparing the highest 1-min values, only match values for very-high speed and sprinting distance, and total distance, were unable to be matched or exceeded by SSG.

Similarly, a large body of evidence has shown SSG are able to stimulate heart rate responses similar to that of competitive matches (Hill-Haas, Dawson, et al., 2009; Hill-Haas et al., 2011; Owen et al., 2004; Rampinini, Impellizzeri, et al., 2007). Values approaching 90% HR_{max} have been reported, in particular during SSG with fewer players (Hill-Haas, Dawson, et al., 2009; Rampinini, Impellizzeri, et al., 2007). Measurements of blood lactate concentration within soccer matches and small-sided games are less well-studied due to the difficulty of measurement during play, however SSG have certainly been shown to elevate blood lactate concentrations above resting levels. Hill-Haas et al. (Hill-Haas, Dawson, et al., 2009) and Rampinini et al. (Rampinini, Impellizzeri, et al., 2007) both report values of approximately 6 $mmol \cdot L^{-1}$ during SSG, while Little and Williams (Little & Williams, 2006) reported responses in the 6-10 $mmol \cdot L^{-1}$ range.

The capacity of SSG to meet these physical objectives ensures the appeal of SSG as a training modality to coaches. However, the precise physical demands of any given SSG are highly variable based upon the specific game design employed (Hill-Haas et al., 2011). Several authors have remarked that soccer practitioners must carefully consider the design of SSG with respect to the intended purpose (Clemente et al., 2012; Dellal, Owen, et al., 2012). Abbott et al. (2018b p. 3229), following comparison of several SSG variations to competitive match time-motion data, conclude that, “no training game format develops overall soccer fitness, with each format eliciting a unique physiological load." It is clear that an understanding of how SSG design affects the resulting physical demands, and how to effectively tailor game design to the required physical objectives is critical for practitioners and coaches.

Several comprehensive reviews have investigated the effects of SSG design on physical demands and physiological responses. These studies routinely assess SSG variations using physiological responses including heart rate (HR), ratings of perceived exertion (RPE), blood lactate concentration (BLa), and movement analysis comprised of GPS-derived running distances or incidences of efforts within speed or acceleration zones (Abbott et al., 2018b; Clemente et al., 2012; Hill-Haas, Dawson, et al., 2009; Hill-Haas et al., 2011; Owen et al., 2014). The most common modifications of SSG design include player number, pitch size, pitch size per player, rule modifications (such as number of ball touches allowed, type of goal, or use of a "floating" neutral player) use of goals and goalkeepers, coach encouragement, and game work and rest durations (Clemente et al., 2012; Clemente, Wong, et al., 2014; Hill-Haas et al., 2011). It is useful to analyse the effect modifying each of these design variables has on the physical demands.

Player number and pitch size

Player number and pitch size are the most frequently investigated variables in SSG research and have both independent and interactive effects on exercise intensity.

Several studies have reported that increases in the absolute and relative pitch area of SSG result in greater HR and BLa responses (Owen et al., 2004; Rampinini, Impellizzeri, et al., 2007). It has been suggested that this is due to the requirement of the players to cover greater distances in the performance of their tactical responsibilities (Hill-Haas et al., 2011). This could also be due to the increased "effective playing time" (Casamichana & Castellano, 2010), as discussed above. The greater space available in larger SSG is thought to lessen the defensive pressure on players, reducing the frequency of mistakes (such as balls lost out of play) and subsequently introducing brief periods of recovery that reduce the overall physiological responses.

Decreasing the number of players involved in a game increases HR and blood lactate responses (Clemente, Wong, et al., 2014; Owen et al., 2004; Rampinini, Impellizzeri, et al., 2007), likely as a result of more frequent offensive and defensive interaction with the ball (Owen et al., 2014), and correspondingly, less time away from the ball to recover. These decreases in physiological responses appear to be greater when the number of players exceeds what the current pitch size can support (Hill-Haas et al., 2011).

Interesting results are reported when the *relative* pitch area and the number of players is increased concurrently. These studies show a decrease in exercise intensity as these variables both increase (Clemente et al., 2019; Gaudino, Alberti, & Iaia, 2014; Katis & Kellis, 2009; Owen et al., 2014; Rampinini, Impellizzeri, et al., 2007). It is not possible to determine whether these changes are the result of the independent effect of increasing player number, or the inability of the additional players to functionally occupy the increased area (and area per player) (Hill-Haas et al., 2011). It may be that the negative effect overall physiological demands imposed by the increasing player number, is of greater magnitude than the positive effect of increased relative pitch area.

This area of the research suffers from a lack of clarity in how studies discuss experimental manipulations. For example, experimentally examining the effect of *player number* requires either a fixed absolute pitch area, or a fixed relative pitch area. In either case of this hypothetical study design, player number, and either relative or absolute pitch area respectively, are being concurrently manipulated. In order to systematically evaluate experimental variables, Hill-Haas et al. (2011) recommend that more studies maintain a constant *relative* pitch area.

Changes in pitch area and player number affect running demands during SSG differently than the physiological responses. Increases in relative and absolute pitch area tend to result in greater total distances covered, more distances covered above high-speed thresholds, and greater peak running speeds (Casamichana & Castellano, 2010; Olthof, Frencken, & Lemmink, 2018), even when combined with concurrent increases in player number (Castellano et al., 2013; Clemente et al., 2019; Clemente, Wong, et al., 2014; Gaudino et al., 2014; Owen et al., 2014). Some studies have reported a sharp increase in distance covered when player numbers are reduced to 5 vs. 5 or less (Clemente et al., 2019; Owen et al., 2014), possibly owing to the lack of positional/tactical stability and overall chaotic nature of SSG with limited players.

Neutral players and unbalanced teams.

There are several ways in which the combination of players and teams can be altered during SSG. Coaches may employ a fixed “overload” design in which the members of one team outnumber the opposition. Alternatively, a “neutral”, “joker”, or “floater” player or players that join with the team in possession of the ball are utilised, effecting a dynamic overload. Additionally, some SSG utilise neutral “wall” or “bouncer” players around the perimeter of the pitch, who can play (typically with limited ball touches permitted) with the team in possession (Dellal, Lago-Peñas, Wong, & Chamari, 2011; Hill-Haas, Coutts, Dawson, & Rowsell, 2010). These design variables are used to mimic sub-phases of competitive matches in which the team has obtained or engineered numerical superiority over the opposition (Bach Padilha et al., 2017; Vilar et al., 2014).

Despite their commonplace use in practice, these game variables have not been well investigated. Hill-Haas et al. (2010) investigated overload and neutral player games (4 vs. 3, 3 vs. 3 + 1, 6 vs. 5, and 5 vs. 5 + 1 player numbers on ~150 m^2 per player pitches), finding no differences in physiological variables between, fixed and variable (floater) overload conditions overall. Within fixed overload games, underload teams experienced greater RPE (15.8 ± 1.5 AU vs. 14.7 ± 1.5 AU) than overload teams. Additionally, greater running demands were recorded by matched player number teams (i.e., excluding the floater player) than overload and underload teams, while floater players experienced greater running demands as individuals (Hill-Haas et al., 2010). This might suggest that the balanced design (variable overload) greater incentivises the players to gain possession and therefore the benefit of the floater player, whereas the fixed overload condition results in a more targeted intensity increase on the underload team.

Goals vs possession

The inclusion of goals and goalkeepers has been shown to affect the physiological responses during SSG. This may be the use of a scoring objective, as opposed to maintaining possession of the ball (ball conservation) (Gaudino et al., 2014; Mallo & Navarro, 2008) or use of alternative-sized goals, typically employed without goalkeepers (Castellano et al., 2013).

Greater physiological responses have been reported in possession-based SSG. Castellano et al. (2013) reported higher mean percentage of HR_{max} in possession games relative to games using a single, untended small (2 x 1.5 m) goal, and regulation goals with goalkeepers (GK). The reductions in HR variables with the addition of goals and GK to 3 vs. 3 (33 x 20 m pitch) SSG (Castellano et al., 2013) show similar findings to Mallo and Navarro (2008). Reductions in HR responses in low player-number SSG with the addition of GK could be due to the increased number of players occupying space on the small playing area, reducing relative pitch area beyond the threshold level (Hill-Haas et al., 2011). On the contrary, Dellal et al. (2008) reported significantly greater heart rate responses in 8 vs. 8 SSG with regulation goals and GK relative to without GK, though this may be due to the respective differences in work duration (2 x 10 min versus 4 x 4 min) between the SSG types.

With regard to movement demands, studies have reported contradictory results. Castellano et al. (2013) reported greater movement demands in possession games; 3 vs. 3, 5 vs. 5, and 7 vs. 7 SSG using a constant relative pitch area (210 m^2 per player) resulted in greater distance covered in higher speed zones and triaxial-accelerometer load (PlayerLoad). However, the study of Gaudino et al. (2014), investigating 5v5, 7v7, and 9v9 games with concurrently increasing relative pitch areas (75-135 m^2 per player, adjusting pitch area for inclusion/exclusion of GK), reported greater maximum running speeds, greater distance covered between 19.8-25.2 $km \cdot h^{-1}$, more accelerations (>3 ms^{-2}) and decelerations (<-3 ms^{-2}) in scoring-based SSG relative to possession. Interestingly, Gaudino et al. (2014) also reported more frequent changes in velocity, and moderate-intensity accelerations (>2 to 3 ms^{-2}) and decelerations (<-2 to -3 ms^{-2}) during possession games. This is possibly indicative of more frequent changes of speed/direction at submaximal running speeds and supports the assertion that possession-objective SSG result in more “multidirectional” movement patterns than the “linear” movement required when a goal is introduced at two ends of the playing area. Additionally, these studies (Castellano et al., 2013; Gaudino et al., 2014) investigated SSG played without the offside rule, which might further differentiate goalscoring and possession-objective games.

Touch limits

Limiting players’ touches on the ball to one (1T) or two (2T) touches appears to increase running demands relative to free-play (FP) SSG, with more varied effects on physiological responses (Dellal, Chamari, Owen, et al., 2011; Dellal, Lago-Peñas, et al., 2011). These increases are likely mediated by the increased technical difficulty of playing under these constraints, as players are forced to reposition more quickly to maintain possession of the ball and/or attempt more duels. Dellal et al. (2011) reported FP games induced greater blood lactate concentration increases across successive 4-min bouts of 4 vs. 4 SSG (75 m^2 per player) than 1T and 2T games, however, this could be attributed to the greater total duration of ball possession and effective playing time. Using the same relative pitch area (75 m^2 per player) and further investigating 2 vs. 2, 3 vs. 3, and 4 vs. 4 games, Dellal et al. (2011) found small increases in blood lactate concentrations in 1T compared to 2T and FP, and a greater RPE in 1T and 2T games compared to FP at all variations of player number.

In terms of running demands, both studies by Dellal et al. (Dellal, Chamari, Owen, et al., 2011; Dellal, Lago-Peñas, et al., 2011) consistently reported increases in total distance, distance covered at higher speeds (13-17 and >17 $km \cdot h^{-1}$), and percentage of total distance covered at these thresholds when employing 1T and 2T rules relative to FP. Interestingly, one other study (Gimenez et al., 2018) only reported an increase in lower intensity movement categories and number of high-intensity accelerations (>4 $m \cdot s^{-2}$) when applying touch limits during SSG in a relatively small (90 m^2 per player) playing area.

However, limiting the permitted touches (particularly one-touch play) may be unsustainable for longer durations (Dellal, Lago-Peñas, et al., 2011). Greater increases in mean percentage of HR_{max} have been reported with repeated bouts of 1T and 2T SSG (Dellal, Lago-Peñas, et al., 2011). As discussed above, limiting touches has also been shown to result in a greater frequency of technical mistakes (Dellal, Hill-Haas, et al., 2011; Dellal, Owen, et al., 2012), at both 1T and 2T depending on player skill level (Dellal, Hill-Haas, et al., 2011), possibly interfering with technical and tactical training objectives.

The effect of these rule modifications has typically only been studied in smaller pitch areas with fewer player numbers. It could be speculated that the increased rate of technical errors might make the use of these rules impractical in SSG with larger pitch areas or with increased player numbers.

Verbal encouragement

Verbal coach encouragement has been consistently cited as resulting in small increases in physiological responses and running demands, however evidence of this is limited. Rampinini et al. (2007) reported increases in mean percentage of HRmax, blood lactate concentrations, and RPE during and following 3 vs. 3 to 6 vs. 6 SSG with coach encouragement compared to without. However, Sampaio et al. (2007) found increases in RPE only. Naturally, the precise nature of verbal encouragement from coaches is a difficult variable to standardise, somewhat limiting the experimental control and manipulation possible.

Training regimen and duration.

The timing and duration of exercise and rest intervals during SSG has not been widely studied. A range of work and rest durations have been used in research, typically from 1-10 min and 90 s to 5 min, respectively (Halouani, Chtourou, Gabbett, Chaouachi, & Chamari, 2014; Hill-Haas et al., 2011). Most SSG are performed using an interval regimen rather than continuously, allowing greater physiological responses and running demands to be maintained over longer cumulative durations. Hill-Haas et al. (2009) compared a 4 x 6-min interval training regimen to the same total duration (24-min) performed continuously in 2 vs. 2, 4 vs. 4, and 6 vs. 6 SSG. However, while the interval regimen resulted in greater distance covered in high-speed zones (13-17.9

$km \cdot h^{-1}$) and a greater number of sprints (>18 $km \cdot h^{-1}$) than in the continuous regimen, the continuous games paradoxically resulted in a greater mean percentage of HR_{max} (87 ± 1 vs. 84 ± 1, $p = 0.001$). These data suggest that neither regimen offers a comparative benefit, however the limited evidence supporting this must be acknowledged.

Fanchini et al., (2011) examined the effects of 2-, 4-, and 6-min game durations on 3 vs. 3 SSG. Interestingly, the 6-min format elicited a lower percentage of HR_{max} (excluding the first minute of each bout) than the 4-min format (89.5 ± 3.1 vs. 87.8 ± 2.8). This could support the presence of a fatigue effect, although RPE did not differ significantly between durations. Alternatively, players could be withholding effort to conserve energy during longer bouts SSG. Overall, the effects these variables have on SSG physiological responses and running demands have not been studied in great detail and warrant further investigation.

Playing position

In addition to the SSG prescriptive variables, there are likely large effects of playing position on the physiological and running demands experienced by a player during SSG. In comparing the movement activity of 80 varied SSG (all 120 m^2 per player) with competitive matches, Abbott et al. (2018b) found that central defenders were more likely to be overloaded relative to match activity during SSG of all sizes, while central midfielders and wide players (defenders and midfielders) were more likely to cover greater distance at high accelerations, and distances at high running speeds, respectively (Abbott et al., 2018b).

Differences in movement demands relate largely to differences in tactical roles (Ade et al., 2016; Mallo et al., 2015). These differences can seemingly be minimised during relatively small playing area or limited player number SSG. Dellal et al. (2012) found similar movement demands and physiological responses between playing positions in 4 vs. 4 games under different task constraints (1T, 2T, FP). From these studies, it could be theorised that SSG with designs more similar to competitive matches, such as larger pitch sizes, greater player numbers, and utilising goalkeepers may increase diversity in tactical roles and therefore exacerbate differences in positional physical demands.

Comparison to isolated training

Small-sided games are clearly able to stimulate an array of physiological responses and running demands. From a practical perspective, it is important to determine if these responses can improve the fitness/conditioning of high-level soccer players. Several studies have compared SSG to established training modalities such as interval running.

Dellal et al. (2008) compared the physiological responses of several SSG (1 vs. 1, 2 vs. 2, 4 vs. 4, 8 vs. 8, and 10 vs. 10) played in small pitch areas with short-duration intermittent running exercises (30:30, 15:15, and 10:10 work-to-rest ratio). The 2 vs. 2 and 8 vs. 8 (plus GK) SSG were able to induce similar HR responses (approximately 80% HR_{max}) to moderate intensity running protocols, but not equivalent to the most intense intermittent running drills (approximately 85% HR_{max}).

Further studies have compared a variety of interval running programmes and SSG-based training interventions longitudinally (Dellal, Varliette, Owen, Chirico, & Pialoux, 2012; Hill-Haas, Coutts, et al., 2009; Impellizzeri et al., 2006; Owen et al., 2012). Overall, these studies consistently demonstrate that structured SSG-based training is able to elicit very similar improvements in a variety of measures of high-intensity intermittent fitness as generic interval running training across short (4 weeks) and medium-term (12 weeks) programmes.

Limitations of SSG

There are, however, limitations to the physical demands that can be elicited during SSG, and some authors (Abbott et al., 2018b; Buchheit & Laursen, 2013a; Dellal et al., 2008; Gabbett et al., 2009; Gabbett & Mulvey, 2008; Hoff & Helgerud, 2004; Owen et al., 2014) have questioned the capacity of SSG to elicit maximal heart rate and running responses, particularly in highly-trained athletes.

It appears that only certain SSG designs are capable of eliciting HR responses similar to that of interval running exercises (Dellal et al., 2008). Buchheit & Laursen (2013a) warn that several aspects of SSG-based training support the additional use of less specific but more easily controlled running-based high-intensity interval training in the physical preparation of elite team sport athletes. This suggestion, beyond the lack of standardisation possible and high within-player variability of responses during SSG, is centred around the difficulty of achieving sustained maximal or near-maximal $\dot{V}O_2$ during SSG, and the subsequent lack of stroke volume enlargement.

Conclusion

Overall, this review has demonstrated both the possible motivation of coaches to employ an SSG-based approach to physical, technical and tactical training, and the means by which the modification of prescriptive variables are able to broadly manipulate the physical and physiological demands of different exercises. Additionally, the research supports the broad equivalence of a structured SSG-based training programme in the development of soccer-specific intermittent fitness when compared with more traditional, isolated forms of training. However, as examined in Chapter 2, sprinting is a critical element of elite soccer performance and training that has been largely absent in the research of integrated, SSG-based training methods.

Part 2: A critical review of the sprint demands during SSG

The literature reviewed above briefly demonstrates that sprinting is an essential element of soccer training, and SSG-based training approaches would give the opportunity to meet sprint training objectives in a way that closely resembles the match-specific cognitive-perceptual skills and physical demands, possibly enhancing the effectiveness of the training and subsequent transfer to competition. However, several authors have questioned the capacity of SSG to elicit the maximal and very-high running speeds that constitute effective sprint training and exposure (Abbott et al., 2018b; Djaoui et al., 2017; Owen et al., 2014). This represents a significant challenge to the feasibility of an SSG-based approach to this aspect of training. This section critically analyses the studies which have reported the sprint demands of SSG and determines a number of future directions for this area of research. Three key questions were identified in order to evaluate the above studies and their respective results: 1) Are the running speeds reported during SSG of maximal intensity? 2) Do the running speeds reach the same level as competitive matches? 3) How are the running speed demands affected by prescriptive variables?

Methodological comments

Several methodologies have been used to report sprint demands during SSG. Most studies examining the sprint demands of SSG report either total running distance above nominal “sprint” thresholds (Dellal, Owen, et al., 2012; Jastrzebski & Radzimiński, 2015; Owen et al., 2014) or the peak sprint speed achieved during SSG variations (Casamichana & Castellano, 2010; Castellano et al., 2013; Djaoui et al., 2017; Gaudino et al., 2014; Gimenez et al., 2018; Kyprianou et al., 2022; Owen et al., 2014). Reporting the distance covered above speed thresholds allows comparison of the overall volume of sprinting performed in different SSG, however the precise speed this running is performed at is unknown, and the particular speed thresholds most commonly used in analysis (ranging from 18-26 km·h^{-1}) may not necessarily constitute proportions of MSS fast enough to be considered a *maximal* sprint training stimulus. While reporting the peak sprint speed of an activity is unable to convey differences in the overall volume of sprinting performed, it may be more useful in determining the basic extent of the sprint demands of SSG as it pertains to reaching maximal or near-maximal running speeds. For this reason, this critical analysis will focus on seven studies reporting peak sprint speed during SSG variations in elite adult players (Casamichana & Castellano, 2010; Castellano et al., 2013; Djaoui et al., 2017; Gaudino et al., 2014; Gimenez et al., 2018; Kyprianou et al., 2022; Owen et al., 2014).

Three studies (Djaoui et al., 2017; Kyprianou et al., 2022; Owen et al., 2014) have reported the peak sprint speed reached (PSS) during a large number of SSG of varied design. Both Owen et al. (2014) and Kyprianou et al. (2022) reported results amongst “small”, “medium”, and “large” groupings, determined by player number and relative playing area, respectively. The remaining four studies (Casamichana & Castellano, 2010; Castellano et al., 2013; Gaudino et al., 2014; Gimenez et al., 2018) examined more limited samples of SSG design, often in crossover experimental designs mixing player number and rule modifications or playing area changes. Only two of these studies (Djaoui et al., 2017; Kyprianou et al., 2022) were primarily investigating peak sprint speed. The primary peak sprint speed findings of these studies are summarised in Table 3.1.

Table 3.1 Summary of studies reporting peak sprint demands of small-sided soccer games.

Study	Participants	SSG Design	Playing Area (m)	Relative Pitch Area (m^2 per player)	Peak Sprint Speed (km·h^{-1})	Peak %-MSS
Kyprianou et al 2019	12 elite youth academy males	Small		11-94	18.9 ± 3.3	
		Medium		96-186	23 ± 2.7	
		Large		197-347	25 ± 2.3	
		Match		Not provided	28.6 ± 1.8	
Owen et al 2014	16 elite male professionals	Small (4v4)			21.6 ± 1.3	
		Medium (5v5, 6v6, 7v7, 8v8)			22.5 ± 0.9	
		Large (9v9, 10v10,11v11)			24.6 ± 0.9	
		4v4 incl GK	30 x 25	93.75	22.6 ± 0.1	
		5v5 incl GK	46 x 40	184	20.6 ± 0.8	
		6v6 incl GK	50 x 44	183	21.4 ± 0.4	
		7v7 incl GK	54 x 45	1734	23.2 ± 0.1	
		8v8 incl GK	60 x 50	187	22.9 ± 0.3	
		9v9 incl GK	70 x 56	218	24.1 ± 0.8	
		10v10 incl GK	80 x 70	280	25.2 ± 1.4	
		11v11 incl GK	100 x 74	336	24.7 ± 0.7	
Gimenez et al 2018	14 Polish professional males	3v3 1T	24 x 32	128	18.7 ± 2.5	
		3v3 2T	24 x 32	128	18.4 ± 2.5	
		3v3 FT	24 x 32	128	18.7 ± 2.5	
Djaoui et al 2017		4v4 + GK	40 x 42	210	22.4 ± 1.6	78.5 ± 6.9

Study	Participants	SSG Design	Playing Area (m)	Relative Pitch Area (m^2 per player)	Peak Sprint Speed ($km \cdot h^{-1}$)	Peak %-MSS
	24 French male professionals (Ligue 1)	5v5 + GK	40 x 36	144	23.1 ± 2.9	80.7 ± 10.1
		5v5 Mini-goals	40 x 30	120	22.7 ± 3.4	79.8 ± 14.4
		5v5 Possession	50 x 40	200	21.1 ± 2.6	74 ± 10.4
		6v6 + GK	40 x 40	133	25 ± 2.3	87.4 ± 7.9
		6v6 + GK	50 x 60	250*	25.7 ± 3.4	89.8 ± 12.2
		7v7 + GK	34 x 38	92	20.0 ± 2.1	69.8 ± 7.9
		7v7 Possession	40 x 50	143	22.5 ± 2.0	78.8 ± 6.2
		8v8 Possession	45 x 50	141	22.7 ± 2.2	79 ± 5.1
		8v8 Mini-goals	60 x 50	187	25.6 ± 3.3	89.1 ± 7.9
		8v8 + GK	60 x 40	150	25.1 ± 1.8	87.9 ± 6.1
		9v9 + GK	50 x 60	167	25.1 ± 2.8	87.8 ± 10.4
		9v9 + GK	70 x 55	214	25.6 ± 3.0	89.2 ± 8.8
		10v10 + GK	60 x 50	150	24.5 ± 2.3	85.7 ± 9.4
		Match	102 x 66	306	28.7 ± 1.9	-
Gaudino et al 2014	26 English Premier League males	5v5 + GK	30 x 30	75	20 ± 1	
		7v7 + GK	45 x 45	98	23 ± 2	
		10v10 + GK	66 x 45	135	26 ± 1	
		5v5 Possession	27 x 27	73	19 ± 1	
		7v7 Possession	37 x 37	98	20 ± 1	
		10v10 Possession	52 x 52	135	23 ± 1	
		5v5 + GK Small	32 x 23	61	18.1 ± 1.5	

Study	Participants	SSG Design	Playing Area (m)	Relative Pitch Area (m^2 per player)	Peak Sprint Speed (km·h^{-1})	Peak %-MSS
Casamichana & Castellano 2010	10 male youth players	5v5 + GK Medium	50 x 35	146	20.4 ± 1.9	
		5v5 + GK Large	62 x 44	227	23.1 ± 2.6	
Castellano et al 2013	14 semi-professional male soccer players	3v3	43 x 30	210, 161 for goal+GK	18.4 ± 2.4	
		5v5	55 x 38	210, 174 for goal+GK	20.3 ± 2.5	
		7v7	64 x 46	210, 184 for goal+GK	21.1 ± 2.6	
		Possession		210	19.5 ± 2.5	
		Mini-goals		210	21.1 ± 2.8	
		Goal+GK		161, 174, 184	20.1 ± 2.3	

Relative pitch area has been recalculated in some instances to include goalkeepers e.g., Casamichana et al., 2013.

*Value in Djaoui study has a corrected number from error in text.

Castellano et al., 2013: 3v3, 5v5, 7v7 values all include possession, mini-goal, and goals+GK.Possession, Mini-goals, Goals+GK values all include 3v3, 5v5 and 7v7.

Are the peak running speeds reported during SSG equivalent to maximal sprint speed?

Overall, the studies in Table 3.1 report group means of peak sprint speed ranging from 18.9 ± 3.3 to 26.7 km·h^{-1}. While it is not possible to determine with certainty, as these studies have largely not reported maximal sprint speeds of the players involved, these running speeds are highly unlikely to represent maximal efforts. This notion is supported by the findings of Djaoui et al. (2017) – the only study to report peak sprint speed during SSG as a percentage of individual player maximum sprint speed (MSS). The peak sprinting speeds across the sample of 14 SSG equated to a range from 69.8 ± 7.9% to 89.8 ± 12.2% MSS, with the majority of SSG variations reaching in the high 70% to mid-80% of MSS (Djaoui et al., 2017).

Do the running speeds reach the same level as competitive matches?

The results of this group of studies also suggest SSG are not able to elicit peak sprint demands of SSG at the same level as competitive matches. Kyprianou et al. (2022) reported that sprints in matches reached 28.6 ± 1.8 km·h^{-1}, a clear increase in absolute peak sprint speed from even the fastest sub-group of SSG (large games). Casamichana et al. (2012) compared a sample of possession, mini-goal, and regulation goal SSG to friendly matches, finding a moderate (ES=0.83, $p<0.01$) increase in peak speed from the collective SSG (20.3 ± 2.6 km·h^{-1}) to competition (27.0 ± 1.8 km·h^{-1}). The difference in SSG and match peak sprint speeds is also clear when considering player MSS. Djaoui et al. (2017) reported absolute and relative peak speeds of 28.7 ± 1.9 km·h^{-1} and 92.4 ± 7.5% MSS in competition (relative peak speed recorded in separate combined sample of professional and amateur players).

One SSG variation (Owen et al., 2014) consisted of the same design as a competitive match (11v11 including GK, 100 x 74 m), but produced a lower peak speed (24.7 ± 0.7 km·h^{-1}) than observed in the above studies. From this result, it could be hypothesised that there are aspects of competitions that make higher peak speeds more likely to be achieved. For example, players may be more motivated to win and therefore expend greater effort, or possibly the extended duration of competition relative to the SSG investigated (15 vs. 90 min in this case) means that a single tactical action that demands very fast sprinting is more likely to have occurred.

How are the running speed demands affected by prescriptive variables?

Several SSG design/prescriptive variables are likely associated with changes in the peak sprint demands. Firstly, increases in both pitch size and the number of players appear to increase peak sprint speed. Across 14 varied SSG, Djaoui et al. (2017) reported positive correlations between pitch area (r=0.45, *moderate*), pitch length (r=0.53, *moderate*), and number of players (r=0.38, *small*). These trends are consistent with studies reporting distance covered and number of efforts in higher (>25.2 km·h^{-1}) speed zones during SSG (Jastrzebski & Radzimiński, 2015; Olthof et al., 2018). However, determining the independent effects of each of these is difficult, as most studies manipulate these variables concurrently (larger pitches are typically occupied by more players) (Djaoui et al., 2017; Gaudino et al., 2014; Kyprianou et al., 2022; Owen et al., 2014). Two studies did examine each of these variables with more experimental control. Casamichana & Castellano (2010) maintained the same player number while varying absolute (and therefore relative) pitch area, finding increased peak speed at each level of increased area. Castellano et al. (2013) examined SSG with consistent relative pitch area (210 m^2 per player) for 3 vs. 3, 5 vs. 5, and 7 vs. 7 games, however, did not adjust this playing area to account for the introduction of GK in the respective goal+GK games (as in (Gaudino et al., 2014). This study (Castellano et al., 2013) reported greater absolute peak sprint speeds in both 7 vs. 7 and 5 vs. 5 games than 3 vs. 3. A positive association between playing area and peak sprint speed is to be expected. Larger playing areas result in greater space between players, increasing the likelihood of running efforts taking place over longer distances that allow acceleration to high speeds.

The apparent positive relationship between player number and peak speed is more difficult to explain. Adding players likely leads to greater position-specific tactical roles and associated physical demands. This could in theory increase the freedom of some players to make faster attacking runs, however, the remaining players (typically central defenders and midfielders) may consequently exhibit a reduced tendency to reach high speeds and the corresponding increase in defenders could discourage attacking runs altogether.

Varying the game objective (e.g. scoring, possession) and the use of alternative goals (such as mini-goals) is likely able to modify the peak sprint speed elicited during SSG (Castellano et al., 2013; Djaoui et al., 2017; Gaudino et al., 2014). Collectively, it appears that introducing a goal-scoring objective results in greater sprint speeds from players than when playing only to maintain possession. Both Djaoui et al. (2017) and Gaudino et al. (2014) demonstrated this relationship, and while Castellano et al. (2013) did not report speed differences between regulation goal (+GK) and possession games, there was indeed a difference between mini-goal and possession games. There are plausible rationales for these effects. When maintaining ball possession is the objective, players are likely to distribute themselves throughout the playing to maximise the space and time each player has available, forcing the defending team to cover a larger area. An even distribution of players throughout the space could result in players needing to make more frequent, short multidirectional movements to attack space or defend opponents. This is evident in the greater total distance, moderate-intensity accelerations and decelerations, and overall energy cost (as measured by metabolic power) in possession games (Gaudino et al., 2014). Conversely, scoring objective games may promote more concentrated defensive and offensive organisation around the goals; it is presumed this requires faster running efforts to quickly generate scoring opportunities against this organised defence (Djaoui et al., 2017). The further result of the concentrated positioning of players around a goal at one pitch end is increased space for the defending team to counterattack, an effect which could be exacerbated by the use of the offside rule. Interestingly, two of the above studies (Castellano et al., 2013; Gaudino et al., 2014) explicitly did not utilise this rule.

Further design variables that might be expected to alter the peak sprint demands during SSG (such as limiting ball touches, verbal coach encouragement, or overload team constructions) have not been investigated sufficiently. Gimenez et al. (2018) did examine the effect of limiting the allowed ball touches on movement demands, however only in small (128 m^2 per player) playing areas with a limited number of players (3 vs. 3).

Limitations

There are several limitations in the data collection, reporting, and interpretation of these studies.

Variation in player MSS

Firstly, interpretation of the absolute peak sprinting speed reporting in these studies is limited by the variation possible in player MSS. Several studies indicate a range between 28-35 $km \cdot h^{-1}$ (Al Haddad et al., 2015; Djaoui et al., 2017; Kyprianou et al., 2022) amongst even elite players. Given these apparent differences in MSS, consideration of individual MSS is therefore necessary in order to accurately quantify the peak sprint demands of soccer-specific exercises and determine their relevance to sprint-training objectives. Only one of the seven studies (Djaoui et al., 2017) report peak sprint speed as a percentage of individual player MSS as measured from an isolated test (such as a 40 m sprint).

Lack of prescriptive variables examined

Secondly, of the numerous SSG design variations possible, current studies have thus far only examined the effects of pitch area and scoring/possession objectives on the sprint demands, and in many cases these effects have not been the primary focus of the investigations. Fixed (e.g., overload) and temporary (e.g., neutral players) numerically advantaged team constructions, work duration and training regimen changes (including work-to-rest ratio and number of work repetitions), constraints on ball touches permitted and other common rule modifications have not been investigated.

Additionally, a common feature of training using SSG in practice is the use of a combination of SSG design variables and rule modifications to attain a desired physical stimulus (Buchheit et al., 2018). This optimisation of SSG design towards sprint outcomes has not been well represented in the literature, perhaps unsurprisingly given the lack of studies in which sprint demands are the primary investigative focus. Previous studies have predominantly investigated SSG using a far-reduced relative pitch area compared to that of a competitive match (approximately 320 m^2 per player for a 100 x 70 m pitch), despite the demonstrated relationships between pitch area and faster peak sprint speeds (Djaoui et al., 2017; Owen et al., 2014). The lack of investigation of match-equivalent (320 m^2 per player) or very-large pitch areas, particularly in combination with other variables likely to increase peak sprint demands, may obscure sprint demands comparable or in excess of those observed in competition.

Lack of experimental control

The analysis of these studies (Casamichana & Castellano, 2010; Castellano et al., 2013; Djaoui et al., 2017; Gaudino et al., 2014; Kyprianou et al., 2022; Owen et al., 2014) is also limited by the issues (addressed further above) regarding experimental manipulation of basic pitch size and player number variables. Only one of relative and absolute pitch area can be experimentally controlled at any time (Sangnier, Cotte, Brachet, Coquart, & Tourny, 2019), however some studies have varied absolute pitch area, relative pitch area, and player number concurrently, resulting in a lack of clarity as to which variables are being investigated. Hill-Haas et al. (2011) recommended more studies maintain a fixed relative pitch area.

Playing position

Only one of the seven studies reviewed reported playing position alongside peak sprint data. Previous studies have shown that playing position has an effect on sprint demands in competitive games (Di Salvo et al., 2009; Rampinini, Impellizzeri, et al., 2007), therefore as SSG increase in player number and similarity to 11v11 matches it is likely that there are differences in demands between playing positions. Mendez-Villanueva et al. (2011) suggest that playing position may selectively influence the expression of MSS.

Future directions:

In summary, the studies reporting speak sprint demands during soccer SSG have demonstrated several key findings. Firstly, the peak sprint speeds elicited during SSG appear to be lesser than competitive matches, and speeds greater than approximately 90% of individual MSS have not been reported. These peak sprint demands are highly dependent upon the prescriptive variables and design of the game, with specific reference to the size of the playing area and the game format (e.g., scoring vs. possession objective).

However, the studies analysed are limited in multiple respects. In order to address the limitations outlined above and add greater depth to the current literature, further research is required. Firstly, this research should aim to build upon the research of Djaoui et al., (2017), wherein the sprint demands are the primary variable of interest, and these demands as a percentage of each individual's MSS to better account for the variation possible between amongst individuals and samples. Secondly, a broader variety of prescriptive variables must be examined. Different game formats, durations, and constraints such as limiting the number of ball touches permitted all have been demonstratable to effect metabolic and non-sprint movement demands during SSG. Clearer experimental design is also necessary, particularly relating to the pitch size, number of players, and the relationship between these variables. Finally, as the number of players involved in the SSG increase, the playing position occupied should be taken into account within the data analysis and research design.

References

Abbott, W., Brickley, G., & Smeeton, N. J. (2018). Positional differences in gps outputs and perceived exertion during soccer training games and competition. *Journal of Strength and Conditioning Research*, *32*(11), 3222–3231.

Ade, J., Fitzpatrick, J., & Bradley, P. S. (2016). High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions. Information for position-specific training drills. *Journal of Sports Sciences*, *34*(24), 2205–2214.

Al Haddad, H., Simpson, B. M., Buchheit, M., Di Salvo, V., & Mendez-Villanueva, A. (2015). Peak match speed and maximal sprinting speed in young soccer players: effect of age and playing position. *International Journal of Sports Physiology and Performance*, *10*(7), 888–896.

Bach Padilha, M., Guilherme, J., Serra-Olivares, J., Roca, A., & Teoldo, I. (2017). The influence of floaters on players' tactical behaviour in small-sided and conditioned soccer games. *International Journal of Performance Analysis in Sport*, *17*(5), 721–736.

Buchheit, M., Lacome, M., Cholley, Y., & Simpson, B. M. (2018). Neuromuscular responses to conditioned soccer sessions assessed via GPS-Embedded accelerometers: Insights into tactical periodization. *International Journal of Sports Physiology and Performance*, *13*(5), 577–583.

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. *Sports Medicine*, *43*(5), 313–338.

Carling, C., McCall, A., Le Gall, F., & Dupont, G. (2015). What is the extent of exposure to periods of match congestion in professional soccer players? *Journal of Sports Sciences*, *33*(20), 2116–2124.

Casamichana, D., & Castellano, J. (2010). Time-motion, heart rate, perceptual and motor behaviour demands in small-sided soccer games: Effects of pitch size. *Journal of Sports Sciences*, *28*(14), 1615–1623.

Casamichana, D., Castellano, J., & Castagna, C. (2012). Comparing the physical demands of friendly matches and small-sided games in semiprofessional soccer players. *Journal of Strength and Conditioning Research*, *26*(3), 837–843.

Castellano, J., Casamichana, D., & Dellal, A. (2013). Influence of game format and number of players on heart rate responses and physical demands in small-sided soccer games. *Journal of Strength and Conditioning Research*, *27*(5), 1295–1303.

Chatzopoulos, D., Drakou, A., Kotzamanidou, M., & Tsorbatzoudis, H. (2006). Girls' soccer performance and motivation: Games vs technique approach. *Perceptual and Motor Skills*, *103*(2), 463–470.

Clemente, F. M., Couceiro, M. S., Martins, F. M. L., & Mendes, R. S. (2012). The usefulness of small-sided games on soccer training. *Journal of Physical Education and Sport*, *12*(1), 93–102.

Clemente, F. M., Martins, F. M. L., & Mendes, R. S. (2014). Periodization based on small-sided soccer games: Theoretical considerations. *Journal of Strength and Conditioning Research*, *36*(5), 34–43.

Clemente, F. M., Sarmento, H., Rabbani, A., Van Der Linden, C., Kargarfard, M., & Costa, I. T. (2019). Variations of external load variables between medium- and large-sided soccer games in professional players. *Research in Sports Medicine*, *27*(1), 50–59.

Clemente, F. M., Wong, D. P., Martins, F. M. L., & Mendes, R. S. (2014). Acute effects of the number of players and scoring method on physiological, physical, and technical performance in small-sided soccer games. *Research in Sports Medicine*, *22*(4), 380–397.

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews*, *41*(3), 154–161.

Davids, K., Kingsbury, D., Bennett, S., & Handford, C. (2001). Information-movement coupling: Implications for the organization of research and practice during acquisition of self-paced extrinsic timing skills. *Journal of Sports Sciences*, *19*(2), 117–127.

Delgado-Bordonau, J. L., & Mendez-Villanueva, A. (2012). Tactical periodization: Mourinho's best kept secret. *Soccer Journal*, (June), 28–34.

Dellal, A., Chamari, K., Owen, A. L., Wong, D. P., Lago-Peñas, C., & Hill-Haas, S. V. (2011). Influence of technical instructions on the physiological and physical demands of small-sided soccer games. *European Journal of Sport Science*, *11*(5), 341–346.

Dellal, A., Chamari, K., Pintus, A., Girard, O., Cotte, T., & Keller, D. (2008). Heart rate responses during small-sided games and short intermittent running training in elite soccer players: A comparative study. *Journal of Strength and Conditioning Research*, *22*(5), 1449–1457.

Dellal, A., Hill-Haas, S. V., Lago-Peñas, C., & Chamari, K. (2011). Small-sided games in soccer: Amateur vs. professional players' physiological responses, physical, and technical activities. *Journal of Strength and Conditioning Research*, *25*(9), 2371–2381.

Dellal, A., Lago-Peñas, C., Wong, D. P., & Chamari, K. (2011). Effect of the number of ball contacts within bouts of 4 vs. 4 small-sided soccer games. *International Journal of Sports Physiology and Performance*, *6*(3), 322–333.

Dellal, A., Owen, A. L., Wong, D. P., Krustrup, P., van Exsel, M., & Mallo, J. (2012). Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. *Human Movement Science*, *31*(4), 957–969.

Dellal, A., Varliette, C., Owen, A. L., Chirico, E. N., & Pialoux, V. (2012). Small-sided games versus interval training in amateur soccer players: Effects on the aerobic capacity and the ability to perform intermittent exercises with changes of direction. *Journal of Strength and Conditioning Research*, *26*(10), 2712–2720.

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine*, *30*(3), 205–212.

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal sprinting speed of elite soccer players during training and matches. *Journal of Strength and Conditioning Research*, *31*(6), 1507–1517.

Fanchini, M., Azzalin, A., Castagna, C., Schena, F., & McCall, A. M. (2011). Effect of bout duration on exercise intensity and technical performance of small-sided games in soccer. *Journal of Strength and Conditioning Research*, *25*(2), 453–458.

Gabbett, T. J. (2006). Skill-based conditioning games as an alternative to tradtional conditioning for rugby league players. *Journal of Strength and Conditioning Research*, *20*(2), 309–315.

Gabbett, T. J., Jenkins, D., & Abernethy, B. (2009). Game-based training for improving skill and physical fitness in team sport athletes. *International Journal of Sports Science & Coaching*, *4*(1), 273–283.

Gabbett, T. J., & Mulvey, M. J. (2008). Time-motion analysis of small-sided training games and competition in elite womens soccer players. *Journal of Strength and Conditioning Research*, *22*(2), 543–552.

Gamble, P. (2006). Implications and applications of training specificity for coaches and athletes. *Strength and Conditioning Journal*, *28*(3), 54–58.

Gaudino, P., Alberti, G., & Iaia, F. M. (2014). Estimated metabolic and mechanical demands during different small-sided games in elite soccer players. *Human Movement Science*, *36*, 123–133.

Gimenez, J. V, Liu, H., Lipinska, P., Szwarc, A., Rompa, P., & Gomez, M. A. (2018). Physical responses of professional soccer players during 4 vs. 4 small-sided games with mini-goals according to rule changes. *Biology of Sport*, *35*(1), 75–81.

Halouani, J., Chtourou, H., Gabbett, T. J., Chaouachi, A., & Chamari, K. (2014). Small-sided games in team sports training: A brief review. *Journal of Strength and Conditioning Research*, *28*(12), 3594–3618.

Hill-Haas, S. V., Coutts, A. J., Dawson, B. T., & Rowsell, G. J. (2010). Time-motion characteristics and physiological responses of small-sided games in elite youth players: The influence of player number and rule changes. *Journal of Strength and Conditioning Research*, *24*(8), 2149–2156.

Hill-Haas, S. V., Coutts, A. J., Rowsell, G. J., & Dawson, B. T. (2009). Generic versus small-sided game training in soccer. *International Journal of Sports Medicine*, *30*(9), 636–642.

Hill-Haas, S. V., Dawson, B. T., Coutts, A. J., & Rowsell, G. J. (2009). Physiological responses and time–motion characteristics of various small-sided soccer games in youth players. *Journal of Sports Sciences*, *27*(1), 1–8.

Hill-Haas, S. V., Dawson, B. T., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in football: A systematic review. *Sports Medicine*, *41*(3), 199–220.

Hill-Haas, S. V., Rowsell, G. J., Dawson, B. T., & Coutts, A. J. (2009). Acute physiological responses and time-motion characteristics of two small-sided training regimes in youth soccer players. *Journal of Strength and Conditioning Research*, *23*(1), 111–115.

Hoff, J., & Helgerud, J. (2004). Endurance and strength training for soccer players. *Sports Medicine*, *34*(3), 165–180.

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., & Rampinini, E. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine*, *27*(6), 483–492.

Jastrzębski, Z., & Radzimiński, L. (2015). Individual vs general time-motion analysis and physiological responses in 4 vs 4 and 5 vs 5 small-sided soccer games. *International Journal of Performance Analysis in Sport*, *15*, 397–410.

Jones, S., & Drust, B. (2007). Physiological and technical demands of 4v4 and 8v8 games in elite youth soccer players. *Kinesiology*, *39*(2), 150–156.

Katis, A., & Kellis, E. (2009). Effects of small-sided games on physical conditioning and performance in young soccer players. *Journal of Sports Science and Medicine*, *8*(3), 374–380.

Kyprianou, E., Di Salvo, V., Lolli, L., Al Haddad, H., Villanueva, A. M., Gregson, W., & Weston, M. (2022). To measure peak velocity in soccer, let the players sprint. *Journal of Strength and Conditioning Research*, 36(1), 273–276.

Lacome, M., Simpson, B. M., Cholley, Y., P, L., & Buchheit, M. (2018). Small-sided games in elite soccer: Does one size fit all? *International Journal of Sports Physiology and Performance*, *13*, 568–576.

Little, T. (2009). Optimizing the use of soccer drills for physiological development. *Strength and Conditioning Journal*, *31*(3), 67–74.

Little, T., & Williams, A. G. (2006). Suitability of soccer training drills for endurance training. *Journal of Strength and Conditioning Research*, *20*(2), 316–319.

Mallo, J., Mena, E., Nevado, F., & Paredes, V. (2015). Physical demands of top-class soccer friendly matches in relation to a playing position using global positioning system technology. *Journal of Human Kinetics*, *47*(1), 179–188.

Mallo, J., & Navarro, E. (2008). Physical load imposed on soccer players during small-sided training games. *Journal of Sports Medicine and Physical Fitness*, *48*(2), 166–171.

Mendez-Villanueva, A., Buchheit, M., Simpson, B. M., Peltola, E., & Bourdon, P. (2011). Does on-field sprinting performance in young soccer players depend on how fast they can run or how fast they do run? *Journal of Strength and Conditioning Research*, *25*(9), 2634–2638.

Miller, A., Harvey, S., Morley, D., Nemes, R., Janes, M., & Eather, N. (2017). Exposing athletes to playing form activity: outcomes of a randomised control trial among community netball teams using a game-centred approach. *Journal of Sports Sciences*, *35*(18), 1846–1857.

Olthof, S. B. H., Frencken, W. G. P., & Lemmink, K. (2018). Match-derived relative pitch area changes the physical and team tactical performance of elite soccer players in small-sided soccer games. *Journal of Sports Sciences*, *36*(14), 1557–1563.

Owen, A. L., Twist, C., & Ford, P. (2004). Small-sided games: The physiological and technical effect of altering pitch size and player numbers. *Insight*, *7*(2), 50–53.

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2012). Effects of a periodized small-sided game training intervention on physical performance in elite professional soccer. *Journal of Strength and Conditioning Research*, *26*(10), 2748–2754.

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2014). Physical and technical comparisons between various-sided games within professional soccer. *International Journal of Sports Medicine*, *35*(4), 286–292.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Abt, G., Chamari, K., Sassi, A., & Marcora, S. M. (2007). Factors influencing physiological responses to small-sided soccer games. *Journal of Sports Sciences*, *25*(6), 659–666.

Roca, A., & Ford, P. R. (2020). Decision-making practice during coaching sessions in elite youth football across European countries. *Science and Medicine in Football*, *4*(4), 263–268.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of Sport and Exercise Psychology*, *35*(2), 144–155.

Sampaio, J. E., Garcia, G., Macas, V., Ibanez, S. J., Abrantes, C., & Caixinha, P. (2007). Heart rate and perceptual responses to 2 x 2 and 3 x 3 small-sided youth soccer games. *Journal of Sports Science and Medicine*, *6*(10), 121–122.

Sangnier, S., Cotte, T., Brachet, O., Coquart, J., & Tourny, C. (2019). Planning training workload in football using small-sided games' density. *Journal of Strength and Conditioning Research*, *33*(10), 2801–2811.

Tan, C. W. K., Chow, J. Y., & Davids, K. (2012). 'How does TGfU work?': examining the relationship between learning design in TGfU and a nonlinear pedagogy. *Physical Education & Sport Pedagogy*, *17*(4), 331–348.

Travassos, B., Vilar, L., Araújo, D., & McGarry, T. (2014). Tactical performance changes with equal vs unequal numbers of players in small-sided football games. *International Journal of Performance Analysis in Sport*, *14*(2), 594–605.

Turner, A. N., & Stewart, P. F. (2014). Strength and conditioning for soccer players. *Strength and Conditioning Journal*, *36*(4), 1–13.

Turner, A. P., & Martinek, T. J. (1999). An investigation into teaching games for understanding: Effects on skill, knowledge, and game play. *Research Quarterly for Exercise and Sport*, *70*(3), 286–296.

Vilar, L., Esteves, P., Travassos, B., Passos, P., Lago-Peñas, C., & Davids, K. (2014). Varying numbers of players in small-sided soccer games modifies action opportunities during training. *International Journal of Sports Science and Coaching*, *9*(5), 1007–1018.

Williams, A. M., Hodges, N. J., North, J. S., & Barton, G. (2006). Perceiving patterns of play in dynamic sport tasks: Investigating the essential information underlying skilled performance. *Perception*, *35*(3), 317–332.

Young, W., & Rogers, N. (2014). Effects of small-sided game and change-of-direction training on reactive agility and change-of-direction speed. *Journal of Sports Sciences*, *32*(4), 307–314.

Chapter 4: Relative peak sprint demands of small-sided games in youth soccer players: The effect of increased pitch area and counterattacking rule modifications

Abstract

Sprinting during soccer training is key for reducing injury and enhancing performance. While many coaches prefer to meet physical training objectives using soccer-specific exercises such as small-sided games (SSG), assessment of SSG sprint demands is limited. We investigated the effect of rule modifications designed to increase sprinting opportunities during SSG. Twenty elite male under-17 (17.1 ± 0.5 years) players (1.76 ± 0.07 m stature, 65.1 ± 6.1 kg body mass) performed nine SSG across three levels of player number (5v5, 7v7, 9v9), within 150 m^2 (SG) and 320 m^2 (LG) relative pitch areas, with an additional 320 m^2 variation (CG) utilising counterattack-focused rule modifications. Individualised GPS variables were recorded using 10 Hz GPS devices. LG and CG resulted in peak sprint speeds of 85-90% of MSS (maximal sprint speed), while only a limited number of players exceeded 95% of MSS in any game. Analysis using a linear-mixed effects model suggested greater relative peak sprint speeds, (LG: effect size (ES)=1.82, $p<0.0001$; CG: ES=1.85, $p<0.0001$), number of efforts >80% MSS (LG: ES=1.28, $p<0.0001$; CG: ES=1.20, $p<0.0001$) and distance covered >80% MSS (LG: ES=1.11, $p<0.0001$; CG: ES=1.34, $p<0.0001$) in LG and CG compared to SG. The 9v9 games elicited greater relative peak speeds (ES=0.681, $p=0.014$) and efforts >80% MSS (ES=0.665, $p=0.017$) than 7v7 SSG. The large relative pitch area (320 m^2) games resulted in similar sprint demands both with and without counterattacking-focused rules. This lack of difference underlines the necessity of monitoring SSG demands in relation to the desired training objective. The results suggest there may be a ceiling to the peak speed SSG can elicit, and that pitch area is the main variable influencing SSG sprint demands.

Introduction

Soccer training exercises such as small-sided games (SSG) that can simultaneously develop physical capabilities alongside technical and tactical elements are attractive to coaches and practitioners as they are thought to promote greater player effort and enjoyment (Little, 2009); enhance the time efficiency of training (Hill-Haas et al., 2011); and have been demonstrated to be effective in improving valid measures of soccer fitness (Dellal, Varliette, et al., 2012; Impellizzeri et al., 2006). However, due to the highly variable nature of the physical demands of SSG, previous research has emphasised that careful consideration of the game design with respect to the desired training stimulus is essential (Abbott et al., 2018b; Clemente, Martins, & Mendes, 2014a; Clemente, Martins, et al., 2014b).

While the metabolic and cardiovascular demands of different SSG have been well investigated (Clemente, Martins, et al., 2014a; Hill-Haas et al., 2011), examination of the sprint demands is limited. Sprinting only represents a small percentage of the total time and distance covered during competition, however sprint efforts often occur at key match-defining moments and are frequently performed immediately prior to goal scoring (Faude et al., 2012). Additionally, both reaching high (95%) percentages of maximal sprint speed (MSS) (Malone et al., 2017) and performing moderate 3-week cumulative sprint (>75% MSS) distances in training (Colby et al., 2014) have been associated with reduced subsequent injury risk in team sport codes. Further understanding of how to modify or maximise the sprint demands of soccer-specific training exercises is critical given these demonstrated roles of sprinting in training and competition.

Previous literature suggests players are unable to reach maximal sprint speeds in SSG or soccer-specific exercises (Abbott et al., 2018b; Kyprianou et al., 2022; Owen et al., 2014). Several authors have reported the absolute peak speeds reached during SSG (Casamichana & Castellano, 2010; Casamichana et al., 2012; Gaudino et al., 2014; Kyprianou et al., 2022; Owen et al., 2014), however the interpretation of these studies is limited by the variation possible in player MSS; several studies report a range between 28-35 km·h^{-1} (Al Haddad et al., 2015; Djaoui et al., 2017; Kyprianou et al., 2022; Mendez-Villanueva, Buchheit, Simpson, et al., 2011). However, this large range does not account for differences in individuals' peak speeds. Consideration of the individual's MSS is therefore necessary in order to accurately report the peak sprint demands of training and competition (Kyprianou et al., 2022). Djaoui et al. (2017) examined peak sprint speed as a percentage of MSS during 14 SSG of varied design, reporting whole-group mean values between 70-90% of MSS. Studies examining competitive matches using proportions of MSS have reported mean values in the 85-90% range (Al Haddad et al., 2015; Djaoui et al., 2017).

The physical demands of SSG appear to be primarily contingent on the design variables employed, including player number, pitch size, relative pitch area, and inclusion/exclusion of goals and goalkeepers, along with numerous possible rule modifications. Current research broadly shows increases in absolute peak running speed and distance covered above higher speed thresholds during SSG with greater pitch areas and player numbers (Abbott et al., 2018b; Casamichana & Castellano, 2010; Djaoui et al., 2017; Gaudino et al., 2014; Owen et al., 2014), though these variables are often manipulated concurrently. There is also support for the use of a goalscoring game objective resulting in increased peak sprint speeds, relative to possession-oriented games (Djaoui et al., 2017; Gaudino et al., 2014). Peak running demands very likely differ between playing positions (Abbott et al., 2018b; Al Haddad et al., 2015), and previous literature has reported position-specific differences in relative sprint demands between faster and slower players (Al Haddad et al., 2015; Mendez-Villanueva, Buchheit, Simpson, et al., 2011).

Further understanding of the sprint demands of SSG, and the degree to which they can be increased may be useful for coaches and practitioners. Despite the demonstrated relationships between relative pitch area and faster peak sprint speeds (Djaoui et al., 2017; Owen et al., 2014), previous studies have predominantly investigated SSG using a far-reduced relative pitch area compared to that of a competitive match (approximately 320 m^2 per player for a 100 x 70-m pitch). Additionally, in practice, coaches typically use a combination of SSG design variables and rule modifications to attain the desired physical stimulus (Buchheit et al., 2018), however this aspect of purposeful or optimised design has not been well represented in the literature. Buchheit et al. (2018) used SSG with an increased emphasis on counter-attacking play as part of a “speed-conditioned” training session. Utilising a combination of these design variables could elicit greater sprint demands during SSG than previously reported.

Accordingly, the primary aims of this study are to report the sprint demands of several SSG variations using individualised GPS data, and to investigate the effect of increasing pitch area per player and addition of counterattack-focused rule modifications on sprint demands. Secondly, differences between playing positions and the influence of faster or slower player MSS on sprint activity during SSG will be examined.

Materials and methods

Participants

Participants were 20 male under-17 players from the academy of a professional club (17.1 ± 0.5 years, 1.76 ± 0.07 m stature, 65.1 ± 6.1 kg body mass). Requirements for participation included being a full-time academy member, free of injury at the time of data collection, and over the age of 16 years. Ethics approval was obtained by the University's Human Ethics Committee and informed consent was obtained from all participants prior to their involvement in the study.

Study Design

To investigate sprint demands during SSG and the effect of the design modifications, we examined SSG across three levels of player number (5v5, 7v7, 9v9) in small (small game – SG; 150 m^2 per player) and large (large game - LG; 320 m^2 per player) relative pitch areas, and an additional variation (counterattack game – CG; 320 m^2 per player) combining the large relative pitch area with two rule modifications designed to increase maximal sprinting. In the CG, firstly, time allowed in possession of the ball within the attacking half was limited to 8, 7, and 6 seconds in 9v9, 7v7, and 5v5 games, respectively. If this time expired, play was restarted by the coach. Secondly, all players of the attacking team were required to be over the halfway line for a goal to be scored. These rules were chosen following consultation with two independent, elite coaches (FIFA "Pro" and "A" coaching licences, respectively) and with final consultation and approval of the coach of the participating team (FIFA "A" licence). The objective of the rule changes was to increase the likelihood of players performing counterattacking tactical actions, which all coaches associated with maximal sprinting opportunities.

Procedures

All testing and SSG were conducted on the same artificial pitch, and all sessions were conducted during the afternoon between 4:30 and 6:00 PM. Mean temperature and relative humidity were 14.1 ± 3.0˚C and 59 ± 10%, respectively. Participant MSS was measured during a maximal 40-m sprint, using 10 Hz GPS (VX350b Log, VX Sport, Lower Hutt, New Zealand) in which the participant was asked to reach their maximum speed as quickly or as slowly as they preferred. The fastest measure of three attempts was recorded as a player's MSS. Sprint testing was conducted during a separate training session prior to data collection, following a 20-minute standardised warm-up.

A single game variation was performed during each data collection session over a total of 7 weeks, comprising 9 sessions total. The data collection was performed in the participating teams in-season period, with each data collection session was performed midweek (in the preceding 3, or 2, days prior to the next match). The nine SSG all included goalkeepers and regulation-sized goals and were played in a 4 x 4-min format, with 3 min of passive rest between each repetition. All restarts of play (excluding possession clock expiry in CG) took place via goalkeepers. SG were played with a relative area of 150 m^2, while LG and CG were played with a relative area of 320 m^2. All pitch area calculations include goalkeepers, and a constant length-to-width ratio was maintained. Pitch sizes are included in Table 4.1.

Table 4.1 Pitch sizes and relative playing areas of the small-sided game variations.

	Length x width (m)		Area per player (m^2)	
	SG	LG / CG	SG	LG / CG
5v5	46 x 33	68 x 47	151.8	319.6
7v7	55 x 38	80 x 56	149.3	320
9v9	62 x 44	90 x 64	151.5	320

SG = small games; LG = large games; CG = counterattack games

Participants were assigned to one of four playing positions by the coaching staff: central defenders (CD), central midfielders (CM), wide players (WD), and forwards (FW). Each team size (5, 7, and 9 players) was assigned a formation (1-2-1, 3-1-2, and 2-4-2 plus goalkeepers, respectively) to be used consistently across variations. Each position within the formation was occupied by players belonging to a predetermined position group or groups wherever possible to standardise tactical roles as much as practically possible.

The movement demands of each game were recorded using 10 Hz GPS, which have shown to be valid and reliable for measures of instantaneous velocity (Varley et al., 2012; Thome et al., 2023). Each participant wore the same GPS device during all data collection sessions to eliminate inter-device error. Devices were fitted in a skin-tight vest securely between the shoulder blades. The fastest sprint speed achieved during the total 16-min of each SSG was recorded as a percentage of individual MSS. The distance covered and number of efforts above 80% of individual MSS was also recorded, along with several generic GPS movement categories (distance covered between 14-19.8 km·h^{-1}, 19.8-25.2 km·h^{-1} and above 25.2 km·h^{-1}) (Di Salvo et al., 2009). The sum of each of these variables during the total 16 minutes of each game variation was used for analysis.

Statistical procedures

A linear mixed-effects model (LMM) was used to analyse the effect of player number (5v5, 7v7, 9v9), rule/pitch area modification (LG, SG, CG), playing position (CD, CM, FW, WD), and the player's mean-centred MSS (km·h^{-1}) on the peak percentage of MSS achieved, total distance covered above 80% of MSS, number of efforts completed above 80% of MSS, and each of the generic movement categories (distance covered between 14-19.8 km·h^{-1}, 19.8-25.2 km·h^{-1} and above 25.2 km·h^{-1}) during the total 16-min of each SSG variation. The mixed-effects framework allowed the use of random intercepts to account for the clustering of repeated measures within individual players and accommodate the unbalanced experimental design. Any variable in which a factor level was significantly associated (F < 0.05) with a change in the dependent variable was further investigated using pairwise testing of the estimated marginal means. Estimated marginal means were compared using a t-test with the Bonferroni correction for multiple analyses and the Kenward-Roger approximation of degrees of freedom. Effect size (Cohen’s d) for each pairwise comparison was calculated using the difference in the estimated marginal mean divided by the residual standard deviation of the associated linear mixed-effects model. All statistical analyses were performed in R (R Core Team, 2019), using lme4 (Bates, Maechler, Bolker, & Walker, 2015), sjPlot, (Ludecke, 2019), and emmeans (Lenth, 2020) packages, and figures produced using ggplot2 (Wickham, 2009). The alpha level was set at <0.05 for all analyses. Descriptive data are expressed as estimated marginal means and 95% confidence intervals.

Results

A total of 105 player-observations were included in the final sample. The 20 participating players recorded a mean MSS of 30.88 ± 1.13 $km \cdot h^{-1}$. The results of the linear mixed-effects models showed several differences between playing position groups (WD, CM, FW) and the reference level (CD), however, post-hoc pairwise testing revealed differences only in the average movement demands; in which WD produced significantly greater distance between 14.4-19.8 $km \cdot h^{-1}$ (effect size (ES)=1.38, p= 0.015). Player MSS was not a significant influence on any of the movement variables according to the linear mixed-effects models. Figure 4.1 shows the percentage of players that exceeded 80%, 90% and 95 of MSS during each of the three SSG pitch size/rule variations; when combining the 320 m^2 per player variations, 90.0%, 35.2%, and 5.6% of players reached these thresholds of MSS, respectively. Table 4.2 shows the estimated marginal means and 95% confidence intervals for each SSG variation and player number group derived from the linear mixed-effects models. Table 4.3 shows the effect size of the difference between each pair of EMM within the groups, and p-value for the associate t-test. The key results are the consistent differences between SG and LG, and SG and CG across each of the movement demand categories, but in particular the peak speed and relative peak speed. Smaller magnitude differences are also observed between 9v9 and 7v7 games across several movement demand categories.

Table 4.2 Estimated marginal means and 95% confidence intervals of grouped SSG variations.

	SSG Player Number and Pitch Size Variations		
	5v5	7v7	9v9
Relative Peak Speed (% MSS)	84.7 (81.6, 87.7)	82.1 (79.7, 84.5)	85.3 (83.2, 87.4)
Distance >80% MSS (m)	13.9 (3.27, 24.5)	10.2 (1.96, 18.4)	21.2 (13.91, 28.5)
Efforts > 80% MSS (num)	1.5 (0.658, 2.34)	1.01 (0.364, 1.65)	1.55 (0.985, 2.12)
Total Distance (m)	2240 (2151, 2329)	2195 (2117, 2274)	2234 (2159, 2309)
Distance 14.4-19.8 km·h^{1} (m)	429 (375, 484)	360 (315, 405)	422 (380, 464)
Distance 19.8-25.2 km·h^{1} (m)	114.8 (82.6, 147)	91.8 (65.1, 119)	135.7 (110.9, 160)
Distance >25.2 km·h^{1} (m)	10.62 (2.328, 18.9)	7.28 (0.974, 13.6)	17.74 (12.232, 23.3)
	Small Game	Large Game	Counterattack Game
Relative Peak Speed (% MSS)	78.3 (75.9, 80.6)	86.8 (84.5, 89.2)	87 (84.6, 89.4)
Distance >80% MSS (m)	1.57 (-6.77, 9.9)	19.97 (11.89, 28.1)	23.73 (15.41, 32.1)
Efforts > 80% MSS (num)	0.225 (-0.43, 0.879)	1.971 (1.34, 2.606)	1.863 (1.21, 2.517)
Total Distance (m)	1987 (1908, 2065)	2342 (2265, 2419)	2341 (2263, 2420)
Distance 14.4-19.8 km·h^{1} (m)	276 (230, 321)	465 (420, 510)	471 (425, 516)
Distance 19.8-25.2 km·h^{1} (m)	39.6 (12.7, 66.4)	147.5 (121.3, 173.8)	155.2 (128.4, 182)
Distance >25.2 km·h^{1} (m)	0.453 (-5.98, 6.88)	15.589 (9.36, 21.82)	19.605 (13.19, 26.02)

Estimated marginal means for player number groups are averaged over the levels of position, pitch area/rule modification, and mean-centred player MSS. Estimated marginal means for pitch area/rule modification groups are averaged over the levels of position, player number, and mean-centred player MSS. MSS: maximal sprint speed; CI: confidence intervals; SSG: small-sided games.

Table 4.3 Effect size and p-values for the pairwise comparisons of SSG player number and prescriptive variable group estimated marginal means.

	Pairwise Comparisons		
	5v5 vs 7v7	5v5 vs 9v9	9v9 vs 7v7
Relative Peak Speed (% MSS)	0.538, p=0.167	-0.143, p=0.875	0.681, p= 0.014
Distance >80% MSS (m)	0.222, p=0.727	-0.443, p=0.282	0.665, p= 0.017
Efforts > 80% MSS (num)	0.359, p=0.428	-0.036, p=0.991	0.396, p=0.216
Total Distance (m)	0.464, p=0.294	0.064, p=0.977	0.400, p=0.253
Distance 14.4-19.8 km·h^1 (m)	0.981, p=0.004	0.102, p=0.939	0.878, p = 0.0017
Distance 19.8-25.2 km·h^1 (m)	0.553, p=0.167	-0.502, p=0.226	1.060, p<0.001
Distance >25.2 km·h^1 (m)	0.242, p=0.674	-0.516, p=0.169	0.760, p=0.004
	Small vs Large	Small vs Counterattack	Large vs Counterattack
Relative Peak Speed (% MSS)	-1.820, p<0.0001	-1.850, p<0.0001	-0.037, p=0.987
Distance >80% MSS (m)	-1.110, p<0.0001	-1.340, p<0.0001	-0.227, p=0.615
Efforts > 80% MSS (num)	-1.280, p<0.0001	-1.200, p<0.0001	0.079, p=0.942
Total Distance (m)	-3.680, p<0.0001	-3.670, p<0.0001	0.010, p=0.999
Distance 14.4-19.8 km·h^1 (m)	-2.680, p<0.0001	-2.760, p<0.0001	-0.079, p=0.943
Distance 19.8-25.2 km·h^1 (m)	-2.600, p<0.0001	-2.780, p<0.0001	-0.185, p=0.725
Distance >25.2 km·h^1 (m)	-1.100, p<0.0001	-1.390, p<0.0001	-0.291, p=0.45

Cohen’s d effect sizes are calculated using the magnitude of difference between EMM values divided by the residual standard deviation of the associated linear mixed-effects model. ES= effect size; MSS: maximal sprint speed; SSG: small-sided games.

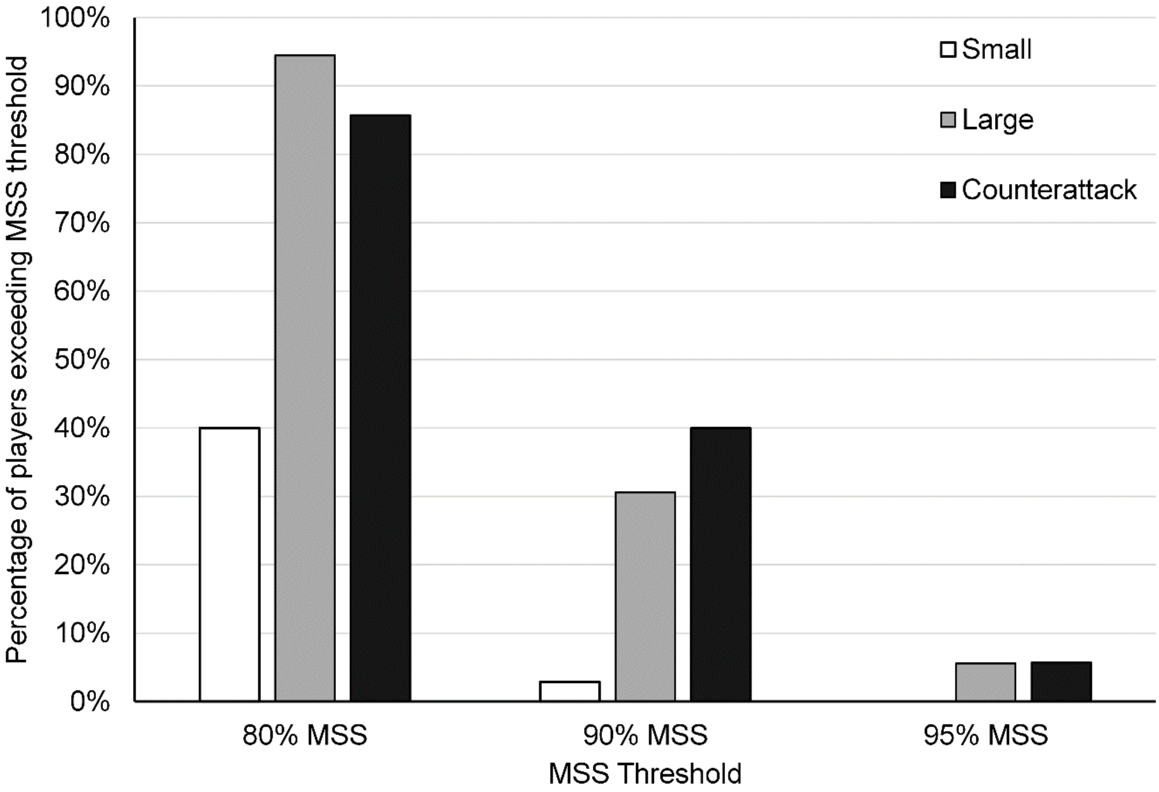


Figure 4.1 Percentage of players that exceeded 80%, 90% and 95% of maximal sprint speed during each of the three SSG pitch size/rule variations.

Discussion

This study investigated the relative sprint demands of 5v5, 7v7, and 9v9 SSG across two levels of relative pitch area, and an additional variation combining the large relative pitch area with counter-attacking focused rule modifications.

MSS and general sprint demands

The participating players recorded similar MSS in the 40-m sprint test to those in other studies of youth and professional players (Al Haddad et al., 2015; Djaoui et al., 2017; Mendez-Villanueva, Buchheit, Kuitunen, et al., 2011), demonstrating that our participant group was of at least equivalent sprinting ability. The relative peak sprint speeds reached during the SSG in the present study are similar to the limited previous studies reporting peak percentages of MSS (Al Haddad et al., 2015; Djaoui et al., 2017). Djaoui et al. (2017) reported approximately 80% and 90% MSS in smaller and larger pitch areas, respectively, despite only including SSG up to 250 m^2 per player. Al Haddad et al. (2015) reported under-17 players reached 87.2 ± 5.7% of MSS during a competitive match using a relative pitch area directly comparable to the LG and CG. Other studies have not reported distance covered or the number of efforts above comparable individualised percentages of MSS. With respect to the distance covered within/above generic movement speed thresholds, the LG and CG variations performed in the present study appear to have elicited greater demands both between 19.8-25.2 $km{\cdot}h^{-1}$(147.5 (95% CI, 121.3, 173.8) and 155.2 (95% CI, 128.4, 182), respectively) and above 25.2 $km{\cdot}h^{-1}$ (15.589 (95% CI, 9.36, 21.82) and 19.605 (95% CI, 13.19, 26.02), respectively) over the 16 min duration than comparable studies (Casamichana & Castellano, 2010; Gaudino et al., 2014; Owen et al., 2014). The SG games resulted in limited distance covered between 19.8-25.2 $km{\cdot}h^{-1}$ and above 25.2 $km{\cdot}h^{-1}$, comparable to other small-moderate relative pitch area SSG (Owen et al., 2014).

Game and variation effects

The results demonstrate that the sprint demands of SSG are significantly affected by the design variables. Firstly, both LG and CG were associated with significantly greater peak sprint speeds (SG < LG, ES=-1.82, p<0.0001; (SG < CG, ES=1.85, p<0.0001) and greater distance covered and number of efforts at high percentages of MSS than SG. These findings are consistent with previous literature reporting lower absolute (Owen et al., 2014) and relative (Djaoui et al., 2017) speeds, and reduced distance covered within higher speed zones when relative pitch area is decreased (Abbott et al., 2018b).

Interestingly, there were no appreciable differences in sprint demands (or any movement category) between LG and CG, despite the addition of the counterattacking-focused rules theoretically introducing greater urgency to progress the ball forward and occupy the attacking half. The continuous nature of the games and relative scarcity of maximal sprinting opportunities (Buchheit et al., 2021), along with the incentive for the defending team to discourage or interrupt attacking play that might lead to these opportunities, might place a practical upper limit on the sprint demands of SSG. This would be accordant with the observation that the sprint demands of the LG and CG are at least equivalent or greater than those reported in other studies.

Alternatively, this result could suggest that relative pitch area is the main variable facilitating the increase in sprint demands from the smaller to larger SSG, and the CG rule modifications do not result in any further detectable increase to these demands. This lack of difference, despite the agreement of multiple highly qualified coaches on the design of the rule modifications, certainly underlines the necessity of monitoring the demands of each SSG in relation to the desired training objective when implementing rule modifications such as in this study.

Smaller differences were also observed in both relative peak sprint speed and efforts above 80% MSS according to the number of players; 7v7 games were associated with significant decreases in both variables compared to the 9v9 games. This could have been mediated by the increased absolute playing area in the 9v9 games (maintaining *relative* playing area SSG across results in larger *absolute* pitch area as player numbers increase). It is logical that larger absolute pitch areas increase the likelihood of performing sprint efforts of the distance required to accelerate to high proportions of MSS (Haugen et al., 2013; Mendez-Villanueva, Buchheit, Simpson, et al., 2011). However, a similar relationship was not observed between the 5v5 and 7v7 games. It is possible that the specific formation played by both teams (3-1-2), or tactical intent/understanding of the players could have influenced the sprinting opportunities of the game in an unforeseen way.

Effects of playing position

While the LMM results generally showed differences between CD and WD playing positions, pairwise differences in sprint demands amongst playing positions were not observed. Other studies have typically found differences in the physical demands between playing positions in both SSG and matches. Abbott et al. (2018) found wide defenders and wide attackers (combined in the present study as WD) produced the greatest very high speed and sprinting distances (per minute during various SSG) (Abbott et al., 2018b), while CM and CD have been shown to cover significantly less distance while sprinting during matches (Mallo et al., 2015; Mendez-Villanueva et al., 2013), while CM also reach significantly lower absolute peak speeds (Al Haddad et al., 2015; Mallo et al., 2015). These differences in activity profile are likely the result of the contrast in tactical roles performed by each playing position. For example, WD and FW players may have greater opportunities to either make or defend long attacking runs into space (Di Salvo et al., 2009; Mendez-Villanueva, Buchheit, Simpson, et al., 2011). CM, and to a lesser extent, CD could be expected to make or defend more frequent, shorter explosive runs that result in lower peak sprint speeds (Abbott et al., 2018b).

These conflicting results could possibly be explained by the reduced statistical power when accounting for multiple comparisons. However, it is possible that the SSG performed in the present study simply did not result in markedly different demands across playing positions. Lower player numbers (such as in the 5v5 games) could in theory homogenise the tactical roles and associated physical demands between positions, though, this is an unlikely explanation for these results in the 7v7 or 9v9 games. The CG could possibly increase the movement demands of players in lesser sprinting playing positions (e.g., central defenders) by forcing movement into the attacking half of the pitch.

MSS effects

In contrast to previous studies (Al Haddad et al., 2015; Mendez-Villanueva, Buchheit, Simpson, et al., 2011), we did not find support for an effect of player MSS on the percentage of MSS achieved in the SSG. While the present study examined the mean-centred MSS of each player as a fixed effect in the linear model, the previous studies (Al Haddad et al., 2015; Mendez-Villanueva, Buchheit, Simpson, et al., 2011) separated players into position groups of faster and slower players for comparison. Interestingly, despite a similar mean and SD of MSS in our participants to those of Al Haddad et al. (2015), we did not record participants as fast as the “fastest players” in the Al Haddad study (34.7 and 35.0 km·h^{-1}). The results of the previous studies also suggest the differing utilisation of MSS may be specific to certain playing positions. It is possible that a larger sample of observations that can analyse this effect separately within each playing position might reveal different results.

Player frequency of reaching high MSS

Considering the results of Malone et al (2017), coaches or practitioners might view the proportion of players meeting high thresholds of MSS (rather than the mean of high velocity movement categories) as a key indicator of the sprint training objectives these SSG are able to meet. In the larger SSG (LG and CG), the majority of players (90.1%) were able to exceed 80% of MSS (Figure 4.1); however, only 35.2% and 5.6% of players exceeded 90% and 95% of MSS, respectively. Therefore, if reaching 80% or 90% is the objective, these large games could be considered useful from a practical perspective; however, a large proportion of players exceeding 95% of MSS does not appear to be feasible. Practitioners utilising SSG need to balance certainty in achieving training objectives with the inherent variability of open-play soccer training exercises and competition (Clemente, Martins, et al., 2014a; Gregson et al., 2010; Hill-Haas et al., 2011).

Limitations

The present study was successful in analysing multiple SSG with elements of design relevant to real-world practice, using a method that appropriately accounts for the unbalanced, repeated-measures nature of soccer training. However, the study design is limited by the exclusion of an additional SSG variation combining the CG rule modifications in conjunction with the SG (150 m^2) pitch areas. This was constrained by the number of sessions available for data collection, and in our consideration, there may have been greater value for practitioners in investigating the optimisation of the variables most likely to increase sprint demands, rather than finding the “true” effect of the CG variation. Additionally, it should be noted that the design variables in the present study were investigated in the presence of several additional conditions, for example, using offside rules, regulation goals and goalkeepers, and using a sample of male-only players. The results therefore may not be generalisable to SSG with markedly different design conditions.

Conclusions

The present study represents a novel contribution to the literature owing to the use of MSS-relative GPS measures to accurately report the sprint demands of several SSG, and the inclusion of games employing a combination of design variables pragmatically to explore how these demands can be maximised. We found that SSG with pitch density equivalent to competitive matches (320 m^2 per player) were able to elicit peak sprint speeds up to approximately 90% MSS, however efforts beyond 95% of MSS were very limited. Interestingly, the purposefully “sprint-focused” CG design resulted in sprint demands comparable to the LG featuring large relative pitch areas with no other modification, while both LG and CG produced sprint demands significantly greater than the smaller relative pitch area (150 m^2) SG. Additionally, the 7v7 games elicited reduced relative peak sprint speed and number of efforts >80% MSS compared to 9v9 games.

The results of this study underline the importance of individualised monitoring of the sprint demands of SSG. Large (320 m^2) relative playing area SSG may provide a suitable game design for eliciting peak sprint speeds of around 90% of MSS. Sprint efforts beyond 90-95% of MSS are very limited in frequency during even large SSG, therefore alternative or isolated sprint exercises might be necessary. Care should be taken in the design and implementation of SSG for physical outcomes, as even when taking expert coach advice into account, rule modifications may have unintended effects that limit viability as a training tool.

References

Abbott, W., Brickley, G., & Smeeton, N. J. (2018). Positional differences in gps outputs and perceived exertion during soccer training games and competition. *Journal of Strength and Conditioning Research*, *32*(11), 3222–3231.

Al Haddad, H., Simpson, B. M., Buchheit, M., Di Salvo, V., & Mendez-Villanueva, A. (2015). Peak match speed and maximal sprinting speed in young soccer players: Effect of age and playing position. *International Journal of Sports Physiology and Performance*, *10*(7), 888–896.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48.

Buchheit, M., Lacome, M., Cholley, Y., & Simpson, B. M. (2018). Neuromuscular responses to conditioned soccer sessions assessed via GPS-embedded accelerometers: Insights into tactical periodization. *International Journal of Sports Physiology and Performance*, *13*(5), 577–583.

Buchheit, M., Simpson, B. M., Hader, K., Lacome, M., Buchheit, M., Simpson, B. M., … Lacome, M. (2021). Occurrences of near-to-maximal speed-running bouts in elite soccer: Insights for training prescription and injury mitigation. *Science and Medicine in Football*, *5*(2), 105–110.

Casamichana, D., & Castellano, J. (2010). Time-motion, heart rate, perceptual and motor behaviour demands in small-sided soccer games: Effects of pitch size. *Journal of Sports Sciences*, *28*(14), 1615–1623.

Casamichana, D., Castellano, J., & Castagna, C. (2012). Comparing the physical demands of friendly matches and small-sided games in semiprofessional soccer players. *Journal of Strength and Conditioning Research*, *26*(3), 837–843.

Clemente, F. M., Martins, F. M. L., & Mendes, R. S. (2014a). Developing aerobic and anaerobic fitness using small sided games: Methodological proposals. *Strength and Conditioning Journal*, *36*(3), 76–87.

Clemente, F. M., Martins, F. M. L., & Mendes, R. S. (2014b). Periodization based on small-sided soccer games: Theoretical considerations. *Journal of Strength and Conditioning Research*, *36*(5), 34–43.

Colby, M. J., Dawson, B. T., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *Journal of Strength and Conditioning Research*, *28*(8), 2244–2252.

Dellal, A., Varliette, C., Owen, A. L., Chirico, E. N., & Pialoux, V. (2012). Small-sided games versus interval training in amateur soccer players: Effects on the aerobic capacity and the ability to perform intermittent exercises with changes of direction. *Journal of Strength and Conditioning Research*, *26*(10), 2712–2720.

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine*, *30*(3), 205–212.

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal sprinting speed of elite soccer players during training and matches. *Journal of Strength and Conditioning Research*, *31*(6), 1507–1517.

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, *30*(7), 625–631.

Gaudino, P., Alberti, G., & Iaia, F. M. (2014). Estimated metabolic and mechanical demands during different small-sided games in elite soccer players. *Human Movement Science*, *36*, 123–133.

Gregson, W., Drust, B., Atkinson, G., & Salvo, V. D. (2010). Match-to-match variability of high-speed activities in premier league soccer. *International Journal of Sports Medicine*, *31*(4), 237–242.

Haugen, T., Tønnessen, E., & Seiler, S. (2013). Anaerobic performance testing of professional soccer players 1995–2010. *International Journal of Sports Physiology and Performance*, *8*(2), 148–156.

Hill-Haas, S. V., Dawson, B. T., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in football: A systematic review. *Sports Medicine*, *41*(3), 199–220.

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., & Rampinini, E. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine*, *27*(6), 483–492.

Kyprianou, E., Di Salvo, V., Lolli, L., Al Haddad, H., Villanueva, A. M., Gregson, W., & Weston, M. (2022). To measure peak velocity in soccer, let the players sprint. *Journal of Strength and Conditioning Research*, 36(1), 273–276.

Lenth, R. (2020). *emmeans: Estimated marginal means, aka least-squares means*. Retrieved from https://cran.r-project.org/package=emmeans

Little, T. (2009). Optimizing the use of soccer drills for physiological development. *Strength and Conditioning Journal*, *31*(3), 67–74.

Ludecke, D. (2019). *sjPlot: Data visualization for statistics in social science*. https://doi.org/10.5281/zenodo.1308157

Mallo, J., Mena, E., Nevado, F., & Paredes, V. (2015). Physical demands of top-class soccer friendly matches in relation to a playing position using global positioning system technology. *Journal of Human Kinetics*, *47*(1), 179–188.

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport*, *20*(3), 250–254.

Mendez-Villanueva, A., Buchheit, M., Kuitunen, S., Douglas, A., Peltola, E., & Bourdon, P. (2011). Age-related differences in acceleration, maximum running speed, and repeated-sprint performance in young soccer players. *Journal of Sports Sciences*, *29*(5), 477–484.

Mendez-Villanueva, A., Buchheit, M., Simpson, B. M., & Bourdon, P. C. (2013). Match play intensity distribution in youth soccer. *International Journal of Sports Medicine*, *34*, 101–110.

Mendez-Villanueva, A., Buchheit, M., Simpson, B. M., Peltola, E., & Bourdon, P. (2011). Does on-field sprinting performance in young soccer players depend on how fast they can run or how fast they do run? *Journal of Strength and Conditioning Research*, *25*(9), 2634–2638.

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2014). Physical and technical comparisons between various-sided games within professional soccer. *International Journal of Sports Medicine*, *35*(4), 286–292.

R Core Team. (2019). *R: A language and environment for statistical computing*. Retrieved from www.R-project.org/

Thome, M., Thorpe, R. T., Jordan, M. J., & Nimphius, S. (2023). Validity of global positioning system technology to measure maximum velocity sprinting in elite sprinters. *The Journal of Strength and Conditioning Research*, 37(12), 2438-2442.

Varley, M. C., Fairweather, I. H., & Aughey1, 2, R. J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *Journal of sports sciences*, *30*(2), 121-127.

Wickham, H. (2009). *ggplot2: Elegant graphics for data analysis*. Retrieved from http://ggplot2.org

Chapter 5: Which soccer small-sided game prescriptive variables are most associated with increases in peak sprint speed?

Abstract

Soccer small-sided games (SSG) are able to elicit an array of physical demands while simultaneously developing technical and tactical abilities. A limited number of studies have investigated the sprint demands of SSG, and importantly, how they are modified by the large number of possible SSG prescriptive variables. This study reports the relative peak sprint demands using 10 Hz GPS of a large sample of game-based soccer training exercises performed by a team of 20 high-level amateur male players (mean age 26.7 ± 4.4 years) over 15 training sessions. The effects of several prescriptive variables on relative peak sprint speed (PSS) were analysed using a linear mixed-effects model including random effects for the individual player and session number. Relative pitch area was associated with a small increase in relative PSS (0.84, 95% CI 0.74, 0.94; $p<0.001$) for each 10 m^2 per player, while game duration showed a similar positive effect (1.08, 95% CI 0.86, 1.30; $p<0.001$) for each additional minute. Employing a scoring game-objective (10.19, 95% CI 7.75, 12.63; $p<0.001$), compared to possession, and including a limit on ball touches permitted (4.78, 95% CI 2.13, 7.44; $p<0.001$) were also associated with increased relative PSS, while including neutral players showed a negative effect (-2.7, 95% CI -5.32, -0.07; $p=0.044$). The present study gives novel insight into a diverse sample of SSG captured in situ, helping to determine which variables are most important when considering design of SSG in relation to sprint or high-speed running training objectives.

Introduction

Soccer small-sided games (SSG) are able to elicit a broad array of physical demands while simultaneously providing opportunities to develop the technical and tactical abilities of players in an environment similar to competition (Davids et al., 2013; Gabbett et al., 2009). Alongside effectiveness in improving measures of intermittent fitness (Dellal, Varliette, et al., 2012; Impellizzeri et al., 2006), SSG are also thought to enhance training time-efficiency and player motivation (Hill-Haas et al., 2011; Little, 2009). These factors have led to a number of SSG-based training frameworks or methodologies (Buchheit et al., 2018; Clemente, Martins, et al., 2014b; Hill-Haas et al., 2011) to meet varied training objectives. However, the variability possible in physical demands according to prescriptive variables such as pitch size and shape, player number, game format, work and rest durations, and rule modifications makes a comprehensive understanding of these effects critical in order to optimise SSG selection for a desired physical stimulus/adaptation (Abbott et al., 2018b; Clemente, Martins, et al., 2014b; Hill-Haas et al., 2011).

Sprinting is viewed as a crucial element of soccer training due to its occurrence during critical actions in competition (Faude et al., 2012; Stølen et al., 2005), and the association between injury incidence and exposure to maximal sprint efforts (Malone et al., 2017) or cumulative sprint volume (Colby et al., 2014). Despite this, there are few studies on the suitability of SSG to meet sprint training objectives, or how SSG may be modified to increase or reduce sprinting demands. Current studies have shown increases in peak sprint speed and distance covered above high intensity and sprint speed thresholds during SSG as pitch area and player number increase concurrently (Gaudino et al., 2014; Owen et al., 2014). Djaoui et al. (Djaoui et al., 2017) also reported positive associations between peak sprint speed and pitch area, pitch length, and number of players, while the introduction of goals has also been shown to result in increased speed relative to possession-objective SSG (Djaoui et al., 2017; Gaudino et al., 2014).

The above studies primarily report distance covered above generic movement speed thresholds or absolute peak sprinting speeds, which are unable to relate the intensity of sprint efforts to an individual's maximum speed (Lovell & Abt, 2013), and may therefore under or over-estimate running demands (Abbott et al., 2018a). Additionally, a number of prescriptive variables which could plausibly modify SSG sprint demands have not been investigated. The use of neutral players or unbalanced team scenarios (Hill-Haas et al., 2010), limitations on the number of ball touches (Dellal, Chamari, Owen, et al., 2011; Dellal, Lago-Peñas, et al., 2011), and a number of additional rule modifications (Hill-Haas et al., 2011), have all been shown to modulate physiological responses or movement demands. However, it is difficult to compare the results of multiple studies analysing each of these variables in isolation. These issues may be addressed by examining the individual-relative sprint demands of a large sample of SSG with diverse prescriptive variables. Examining these effects concurrently will also ensure that ecological factors such as coach instruction or encouragement, player selection, and competitive level are controlled.

This study aims to determine and compare the effects of multiple SSG prescriptive variables on the *relative* peak sprint achieved during play. This will enhance the understanding of how to modify SSG to increase or decrease the associated sprint demands, allowing coaches and practitioners to select exercises that meet individualised training objectives.

Method

Experimental overview

In order to analyse the effect of varied SSG prescriptive variables on relative peak sprint speed, an observational approach was used to record the SSG variables utilised during all team exercises across a 7-week training period during the in-season phase, while using GPS devices to capture the associated movement demands of each exercise.

Participants

Participants were 20 players (mean age 26.7 ± 4.4 years) of an amateur team playing in Oceania's highest tier of club competition. All participants were full-time members of the squad, completing five training sessions and one competitive match during a typical week. Each player was assigned to a playing position group according to their most frequently played position during the current season. Ethics approval was obtained from the University's Human Ethics Committee and all participants gave informed consent.

Procedures

The movement demands of each player were monitored during all team activities using a 10 Hz GPS device (VX Sport, Lower Hutt, New Zealand) worn in a secure vest. GPS devices sampling at 10 Hz have been shown to be valid and reliable for reporting maximal velocity (Thome et al., 2023). Each player used the same GPS device throughout the study to eliminate inter-device error. On three occasions during this training period, all players performed 3-5 repetitions of a 30-40 m maximal effort sprint, from a standing start and with 60 seconds rest between repetitions, weekly as part of their planned training. The highest speed ($km \cdot h^{-1}$) reached by each player during all training activities throughout the duration of the study was recorded as the player's maximal sprint speed (MSS). Training sessions took place at 22.7 ± 3.5°C ambient temperature and 66 ± 8.7% relative humidity.

The prescriptive variables (pitch sizes, number of players, inclusion of any rule modifications) were recorded during any team activity that met the following criteria for a SSG: A scoring or possession game objective, clearly defined teams and area of play (length and width), and continuous "open" play within each game repetition. These SSG were included in the final data set. Activities which did not meet these criteria were discarded; these included isolated passing, finishing, transition attacking or defending activities, and activities with a constant exchange of players between teams beyond 1-3 "neutral" players. The peak speed of each player-repetition was recorded as a percentage of the player's MSS. All inactive time between repetitions or separate activities was removed from the data.

Statistical analyses

A linear mixed-effects model was used to analyse the impact of different prescriptive variables on the peak percentage of MSS reached by each player in each SSG period. Both the individual player and training session date were included in the model as random effects. This method is able to account for the repeated measures within each individual and training session, and the unbalanced data structure. The variables selected for inclusion as fixed effects in the linear mixed-effects model after assessing sample size and collinearity include pitch area per player (m^2), duration (min), possession or scoring game objective, inclusion/exclusion of neutral players, difference in number players per team (overload), ball touch restrictions (inclusive of 1, 2, and 3-touch limits), and the assigned playing position. Pitch area per player was rescaled prior to inclusion in the linear mixed-effects model; the regression coefficient represents the effect of each 10 m^2 increase in pitch area per player on relative peak sprint speed. All data analyses and figures were produced in R (R Core Team, 2019) using the *lme4* (Bates et al., 2015), *ggplot2* (Wickham, 2009), and *sjPlot* (Ludecke, 2019) packages. The alpha level for analysis was set at $p<0.05$. All descriptive data are presented as mean ± SD.

Results

The mean MSS of the participating players was 32.1 ± 1.3 $km \cdot h^{-1}$. A total of 1,243 SSG observations were included in the final sample. Table 5.1 reports the mean ± SD and frequencies of continuous categorical prescriptive variables, respectively, within groups according to the peak percentage of MSS reached by each player. The mean peak percentage of MSS reached across the complete sample of SSG observations was 63 ± 12%.

The results of the linear mixed model are reported in Table 5.2. A 10 m^2 increase in the pitch area per player was associated with an increase in the peak percentage of MSS reached during the SSG (0.84, 95% CI 0.74, 0.94; $p<0.001$). The observations in the study included SSG ranging from 13-290 m^2 per player. When considering the practical upper bound of relative pitch area (number of possible 10 m^2 per player increases), this effect could be considered large. The duration of the SSG period was also associated with an increase in the peak percentage of MSS reached (1.08, 95% CI 0.86, 1.30; $p<0.001$). The mean duration of all SSG observations was 4.26 ± 3.14 min. Utilising a scoring objective was associated with the largest increase in the peak percentage of MSS (10.19, 95% CI 7.75, 12.63; $p<0.001$) of any categorical variable, when compared to possession objective games. In the sample, a scoring objective comprised regulation goals and goalkeepers in 98.3% (870/885) of observations. Inclusion of a neutral player was associated with a decrease in the peak percentage of MSS reached (-2.7, 95% CI -5.32, -0.07; $p=0.044$). Including a restriction on the number of ball touches allowed by each player was associated with an increase in the peak percentage of MSS reached (4.78, 95% CI 2.13, 7.44; p<0.001). Both the inclusion of an overload player in the SSG, and each of the playing position groups were not associated with a significant change in the peak percentage of MSS reached.

Table 5.1 Summary of mean ± SD and frequency of SSG prescriptive variables within peak percentage of MSS groups.

	Peak percentage of MSS			
Prescriptive variables	**20 - 40%**	**40 - 60%**	**60 - 80%**	**80 - 100%**
	N = 46	N = 481	N = 630	N = 86
Duration (min)	3.35 ± 0.96	3.34 ± 2.21	4.82 ± 3.65	5.74 ± 2.75
Pitch length (m)	12.2 ± 4.64	27.3 ± 10.7	42.8 ± 18.7	71.1 ± 19.8
Pitch width (m)	10.9 ± 5.18	25.8 ± 9.59	39.1 ± 14.5	56.0 ± 11.7
Area (m^2)	156 ± 184	789 ± 654	1832 ± 1479	4099 ± 1613
Player number	8.00 ± 2.35	12.9 ± 2.98	16.1 ± 3.64	20.6 ± 2.73
Pitch area per player (m^2)	17.1 ± 11.7	57.0 ± 33.5	104 ± 59.9	193 ± 64.4
Goalkeeper inclusion	2 (4.35%)	279 (58.0%)	505 (80.2%)	84 (97.7%)
Game objective				
Possession	44 (95.7%)	200 (41.6%)	114 (18.1%)	0 (0.00%)
Scoring	2 (4.35%)	281 (58.4%)	516 (81.9%)	86 (100%)
Limited ball touches	22 (47.8%)	174 (36.2%)	145 (23.0%)	7 (8.14%)
Neutral player/s inclusion	29 (63.0%)	145 (30.1%)	123 (19.5%)	4 (4.65%)
Unbalanced teams	15 (32.6%)	66 (13.7%)	68 (10.8%)	5 (5.81%)

SSG: small-sided games; MSS: maximal sprint speed.

Table 5.2 Linear mixed-effect model results analysing the effect of prescriptive variables on the peak sprint speed attained during SSG as a percentage of MSS (n=1243).

Predictors	**Variable Level**	**Estimates**	**95% CI**	**p**
Intercept		42.55	39.25 – 45.84	**<0.001**
Pitch area per player (10)		0.84	0.74 – 0.94	**<0.001**
Duration (1 min)		1.08	0.86 – 1.30	**<0.001**
Touch restriction	No (reference)	0	-	**-**
	Yes	4.78	2.13 – 7.44	**<0.001**
Game objective	Possession (reference)	0	-	**-**
	Scoring	10.19	7.75 – 12.63	**<0.001**
Overload	No (reference)	0	-	-
	Yes	0.26	-2.57 – 3.09	0.859
Neutral players	No (reference)	0	-	**-**
	Yes	-2.70	-5.32 – -0.07	**0.047**
Playing position	AM (reference)	0	-	-
	CD	1.21	-1.38 – 3.80	0.376
	CM	-0.23	-2.77 – 2.30	0.860
	FW	-0.46	-3.58 – 2.65	0.776
	WB	0.85	-1.78 – 3.47	0.538

Values are slope estimates describing the linear relationship between each fixed effect and relative peak speed, in relation to the reference level (factor variables) or one unit of change (continuous variables). CI = Confidence interval; AM = attacking midfielders; CD = central defenders; CM = central midfielders; WB = wing-backs; FW = forwards. P-values are calculated via conditional F-tests using the Kenward-Roger approximation of degrees of freedom.

Discussion

This study examined the relationships between several key SSG prescriptive variables and the sprint speed achieved during play relative to an individual player's MSS. Pitch area, game objective, utilising neutral players and touch limitations were all associated with significant changes in relative peak sprint speed. These findings give further insight into the modification of sprint demands according to SSG design.

Relative pitch area

Each 10 m^2 increase in pitch area per player was associated with a relatively small increase in the relative peak sprint speed elicited during SSG (0.84, 95% CI 0.74, 0.94). However, very large increases in pitch area are possible in practice. For example, the model suggests ten increases of 10 m^2 (100 m^2) would result in an 8.4% (95% CI 7.4, 9.4) increase in the peak percentage of MSS attained. Further increases of this magnitude are realistic; the SSG analysed in this sample ranged from 13 to 290 m^2 per player. This is supported by a number of studies linking increased area per player with increased absolute and relative peak sprint speed (Casamichana et al., 2012; Djaoui et al., 2017; Gaudino et al., 2014; Owen et al., 2014), in addition to greater total distance covered and distance above high-speed and sprint thresholds (Abbott et al., 2018b; Casamichana & Castellano, 2010; Gaudino et al., 2014; Olthof et al., 2018). Using a unique modelling approach, Sangnier et al. (2019) determined SSG above 340 m^2 per player as the best design approach to elicit sprint training at approximately 85% of "match density" (quantified as the number of efforts and metres over 21 $km \cdot h^{-1}$ per minute). Combined with previous findings, these results underline relative pitch area as perhaps the primary factor in determining the peak speed demands of SSG.

Scoring vs. possession

Utilising a scoring objective when compared to possession objective games was associated with the largest increase in relative peak speed of all categorical prescriptive variables in the analysis (10.19, 95% CI 7.75, 12.63). The scoring objective observations in the sample almost exclusively included goalkeepers and regulation-sized goals. This result is consistent with previous research (Gaudino et al., 2014) and Djaoui et al. (2017), in which the use of goals was associated with greater absolute and relative peak speeds. Interestingly, Castellano, et al. (2013) found contrary results, with possession SSG on a 210 m^2 per player pitch resulting in greater absolute peak speed reached and metres within high-intensity zones. It has been suggested that the greater peak speeds observed in goal-scoring SSG are the result of higher intensity efforts to create or defend goalscoring opportunities (Djaoui et al., 2017); it seems logical that the use of goals elicit a more pronounced “linear” (or bi-linear) nature of the play during these games, relative to more multidirectional possession SSG (Gaudino et al., 2014). All scoring objective games in the study were played using the offside rule; this possibly exacerbates the difference between scoring and possession objective games due to increased space behind the defence. However, neither Castellano et al. (2013) nor Gaudino et al (2014) utilised the offside rule, despite their contrary findings.

Duration

Previous studies examining duration of SSG have found that measures such as distance covered per minute decrease as the duration or rolling average duration of the activity increases (Abbott et al., 2018b; Delaney et al., 2017). Interestingly, our data show each 1-min increase in SSG work duration was associated with an increase in relative peak speed reached by the player (1.08, 95% CI 0.86, 1.30). Similar to pitch area, multiple increases in duration are possible; the mean duration of the SSG observations was 4.3 ± 3.1 min, while the maximum duration was 17-min. The difference in findings between the present and previous studies may be due to the use of peak speed as the main outcome variable, and the inherent sensitivity of peak speed to singular sprint actions that are not necessarily representative of a high volume of sprint demands. Maximal sprinting is relatively infrequent during match-play (Buchheit et al., 2021). Longer work durations could therefore lead to higher relative peak speeds by increasing the chances a player is exposed to at least one opportunity to reach a high percentage of MSS.

The specific objective of SSG-based training exercises might be influential in determining how this result impacts game design. If singular, maximal sprint efforts are desired during continuous-play SSG, longer work durations may be helpful. In contrast, as demonstrated by previous studies (Abbott et al., 2018b; Delaney et al., 2017), shorter durations may be useful when attempting to maintain a continuously high rate of distance covered at lower movement intensity thresholds.

Touch limits

Introducing a limit on the number of ball-touches each player was permitted (one-, two-, and three-touch limits inclusive) was associated with an increase in the relative peak speed achieved (Table 5.2). This task constraint has previously been shown to result in increased distance covered above high-intensity and sprinting thresholds, and increased perceived exertion compared to free play SSG of the same duration (Dellal, Chamari, Owen, et al., 2011; Dellal, Hill-Haas, et al., 2011; Dellal, Lago-Peñas, et al., 2011; Dellal, Owen, et al., 2012). The increase in average intensity reported in previous studies, however, is typically accompanied by a significant increase in technical errors such as incomplete passes and balls lost out of play (Dellal, Hill-Haas, et al., 2011; Dellal, Lago-Peñas, et al., 2011; Dellal, Owen, et al., 2012). These decrements in movement activity and increases in technical errors over a number of repeated games may result in this rule modification only being viable for short durations or a limited number of repetitions.

Neutral players and unbalanced teams

The inclusion of neutral players, and unbalanced player numbers were analysed at a whole-group level (i.e., all observations of an exercise contribute to this category, rather than the neutral player(s) only). Including a neutral player or players in the SSG was associated with a small reduction in relative peak speed compared to other fixed variable effects (-2.80, 95% CI -5.32, -0.07) while the overload condition effect was not significant. One possible explanation is that the additional player or players lead to the outnumbered team becoming more conservative in their positioning, reducing the opportunity or need for players from both teams to quickly sprint into space (Hill-Haas et al., 2010; Vilar et al., 2014). The effect of these variables could have been obscured by the method of analysis. Each of these variables could be examined on an individual level, for example comparing the overload team to the underload team directly, or the neutral player(s) to the remaining players in the same SSG. Previous research (Hill-Haas et al., 2010) has indicated that the movement demands on the neutral player in terms of total distance covered are greater than those of the remaining players.

Position differences

In contrast to previous studies, there were no differences in relative peak sprint speed present between the five playing position groups. Previous studies have reported positional differences in peak speeds (Djaoui et al., 2017) and distance covered above high speed and sprinting thresholds (Abbott et al., 2018b; Dellal, Owen, et al., 2012) during SSG comparable to those observed in competition (Al Haddad et al., 2015; Mallo et al., 2015), particularly when utilising goals and goalkeepers (Hill-Haas et al., 2011). While the lack of differences between position groups could indicate that the sample of SSG observed in the study did not emphasise position-specific play, the majority of the observations in the sample were of a broad design in which position-specific differences have previously been demonstrated. For example, 70% of observations were scoring objective games, while the mean number of players in each observation was 14.9 ± 4.1.

Limitations

Some aspects of the study design limit the results and practical recommendations. Firstly, it is important to note the limitations of reporting *peak sprint speed*, primarily that greater peak sprint values do not necessarily represent a high volume of sprinting or distance covered at high percentages of MSS during the observed SSG. However, the short mean duration of the observations in the study possibly mitigates the loss of information over a time epoch that is inherent in a peak measurement. Consequently, it is the view of the authors that the data and analysis are suitable with respect to describing the effects of the prescriptive variables on gross peak sprint intensity, rather than describing or comparing the precise training load of each SSG. Secondly, in practice it is likely that the SSG variables, along with other factors such as coach instruction, player motivation or understanding interact to result in a unique activity pattern in each SSG. It is possible that all of these separate elements of SSG design could be modified in concert to achieve a significantly greater sprint intensity/stimulus.

Practical applications

Overall, this study illustrates how several prescriptive variables are associated with increases or decreases in relative peak sprint speed during SSG. Modifying SSG to increase the relative pitch area, using a scoring rather than possession game objective, removing neutral players, and increasing the duration of play should increase the peak sprint speed that players can reach. Limiting the number of ball touches may also increase peak sprint demands, however, this might be applied cautiously given the associated increases in technical errors. It is unclear to what degree combining each of these sprint-increasing variables would maximise sprint demands, and further changes in peak sprint speed are likely attainable according to coach instruction or tactical emphasis. For example, emphasising counterattacking play (Buchheit et al., 2018) and/or high defensive lines may be a crucial element if eliciting maximal or near-maximal peak sprint speeds is the objective.

References

Abbott, W., Brickley, G., & Smeeton, N. J. (2018a). An individual approach to monitoring locomotive training load in English Premier League academy soccer players. *International Journal of Sports Science & Coaching*, *13*(3), 421–428.

Abbott, W., Brickley, G., & Smeeton, N. J. (2018b). Positional differences in gps outputs and perceived exertion during soccer training games and competition. *Journal of Strength and Conditioning Research*, *32*(11), 3222–3231.

Al Haddad, H., Simpson, B. M., Buchheit, M., Di Salvo, V., & Mendez-Villanueva, A. (2015). Peak match speed and maximal sprinting speed in young soccer players: effect of age and playing position. *International Journal of Sports Physiology and Performance*, *10*(7), 888–896.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48.

Buchheit, M., Lacome, M., Cholley, Y., & Simpson, B. M. (2018). Neuromuscular responses to conditioned soccer sessions assessed via GPS-embedded accelerometers: Insights into tactical periodization. *International Journal of Sports Physiology and Performance*, *13*(5), 577–583.

Buchheit, M., Simpson, B. M., Hader, K., Lacome, M., Buchheit, M., Simpson, B. M., … Lacome, M. (2021). Occurrences of near-to-maximal speed-running bouts in elite soccer: Insights for training prescription and injury mitigation. *Science and Medicine in Football*, *5*(2), 105–110.

Casamichana, D., & Castellano, J. (2010). Time-motion, heart rate, perceptual and motor behaviour demands in small-sided soccer games: Effects of pitch size. *Journal of Sports Sciences*, *28*(14), 1615–1623.

Casamichana, D., Castellano, J., & Castagna, C. (2012). Comparing the physical demands of friendly matches and small-sided games in semiprofessional soccer players. *Journal of Strength and Conditioning Research*, *26*(3), 837–843.

Castellano, J., Casamichana, D., & Dellal, A. (2013). Influence of game format and number of players on heart rate responses and physical demands in small-sided soccer games. *Journal of Strength and Conditioning Research*, *27*(5), 1295–1303.

Clemente, F. M., Martins, F. M. L., & Mendes, R. S. (2014). Periodization based on small-sided soccer games: Theoretical considerations. *Journal of Strength and Conditioning Research*, *36*(5), 34–43.

Colby, M. J., Dawson, B. T., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *Journal of Strength and Conditioning Research*, *28*(8), 2244–2252.

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews*, *41*(3), 154–161.

Delaney, J. A., Thornton, H. R., Rowell, A. E., Dascombe, B. J., Aughey, R. J., & Duthie, G. M.

(2017). Modelling the decrement in running intensity within professional soccer players. *Science and Medicine in Football*, *2*(2), 86–92.

Dellal, A., Chamari, K., Owen, A. L., Wong, D. P., Lago-Peñas, C., & Hill-Haas, S. V. (2011). Influence of technical instructions on the physiological and physical demands of small-sided soccer games. *European Journal of Sport Science*, *11*(5), 341–346.

Dellal, A., Hill-Haas, S. V., Lago-Peñas, C., & Chamari, K. (2011). Small-sided games in soccer: Amateur vs. professional players' physiological responses, physical, and technical activities. *Journal of Strength and Conditioning Research*, *25*(9), 2371–2381.

Dellal, A., Lago-Peñas, C., Wong, D. P., & Chamari, K. (2011). Effect of the number of ball contacts within bouts of 4 vs. 4 small-sided soccer games. *International Journal of Sports Physiology and Performance*, *6*(3), 322–333.

Dellal, A., Owen, A. L., Wong, D. P., Krustrup, P., van Exsel, M., & Mallo, J. (2012). Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. *Human Movement Science*, *31*(4), 957–969.

Dellal, A., Varliette, C., Owen, A. L., Chirico, E. N., & Pialoux, V. (2012). Small-sided games versus interval training in amateur soccer players: Effects on the aerobic capacity and the ability to perform intermittent exercises with changes of direction. *Journal of Strength and Conditioning Research*, *26*(10), 2712–2720.

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal sprinting speed of elite soccer players during training and matches. *Journal of Strength and Conditioning Research*, *31*(6), 1507–1517.

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, *30*(7), 625–631.

Gabbett, T. J., Jenkins, D., & Abernethy, B. (2009). Game-based training for improving skill and physical fitness in team sport athletes. *International Journal of Sports Science & Coaching*, *4*(1), 273–283.

Gaudino, P., Alberti, G., & Iaia, F. M. (2014). Estimated metabolic and mechanical demands during different small-sided games in elite soccer players. *Human Movement Science*, *36*, 123–133.

Hill-Haas, S. V., Coutts, A. J., Dawson, B. T., & Rowsell, G. J. (2010). Time-motion characteristics and physiological responses of small-sided games in elite youth players: The influence of player number and rule changes. *Journal of Strength and Conditioning Research*, *24*(8), 2149–2156.

Hill-Haas, S. V., Dawson, B. T., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in football: A systematic review. *Sports Medicine*, *41*(3), 199–220.

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., & Rampinini, E. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine*, *27*(6), 483–492.

Little, T. (2009). Optimizing the use of soccer drills for physiological development. *Strength and Conditioning Journal*, *31*(3), 67–74.

Lovell, R., & Abt, G. (2013). Individualization of time-motion analysis: a case-cohort example. *International Journal of Sports Physiology and Performance*, *8*(4), 456–458.

Ludecke, D. (2019). *sjPlot: Data visualization for statistics in social science*. https://doi.org/10.5281/zenodo.1308157

Mallo, J., Mena, E., Nevado, F., & Paredes, V. (2015). Physical demands of top-class soccer friendly matches in relation to a playing position using global positioning system technology. *Journal of Human Kinetics*, *47*(1), 179–188.

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport*, *20*(3), 250–254.

Olthof, S. B. H., Frencken, W. G. P., & Lemmink, K. (2018). Match-derived relative pitch area changes the physical and team tactical performance of elite soccer players in small-sided soccer games. *Journal of Sports Sciences*, *36*(14), 1557–1563.

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2014). Physical and technical comparisons between various-sided games within professional soccer. *International Journal of Sports Medicine*, *35*(4), 286–292.

R Core Team. (2019). *R: A Language and Environment for Statistical Computing*. Retrieved from www.R-project.org/

Sangnier, S., Cotte, T., Brachet, O., Coquart, J., & Tourny, C. (2019). Planning Training workload in football using small-sided games' density. *Journal of Strength and Conditioning Research*, *33*(10), 2801–2811.

Stølen, T., Chamari, K., Carlo, C., & Wisløff, U. (2005). Physiology of soccer: An update. *Sports Medicine*, *35*(6), 501–536.

Thome, M., Thorpe, R. T., Jordan, M. J., & Nimphius, S. (2023). Validity of global positioning system technology to measure maximum velocity sprinting in elite sprinters. The *Journal of Strength and Conditioning Research*, 37(12), 2438-2442.

Vilar, L., Esteves, P., Travassos, B., Passos, P., Lago-Peñas, C., & Davids, K. (2014). Varying numbers of players in small-sided soccer games modifies action opportunities during training. *International Journal of Sports Science and Coaching*, *9*(5), 1007–1018.

Wickham, H. (2009). *ggplot2: Elegant graphics for data analysis*. Retrieved from http://ggplot2.org

Chapter 6: Analysis of peak sprint demands during scenario-based soccer-specific exercises

Abstract

Sprinting is a critical element of physical preparation for elite soccer. Scenario-based soccer-specific exercises consisting of short phases of constrained play may address the limitations inherent to small-sided games with respect to eliciting near-maximal sprinting. This study used 10 Hz global position system (GPS) devices to record 22 male players' peak sprint speed as a percentage of their individual MSS (maximum sprint speed) during 18 different soccer-specific exercises performed over 30 training sessions by a high-level amateur team. Prescriptive variables including the size of the playing area, team construction, and addition of defenders and goalkeepers were used to group exercises into three categories for analysis: i) unopposed pattern-play, ii) crossing and finishing, and iii) counterattacking games. The full sample of 353 observations elicited a peak sprint speed of 71 ± 12% of MSS, with 22.1% (78/353) and 4.8% (17/353) of observations reaching 80% and 90% of MSS, respectively. Analysis using a linear-mixed effects model revealed that counterattacking games elicited greater relative peak sprint speed than pattern-play exercises (-7.64%, 95% CI -14.62%, -0.66%; p=0.032). Faster players reached greater absolute (0.34 km·h^{-1-}, 95% CI 0.06, 0.61; p=0.018), but slower relative (-1.1%, 95% CI: -1.98, -0.22; p=0.015) peak speeds, while several position-specific differences were observed. More limited univariable models also revealed single-phase exercises, balanced team construction, and opposed exercises were all significantly associated with increases in relative peak sprint speed. This study demonstrates that generally, these soccer-specific exercises elicit a low level of sprint demands, however some counterattacking exercises with specific prescriptive variables show promise in eliciting near-maximal sprint efforts.

Introduction

There are several factors which might lead soccer coaches to prefer or prioritise the use of soccer-specific exercises in the physical preparation of elite players, including time-efficiency, motivation, greater sport-specificity of physical demands (Clemente, Martins, et al., 2014a; Hill-Haas et al., 2011), and opportunities for technical and tactical learning through decision-making and cognitive-perceptual specificity (Davids et al., 2013; Gabbett et al., 2009). Previous research has primarily investigated small-sided soccer games (SSG), highly modifiable exercises which closely resemble competition. While SSG are able to elicit a broad array of physical and physiological demands appropriate for training (Clemente, Martins, et al., 2014b, 2014a; Hill-Haas et al., 2011), several studies have called into question the limitations of SSG with respect to their ability to elicit very high-speed running and sprinting demands at a similar or greater level to competition (Abbott et al., 2018a; Djaoui et al., 2017; Gaudino et al., 2014); Chapter 4, Chapter 5). Sprinting is a key activity in soccer training in relation to injury incidence (Colby et al., 2014; Malone et al., 2017) and is present both throughout matches (Buchheit et al., 2021) and during critical goalscoring actions (Faude et al., 2012). It appears that SSG are unable to *reliably* elicit sprint efforts of 90% or greater of maximum sprint speed (MSS) (Abbott et al., 2018a; Djaoui et al., 2017; Gaudino et al., 2014); Chapter 5), even when prescriptive variables linked to sprinting are maximised (Chapter 4). This may be due to the freedom of players to adopt more conservative positioning, disincentivising explosive attacking (and concurrently defending) runs over longer distances.

Accordingly, coaches and practitioners may find it necessary to meet sprint-training objectives using traditional, isolated running exercises (Abbott et al., 2018a). However, given the potential benefits to skilled performance practice (Davids et al., 2013; Roca

& Ford, 2020), it is worthwhile to explore if there are other soccer-specific exercises that allow the realisation of sprint-training objectives while preserving the active decision-making opportunities present in SSG. Other than SSG, soccer teams perform non-continuous shooting/finishing, counterattacking, phase-of-play, and passing exercises with varying levels of constraints, structure, opposition, and decision-making in training (Roca & Ford, 2020).

Some of these drills represent sub-phases of competition or scenarios in which high-speed sprinting appears to be likely. For example, straight-line sprinting is frequently performed during goalscoring actions (Faude et al., 2012), and as such may be reasonably expected to be present in representatively designed shooting and finishing drills. Small-sided games with constraints to promote counterattacking play were previously suggested by Buchheit et al (2018) to be representative of exercises performed during typical "speed-focused" days within a training microcycle; isolating the phases of counterattacking play could therefore elicit significant sprint demands.

These exercises also possess several modifiable features which could plausibly enhance the likelihood of players reaching high percentages of MSS. For example, in these exercises, coaches are able to exercise greater control over the starting positions, distance, nature (i.e., with or without the ball), and previous or subsequent technical actions of the players with respect to the running demands. Overload situations (using greater number or attackers vs. defenders), which have previously been demonstrated to promote increased peak sprint speed during SSG (Chapter 5), can be easily constructed, while manipulable work-to-rest ratios and shorter overall work durations could minimise the effects of fatigue within each exercise that would be detrimental to the performance of sprint efforts (Girard et al., 2011).

This study aims to report the sprint demands of these scenario-based soccer-specific exercises, and the effect of prescriptive variables such as decision-making, opposition level, playing area, and number of players on the sprint demands has not been previously reported. This will firstly help practitioners gain a greater understanding of the sprint demands elicited by a broader spectrum of soccer-specific exercises that includes SSG, semi-opposed, or unopposed, finishing exercises, and secondly, assist in determining which prescriptive variables are critical when designing speed-oriented soccer exercises.

Methods

Experimental approach to the problem

In order to analyse the relative sprint demands and influence of drill structure and design during “scenario-based” soccer-specific exercises, an observational approach was used to record the movement demands and prescriptive variables of soccer training exercises meeting the inclusion criteria. A linear mixed-effects model was then used to determine the influence of prescriptive and descriptive (playing position, player MSS) variables on the relative peak sprint speed elicited during soccer-specific exercises. The criteria for inclusion within the sample were firstly that each exercise involved the ball and was played in a non-continuous format with brief periods of active play (less than 30 s continuously). This may be a sequence of attacking and defending phases, but excludes continuous small-sided games, possession games, and open-play tactical drills. Exercises did not require active opposition, however stationary and/or repetitive skill practice exercises were excluded.

Participants

Twenty-two male players aged 27.4 ± 4.1 years volunteered to participate in the study. The participants belonged to a club competing in the highest competitive level in the Oceania Federation. All participants were full-time members of the squad, completing four training sessions and one competitive match during a typical week. Ethics approval was obtained from the University's Human Ethics Committee and all participants provided written informed consent. Each player was allocated a playing position descriptor from one of centre-back (CB), full-back (FB), central midfielder (CM), and forward (FW) according to their predominant role during competition.

Data Collection

There were 30 training sessions in which exercises meeting the study criteria were performed across the 2019-20 and 2020-21 competitive seasons. Average ambient temperature and relative humidity during included training sessions were 21.8 ± 2.4 °C, and 63.2 ± 12%, respectively. Shaded ambient temperature and relative humidity were measured at the commencement of each training session using a portable weather station (Aercus Instruments WS1173, Auckland, New Zealand).

Movement demands during training exercises were recorded using 10 Hz global positioning system (GPS) units (VX Sport, Wellington, New Zealand) worn in a secure vest, with each player using the same unit for the duration of the study whenever possible to eliminate inter-device error. The movement activity recording for each exercise was recorded in the largest possible block of continuous recording to limit sample size inflation e.g., each observation typically contains multiple efforts or repetitions for a given player. The peak running speed ($km \cdot h^{-1}$), and relative peak running speed (expressed as the percentage of MSS achieved), were collected for each observation. Player MSS was determined using 10 Hz GPS measurement of all training and match activity over the course of a full season. Players completed 3-5 repetitions of 30-40 m maximal sprint efforts from a standing start, on 4 separate occasions throughout the study duration. Maximal sprint efforts were conducted immediately following a standardised warm up.

Statistical Analyses

A linear mixed-effects model was utilised to examine the influence of different prescriptive variables on both the relative and absolute peak speed reached in each exercise. This analysis method was chosen due to the ability to account for the repeated measures within each individual and training session, and the unbalanced data structure with multiple missing values. Player identification code and training session date were included as random effects in the model. The variables included as fixed effects in the linear mixed-effects model included playing position, player MSS, minimum pitch length, and the drill category. Player MSS was rescaled prior to inclusion in the model to centre on a mean of 0 km·h^{1}. Minimum pitch length represented the shortest distance between the starting position of involved players and the goal-line. The drill categories ("pattern play", "finishing", and "counterattack") were chosen to represent the consistent grouping of specific prescriptive variables such as activity objective, starting positions, or level of opposition. A summary of criteria for each category is included in Table 6.1.

Model parameter estimates, the associated confidence intervals (CIs), and p-values are reported. Parameter estimates describe the linear relationship between each prescriptive variable and relative peak speed. Estimates for factor variables (e.g., position and drill category) compare each variable level to a reference level (CB and counterattack levels, respectively), while estimates for continuous variables are proportionate to one unit of change in the predictor variable (e.g., 1 min, or 1 m). P-values are calculated via conditional F-tests using the Kenward-Roger approximation of degrees of freedom. Follow-up pairwise Bonferroni-adjusted t-tests of estimated marginal means were carried out for each factor variable to further analyse differences between each pair of factor levels.

Additionally, in order to approximate the effects of more specific prescriptive variables, univariable models with a reduced model specification were also calculated. These models include the same random effects as the main model, and drill duration, player MSS, playing position, minimum drill length as fixed effects. Each remaining prescriptive variable (drill phases, team structure, decision-making level) was included as a fixed effect in each given model. These models are unable to control for effects of other prescriptive variables in determining slope estimates and therefore do not provide the same level of evidence as the primary mixed-effects model. All data analyses and figures were produced in R (R Core Team, 2019) using the *lme4* (Bates et al., 2015), *ggplot2* (Wickham, 2009), and *sjPlot* (Ludecke, 2019) packages. The alpha level for analysis was set at $p<0.05$. All descriptive data are presented as mean ± SD.

Results

The 30 training sessions included in the final sample contain 18 unique soccer-specific exercises. The MSS of the 22 participating players was 32.1 ± 1.4 $km \cdot h^{-1}$. Overall, 22.1% (78/353) and 4.8% (17/353) of all drill observations reached 80% and 90% MSS, respectively. A summary of the prescriptive variables of the sampled exercises is included in Table 6.2

The results of the linear mixed-effect model examining the influence of the prescriptive variables on the relative peak sprint speed is reported in

Table 6.3. Significant fixed effects are reported for each of the position groups relative to the reference group (CB vs. CM [4.67%, 95% CI 1.36%, 7.99%; p=0.006], CB vs FB [9.82%, 95% CI 6.16%, 13.48%; p<0.001], CB vs. FW [6.93%, 95% CI 3.59%, 10.27%; p<0.001]), drill duration (0.84%, 95% CI 0.49%, 1.18%; p<0.001), player MSS (-1.1%, 95% CI -1.98%, -0.22%; p=0.015), and the pattern play category relative to the counterattack category (-7.64%, 95% CI -14.62%, -0.66%; p=0.032).

Table 6.4 reports the estimated marginal means (EMM) of each of the playing positions and exercise categories derived from the linear mixed-effects model, while Table 6.5 reports the results of pairwise t-testing between each of these groups.

Significant model estimates were observed in three of the separate relative peak speed univariable models. Single-phase exercise design was associated with decreased relative peak sprint speed compared to multi-phase exercise design (-7.56, 95% CI -14.44, -0.69; p=0.031), while opposed conditions were associated with faster relative peak speeds than unopposed (7.56, 95% CI 0.69, 14.44; p= 0.031). When considering team structure, balanced exercises (distinct from unbalanced) were associated with greater peak sprint speeds (10.72, 95% CI 1.88, 19.55; p=0.017).

Several significant effects were also observed using the linear mixed-effects model of the absolute peak sprint speed, including for each of the position groups relative to the reference group (CB vs. CM [1.44, 95% CI 0.39, 2.49; p=0.007], CB vs FB [3.09, 95% CI1.93, 4.25; p<0.001], CB vs. FW [2.19, 95% CI 1.14, 3.25; p<0.001]), drill duration (0.27, 95% CI 0.16, 0.38; p<0.001), player MSS (0.34, 95% CI 0.06, 0.61; p=0.018), and the pattern play category relative to the counterattack category (-2.41, 95% CI -4.66, -0.15; p=0.036).

Table 6.1 Summary of prescriptive variable criteria for each of the exercise categories used in the main analysis.

Category	Prescriptive variables	Description
Counterattack	Opposed (primarily overload); active decision-making; multi-phase; no crossing	Multi-phase exercises in which players attack and subsequently defend, often in increasing numbers e.g., 1 vs. 0, 2 vs. 1, 3 vs. 2.

Finishing	Unopposed; no decision-making, single phase; crossing included	Unopposed exercises most frequently involving a short passing combination and shooting opportunity for 1-3 players, sometimes including crossing.
Pattern Play	Unopposed; limited or semi-structured decision-making; single phase; crossing included	Unopposed, mostly predetermined passing exercises 6-10 players over large pitch areas, culminating in a finishing opportunity.

Table 6.2 Summary of prescriptive variables across the exercise categories (mean ± SD, or frequency, where applicable).

Prescriptive Variables		All	Counterattack	Finishing	Pattern Play
		N=353	*N=158*	*N=71*	*N=124*
Duration (min)		11.3 (6.37)	8.11 (7.54)	12.9 (3.70)	14.4 (3.37)
Drill Length (m)		40.4 (12.2)	33.9 (5.27)	29.5 (5.04)	54.9 (6.47)
Minimum Length (m)		26.6 (8.49)	33.4 (6.47)	18.1 (7.67)	22.9 (2.21)
Maximum Players		6.42 (2.79)	5.77 (1.89)	3.00 (0.00)	9.21 (1.61)
Internal Start Position		53.0% (187/353)	2.53% (4/158)	83.1% (59/71)	100% (124/124)
Crossing		47.3% (167/353)	0.0% (0/158)	73.2% (52/71)	92.7% (115/124)
Opposed		44.8% (158/353)	100% (158/158)	0% (0/71)	0% (0/124)
Team Structure	Balanced	10.8% (38/353)	24.1% (38/158)	0% (0/71)	0% (0/124)
	Unbalanced	34.0% (120/353)	75.9% (120/158)	0% (0/71)	0% (0/124)
	Unopposed	55.2% (195/353)	0.0% (0/158)	100% (71/71)	100% (124/124)
Phases	Multi-phase	44.8% (158/353)	100% (158/158)	0% (0/71)	0% (0/124)
	Single-phase	55.2% (195/353)	0% (0/158)	100% (71/71)	100% (124/124)
Decision Making	Semi-structured	21.5% (76/353)	0% (0/158)	9.86% (7/71)	55.6% (69/124)
	Yes	44.8% (158/353)	100% (158/158)	0% (0/71)	0% (0/124)

Table 6.3 Linear mixed-effects model results analysing the effect of drill category, prescriptive variables, playing position, and player MSS variables on the peak sprint speed attained during soccer-specific exercises as a percentage of MSS.

Fixed effects	Estimate	95% CI	P-value
Intercept	57.27%	44.35 – 70.20%	**<0.001**
Position			
CB vs. CM	4.67%	1.36 – 7.99%	**0.006**
CB vs. FB	9.82%	6.16 – 13.48%	**<0.001**
CB vs. FW	6.93%	3.59 – 10.27%	**<0.001**
Duration	0.84%	0.49 – 1.18%	**<0.001**
Minimum drill length	0.15%	-0.21 – 0.50%	0.417
Player MSS	-1.1%	-1.98 – -0.22%	**0.015**
Drill category			
Counterattack vs. finishing	-6.86%	-15.58 – 1.86%	0.123
Counterattack vs. pattern play	-7.64%	-14.62 – -0.66%	**0.032**

Estimates of the linear relationship between each fixed effect and relative peak speed. P-values are calculated via a conditional F-test using the Kenward-Roger approximation of degrees of freedom. CI: confidence interval, CB: central defenders, CM: central midfielders, FB: full-backs, FW: forwards and wide players, MSS: maximal sprint speed.

Table 6.4 Estimated marginal means and 90% confidence internal for each playing position and drill category group.

Group		EMM	95% CI
Position	CB	65.83	60.93 - 70.7
	CM	70.5	65.82 - 75.1
	FB	75.65	70.71 - 80.5
	FW	72.76	68.22 - 77.3
Category	Counterattack	76.02	69.51 - 82.52
	Finishing	69.16	61.47 - 76.84
	Pattern Play	68.38	62.71 - 74.04

Estimated marginal mean values for each group are derived from the linear mixed-effects model in Table 6.3 via the *emmeans* package for R. EMM: estimated marginal means, CI: confidence interval, CB: central defenders, CM: central midfielders, FB: full-backs, FW: forwards and wide players.

Table 6.5 Estimated marginal mean contrasts and associated P-value for each pair of playing position and drill category groups.

Contrast		EMM Difference	P-value
Position	CB vs. CM	-4.67	**0.048**
	CB vs. FB	-9.82	**<0.001**
	CB vs. FW	-6.93	**0.002**
	CM vs. FB	-5.15	**0.034**
	CM vs. FW	-2.26	0.506
	FB vs. FW	2.89	0.343
Category	Counterattack vs. Finishing	6.86	0.291
	Counterattack vs. Pattern Play	7.64	0.098
	Finishing vs. Pattern Play	0.78	0.966

Table values are contrasts between the estimated marginal means of the respective groups. P-values are calculated via a t-test of these means using the Kenward-Roger approximation of the degrees of freedom and Bonferroni adjustment for multiple comparisons. EMM: estimated marginal means, CI: confidence interval, CB: central defenders, CM: central midfielders, FB: full-backs, FW: forwards and wide players.

Table 6.6 Raw prescriptive variables of each drill included in the linear mixed-effects model analysis.

Drill	N	% MSS	Duration (min)
Counterattack 1	15	92.2 ± 4.9	18.5
Counterattack 2	10	87.4 ± 4.8	12.7 ± 0
Counterattack 3	3	85 ± 0	6.3
Finishing 1	4	82.3 ± 3.4	7.8
Counterattack 4	14	77.6 ± 8.3	17.5
Finishing 2	8	77.4 ± 6.7	16.7 ± 1.23
Counterattack 5	24	76.4 ± 6.4	7.4 ± 1.4
Counterattack 6	11	75.9 ± 5.3	20.2
Counterattack 7	4	75 ± 7	11.4
Counterattack 8	20	72.4 ± 9.9	0.9 ± 0.25
Finishing 3	6	70.5 ± 4.1	21.7
Pattern play 1	102	70.5 ± 11.1	14.3 ± 3.7
Finishing 4	29	70.3 ± 5.9	11.7 ± 1.1
Finishing 5	7	69.3 ± 5.5	15.4
Finishing 6	17	69.1 ± 7.3	10.1 ± 0.7
Pattern play 2	9	67.1 ± 11	14.3
Pattern play 3	13	62.2 ± 15	15.2
Counterattack 9	57	58.8 ± 11.1	2.6 ± 4.9

MSS: maximal sprint speed.

Discussion

This study examined the relative peak speed demands of several non-continuous, scenario-based soccer-specific exercises. Exercise category, playing position, player MSS, and exercise duration were all associated with changes in the peak speed demands during these exercises. These findings help inform exercise selection and design, and further clarify the practicality of meeting sprint objectives in training using soccer-specific exercises.

The peak sprinting speeds across the sample as a whole, and in the majority of exercises, were comparatively lower than those reported during previous studies of SSG and competition (Al Haddad et al., 2015; Djaoui et al., 2017; Kyprianou et al., 2022; Owen et al., 2014). Additionally, a limited number of observations reached high proportions of MSS, with 22.1% (78/353) and 4.8% (17/353) of all drill observations reaching at least 80% and 90% MSS, respectively. The soccer-specific exercises analysed therefore do not appear to be effective in meeting sprint objectives when compared with more commonly utilised SSG. There was however considerable variability (whole sample mean 71 ± 12% of MSS) in relative peak speed across the sample, which appears to be primarily attributable to between-exercise, rather than within-exercise, differences. This variability in sprint responses during soccer-specific exercises is arguably positive with regard to the viability of these exercises to elicit high percentages of MSS, at least when prescriptive variables are optimised. For example, as illustrated in Figure 6.1 and Table 6.6, one counterattacking exercise (drill 1) elicited an average peak sprint speed above 90% of MSS, while three drills (counterattack drills 2, 3, and finishing drill 1) elicited average peak speeds greater than 80% of MSS.

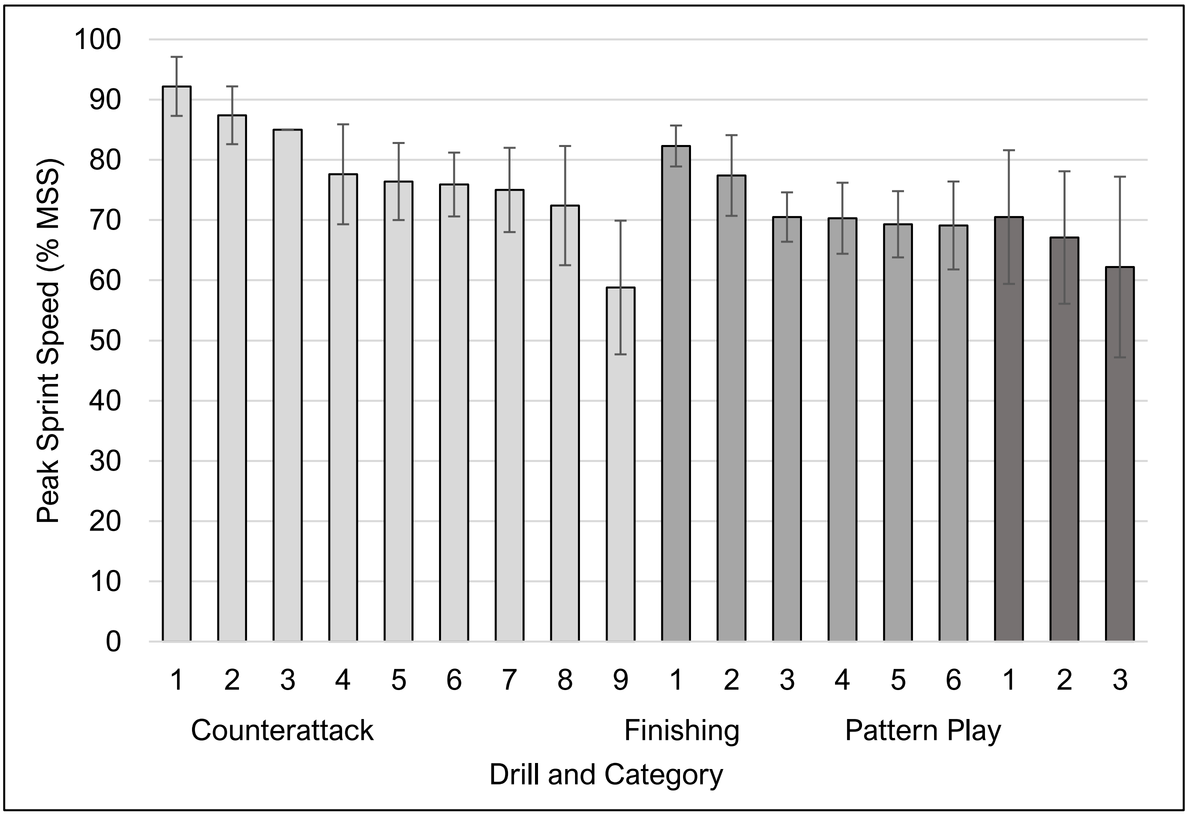


Figure 6.1 Raw mean ± SD of peak sprinting speed during three subcategories of soccer-specific exercises

Prescriptive variables and exercise categories

The results of the linear mixed-effects model showed limited differences between exercise categories. The counterattack exercises elicited greater peak sprint speeds than pattern play exercises (7.64, 90% CI -14.62 – -0.66, p=0.032), and a similar magnitude (but non-significant) marginal increase when compared to finishing exercises, while controlling for differences in other prescriptive variables (duration, drill length, etc). Due to the grouping of the prescriptive variables within exercise categories in the analysis, the exact prescriptive variables responsible for these effects (amongst those clustered within the counterattack category) are not determinable. Nonetheless, the results of the univariable modelling (which do not control for the effects of other prescriptive variables except minimum length, duration, or player MSS) loosely support an association between increased relative peak sprint speed and multi-phase exercise design compared to single-phase, and opposed play compared to unopposed play.

The counterattack exercises were exclusively played under opposed conditions (and almost exclusively in overload situations) and contained multiple phases in which players would attack and subsequently defend. This increased time/spatial pressure, and requirement to continuously regulate movement and behaviour in relation to the opposition, as well as teammates, was therefore the distinguishing feature of these exercises as compared to the more structured finishing and pattern-play exercises. It appears that players are provided with either more sprint opportunities, or more effective opportunities to reach greater running speed under these conditions/constraints. Similar effects were previously reported in analysis of soccer SSG with different team structures. The addition of neutral players to the team in possession, thereby easing the time/spatial pressure on the players (Vilar et al., 2014), has previously been shown to reduce the overall peak sprint demands (Chapter 5).

Effect of MSS

The linear mixed-effect model revealed an association between player MSS and the peak speed elicited during the training exercises, as faster players reached faster absolute (0.34, 95% CI 0.06, 0.61; p=0.018), and slower relative (-1.1, 95% CI: -1.98, -0.22; p=0.015) peak running speeds, per unit of MSS difference. In effect, this may be viewed as a compensatory mechanism by the slower players, who must account for their reduced MSS by reaching greater relative peak speeds in a given scenario. The authors' previous studies have not demonstrated this relationship between player MSS and peak sprint speed during SSG (Chapters 4 and 5). However, using a different method, Al Haddad et al. (2015) reported similar results in which the fastest player of each position group expressed their MSS advantage in competition compared to their slower peers, to the effect of a greater absolute speed and reduced relative speed. It appears that faster players experience the dynamic demands of the competition and training environment differently to slower players. This may have implications for the feasibility of prescribing soccer exercises with the purpose of eliciting maximal or near-maximal running efforts, in that the relative scarcity these efforts could be exacerbated for the fastest players.

Effect of duration

The overall duration of each drill appears to affect the resulting peak sprinting speed. For each minute of increase in exercise duration, there were associated increases in both relative (0.84%; 95% CI: 0.49, 1.18%; $p<0.001$) and absolute (0.27 $km \cdot h^{-1}$; 95% CI: 0.16, 0.38 $km \cdot h^{-1}$; $p<0.001$) peak sprint speed. These results are expected, and consistent with previous observations across varied soccer SSG using a similar method (Chapter 5). The positive association observed is likely influenced by the sensitivity of *peak* speed to a single value or effort, in contrast with average speed or cumulative distance covered above high-speed running thresholds. In the present study, all exercises were non-continuous (via the inclusion criteria) and consisted of multiple short phases or repetitions. Greater overall exercise durations clearly allow a greater number of potential repetitions or “sampling” of the running opportunities, of which a single effort is more likely to be performed at a greater speed. The use of peak speed as the primary variable in the present study is justified in the context of other research, as eliciting even a single effort at maximal or near maximal speed may be relevant with respect to reducing risk of injury (Malone et al., 2017). Consequently, extending the duration or increasing the “sample size” of exercises may be a useful design consideration if eliciting single efforts at high percentages of MSS is the training objective, provided sufficient rest between efforts.

Position differences

The modelling and subsequent pairwise testing indicate several position-specific differences in the relative peak speed responses while controlling for each of the prescriptive variables. Central defenders reached slower peak speeds than central midfielders (-4.67; p=0.048), full-backs (-9.82; p<0.001), and forwards (-6.93; p=0.002), while central midfielders reached slower peak speeds than full-backs (-5.15; p=0.034). Central defenders and midfielders experiencing less frequent and lower intensity sprint demands is typical when analysing soccer match-play and training (Ade et al., 2016; Bush et al., 2015; Mallo et al., 2015) and is typically thought to result from differences in tactical roles (Ade et al., 2016; Di Salvo et al., 2009; Rampinini, Coutts, et al., 2007).

One possible explanation for these results is that players self-select opportunities to express their sprint ability according to the same physical/tactical traits that lead them to be selected in their respective position. For example, compared to central defenders, forwards may be more likely to take opportunities to make explosive attacking runs based on their (perceived or real) ability in this area, and interpretation of their tactical role via the coach.

Limitations

There are several factors which should be accounted for in the interpretation of this study. Firstly, very few studies have analysed movement data outside of an SSG-based framework. While this study is therefore able to establish a baseline for further research, there is a lack of research examining or classifying similar training exercises. While analysing more prescriptive variables (such as those investigated in the univariable modelling) would have been preferable, the structure of the sample with respect to the inherent clustering of prescriptive variables within the three exercise categories (and subsequent rank-deficiency within the mixed-effects model structure) made this approach not viable.

Secondly, the participating players are not full-time professional soccer players. However, the team plays in the highest tier of soccer competition in the Oceania Federation, and trains frequently (4 trainings and 1 match per week). While they are likely to possess different physical capabilities to elite professional players (Bradley et al., 2009), the mean MSS of the group (32.1±1.4 $km\cdot h^{-1}$) is comparable to those reported in studies of professional players (Djaoui et al., 2017), and slightly lower than reported in studies of elite European players (Buchheit et al., 2021).

Finally, due to the observational method used in the present study, the findings are strongly influenced by the prescriptive choices and exercise design of the participating team's coaching staff. The coaching staff must, however, balance multiple factors in the selection and execution of training exercises, including player motivation and enjoyment, the tactical needs of the team, and variety. It could therefore be argued that the results of the study serve as a critique of these choices with respect to training specificity. Theoretically, a substantial proportion of training exercises leading to goal-scoring actions *should* provide players with the opportunity to sprint, as is present in a larger proportion of goals scored in competition (Faude et al., 2012). As such, it is evident the physical aspect of specificity is not being attained in these drills.

Conclusions

Overall, the soccer-specific exercises analysed in the present study elicited a range of peak speed responses. Some expected (playing position or MSS dependent) and previously unreported (drill category and prescriptive variable) differences in relative peak speed have been illustrated within the present sample that further inform the relationship between soccer exercise design and peak running demands. However, it is critical to note that none of the prescriptive variables appear (on average) able to reliably elicit peak running speeds above 90% MSS. This represents a significant obstacle to the idea that soccer-specific exercises in a broad sense can provide the opportunity to reach maximal or near-maximal sprint speeds.

Nonetheless, the exercises reaching the very fastest peak speeds in the sample did show some promise. If coaches/practitioners prefer to conduct sprint training in a more soccer-specific manner and reach >95% of peak sprint speed, hybrid exercises (such in Jastrzebski et al. (2015) without decision-making opportunities and with limited soccer-specific elements such as dribbling during a sprint, or very simple shooting exercises that prioritise the sprint components, may represent the limit of soccer-specificity or task decomposition.

References

Abbott, W., Brickley, G., & Smeeton, N. J. (2018). An individual approach to monitoring locomotive training load in English Premier League academy soccer players. *International Journal of Sports Science & Coaching*, *13*(3), 421–428.

Ade, J., Fitzpatrick, J., & Bradley, P. S. (2016). High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions. Information for position-specific training drills. *Journal of Sports Sciences*, *34*(24), 2205–2214.

Al Haddad, H., Simpson, B. M., Buchheit, M., Di Salvo, V., & Mendez-Villanueva, A. (2015). Peak match speed and maximal sprinting speed in young soccer players: Effect of age and playing position. *International Journal of Sports Physiology and Performance*, *10*(7), 888–896.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences*, *27*(2), 159–168.

Buchheit, M., Lacome, M., Cholley, Y., & Simpson, B. M. (2018). Neuromuscular responses to conditioned soccer sessions assessed via GPS-embedded accelerometers: Insights into tactical periodization. *International Journal of Sports Physiology and Performance*, *13*(5), 577–583.

Buchheit, M., Simpson, B. M., Hader, K., Lacome, M., Buchheit, M., Simpson, B. M., … Lacome, M. (2021). Occurrences of near-to-maximal speed-running bouts in elite soccer: Insights for training prescription and injury mitigation. *Science and Medicine in Football*, *5*(2), 105–110.

Bush, M., Barnes, C., Archer, D. T., Hogg, B., & Bradley, P. S. (2015). Evolution of match performance parameters for various playing positions in the English Premier League. *Human Movement Science*, *39*, 1–11.

Clemente, F. M., Martins, F. M. L., & Mendes, R. S. (2014a). Developing aerobic and anaerobic fitness using small sided games: Methodological proposals. *Strength and Conditioning Journal*, *36*(3), 76–87.

Clemente, F. M., Martins, F. M. L., & Mendes, R. S. (2014b). Periodization based on small-sided soccer games: Theoretical considerations. *Journal of Strength and Conditioning Research*, *36*(5), 34–43.

Colby, M. J., Dawson, B. T., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *Journal of Strength and Conditioning Research*, *28*(8), 2244–2252.

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews*, *41*(3), 154–161.

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine*, *30*(3), 205–212.

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal sprinting speed of elite soccer players during training and matches. *Journal of Strength and Conditioning Research*, *31*(6), 1507–1517.

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, *30*(7), 625–631.

Gabbett, T. J., Jenkins, D., & Abernethy, B. (2009). Game-based training for improving skill and physical fitness in team sport athletes. *International Journal of Sports Science & Coaching*, *4*(1), 273–283.

Gaudino, P., Alberti, G., & Iaia, F. M. (2014). Estimated metabolic and mechanical demands during different small-sided games in elite soccer players. *Human Movement Science*, *36*, 123–133.

Girard, O., Mendez-Villanueva, A., & Bishop, D. (2011). Repeated-sprint ability: factors contributing to fatigue. *Sports Medicine*, *41*(8), 673–694.

Hill-Haas, S. V., Dawson, B. T., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in football: A systematic review. *Sports Medicine*, *41*(3), 199–220.

Jastrzębski, Z., & Radzimiński, L. (2015). Individual vs general time-motion analysis and physiological responses in 4 vs 4 and 5 vs 5 small-sided soccer games. *International Journal of Performance Analysis in Sport*, *15*, 397–410.

Kyprianou, E., Di Salvo, V., Lolli, L., Al Haddad, H., Villanueva, A. M., Gregson, W., & Weston, M. (2022). To measure peak velocity in soccer, let the players sprint. *Journal of Strength and Conditioning Research*, 36(1), 273–276.

Ludecke, D. (2019). *sjPlot: Data visualization for statistics in social science*. https://doi.org/10.5281/zenodo.1308157

Mallo, J., Mena, E., Nevado, F., & Paredes, V. (2015). Physical demands of top-class soccer friendly matches in relation to a playing position using global positioning system technology. *Journal of Human Kinetics*, *47*(1), 179–188.

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport*, *20*(3), 250–254.

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2014). Physical and technical comparisons between various-sided games within professional soccer. *International Journal of Sports Medicine*, *35*(4), 286–292.

R Core Team. (2019). *R: A language and environment for statistical computing*. Retrieved from www.R-project.org/

Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007). Variation in top level soccer match performance. *International Journal of Sports Medicine*, *28*(12), 1018–1024.

Roca, A., & Ford, P. R. (2020). Decision-making practice during coaching sessions in elite youth football across European countries. *Science and Medicine in Football*, *4*(4), 263–268.

Vilar, L., Esteves, P., Travassos, B., Passos, P., Lago-Peñas, C., & Davids, K. (2014). Varying numbers of players in small-sided soccer games modifies action opportunities during training. *International Journal of Sports Science and Coaching*, *9*(5), 1007–1018.

Wickham, H. (2009). *ggplot2: Elegant graphics for data analysis*. Retrieved from http://ggplot2.org

Chapter 7: Absolute and relative sprint demands of high-level amateur soccer matches: What are we preparing for?

Abstract

Sprinting is a fundamental element of elite soccer performance, while simultaneously playing a key role in injury aetiology and management of injury risk. Despite the large variation possible in individual maximal sprinting speed (MSS), quantification of competition demands using individualised movement thresholds is limited. This study analysed the absolute and relative sprint demands of 12 high-level amateur men's soccer matches as recorded by global position system (GPS) devices. The average peak sprint speed achieved was 29.1 ± 2.1 km·h^{-1} (89.4 ± 5.8% of MSS). Players reached 90% and 95% of MSS in 44.7% and 16.7% of all match halves included in the analysis, respectively. First halves produced fewer sprints (0.34 ± 0.60 efforts vs 0.63 ± 0.95 efforts, $p=0.002$) and less distance covered (3.96 ± 7.36 m vs 7.73 ± 12.2 m, $p=0.003$) above 90% of MSS compared to second halves. Several position-specific differences were evident in generic movement variables, while differences in sprint demands were only apparent between central midfielders and forwards. Several effects were revealed according to player sprint ability. For each 1 km·h^{-1} increase in MSS, players reached higher absolute sprinting speeds (0.63 km·h^{-1}, 95% CI 0.32, 0.94; $p<0.001$) and covered greater distances above generic sprint thresholds (10.09 m, 95% CI 2.1, 18.1; $p=0.013$). In summary, significant sprint demands are present in soccer competition, even at the sub-elite level. Positional differences in sprint demands within match halves could have a large influence on the suggested sprint exposure required in training. Given the influence of player MSS on the distance covered above absolute sprint thresholds, these values may therefore not be as useful as a measure of the training stimulus provided by competition.

Key words: Soccer, Sprinting, Injury

Introduction

Sprinting is a fundamental element of competition in elite soccer and players are frequently required to sprint during goalscoring actions that decide match outcomes (Faude et al., 2012). However, sprinting is a demanding exercise with an associated level of injury risk. Sprinting is the predominant aetiology of hamstring strain injuries (Woods et al., 2004), which have been reported to result in the greatest injury burden as a combination of frequency and severity (Ekstrand et al., 2011). Given the financial (Hickey, Shield, Williams, & Opar, 2014) and competitive (Hägglund et al., 2013) cost of injuries in elite sport, it is not surprising that many studies seek to understand how to effectively and safely prepare players to meet the demands of training and competition with regards to sprinting.

Progressive exposure of players to maximal and near-maximal running in training is increasingly viewed as a key component in injury prevention and HSI rehabilitation (Buckthorpe, Wright, Virgile, & Gimpel, 2019; Colby et al., 2014; Malone et al., 2017; Mendiguchia et al., 2017). Malone et al. (2017) suggested that even a single effort above 90% of maximal sprint speed (MSS) within a training week may have a protective effect against injury. Buchheit et al. (2020) further recommended that amongst elite professional teams, a cumulative volume of sprinting in accordance with the frequency of matches played should be maintained in order to avoid sudden increases in the total sprint demands experienced. For example, to prepare for periods of condensed competition schedules (often playing 3 matches in 7 days) (Carling et al., 2015), players should be gradually conditioned to perform a total weekly sprinting volume of approximately 2- to 3-fold a typical match. The match itself also provides a key opportunity for this sprint training stimulus and may comprise the entire weekly sprint exposure for starting players, while additional sprint training opportunities are likely required for substitutes and non-playing team members (Buchheit et al., 2021). However, determining the quantity and quality of sprinting to perform in elite soccer training in order to reduce injuries, prepare for competition, or enhance sprint ability is clearly a complex issue, encompassing individual dose-response differences, injury history, and position or individual-specific match roles among other factors (Ade et al., 2016; Halson, 2014; Weston, 2013).

The sprint ability of elite soccer players can vary substantially (Al Haddad et al., 2015; Djaoui et al., 2017; Kyprianou et al., 2022; Mendez-Villanueva, Buchheit, Simpson, et al., 2011). As a result, individualised or relative measures of sprint demands may be more informative than absolute measures (Lovell & Abt, 2013; Weston, 2013) with respect to either the possible "protective" effect of sprinting (Malone et al., 2017), or of the training stimulus in general (Weston, 2013). Quantification of match demands is also surprisingly limited, particularly when considering studies that have accounted for MSS of the participants. Al Haddad et al. (2015) and Djaoui et al. (2017) both reported relative peak speeds during competition of approximately 90% of MSS, while further studies primarily report absolute peak speeds between 27-30 km·h^{-1} (Bradley et al., 2009; Kyprianou et al., 2022; Oliva-Lozano, Fortes, & Muyor, 2023). To the authors' knowledge, only one study has reported the number of efforts above MSS thresholds in a detailed, position-specific manner (Buchheit et al., 2021). To date, no study has combined these approaches to give a full overview of both generic and individualised sprint variables during competition.

This study aims to describe the sprint demands of high-level amateur soccer competition using the frequency of efforts, distance covered, and peak speeds reached within both individualised and absolute measurement approaches. This information can assist coaches and practitioners in further contextualising the planning of sprint training, injury prevention, and physical preparation.

Methods

Approach to the Problem

In order to examine the relative sprint demands of competitive matches, movement data from 12 competitive matches (10 regular season and 2 playoff matches) were analysed along with several descriptive variables using a linear mixed-effect model framework. Data from the 1st and 2nd half of each match were analysed separately, and only complete halves of play included in the final sample. Players that were substituted into or out of play during a half were removed from the sample to ensure playing time and match situation was consistent amongst participating players for a given match-day. Only results from matches without a red card were included in the analysis due to the inconsistent effects of unbalanced player numbers on tactical and physical demands.

Subjects

Seventeen male players aged 27.3 ± 3.7 years (mean ± SD) volunteered to participate in the study. The participants belonged to a club competing in the highest competitive tier of domestic soccer in New Zealand. All participants were full-time members of the squad, completing four training sessions and one competitive match during a typical week. Ethical approval was obtained from the University's Human Ethics Committee and all participants gave informed consent. Each player was allocated a playing position descriptor from one of centre-back (CB), full-back (FB), central midfielder (CM), and forward (FW) according to their predominant role during competition.

Procedures

Movement demands during competition were recorded using 10 Hz global positioning system (GPS) units (VX Sport, Wellington, New Zealand) worn in a secure vest, while each player used the same unit for the duration of the study whenever possible to eliminate inter-device error. The MSS of each player was determined using 10 Hz

GPS, recorded as the greatest speed reached in all training and competition activity throughout the given season. Players completed 3-5 maximal sprint efforts from a standing start over 30-40 m on four occasions in the course of normal training throughout the study duration. Absolute and individualised movement demands were collected. Absolute data include the peak running speed ($km \cdot h^{-1}$), total distance covered, distance covered between 14.4-19.8 $km \cdot h^{-1}$, distance covered between 19.8-25.2 $km \cdot h^{-1}$, and distance covered above 25.2 $km \cdot h^{-1}$. Individualised demands include the relative peak running speed (as a proportion of player MSS), distance covered and number of efforts above 80% of MSS, and distance covered and number of efforts above 90% of MSS.

Statistical Analyses

Linear mixed-effects models were utilised to examine the influence of different descriptive factors on each of the movement demand (dependent) variables collected during the study. This analysis method was chosen due to the ability to account for the repeated measures within each individual and match date, and the unbalanced data structure with multiple missing values (due to player selection). The variables included as fixed effects in the 9 linear mixed-effects models (one for each dependent variables) were the playing position groups (CB, FB, CM, FW), match half (1st or 2nd half), and individual MSS. Player MSS was rescaled (mean-centred) prior to inclusion in the model. Player identification code and competition date were included as random effects in the model.

Linear mixed-effects model parameter estimates for the effect of MSS on each dependent variable are reported, alongside the associated confidence intervals (CIs), and p-values. P-values were calculated via conditional F-tests using the Kenward-Roger approximation of degrees of freedom. For each playing position and match half, estimated marginal means were calculated according to the linear mixed-effects model for each dependent variable. Estimated marginal means were then compared using pairwise Bonferroni-adjusted t-tests. All data analyses were produced in R (R Core Team, 2019) using the *lme4* (Bates et al., 2015), *ggplot2* (Wickham, 2009), and *sjPlot* (Ludecke, 2019) packages. The alpha level for analysis was set at $p<0.05$. All descriptive data are presented as mean ± SD.

Results

A total of 228 complete match halves were included in the final sample for analysis. The mean MSS of the participating players as recorded in the course of training was 32.2 ± 1.4 km·h^{-1}. Table 7.1 reports the mean ± SD for each of the movement demand variables across all halves included in the analysis.

Table 7.1 Raw mean ± SD, and frequency of reaching 80, 85, 90, and 95% of MSS for all match halves included in the analysis.

Variable	**All** *n=228*	**1st Half** *n=130*	**2nd Half** *n=98*
Peak Speed (km·h^{-1})	29.1 ± 2.11	29.0 ± 2.02	29.3 ± 2.22
Relative Peak Speed (% MSS)	89.4 ± 5.8	89.1 ± 5.6	89.7 ± 6.1
Total Distance (m)	5381 ± 456	5445 ± 441	5296 ± 464
Distance covered 14.4-19.8 km·h^{-1} (m)	824 ± 224	846 ± 223	796 ± 223
Distance covered 19.8-25.2 km·h^{-1} (m)	264 ± 97.3	264 ± 98.8	265 ± 95.6
Distance covered >25.2 km·h^{-1} (m)	55.4 ± 42	52.0 ± 41.7	59.8 ± 42.3
Distance covered 80-100% MSS (m)	38.6 ± 34.1	32.0 ± 26.4	34.4 ± 30.2
Distance covered 90-100% MSS (m)	5.58 ± 9.9	3.96 ± 7.36	7.73 ± 12.2
Number of efforts 80-100% MSS (num)	2.55 ± 2.2	2.20 ± 1.88	1.94 ± 1.75
Number of efforts 90-100% MSS (num)	0.46 ± 0.78	0.34 ± 0.60	0.63 ± 0.95
Reached 80% MSS*	94.7% (216/228)	94.6% (123/130)	94.9% (93/98)
Reached 85% MSS*	78.5% (179/228)	77.7% (101/130)	79.6% (78/98)
Reached 90% MSS*	44.7% (102/228)	41.5% (54/130)	49.0% (48/98)
Reached 95% MSS*	16.7% (38/228)	13.1% (17/130)	21.4% (21/98)

MSS: maximal sprint speed. *Denotes variable reporting frequency of reaching percentages of MSS as determined by individual maximal sprint speed.

The linear mixed-effects models revealed a significant association between player MSS and absolute peak speed (0.63 km·h^{-1}, 95% CI 0.32, 0.94; $p<0.001$), distance covered above 25.2 km·h^{-1} (10.09 m, 95% CI 2.1, 18.1; $p=0.013$), and distance covered between 80-100% MSS (-7.25 m, 95% CI -13.87, -0.63; $p=0.032$). Player MSS was not significantly associated with changes in relative peak speed (-0.86%, 95% CI -1.81, 0.08, $p=0.074$), distance covered between 14.4-19.8 km·h^{-1} (-20.7 m 95% CI -69.9, 28.45; $p=0.41$), distance covered between 19.8-25.2 km·h^{-1} (3.56 m, 95% CI -12.45, 19.57; $p=0.663$), distance covered between 90-100% MSS (-1.27 m, 95% CI -2.67, 0.13; $p=0.075$), number of efforts between 80-100% MSS (-0.38, 95% CI -0.84, 0.07; $p=0.099$), and number of efforts between 90-100% MSS (-0.1, 95% CI -0.24, 0.05; $p=0.2$). Pairwise testing of the movement variable estimated marginal means revealed significant differences between the 1st and 2nd halves for the number of efforts (-0.277, $p=0.002$) and distance covered (-3.704, P-0.003) above 90% of MSS only. Tables 7.2 and 7.3 report the estimated marginal means of each of the movement variables across the four playing position groups, and the pairwise differences and associated p-value between these groups, respectively.

Table 7.2 Estimated marginal means (95% CI) of the movement demand variables for each playing position.

Variable	EMM (95% CI)			
	CB	CM	FB	FW
Relative Peak Speed (% MSS)	88.6 (84.86, 92.34)	86.85 (83.64, 90.06)	89.99 (86.85, 93.12)	92.05 (88.91, 95.19)
Peak Speed (km·h^{-1})	28.85 (27.62, 30.09)	28.31 (27.26, 29.37)	29.32 (28.29, 30.35)	30.03 (28.99, 31.06)
Distance covered 14.4-19.8 km·h^{-1} (m)	602.1 (447.06, 757.14)	973.16 (833.21, 1113.1)	751.12 (624.24, 878)	825.85 (689.02, 962.68)
Distance covered 19.8-25.2 km·h^{-1} (m)	169.19 (107.94, 230.45)	274.74 (220.09, 329.38)	269.22 (218.04, 320.4)	327.72 (274.41, 381.02)
Distance covered >25.2 km·h^{-1} (m)	48.42 (19.44, 77.4)	42 (16.43, 67.57)	57.9 (34.41, 81.39)	75.81 (50.97, 100.66)
Distance covered 80-100% MSS (m)	34.33 (10.05, 58.62)	25.96 (4.57, 47.35)	41.84 (22.08, 61.6)	53.68 (32.88, 74.48)
Distance covered 90-100% MSS (m)	5.03 (-0.76, 10.82)	2.75 (-2.2, 7.69)	5.66 (0.63, 10.68)	9.66 (4.83, 14.49)
Efforts 80-100% MSS (num)	2.25 (0.66, 3.83)	1.88 (0.47, 3.28)	2.45 (1.17, 3.72)	3.8 (2.43, 5.16)
Efforts 90-100% MSS (num)	0.39 (-0.16, 0.94)	0.22 (-0.26, 0.7)	0.48 (0.03, 0.93)	0.81 (0.34, 1.28)

Estimated marginal mean values for each playing position are derived from the linear mixed-effects models for each dependent variable via the *emmeans* package for R, and control for differences in player maximal sprint speed and half. EMM: Estimated marginal means, CI: Confidence interval, MSS: Maximal sprint speed, CB: central defenders, CM: central midfielders, FB: fullbacks, FW: forwards.

Table 7.3 Pairwise differences of the estimated marginal means (95% CI) of the movement demand variables for each playing position.

Variable	∆EMM					
	CB vs CM	**CB vs FB**	**CB vs FW**	**CM vs FB**	**CM vs FW**	**FB vs FW**
Relative Peak Speed (% MSS)	1.753, p=0.724	-1.387, p=0.814	-3.449, p=0.203	-3.14, p=0.211	-5.202, p=0.018*	-2.062, p=0.546
Peak Speed (km·h^{-1})	0.54, p=0.763	-0.463, p=0.808	-1.172, p=0.185	-1.003, p=0.234	-1.712, p=0.018*	-0.71, p=0.511
Distance covered 14.4-19.8 km·h^{-1} (m)	-371.059, p<0.001**	-149.02, p=0.024*	-223.75, p=0.015*	222.039, p<0.001**	147.309, p=0.074	-74.73, p=0.578
Distance covered 19.8-25.2 km·h^{-1} (m)	-105.542, p=0.005*	-100.027, p=0.001**	-158.523, p<0.001**	5.515, p=0.995	-52.981, p=0.163	-58.496, p=0.094
Distance covered >25.2 km·h^{-1} (m)	6.423, p=0.964	-9.481, p=0.843	-27.393, p=0.209	-15.904, p=0.506	-33.816, p=0.045*	-17.912, p=0.441
Distance covered 80-100% MSS (m)	8.376, p=0.88	-7.508, p=0.866	-19.35, p=0.338	-15.884, p=0.357	-27.725, p=0.052	-11.842, p=0.634
Distance covered 90-100% MSS (m)	2.281, p=0.789	-0.629, p=0.994	-4.634, p=0.273	-2.91, p=0.64	-6.915, p=0.043*	-4.005, p=0.346
Efforts 80-100% MSS (num)	0.369, p=0.961	-0.2, p=0.988	-1.551, p=0.194	-0.569, p=0.791	-1.92, p=0.035*	-1.35, p=0.181
Efforts 90-100% MSS (num)	0.164, p=0.916	-0.09, p=0.978	-0.422, p=0.361	-0.254, p=0.665	-0.587, p=0.079	-0.333, p=0.466

Values shown are the differences between estimated marginal means for each playing position group. P-values are calculated from t-tests using the Kenward-Roger approximation of degrees of freedom. EMM: estimated marginal means, CI: Confidence interval, MSS: maximal sprint speed, CB: central defenders, CM: central midfielders, FB: fullbacks, FW: forwards. * Denotes statistically significant T-test result at the p<0.05 level. ** Denotes statistically significant T-test result at the p<0.001 level.

Discussion

The main purpose of this study was to thoroughly describe the sprint demands of competitive soccer matches using relative or individualised performance variables. The present sample of matches played by high-level amateur players displayed significant sprint demands, similar to those reported amongst the most elite levels of competition (Buchheit et al., 2021; Djaoui et al., 2017). Using a linear mixed-effects model, position-specific differences in absolute running variables were observed, while limited differences in sprint demands were evident only between central midfielders and forwards. Sprint demands increased in the second half of matches, and player MSS had a significant effect on absolute peak sprint speed, and distances covered above 25.2 $km \cdot h^{-1}$ and between 80-100% of MSS. This study provides valuable data to underline the prevalence of near-maximal sprint demands across different competitive levels of soccer, and aids in contextualising training objectives.

Overall match sprint demands

On average, players reached a peak speed of 29.1 ± 2.1 $km \cdot h^{-1}$ during each complete match half, corresponding to 89.4 ± 5.8% of individual MSS. Both the absolute and relative peak sprint demands observed in the present study are broadly in line with those reported in the limited number of previous studies (Al Haddad et al., 2015; Bradley et al., 2009; Djaoui et al., 2017; Kyprianou et al., 2022), despite differences in competitive level. The players in the present study also performed very similarly to those of Buchheit et al. (2020) with respect to the number of efforts and distance covered above 80% and 90% of MSS. In a key finding, players reached 95% of MSS in 16.7% of total halves, and 90% of MSS in 44.7% of total halves. This is a key finding as it demonstrates that, while maximal sprint efforts are not widespread, several outfield players can still be expected to exceed 95% of MSS over the course of a full match.

Collectively, it is clear soccer match-play elicits significant sprint demands that approach MSS. This underlines the importance of training both to develop sprint ability and endure repeated maximal sprint demands over the course of a competitive season. The peak sprint speed demands evident during competition in the present study are also considerably greater than those reported during common soccer-specific exercises such as small-sided games (SSG) (Djaoui et al., 2017; Kyprianou et al., 2022; Owen et al., 2014), as summarised in Table 7.4. These differences in peak speed may be due to the increased playing area in official matches when compared to training exercises (Djaoui et al., 2017). These findings show the key role of competitive matches in providing players with a soccer-specific sprint training stimulus (Buchheit et al., 2021), while also highlighting that, outside of competition, isolated sprinting exercises are likely required in order to consistently reach sprinting speeds greater than 95% of MSS.

Competitive level of players

The similarity of the absolute and relative sprint demands reported in the present study, when compared to studies investigating professional players at nominally higher competitive levels, e.g., English Premier League (Bradley et al., 2009), French Ligue 1 (Buchheit et al., 2021; Djaoui et al., 2017), and elite academy environments (Al Haddad et al., 2015; Kyprianou et al., 2022) is also a key result. This could infer that the players in the current study are of a similar physical ability as those in higher competitive levels, or more likely, that the lower competitive level does not appear to alter the frequency or intensity of the sprint demands. Interestingly, previous studies analysing the physical demands across multiple competitive tiers of professional soccer (Bradley et al., 2013) demonstrated greater high-intensity running (19.8-25.2 $km \cdot h^{-1}$) and sprint (>25.2 $km \cdot h^{-1}$) distances covered in lower competitive tiers. Differences in frequency and intensity of the acceleration demands, however, may still persist across competitive levels (Ingebrigtsen, Dalen, Hjelde, Drust, & Wisløff, 2015). It is plausible that players at the highest levels of the game are tactically and technically more astute, and as such better able to positively effect performance outcomes through shorter, explosive movements.

Table 7.4 Peak sprinting speeds during common soccer training exercises.

Study	Sample	Training exercise	Peak sprint speed ($km \cdot h^{-1}$)
Owen et al., 2014 (29)	16 elite male professional soccer players	Small-sided games (4 vs. 4)	21.6 ± 1.3
		Medium-sided games (5 vs. 5, 6 vs. 6, 7 vs. 7, 8 vs. 8)	22.5 ± 0.9
		Large-sided games (9 vs. 9, 10 vs. 10, 11 vs. 11)	24.6 ± 0.9
Djaoui et al., 2017 (11)	14 full-time professional players from French Ligue 1	4 vs. 4	22.4 ± 1.6
		5 vs. 5	23.1 ± 2.9
		5 vs. 5 Possession	21.1 ± 2.6
		5 vs. 5 Mini goals	22.7 ± 3.4
		6 vs. 6 (40 x 40 m)	25.0 ± 2.3
		6 vs. 6 (50 x 60 m)	25.7 ± 3.4
		7 vs. 7	19.9 ± 2.1
		7 vs. 7 Possession	22.5 ± 2.0
		8 vs. 8	25.1 ± 1.8
		8 vs. 8 Possession	22.7 ± 2.2
		8 vs. 8 Mini goals	25.6 ± 3.3
		9 vs. 9 (50 x 60 m)	25.1 ± 2.8
		9 vs. 9 (70 x 55 m)	25.6 ± 3.0
		10 vs. 10	24.5 ± 2.3
		Matches (11 vs. 11)	28.7 ± 1.9
Kyprianou et al. 2019 (20)	12 full-time male soccer players from an elite academy	Small-sided games	18.9 ± 3.3
		Medium-sided games	23.0 ± 2.7
		Large-sided games	25.0 ± 2.3
		Matches	28.6 ± 1.8

MSS effects

According to the linear mixed-effects modelling, greater MSS was associated with increases in both absolute peak speed and distance covered above 25.2 $km \cdot h^{-1}$, and negatively associated with the distance covered between 80-100% of MSS.

Explanation of these two positive relationships appears straightforward; faster players are able to reach greater peak speeds and more easily accrue distance above generic sprint speed thresholds during competition. Several studies investigating the application of individualised movement speed thresholds have reported similar results in both training (Abbott et al., 2018a) and competition (Lovell & Abt, 2013). These effects call into question the usefulness of absolute sprint thresholds when considering the sprint training stimulus provided in competition. Whilst faster and slower players experience similar levels of relative sprint demands (implied in the lack of association between MSS and relative peak sprint speed), this stress or demand is underrepresented according to the variables that rely on the absolute sprint speed threshold (25.2 km·h^{-1}).

The mechanism behind a negative relationship between MSS and the distance covered between 80-100% of MSS is less clear. It is possible that the slower players were more likely to reach 80% of their MSS, during match actions with a “fixed” absolute speed demand (Mendez-Villanueva, Buchheit, Simpson, et al., 2011). In the context of the positive associations reported above, it may be that faster players covered substantial distances while sprinting over 25.2 km·h^{-1}, but below 80% of their MSS (average 27.1 km·h^{-1} for the 5 fastest players, compared to 24.5 km·h^{-1} for the 5 slowest). Mendez-Villanueva et al. (2011) investigated differences between the fastest player and slower players within the same position group, finding differences in the utilisation of MSS according to both these descriptors and playing position. While Al Haddad et al. (2015) did not necessarily corroborate these findings, it does appear from the collective results that players with greater and lesser sprinting ability experience the dynamic demands of competition differently according to the analysis method used to determine movement demands. Whether these relative differences alter the physiological responses or training stimulus in a meaningful way requires further research.

Position differences

With respect to the contrasts in high-intensity running demands between playing positions, the present results are in agreement with previous research. Several differences, particularly between central defenders and all other position groups, were observed in the distance covered between 14.4-19.8 and 19.8-25.2 $km \cdot h^{-1}$ during matches. It is broadly accepted that different playing positions perform distinct tactical roles, resulting in differing activity profiles (Ade et al., 2016; Oliva-Lozano et al., 2020).

Sprint demands were less varied amongst playing positions, with only central midfielders performing less sprinting than forwards across several variables. Reduced sprint demands for central midfielders when compared to other positions has been a consistent finding (Bradley et al., 2009), as has the overall lack of position-specific differences evident in near-to-maximal, relative sprint demands (Buchheit et al., 2021). Given that the sprint activity profile for each position differs in contextual variables (e.g. attacking/defending, with/without ball possession, within attacking/defending half), while these contextual variables are associated with significant differences in absolute sprint distance and peak running speed (Oliva-Lozano et al., 2021), position-specific differences in sprint demands are expected in competition. It is possible that the low frequency of sprint efforts and high match-to-match variability in sprint demands (Gregson et al., 2010) make any differences difficult to detect, particularly when correcting for multiple comparisons in a smaller sample size. However, taken with the above results concerning player MSS, the present results suggest that differences in sprint performance between players are more attributable to each player's physical characteristics, than playing positions *per* *se* (though, physical characteristics are more than likely to inform selection and identification of players into these positions).

Half effects

Both the number of efforts and total distance covered above 90% of MSS were greater in the second compared to the first half, while no other differences between match halves were observed. The results of previous research are inconsistent, with studies both showing no differences in sprint demands between halves (Buchheit et al., 2021), or greater demands during 1st halves (Oliva-Lozano et al., 2021). More broadly, absolute movement thresholds typically exhibit reductions between the first and second halves, though these are often accompanied by increases in late-match, within-half epochs (e.g., 5-min or 15-minute), considered to be related more to effective playing time and match situation (e.g., current score) (Bradley & Noakes, 2013). A similar rationale may explain these findings, where match situation dictates more frequent and intense sprint actions during the 2nd half.

Limitations

There are some limitations that must be considered with the results of the present study. Firstly, the combination of relative infrequency and high variability of measures within small intervals such as efforts or distance covered above 90% MSS during matches make appropriate analysis difficult without very large samples, particularly when comparing playing position groups. While the present sample size is comparable with those of several previous studies (Ingebrigtsen et al., 2015; Oliva-Lozano et al., 2021) the results of studies such as Buchheit et al. (2020) with an approximately 10-fold greater sample size may be more sensitive. Secondly, match running demands are understood to be subject to several contextual and environmental effects, including ambient temperature and humidity (Trewin et al., 2017), contrast in the teams' competitive levels (Rampinini et al., 2009), current match scores (Lago-Peñas et al., 2010), and team formations (Tierney et al., 2016), among other factors. These factors, which were not explored in the current study, may have influenced the results.

Practical Applications

The results of the present study are in agreement with previous research suggesting that competitive soccer has moderate-to-high sprinting demands, with players reaching an average of 89.4 ± 5.8 of MSS during each half. Furthermore, efforts above 95% of each player's MSS were reasonably frequent, occurring in 16.7% of all match halves. From a practical perspective, these results underline that in order to prepare effectively for the "worst-case scenario" of sprint demands during competition, soccer players must be conditioned to perform sprint efforts as high as (or above) 95% of MSS.

Previous research has recommend that players perform a consistent volume of sprinting in accordance with the frequency of matches they are required to play, in order to avoid sudden increases in the total volume of sprinting that increase the risk of injury (Buchheit et al., 2021; Malone et al., 2017). The position-specific differences in match sprinting demands reported in the current study support divergent training requirements for certain playing positions, even at sub-elite competitive levels. For example, to prepare for the demands of 3 matches in 7 days, forwards might require approximately 5-6 efforts above 90% of MSS per week, while central midfielders require 2-3 efforts above 90% MSS. During these periods of fixture congestion, this volume of sprinting may be met entirely through competition demands, though the high match-to-match variation also reported presently necessitates continuous monitoring and adjustment of the sprint training stimulus provided. Substitutes or non-playing team members would certainly require additional sprinting outside of competition, which, given the results of studies examining sprint demands of SSG

(Djaoui et al., 2017; Kyprianou et al., 2022; Owen et al., 2014) likely necessitates additional isolated sprint training.

Additionally, this study demonstrated that faster and slower players utilise their sprint ability differently in competition, with faster players reaching higher peak speeds and accumulating greater distance covered above conventional sprint speed thresholds. Given the variation possible in player MSS and clear influence on conventional sprint threshold metrics, relative measures such as the distance covered above 80% or 90% of MSS may be more informative with respect to interpreting the training stimulus provided by competition.

Overall, this study provides further quantification of the individualised sprint demands of competitive soccer matches. The sprint demands of competition from several analysis perspectives, including the absolute and relative peak speeds achieved; the number of efforts and distance covered at high percentages of MSS; and the frequency of players reaching high percentages of MSS have been described. These aspects have been investigated using an analysis framework that appropriately controls for the repeated measures of players and matches. Furthermore, this study underlines the need for position-specific and individual-specific sprint preparation of players at all competitive levels of soccer.

References

Abbott, W., Brickley, G., & Smeeton, N. J. (2018). An individual approach to monitoring locomotive training load in English Premier League academy soccer players. *International Journal of Sports Science & Coaching*, *13*(3), 421–428.

Ade, J., Fitzpatrick, J., & Bradley, P. S. (2016). High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions. Information for position-specific training drills. *Journal of Sports Sciences*, *34*(24), 2205–2214.

Al Haddad, H., Simpson, B. M., Buchheit, M., Di Salvo, V., & Mendez-Villanueva, A. (2015). Peak match speed and maximal sprinting speed in young soccer players: effect of age and playing position. *International Journal of Sports Physiology and Performance*, *10*(7), 888–896.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48.

Bradley, P. S., Carling, C., Gomez Diaz, A., Hood, P., Barnes, C., Ade, J., … 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.

Bradley, P. S., & Noakes, T. D. (2013). Match running performance fluctuations in elite soccer: Indicative of fatigue, pacing or situational influences? *Journal of Sports Sciences*, *31*(15), 1627–1638.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences*, *27*(2), 159–168.

Buchheit, M., Simpson, B. M., Hader, K., Lacome, M., Buchheit, M., Simpson, B. M., … Lacome, M. (2021). Occurrences of near-to-maximal speed-running bouts in elite soccer: Insights for training prescription and injury mitigation. *Science and Medicine in Football*, *5*(2), 105–110.

Buckthorpe, M., Wright, S., Virgile, A., & Gimpel, M. (2019). Infographic. Recommendations for hamstring injury prevention in elite football: Translating research into practice. *British Journal of Sports Medicine*, *55*(12), 699–700.

Carling, C., McCall, A., Le Gall, F., & Dupont, G. (2015). What is the extent of exposure to periods of match congestion in professional soccer players? *Journal of Sports Sciences*, *33*(20), 2116–2124.

Colby, M. J., Dawson, B. T., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *Journal of Strength and Conditioning Research*, *28*(8), 2244–2252.

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal sprinting speed of elite soccer players during training and matches. *Journal of Strength and Conditioning Research*, *31*(6), 1507–1517.

Ekstrand, J., Hägglund, M., & Waldén, M. (2011). Epidemiology of muscle injuries in professional football (soccer). *American Journal of Sports Medicine*, *39*(6), 1226–1232.

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, *30*(7), 625–631.

Gregson, W., Drust, B., Atkinson, G., & Salvo, V. D. (2010). Match-to-match variability of high-speed activities in premier league soccer. *International Journal of Sports Medicine*, *31*(4), 237–242.

Hägglund, M., Waldén, M., Magnusson, H., Kristenson, K., Bengtsson, H., & Ekstrand, J. (2013). Injuries affect team performance negatively in professional football: An 11-year follow-up of the UEFA Champions League injury study. *British Journal of Sports Medicine*, *47*(12), 738–742.

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine*, *44 Suppl 2*, S139-47.

Hickey, J., Shield, A. J., Williams, M. D., & Opar, D. A. (2014). The financial cost of hamstring strain injuries in the Australian Football League. *British Journal of Sports Medicine*, *48*(8), 729–730.

Ingebrigtsen, J., Dalen, T., Hjelde, G. H., Drust, B., & Wisløff, U. (2015). Acceleration and sprint profiles of a professional elite football team in match play. *European Journal of Sport Science*, *15*(2), 101–110.

Kyprianou, E., Di Salvo, V., Lolli, L., Al Haddad, H., Villanueva, A. M., Gregson, W., & Weston, M. (2022). To measure peak velocity in soccer, let the players sprint. *Journal of Strength and Conditioning Research*, 36(1), 273–276.

Lago, C., Casais, L., Dominguez, E., & Sampaio, J. (2010). The effects of situational variables on distance covered at various speeds in elite soccer. *European Journal of Sport Science*, *10*(2), 103–109.

Lovell, R., & Abt, G. (2013). Individualization of time-motion analysis: a case-cohort example. *International Journal of Sports Physiology and Performance*, *8*(4), 456–458. Retrieved

Ludecke, D. (2019). *sjPlot: Data visualization for statistics in social science*. https://doi.org/10.5281/zenodo.1308157

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport*, *20*(3), 250–254.

Mendez-Villanueva, A., Buchheit, M., Simpson, B. M., Peltola, E., & Bourdon, P. (2011). Does on-field sprinting performance in young soccer players depend on how fast they can run or how fast they do run? *Journal of Strength and Conditioning Research*, *25*(9), 2634–2638.

Mendiguchia, J., Martinez-Ruiz, E., Edouard, P., Morin, J. B., Martinez-Martinez, F., Idoate, F., & Mendez-Villanueva, A. (2017). A multifactorial, criteria-based progressive algorithm for hamstring injury treatment. *Medicine and Science in Sports and Exercise*, *49*(7), 1482–1492.

Oliva-Lozano, J. M., Fortes, V., Krustrup, P., & Muyor, J. M. (2020). Acceleration and sprint profiles of professional male football players in relation to playing position. *PLoS ONE*, *15*(8), e0236959.

Oliva-Lozano, J. M., Fortes, V., & Muyor, J. M. (2023). When and how do elite soccer players sprint in match play? A longitudinal study in a professional soccer league. *Research in Sports Medicine*, *31*(1), 1–12.

Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2014). Physical and technical comparisons between various-sided games within professional soccer. *International Journal of Sports Medicine*, *35*(4), 286–292.

R Core Team. (2019). *R: A language and environment for statistical computing*. Retrieved from www.R-project.org/

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisløff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level. *Journal of Science and Medicine in Sport*, *12*(1), 227–233.

Tierney, P. J., Young, A., Clarke, N. D., & Duncan, M. J. (2016). Match play demands of 11 versus 11 professional football using global positioning system tracking: Variations across common playing formations. *Human Movement Science*, *49*, 1–8.

Trewin, J., Meylan, C., Varley, M. C., & Cronin, J. (2017). The influence of situational and environmental factors on match-running in soccer: a systematic review. *Science and Medicine in Football*, *1*(2), 183–194.

Weston, M. (2013). Difficulties in determining the dose-response nature of competitive soccer matches. *Journal of Athletic Enhancement*, *2*(1).

Wickham, H. (2009). *ggplot2: Elegant graphics for data analysis*. Retrieved from http://ggplot2.org

Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., & Hodson, A. (2004). The Football Association Medical Research Programme: an audit of injuries in professional football--analysis of hamstring injuries. *British Journal of Sports Medicine*, *38*(1), 36–41.

Chapter 8: Discussion and Conclusions

The aim of this thesis was to investigate the relative sprint demands of different forms of soccer-specific training exercises and competition. The manipulation and planning of sprinting within elite soccer training is critical given the central role that sprinting plays in key competitive actions, and the incidence and burden of sprinting-related injuries in soccer. The studies in this thesis were designed to enhance understanding of the extent to which soccer-specific exercises are able to elicit maximal or near-maximal sprint demands, and to aid coaches and practitioners in exercise design and choice by examining how different prescriptive variables are able to influence these demands. The following discussion section will summarise the collective findings of the thesis in the context of the previous research. The practical applications, limitations of the collective studies, and future research directions will then be presented.

Firstly, it is important to briefly summarise the purpose of each of the experimental studies and their main findings, and the relationship between each of the experimental chapters. Chapters 4 and 5 both examined the effect of prescriptive variables on the physical demands of soccer-specific small-sided games within high level training environments. Chapter 4 used a cross-sectional design to investigate three levels each of both player number and relative pitch area/rule modifications. Larger pitch areas and greater player numbers resulted in greater peak sprint speeds, distance covered and number of efforts over 80% of MSS. However, most large-relative-playing-area SSG were not able to elicit an average peak sprint speed above 85-90% of MSS despite the intentional selection of prescriptive variables to encourage sprinting actions.

Chapter 5 used an inductive approach and a large sample of SSG, in which a wider array of prescriptive variables were able to be captured compared to Chapter 4. The overall effect of these prescriptive variables on the resulting peak sprint speed could then be determined using a linear mixed-effects regression approach. Several variables, including relative pitch area, game duration, game objective, and touch constraints were shown to exhibit significant effects on the peak speed achieved on an individual level.

Chapter 6 uses a similar inductive approach to Chapter 5 to examine scenario-based soccer-specific exercises. These exercises differ significantly from SSG, in that they are not able to be readily described using the same criteria (player number, pitch size, playing duration) but still maintain a high level of soccer-specificity with respect to decision-making and technical actions. This study was designed to address the “blind spot” of exercises excluded from Chapter 4 and Chapter 5. The hallmark of these exercises was considerable variability in the peak sprint speeds elicited, with a small but promising subset of exercises demonstrating average speeds above 90% of MSS. More broadly, this study showed greater sprint demands during exercises with opponent or time pressure, and greater absolute sprint speeds elicited from faster players independent of other prescriptive variables.

Finally, Chapter 7 provided a descriptive analysis of the sprint demands during competition as performed by the participating team in Chapters 5 and 6. This analysis served to contextualise the sprint demands reported from the training environment, and underlined the gap between what are widely used soccer-specific exercises that make up a large proportion of the training that teams perform, and the competition that players are being ostensibly trained to perform in. This study, utilising New Zealand-based players, also provides breadth to a body of literature primarily populated with data from elite European competitions.

There are several key findings that can be synthesised from the above studies collectively. These findings will be examined further in the following sections.

Main Findings

Main Finding 1: Small-sided games are only able to reliably elicit sprint efforts of 85-90% of maximal sprint speed (MSS) and sprint efforts above 95% of MSS are exceptionally infrequent.

The results of Chapter 4 and Chapter 5 suggest that there may be a practical upper limit to the achievable sprint demands during SSG in training. The SSG examined in Chapter 4, particularly when considering the two large relative pitch area (320 m^2 per player) variations, were able to elicit peak sprint speeds of between 85-90% of MSS, irrespective of player number. In addition to these average values, 35.2% (25/71) of player observations exceeded 90% of MSS at least once during the 4 x 4-min games.

Across both Chapters 4 and 5 however, sprint efforts reaching greater than 95% of MSS were exceptionally infrequent. The total proportion of players that reached 95% of MSS in the large and counterattacking game variations of Chapter 4 was 5.5% (2/36) and 5.7% (2/35), respectively, while only 0.24% (3/1243) of total SSG observations reached 95% of MSS across the Chapter 5 sample. The similarity in overall sprint demands between the ’large’ and 'counterattacking’ games in Chapter 4, despite the addition of rule modifications expected to increase sprint opportunities, further supports the idea that these games may have reached the upper limit of SSG sprint demands in a practical sense.

This finding of an upper limit to the sprint intensity of SSG is in line with the limited number of previous studies (Casamichana et al., 2012; Djaoui et al., 2017; Kyprianou et al., 2022; Owen et al., 2014) reporting peak sprinting speed during SSG, though it should be noted that only Djaoui et al. (2017) reported results as a percentage of individual MSS. Each of these studies found that SSG did not elicit peak running speeds greater than approximately 90% of either sprint-test derived player MSS or peak running speed during a competitive match. The results of Djaoui et al. (2017) are particularly comparable to the present thesis, where a limited number of positional groups were able to average over 90% MSS for a given SSG variation, however none of the overall averages for each of the 14 studied SSG variations were greater than 89.8 ± 12.8% of MSS. The studies comprising the present thesis form important additional evidence amongst the existing literature. To the author's knowledge, no previous study has investigated a similarly broad range of SSG design and sample size (Chapter 5) nor the direct and intentional maximisation of prescriptive variables (Chapter 4) likely to increase sprint speeds during SSG play.

There are several potential explanations for the apparent inability of SSG to reliably exceed 95% of MSS. Firstly, it is possible that there is a lack of motivation and/or competition in training to elicit sprinting at this intensity. However, players have consistently been found to achieve higher speeds during competitive match-play compared to training activities (Al Haddad et al., 2015; Casamichana et al., 2012; Kyprianou et al., 2022), with these differences typically attributed to the prescriptive variables of the training exercises (Casamichana et al., 2012). Additionally, competitive matches have exhibited only a marginal increase in the frequency which players reach 95% of MSS compared to training activities (Buchheit et al., 2021). Secondly, the peak running speed of SSG could be limited by the effects of fatigue during continuous play. However, this straightforward explanation is contrary to the results of Chapter 5, where each minute of added duration had an overall positive effect on the peak sprinting speed achieved, while controlling for all other variables.

Finally, in Chapter 4, sprint efforts greater than 95% of MSS were present but markedly infrequent, while in Chapter 5, greater SSG duration was associated with increased peak sprint speed. These findings together support a rationale in which the limited overall playing durations of SSG serve to reduce the likelihood that players are exposed to a tactical situation demanding a maximal sprint effort during a given training session. Maximal sprint efforts during SSG require an evidently rare confluence of factors such as the size of the playing area, positioning of the opponents, and tactical necessity (such as an opportunity to score or deny a goal). This infrequent nature of these opportunities could be further impacted by the opportunity during free-play SSG that teams and players have to adjust their positioning to better defend their goal (i.e., taking up more conservative positioning). As sprinting is a common feature of goal-scoring actions (Faude et al., 2012), it is logical that teams seek to reduce the frequency of these actions and therefore the opportunity to sprint.

Main Finding 2: The prescriptive variables used during SSG for soccer significantly influence the sprint and high-speed running demands elicited, with playing area emerging as the most significant factor in shaping these demands.

The results of both Chapter 4 and Chapter 5 demonstrate that the relative size of the playing area appears to be the most important amongst several prescriptive variables that are able to influence the sprint running demands elicited by SSG. This finding is in accordance with the limited number of studies that have previously reported peak running speeds across a wide variety of absolute and relative playing areas (Djaoui et al., 2017; Kyprianou et al., 2022; Owen et al., 2014). It follows logically that in order to reach a high speed during a single running effort, a certain minimum distance is required. A number of studies have demonstrated that larger pitch areas increase the typical distance between teammates (Silva, Vilar, Davids, Araújo, & Garganta, 2016), and in some cases, opponents (Olthof et al., 2018), thus increasing the likelihood that the technical or tactical opportunities afforded to players are further apart. Similarly, larger playing areas likely increase the chances that faster running speeds can be used to create an advantage over the opponent such as in counter-attacking scenarios. Demonstrating these effects using the ratio between pitch area and player number (relative pitch area) is important when making comparisons to the previous literature, where player number and pitch size were frequently manipulated concurrently.

In addition to the effects of relative playing area, employing a goal-scoring rather than possession objective, limiting the allowed ball touches, and using a balanced number of players for each team (as compared to neutral player or “overload” team constructions) all produced significant positive effects on the relative peak sprint speed elicited across a large sample of varied SSG in Chapter 5.

The use of a goal-scoring objective was the most influential categorical variable in Chapter 5 (10.19% increase in relative peak sprint speed). The addition of goals to SSG is thought to promote more “linear” patterns of play and positioning when compared to more multidirectional possession games (Gaudino et al., 2014). Teams are incentivised to quickly attack and defend the goals at either end of the pitch, as compared to possession games where all parts of the playing area are equally “valuable”. Gaudino et al. (2014) has previously demonstrated an increase in sprint demands in scoring relative to possession games consistent with the increased sprint speeds demonstrated in Chapter 5.

Previous research has demonstrated how limiting the number of ball touches allowed during SSG results in increased physiological responses and distance covered above 17-18 $km \cdot h^{-1}$ (Dellal, Chamari, Owen, et al., 2011; Dellal, Lago-Peñas, et al., 2011), in accordance with our findings. It is thought that the increased physical demands during these SSG are a result of the need for players to reposition more quickly in order to maintain possession and create scoring opportunities. This enhancement of time and spatial pressure also serves as a likely explanation for the positive effects of balanced team construction (as opposed to “overload” or unbalanced games) on sprint demands in Chapter 5. Balanced teams may ensure each player is subject to a consistent level of time and spatial pressure that enhances both the physiological and running demands (Hill-Haas, Dawson, et al., 2009), rather than overload/underload game designs where teams may be more conservative due to the difficulty of maintaining possession (underload) or able to reposition more slowly due to the extra time and space afforded (overload).

Despite the lack of maximal or near-to-maximal sprint efforts produced during Chapters 4 and 5, understanding in greater depth which variables are likely to enhance the very high-speed running demands of small-sided games is a critical finding of this thesis, helping coaches to plan the physical load associated with soccer training.

Main Finding 3: Select scenario-based soccer-specific exercises elicit promising peak speed demands and have prescriptive similarities to the most successful SSG.

From the main findings of Chapters 4 and 5 above, it could be concluded that further constraining soccer-specific exercise design is necessary in order to elicit near-maximal sprint efforts more reliably. This would be associated with a trade-off of reduced specificity when compared to typical SSG (i.e., players are not required to continuously regulate their decision-making for extended periods of play across wide variety of tactical and technical situations).

Accordingly, Chapter 6 examined soccer-specific exercises of shorter durations of play (often performed in a rotation fashion where a small number of players are involved briefly before resting), greater constraints on player positioning, and utilising more direct goal-attacking or defending objectives (rather than keeping possession or winning a game). While the sprint demands elicited across the study as a whole were varied, certain examples in the counterattacking games of Chapter 6 can be highlighted both for their potential to elicit intense sprint actions while preserving soccer-specific decision-making actions, and the key practical features demonstrated in achieving this.

In particular, one variation of the counterattacking game elicited peak sprint speeds of 92.2 ± 4.9% of MSS, with all players exceeding 85% of MSS, and 8/15 players exceeding 90% of MSS. This exercise was a multi-phase 3 vs. 3 counterattacking game played towards a regulation-sized goal. One of the defending team began each drill repetition at a 5-m disadvantage behind the attacking players (who begin play at their own goal-line), and require a linear sprint to join and affect the play. The attacking team of 3 would first attack quickly until a scoring opportunity before defending their own goal against the 3 original defenders.

There are several key features of this exercise that may have contributed to the relative success in eliciting near-maximal sprinting during soccer exercises and may be practically applicable when considering design of these soccer-specific exercises. Unsurprisingly, several of these features are either directly comparable or conceptually similar to the prescriptive variables that were able to elicit greater sprint speeds during SSG in Chapter 4 and Chapter 5.

Firstly, the inclusion of a recovering player creates a near-guarantee of a near-maximal sprint effort from one player per repetition, as the length of the playing area (33 m, plus the additional 5 m for the recovering player) is a long enough distance to allow players to reach near-maximal speed (Haugen, Seiler, Sandbakk, & Tønnessen, 2019). Secondly, the short duration repetitions allow management of the work-to-rest ratio to minimise the effects of fatigue for each player. The short duration repetitions and frequent resetting also maximise the total number of recovery sprint efforts for each player over the total exercise duration. Finally, there is considerable time and spatial pressure applied to the attacking players, incentivising fast-paced play to exploit their numerical advantage before the recovering player is able to join the defending team. While there are no comparable studies examining a similar sample of soccer-specific exercises, these scenario-based exercises are common in elite soccer practice (Roca & Ford, 2020). The results of Chapter 6 suggest that these may present an opportunity to elicit near maximal sprint speeds with low variability across a training group, however further research is needed.

Main Finding 4: Match demands are greater than training demands, highlighting a significant need for practitioners to employ isolated sprinting exercises to adequately prepare players for competition.

Chapter 7 examined the relative sprint demands of competitive matches in order to further contextualise the training demands reported in Chapters 4, 5, and 6. While the relative peak sprint speeds during competition were comparable to the fastest soccer-specific training exercises reported in Chapter 4 and Chapter 5, the frequency with which players were able to exceed 90% and 95% of MSS was considerably greater. These findings are important as they further highlight the limitations of SSG and soccer-specific training in general, not just with respect to eliciting a level of sprint demands consistent with guidelines for enhancing sprint ability (Haugen et al., 2014), but also with respect to recreating the same physical demands as competitive matches. It is also important to remember that specificity or replication of physical demands with respect to competition is only one potential training objective, and coaches must balance this with other aspects of player performance in the planning and execution of training. Additionally, these findings underline the key role competitive matches can play in providing players with a soccer-specific sprint training stimulus throughout a competitive period (Buchheit et al., 2021).

These differences in the frequency of players exceeding near-to-maximal sprint speeds could be due to the relatively larger playing area of official matches when compared to most training exercises (Djaoui et al., 2017). The sprint demands observed in Chapter 4, in which a match-derived relative playing area (320 m^2 per player) was used to promote sprint opportunities appear to contradict this hypothesis. However, as reported in Chapter 5, the overall duration of an activity has a somewhat counterintuitive positive effect on the peak sprinting speed, which we hypothesise is due to the increased chances of each player encountering a clear maximal sprinting opportunity. This same factor could be partially responsible for the increased sprint demands during competition compared to training and explain why the SSG played in Chapter 6 (16 min total duration) failed to elicit the same level of sprint intensity despite the optimised conditions. Djaoui et al. (2017) further suggests that differences in the sprint demands between training exercises and competitive matches may be related to player motivation, however, to the author's knowledge this has not been investigated directly.

Ultimately, the differences between the sprint demands typically elicited during training exercises such as SSG and competitive matches underline firstly the need for coaches and practitioners to include isolated sprint training to effectively prepare players for competition, and secondly the potential usefulness of 11-a-side matches in achievement of near-maximal sprint speeds.

Practical Applications

The data reported in this thesis clearly demonstrate that SSG do not enable players to reach maximal sprinting speeds (>95% of MSS). From a practical perspective, it is therefore critical that SSG are not utilised in lieu of isolated maximal speed training to develop sprint ability. However, physical preparation for elite soccer teams must ensure players are able to meet the diverse physical demands in competition. Sprint training for soccer can be stratified into more specific sub-objectives beyond simply enhancing sprint speed. For example, 90% of MSS has been used as a critical threshold in providing a sufficient sprint stimulus to reduce injury risk (Malone et al., 2018). Additionally, the accumulation of distance covered at very high (but submaximal) running speeds is frequently an element of the planning and organisation of training at the elite level (Buchheit et al., 2021).

Using SSG to elicit sprint efforts of approximately 90% of MSS is achievable in practice. However, reaching these speeds requires that SSG are designed with specific prescriptive variables. Of the large number of potential variables, the present studies show that maximising the relative playing area is the single most impactful variable in raising the relative peak speed of the sprint efforts performed by players. In addition to a large relative playing area, using goal-scoring, rather than possession-oriented SSG designs, ensuring balanced teams (rather than overload designs), and employing a limit to the number of ball touches allowed per player are likely to enhance the chances of eliciting speeds of approximately 90% MSS.

Across the data reported in this thesis, competitive matches were able to elicit maximal and near-maximal sprint speeds far more frequently than any of the soccer-specific training exercises. This finding reinforces the practical recommendation above regarding the inclusion of isolated maximal sprinting in training of elite soccer players, and further stresses the relevance of 11-a-side match-play for physical preparation. This finding raises questions about the potential for further optimisation of SSG to elicit sprinting, despite the specific focus on this outcome in Chapter 4 and Chapter 5.

The key findings of this thesis have a number of implications for coaches and practitioners planning and designing integrated approaches to soccer training. Firstly, the lack of near-maximal sprinting consistently observed during the soccer specific exercises in this thesis make it clear that it is essential to include isolated sprinting in the planning of an integrated training approach. Secondly, setting clear objectives for specific training exercises is critical with respect to sprinting. When designed appropriately, these exercises may be more useful in meeting *volume* or *exposure*-based objectives, rather than *intensity* or *developmental* objectives. Finally, training plans that account for the variability in sprint demands during SSG and other soccer-specific exercises are necessary. Both unstructured SSG and scenario-based exercises elicit highly variable peak speed demands in general, with inconsistent effects of playing position and individual MSS. Live data monitoring approaches through GPS or LPS may be useful in allowing players the opportunity to meet sprint training objectives through soccer exercises, while still allowing the coach or practitioner to guarantee these objectives are met through isolated sprinting if necessary.

Limitations

There are several limitations of the present thesis. Firstly, the reliance on regression approaches to the statistical analyses makes it difficult to direct the findings into practical examples (with the exception of Chapter 4). For example, simply maximising all of the variables associated with increased sprint speed in Chapter 5 would likely not result in a practically feasible SSG.

A number of the present studies focussed primarily on the peak speed elicited by players during different soccer-specific exercises. The use of peak speed may be a limiting factor of these studies. Peak speed is one-dimensional, and does not reflect the number, frequency, or distance covered during the sprint efforts during the soccer activities in question. These factors make it difficult to draw conclusions about the overall training stimulus. However, the variability in threshold-based measures such as the distance or number of efforts over a certain speed equally make these difficult to use in analysis, requiring very large sample sizes. The use of peak speed throughout Chapters 5 and 6 ensure that each exercises provided a valid analysis point to the regression modelling approach.

There were aspects of the sample size and sampling procedure that likely limit the applicability of the results. Primarily, the training and competition exercises analysed within this thesis were largely performed by a single team (apart from Chapter 4). It is possible that conclusions drawn about the physical demands of training exercises are an intentional product of the training delivered by the team staff. In addition, the Chapter 6 data collection was open-ended in order to reach an acceptable sample size of scenario-based exercises. This extended data collection period could have provided an even greater sample for the SSG modelling approach of Chapter 5 and potentially improved the quality of results in this study. However, the descriptive aspects of the SSG performed in training were not part of this data collection due to the transition to focus on scenario-based exercises. While this choice was reasonable in the real-time process of conducting each of the present studies, in hindsight this represents a missed opportunity for a stronger set of findings around SSG.

The importance of sprint training and providing a regular sprint stimulus to soccer players due to the potentially positive effects on injury prevention (in particular, hamstring strain injuries) is outlined a number of times throughout the thesis. However, evidence directly assessing claims of a functional sprint speed threshold (e.g., 90% of MSS) that players must achieve regularly for a preventative effect, is scarce (Malone et al., 2017). Prospective injury data were not collected during the present studies due to the relatively small sample sizes used.

The claim that relative pitch area is the most impactful variable with respect to increasing opportunities for players to sprint during SSG is central to this thesis. By analysing the ratio between the total playing area and the total number of players, the present studies have avoided the limitations of previous research in which pitch area and player number were manipulated concurrently, obscuring the independent effects of each variable. However, the use of the relative pitch area as a ratio also limits the interpretation of the present studies, as it is not possible to determine whether it is the use of greater playing areas, fewer players, or a combination of both of these factors that most significantly enhances the running speeds elicited during SSG. It is almost certainly incorrect to assume that the relative pitch area of a SSG has a linear effect on the sprint speed. For example, a pitch area of 320 m^2 for a 2 vs. 2 SSG would clearly elicit different physical demands when compared to 8 vs. 8 SSG played in the same relative area. It is possible that increasing the pitch area could play a more dominant role than reducing player number in eliciting greater sprint demands, as demonstrated in Chapter 4 where altering the number of players had inconsistent effects on the sprint demands (despite maintaining a constant relative pitch area). These results, alongside those of Silva et al. (2016), where increasing or decreasing the number of players in a fixed playing area resulted in teams dispersing over a greater area while maintaining very similar distances to their opponents, highlights the complex adaptive behaviour of teams and individuals during SSG, and the need to carefully analyse the overall combination of prescriptive variables. There are likely minimum and maximum values, respectively, to which the player number can be minimised for a given playing area, or pitch size can be maximised for a given player number, before the teams and players "adapt" their behaviour in a way that is not optimal to either eliciting sprinting or ensuring technical/tactical relevancy.

Future Directions

1. Future research should consider reporting descriptive data that reflect the players' individual MSS during soccer training exercises and matches, even if alongside more generic movement analysis variables. A greater volume of research assessing these demands will allow researchers and practitioners alike to better understand the demands of training exercises in relative terms.
2. Further exploration of the tactical and technical activities that are likely to elicit maximal or near maximal sprinting in elite soccer would be beneficial. Faude et al. (2012) demonstrated a clear connection between goalscoring opportunities and sprinting, while more recent studies such as Oliva-Lozano et al. (2021), have begun to consider location within the field of play, possession of the ball, and linear vs. non-linear trajectory in analysis of sprint activities. Combining this approach with data that reflect individual MSS across a large sample of this data could provide significant insight into developing training

exercises that are able to elicit maximal sprinting while maintaining complete specificity.

3. Counter-attacking scenario-based exercises should be explored in more depth. These exercises show potential as a training method for eliciting match specific or even maximal sprint efforts.
4. The delivery and programming of isolated sprint exercises amongst a predominantly integrated approach to training should be considered. The timing within the weekly microcycle, volume and distance of sprints to perform to best prepare players for competitive schedules, and relative benefits of free-sprint versus sprint-adjacent resistance exercises such as resisted or assisted sprinting are all topics that would add to the body of literature.

References

Al Haddad, H., Simpson, B. M., Buchheit, M., Di Salvo, V., & Mendez-Villanueva, A. (2015). Peak match speed and maximal sprinting speed in young soccer players: Effect of age and playing position. *International Journal of Sports Physiology and Performance*, *10*(7), 888–896.

Buchheit, M., Simpson, B. M., Hader, K., Lacome, M., Buchheit, M., Simpson, B. M., … Lacome, M. (2021). Occurrences of near-to-maximal speed-running bouts in elite soccer: Insights for training prescription and injury mitigation. *Science and Medicine in Football*, *5*(2), 105–110.

Casamichana, D., Castellano, J., & Castagna, C. (2012). Comparing the physical demands of friendly matches and small-sided games in semiprofessional soccer players. *Journal of Strength and Conditioning Research*, *26*(3), 837–843.

Dellal, A., Chamari, K., Owen, A. L., Wong, D. P., Lago-Peñas, C., & Hill-Haas, S. V. (2011). Influence of technical instructions on the physiological and physical demands of small-sided soccer games. *European Journal of Sport Science*, *11*(5), 341–346.

Dellal, A., Lago-Peñas, C., Wong, D. P., & Chamari, K. (2011). Effect of the number of ball contacts within bouts of 4 vs. 4 small-sided soccer games. *International Journal of Sports Physiology and Performance*, *6*(3), 322–333.

Djaoui, L., Chamari, K., Owen, A. L., & Dellal, A. (2017). Maximal sprinting speed of elite soccer players during training and matches. *Journal of Strength and Conditioning Research*, *31*(6), 1507–1517.

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences*, *30*(7), 625–631.

Gaudino, P., Alberti, G., & Iaia, F. M. (2014). Estimated metabolic and mechanical demands during different small-sided games in elite soccer players. *Human Movement Science*, *36*, 123–133.

Haugen, T., Seiler, S., Sandbakk, Ø., & Tønnessen, E. (2019). The training and development of elite sprint performance: An integration of scientific and best practice literature. *Sports Medicine - Open*, *21*(44).

Haugen, T., Tønnessen, E., Leirstein, S., Hem, E., & Seiler, S. (2014). Not quite so fast: effect of training at 90% sprint speed on maximal and repeated-sprint ability in soccer players. *Journal of Sports Sciences*, *32*(20), 1979–1986.

Hill-Haas, S. V., Dawson, B. T., Coutts, A. J., & Rowsell, G. J. (2009). Physiological responses and time–motion characteristics of various small-sided soccer games in youth players. *Journal of Sports Sciences*, *27*(1), 1–8.

Kyprianou, E., Di Salvo, V., Lolli, L., Al Haddad, H., Villanueva, A. M., Gregson, W., & Weston, M. (2022). To measure peak velocity in soccer, let the players sprint. *Journal of Strength and Conditioning Research*, 36(1), 273–276.

Malone, S., Owen, A. L., Mendes, B., Hughes, B., Collins, K., & Gabbett, T. J. (2018). High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? *Journal of Science and Medicine in Sport*, *21*(3), 257–262.

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport*, *20*(3), 250–254.

Oliva-Lozano, J. M., Fortes, V., & Muyor, J. M. (2023). When and how do elite soccer players sprint in match play? A longitudinal study in a professional soccer league. *Research in Sports Medicine*, *31*(1), 1–12.

Olthof, S. B. H., Frencken, W. G. P., & Lemmink, K. (2018). Match-derived relative pitch area changes the physical and team tactical performance of elite soccer players in small-sided soccer games. *Journal of Sports Sciences*, *36*(14), 1557–1563.

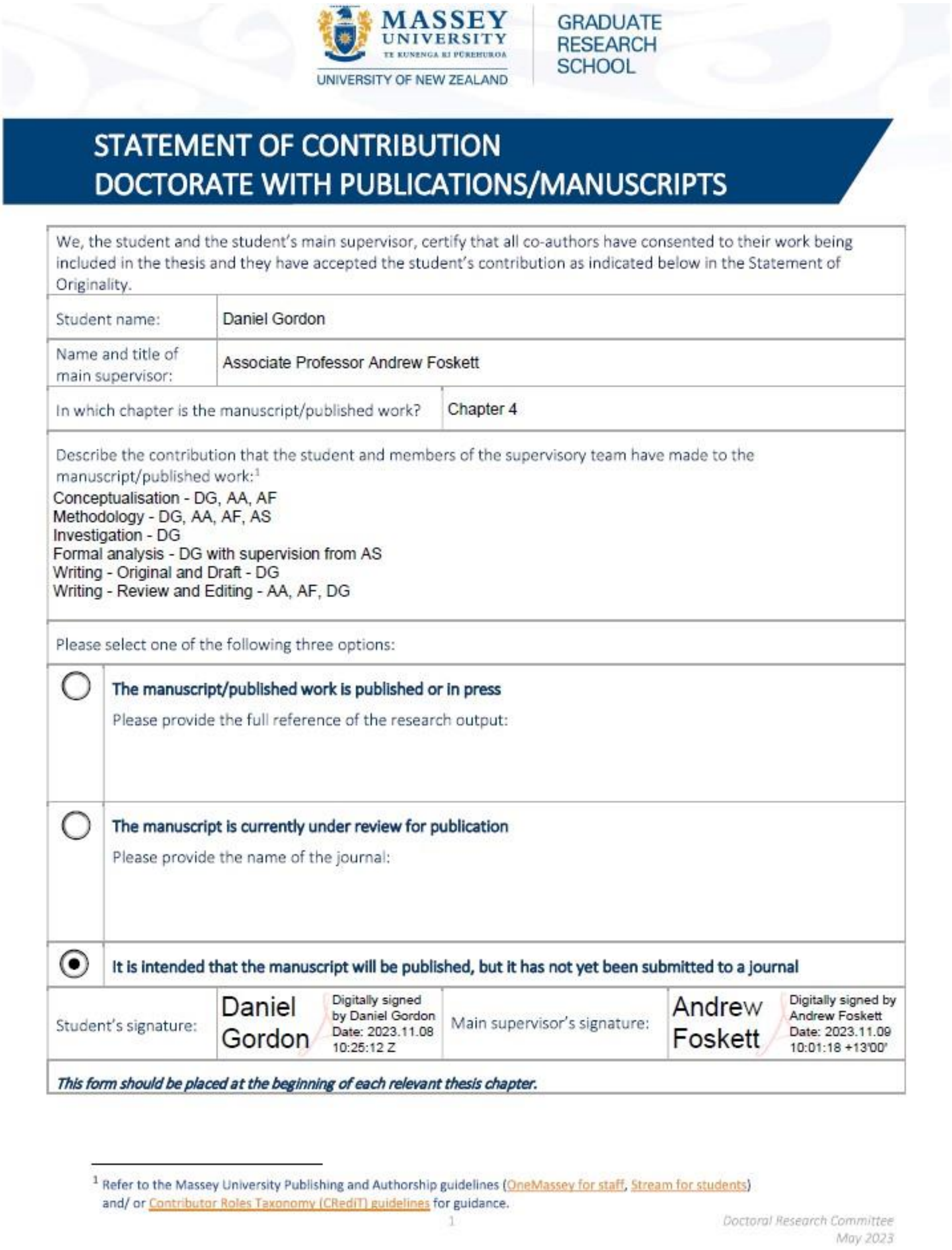
Owen, A. L., Wong, D. P., Paul, D., & Dellal, A. (2014). Physical and technical comparisons between various-sided games within professional soccer. *International Journal of Sports Medicine*, *35*(4), 286–292.

Roca, A., & Ford, P. R. (2020). Decision-making practice during coaching sessions in elite youth football across European countries Decision-making practice during coaching sessions in elite youth football across. *Science and Medicine in Football*, *4*(4), 263–268.

Silva, P., Vilar, L., Davids, K., Araújo, D., & Garganta, J. (2016). Sports teams as complex adaptive systems: manipulating player numbers shapes behaviours during football small-sided games. *SpringerPlus*, *5*(191).

Chapter 9: Appendices

Appendix A: Statement of Contribution – Chapter 4



MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Daniel Gordon
Name and title of main supervisor:	Associate Professor Andrew Foskett
In which chapter is the manuscript/published work?	Chapter 4

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Conceptualisation - DG, AA, AF
Methodology - DG, AA, AF, AS
Investigation - DG
Formal analysis - DG with supervision from AS
Writing - Original and Draft - DG
Writing - Review and Editing - AA, AF, DG

Please select one of the following three options:

○ **The manuscript/published work is published or in press**
Please provide the full reference of the research output:

○ **The manuscript is currently under review for publication**
Please provide the name of the journal:

● **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Daniel Gordon Digitally signed by Daniel Gordon Date: 2023.11.08 10:25:12 Z	Main supervisor's signature:	Andrew Foskett Digitally signed by Andrew Foskett Date: 2023.11.09 10:01:18 +13'00'

This form should be placed at the beginning of each relevant thesis chapter.

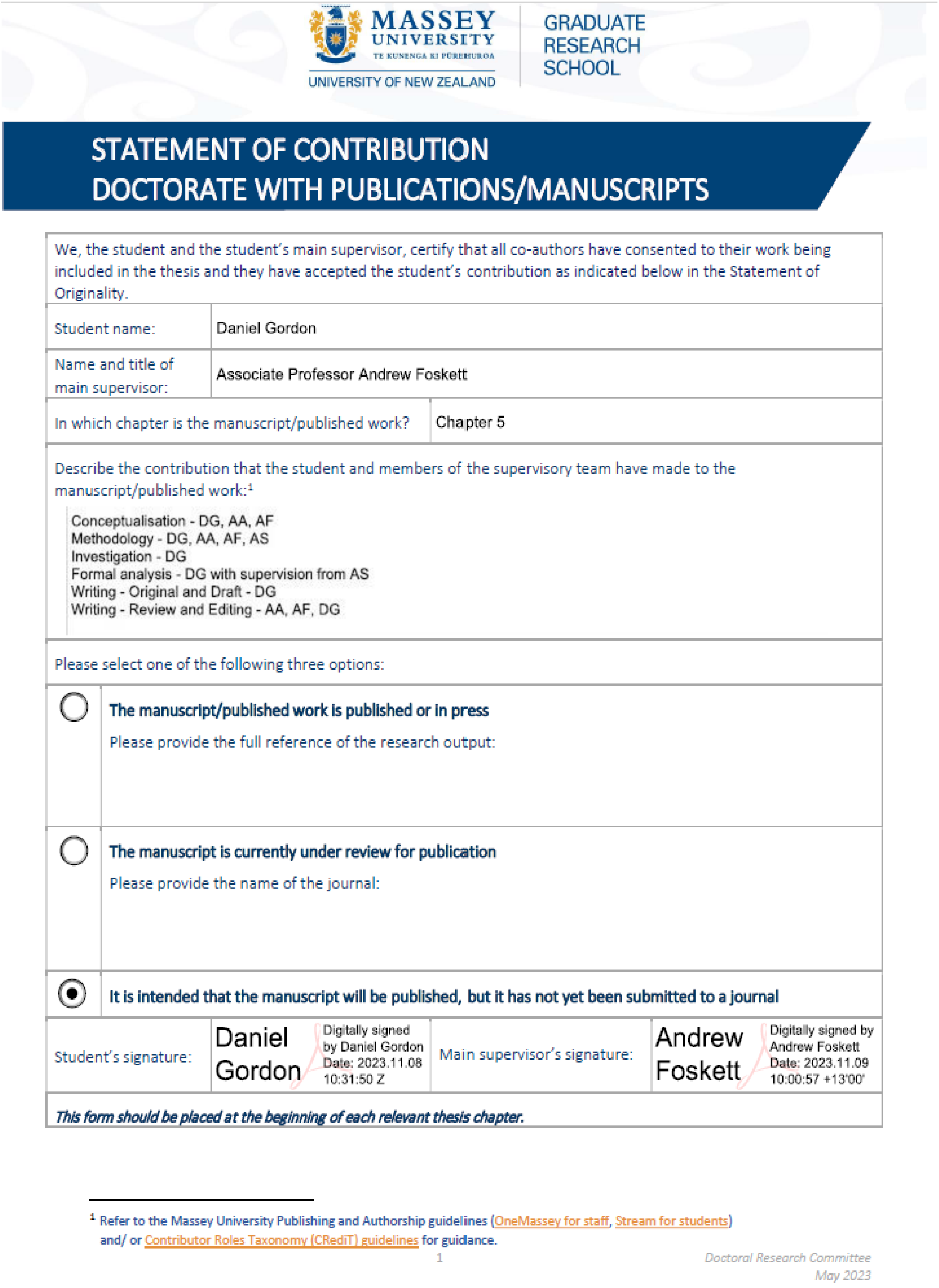
---

[1] Refer to the Massey University Publishing and Authorship guidelines (OneMassey for staff, Stream for students) and/ or Contributor Roles Taxonomy (CRediT) guidelines for guidance.

1

Doctoral Research Committee
May 2023

Appendix B: Statement of Contribution – Chapter 5



MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Daniel Gordon
Name and title of main supervisor:	Associate Professor Andrew Foskett
In which chapter is the manuscript/published work?	Chapter 5

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Conceptualisation - DG, AA, AF
Methodology - DG, AA, AF, AS
Investigation - DG
Formal analysis - DG with supervision from AS
Writing - Original and Draft - DG
Writing - Review and Editing - AA, AF, DG

Please select one of the following three options:

○ **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

○ **The manuscript is currently under review for publication**

Please provide the name of the journal:

● **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Daniel Gordon Digitally signed by Daniel Gordon Date: 2023.11.08 10:31:50 Z	Main supervisor's signature:	Andrew Foskett Digitally signed by Andrew Foskett Date: 2023.11.09 10:00:57 +13'00'

This form should be placed at the beginning of each relevant thesis chapter.

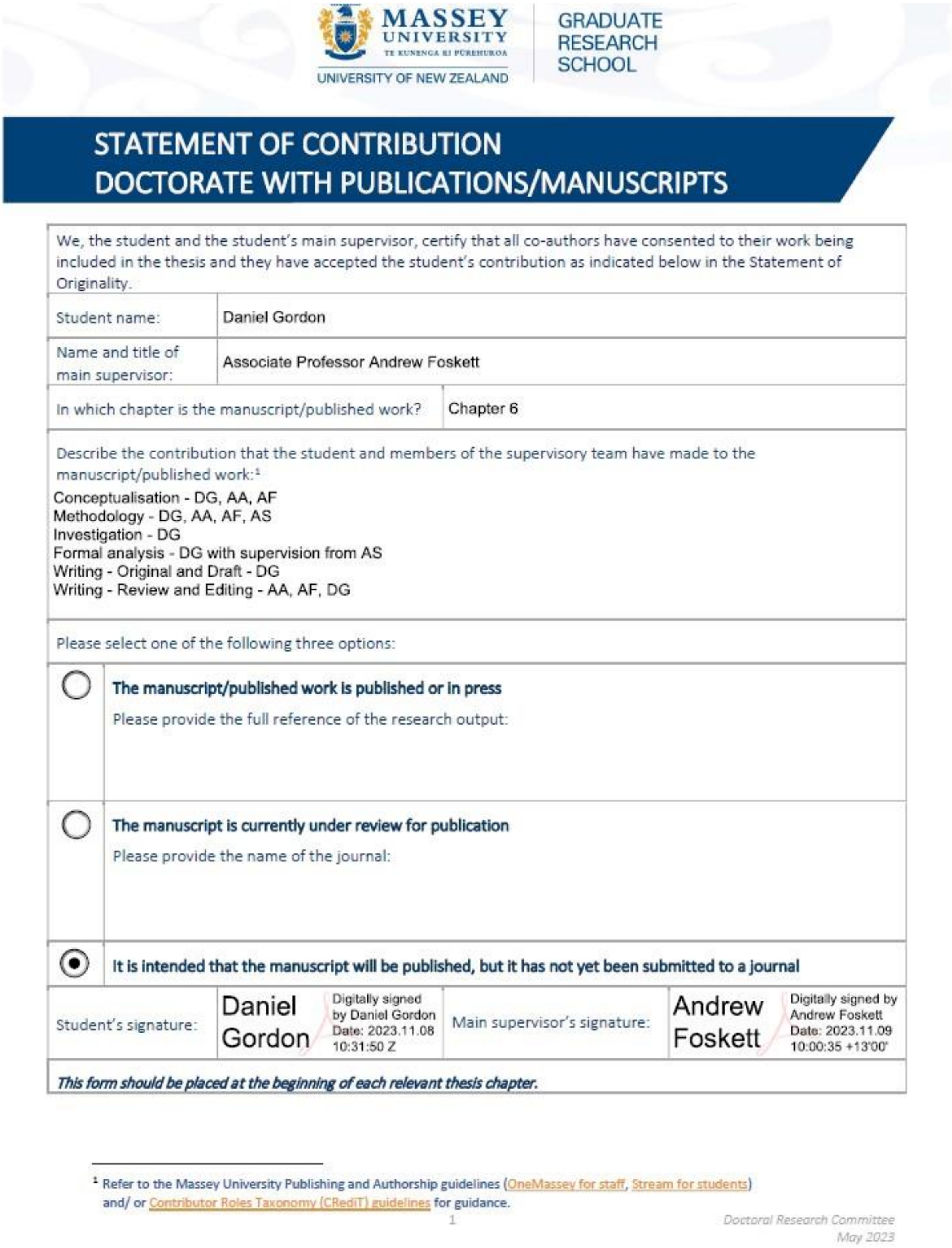
---

[1] Refer to the Massey University Publishing and Authorship guidelines (OneMassey for staff, Stream for students) and/ or Contributor Roles Taxonomy (CRediT) guidelines for guidance.

1

Doctoral Research Committee
May 2023

Appendix C: Statement of Contribution – Chapter 6



MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE
RESEARCH
SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Daniel Gordon
Name and title of main supervisor:	Associate Professor Andrew Foskett
In which chapter is the manuscript/published work?	Chapter 6

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Conceptualisation - DG, AA, AF
Methodology - DG, AA, AF, AS
Investigation - DG
Formal analysis - DG with supervision from AS
Writing - Original and Draft - DG
Writing - Review and Editing - AA, AF, DG

Please select one of the following three options:

○ **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

○ **The manuscript is currently under review for publication**

Please provide the name of the journal:

● **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Daniel Gordon Digitally signed by Daniel Gordon Date: 2023.11.08 10:31:50 Z	Main supervisor's signature:	Andrew Foskett Digitally signed by Andrew Foskett Date: 2023.11.09 10:00:35 +13'00'

This form should be placed at the beginning of each relevant thesis chapter.

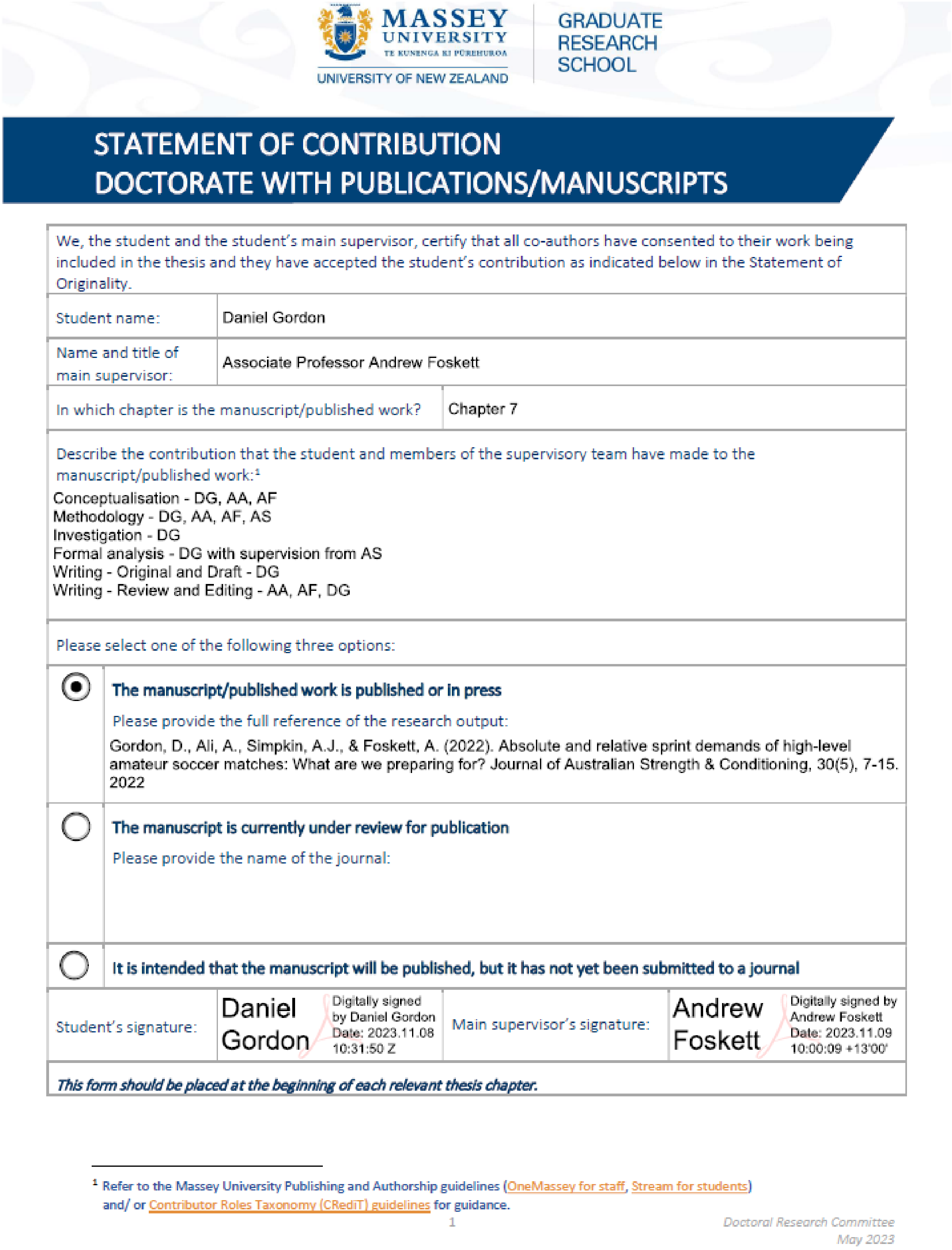
---

[1] Refer to the Massey University Publishing and Authorship guidelines (OneMassey for staff, Stream for students) and/ or Contributor Roles Taxonomy (CRediT) guidelines for guidance.

1

Doctoral Research Committee
May 2023

Appendix D: Statement of Contribution – Chapter 7



MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Daniel Gordon
Name and title of main supervisor:	Associate Professor Andrew Foskett
In which chapter is the manuscript/published work?	Chapter 7

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Conceptualisation - DG, AA, AF
Methodology - DG, AA, AF, AS
Investigation - DG
Formal analysis - DG with supervision from AS
Writing - Original and Draft - DG
Writing - Review and Editing - AA, AF, DG

Please select one of the following three options:

● **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

Gordon, D., Ali, A., Simpkin, A.J., & Foskett, A. (2022). Absolute and relative sprint demands of high-level amateur soccer matches: What are we preparing for? Journal of Australian Strength & Conditioning, 30(5), 7-15. 2022

○ **The manuscript is currently under review for publication**

Please provide the name of the journal:

○ **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

Student's signature:	Daniel Gordon	Digitally signed by Daniel Gordon Date: 2023.11.08 10:31:50 Z	Main supervisor's signature:	Andrew Foskett	Digitally signed by Andrew Foskett Date: 2023.11.09 10:00:09 +13'00'

This form should be placed at the beginning of each relevant thesis chapter.

---

[1] Refer to the Massey University Publishing and Authorship guidelines (OneMassey for staff, Stream for students) and/ or Contributor Roles Taxonomy (CRediT) guidelines for guidance.