Athlete Monitoring: Secondary Prevention of Groin and Hamstring Injury in Male Professional Development Football

Submitted by

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Preface

The catalyst for this PhD research project was my experiences from over 15 years of clinical physiotherapy practice in professional development and professional football. In this time so many talented football players; both the aspirational young and seasoned professional have required management and rehabilitation of groin and hamstring injury problems. Far too many (groin problems especially) I always thought. Anecdotally, load was most often at the centre of these problems. The prevailing impression was one of underprepared young players, ill prepared recruits, far from ready for full-time elite training levels. Often the players were accustomed to only half the amount of training. Similarly, impressions from pre-season periods at the professional level were that players went ‘from being on holiday to high-intensity training overnight’. It rarely made sense and it seemed something positive and healthy (i.e. training and physical preparation) turned negative; causing injury with all the unwanted consequences on players and team that injury produces.

Despite developing successful rehabilitation programs, refining clinical skills and educating coaches and players in the importance of injury prevention; change seemed slow and limited. Sports physiotherapy is a passion, but I was questioning its current application; it has such a limited impact, beyond the individual player, on prevention and therefore performance. Considerable knowledge and expertise remains untapped in the current clinical model where physiotherapists predominantly treat injuries once they have occurred; and prevention is restricted to exercise application in the gym or on the pitch. How can (and should?) contemporary clinical sports physiotherapy extend into leading high-performance sport in prevention and performance? Each year, I studied the available literature and reflected on our experiences together with others, to improve the situation for the players and teams: we applied exercise-based injury prevention programs based on best available evidence, including eccentric adductor and hamstring strengthening well before it had an evidence-base. However, change remained slow and still not substantial. Something was missing. A coach and player
supported and integrated systems approach to prevention and performance in football always made more sense. A breakthrough occurred, with a fantastic group of coaches wanting a similar approach. A move to a more proactive medical performance systems approach was discussed and eventually pursued. This PhD thesis is the culmination of this process: one that has been the most satisfying, evolving and yet challenging professional experience to date. Pursuing a PhD part-time whilst working full-time in elite football is not without challenges. This has clearly been off-set by the satisfaction of having executed this body of work in the applied ‘real world’ setting.
Abstract

Lower limb injuries to the thigh muscles are common in football and impact on player development and team success. Injury incidence is highest in match play, especially late in halves and during congested match schedules. Despite growing knowledge of potential risk factors, mechanisms, incidence, burden and injury prevention in football, current prevention approaches have not changed the incidence. Alternative and complementary prevention systems are warranted. Overall this thesis aims to introduce a novel prevention system based on primary, secondary and tertiary prevention of groin problems and hamstring strain injuries in football. This thesis is focused on highlighting the potential of athlete monitoring as a successful secondary prevention strategy in male professional development football players. Secondary prevention is a two-step clinical process aimed at early detection and management of impairments, risk or susceptibility of injury. It relies on knowledge of post-match recovery responses.

Study One is a longitudinal cohort study highlighting the introduction of in-season monitoring of hip and groin strength, health and function in professional development players over two consecutive seasons. It aimed to compare in-season hip and groin strength, health and function data to pre-season baseline data. Study Two examined the effect of congested match play during an international tournament on hip adductor strength and function in U17 National team players. Study Three investigated the acute effect of football match play on hamstring strength and lower limb flexibility in professional development players. Study Four examined the effect of congested match play on hamstring strength and lower limb flexibility in professional development players. Finally, Study Five is a cohort study designed to introduce a novel hamstring strain injury prevention system using primary, secondary and tertiary prevention strategies. It identifies the potential for secondary prevention of hamstring strain injury in elite male football compared to standard practice (primary and tertiary prevention).
Statement of Authorship

I, Martin Wollin, declare that this thesis includes work by the author that has been published or submitted for publication as described in the text. Except where reference is made in the text of this thesis, this thesis contains no other material published elsewhere or extracted in whole or in part from a thesis accepted for the award of any other degree or diploma. No other person’s work has been used without due acknowledgement in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution. Regarding the extent of collaboration with another person or persons, although the publications involve joint authorship, I have made a significant and leading contribution to the work, equivalent to that expected for a traditional thesis. I am first author on all publications presented in this thesis. This research project was approved by the relevant Human Ethics Committees (Ethics approval number: 2013008). Letters of ethics approval are placed in Appendix A, B and C. This work was supported by an Australian Government Research Training Program Scholarship.

Signed:

Date: 10/07/2018
Acknowledgements

It is with excitement, a degree of surprise, and great satisfaction that I find myself writing these closing words to this long, hard PhD journey. It could not have been done without the involvement of some exceptional people, to whom I am forever grateful.

Thank you to the coaches, staff and players at the Football Federation Australia Centre of Excellence and Australian U17 National Team programs who participated and supported the research. This PhD would not have been possible without your explicit support. A particular recognition to Head Coach Mr Tony Vidmar and Technical Director Mr Peter De Roo who supported the research studies and overall paradigm shift to a proactive medical performance model outlined in this thesis. Your clear and communicated quest for having fit and fresh players ready to train at maximum intensity with your best player’s available more often were a central theme of this model. ‘Optimising training and match exposure’ was the key outcome and motto.

To my supervisors, Dr Tania Pizzari and Dr Kristian Thorborg who have made an outstanding contribution in guiding me through the many challenges of this PhD study. Dr Tania Pizzari is probably the most humble and friendly high performing professional going around. Your knowledge, reasoning and expertise is greatly complemented by your relaxed and confident manner. Your ability to clearly grasp both the clinicians and researcher’s perspective is outstanding and has been most helpful to me during this PhD process. I could not have done this without your expert supervision and patience. You are a great friend and inspiration. I hope that we can continue working together in the future.

To, Dr Kristian Thorborg, a.k.a ‘The Great Dane’. Many years has passed since we studied together in Melbourne. Your research career since is most impressive and an inspiration in the way you have produced clinically relevant research over the years. I have been very fortunate to have you involved in this project, sharing your expertise in groin, hamstring and football. You
have executed your role with Scandinavian precision and flawless timing along with the occasional ‘Danish Dynamite’! I look forward to our ongoing friendship and future opportunities of working with you again.

It has been a privilege to execute the majority of this work in the Department of Physical Therapies at the Australian Institute of Sport (AIS). I would like to acknowledge Head of Department Mr Craig Purdam for supporting this work and allowing the pursuit of the proactive medical performance model in this way. The AIS Physical Therapies team; Dr Mick Drew for the many chats and discussing new ideas (and input to Figure 1), Dr Paula Charlton for proof reading the thesis, Mr Vince Cosentini and my Postgraduate Scholars for research assistance and contributions to the football program.

Last but certainly not least to my wife Leah and children who have endured this emotional rollercoaster with me. I could not have done this without your unwavering support, motivation and occasional reality check. I am forever grateful to you for allowing me this opportunity to further myself and pursue my professional interest while raising a young family and working full-time. Leah, this achievement is as much yours as mine! As this chapter is closing I look forward to the rest of our lives together.
Publications and Presentations

Publications forming part of the thesis


Other relevant publications during the candidature not forming part of this thesis


International Conference Presentations


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<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Abd</td>
<td>Abductor</td>
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<tr>
<td>Add</td>
<td>Adductor</td>
</tr>
<tr>
<td>ADL</td>
<td>Activities of daily living</td>
</tr>
<tr>
<td>Add:Abd</td>
<td>Adductor to abductor strength ratio</td>
</tr>
<tr>
<td>AFE</td>
<td>Attributable fractions in the exposed</td>
</tr>
<tr>
<td>AFP</td>
<td>Attributable fractions in the population</td>
</tr>
<tr>
<td>AKE</td>
<td>Active knee extension</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>ARF</td>
<td>Australian rules football</td>
</tr>
<tr>
<td>AU</td>
<td>Arbitrary units</td>
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<tr>
<td>BFh</td>
<td>Biceps femoris long head</td>
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<tr>
<td>C</td>
<td>Celsius</td>
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<tr>
<td>CI95%</td>
<td>Confidence interval 95%</td>
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<tr>
<td>cm</td>
<td>Centimetre</td>
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<tr>
<td>CON</td>
<td>Control group</td>
</tr>
<tr>
<td>ES</td>
<td>Effect size</td>
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<tr>
<td>FIFA</td>
<td>Fédération Internationale de Football Association</td>
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<tr>
<td>GLMM</td>
<td>General linear mixed model</td>
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<tr>
<td>H</td>
<td>Hour</td>
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<tr>
<td>INT</td>
<td>Intervention group</td>
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<tr>
<td>IRR</td>
<td>Incidence rate ratio</td>
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<tr>
<td>HAGOS</td>
<td>Hip and groin outcome score</td>
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<tr>
<td>HI</td>
<td>Hamstring injury</td>
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<tr>
<td>HS</td>
<td>Hamstring strain</td>
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<tr>
<td>ICC</td>
<td>Intra class coefficient</td>
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<tr>
<td>IQR</td>
<td>Interquartile range</td>
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<tr>
<td>Kg</td>
<td>Kilogram</td>
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<tr>
<td>Km</td>
<td>Kilometre</td>
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<tr>
<td>LMM</td>
<td>Linear mixed model</td>
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<tr>
<td>M</td>
<td>Metre</td>
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<td>Abbreviation</td>
<td>Description</td>
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</tr>
<tr>
<td>MDC</td>
<td>Minimal detectable change</td>
</tr>
<tr>
<td>MDC$_{95}$</td>
<td>Minimal detectable change 95% confidence interval</td>
</tr>
<tr>
<td>MVC</td>
<td>Maximal voluntary contraction</td>
</tr>
<tr>
<td>MVIC</td>
<td>Maximal voluntary isometric contraction</td>
</tr>
<tr>
<td>N</td>
<td>Newtons</td>
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<tr>
<td>NHE</td>
<td>Nordic hamstring exercise</td>
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<tr>
<td>Nm</td>
<td>Newton metre</td>
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<tr>
<td>NRS</td>
<td>Numerical rating scale</td>
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<tr>
<td>OR</td>
<td>Odds ratio</td>
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<tr>
<td>PA</td>
<td>Physical activity</td>
</tr>
<tr>
<td>PKB</td>
<td>Prone knee bend</td>
</tr>
<tr>
<td>PRE</td>
<td>Pre-match</td>
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<tr>
<td>POST</td>
<td>Post-match</td>
</tr>
<tr>
<td>RCT</td>
<td>Randomised controlled trial</td>
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<tr>
<td>RESTQ-SPORT</td>
<td>Recovery stress questionnaire for athletes</td>
</tr>
<tr>
<td>ROM</td>
<td>Range of motion</td>
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<tr>
<td>RPE</td>
<td>Rate of perceived exertion</td>
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<tr>
<td>S&amp;C</td>
<td>Strength and conditioning</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
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<tr>
<td>SEM</td>
<td>Standard error of measurement</td>
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<tr>
<td>sRPE</td>
<td>Sessional rate of perceived exertion</td>
</tr>
<tr>
<td>U</td>
<td>Under</td>
</tr>
<tr>
<td>QOL</td>
<td>Quality of life</td>
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<tr>
<td>5-second AST</td>
<td>Bilateral long lever 5-second adductor squeeze test</td>
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<tr>
<td>95%CI</td>
<td>95% confidence interval</td>
</tr>
<tr>
<td>°/s$^1$</td>
<td>Degree of angular velocity per second</td>
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Thesis Aim

Firstly, to introduce a novel injury prevention system based on primary, secondary and tertiary prevention and risk-factor based interventions of groin problems and hamstring strain injury in elite football. Secondly, to highlight and investigate athlete monitoring as a secondary prevention strategy in male professional development football.

Objectives of The Thesis

The objectives were to:

1. Conduct a narrative review of groin and hamstring injury problems in elite male football that outline the physical demands and player responses to elite football, while providing essential background information of physiological and musculoskeletal stresses placed on the groin and hamstrings regions.
2. Introduce a secondary prevention strategy for groin problems and to compare hip and groin strength, health and function at pre-season screening with regular in-season test results.
3. Establish the effect of football match congestion on hip adductor strength, pain and recovery in male professional development players.
4. Investigate the acute effect of a competitive football match on isometric hamstring strength and lower limb flexibility measures associated with hamstring injury risk.
5. Investigate the effect of football match congestion on isometric hamstring strength and lower limb flexibility measures associated with hamstring injury risk.
6. Introduce a novel hamstring strain injury prevention system by providing a framework for primary, secondary and tertiary prevention and risk-factor based interventions. To highlight the potential of athlete monitoring as a secondary prevention strategy to reduce this injury in elite football.
Thesis Outline

This thesis comprises an introductory narrative review, a series of published articles and a submitted manuscript. The narrative review focuses on groin problems and hamstring injury in elite male football. It outlines the physical demands of and player response to elite football and provides essential background information to understand the physiological and musculoskeletal stresses placed on the groin and hamstring regions. Further, the narration covers epidemiology, current state of prevention and introduces alternative and complementary systems and strategies to prevent groin problems and hamstring strain injury in elite male football.

The thesis contains four published manuscripts in peer reviewed journals and one additional submitted manuscript currently under review. The five articles are presented in the format in which they were published or submitted for publication by the respective journal. Each publication is presented as an individual chapter. These chapters employ the accepted formatting for the respective publishing journal.

This thesis presents two studies on athlete monitoring relating to groin problems, and three papers concerning hamstring injury. Chapter Two studied hip and groin strength, health and function in professional development football players over two consecutive seasons. Clinical screening of players is recommended for the prevention of groin problems in elite football, but there are no evidence-based published frameworks or concepts available to clinicians in the literature. This Chapter describes a secondary prevention strategy and compares players’ unilateral hip adductor and abductor strength and hip and groin outcome scores (HAGOS) at pre-season screening with regular in-season test results.

In Chapter Three the effect of football match congestion on the bilateral long lever 5-second hip adductor squeeze test (5-second AST) and associated pain ratings were investigated. The susceptibility of developing groin problems is increased during match congestion and hip adductor strength deficits are an established intrinsic risk factor. Despite this there are no
published studies that investigate the effect of match congestion on elite male football players’ hip adductor strength and pain.

Chapters Four, Five and Six cover the hamstrings in football. Chapter Four investigated the acute effect of a competitive football match on isometric hamstring strength and lower limb flexibility measures associated with hamstring injury risk. Prior to this study there was no information on the acute effect of match play on this hamstring strength test and lower limb flexibility tests in professional development football players. Most reported findings relate to match simulation protocols and data from competitive matches is limited.

In Chapter Five the effect of football match congestion on the same clinical screening tests used in Chapter Four was examined. Match congestion is associated with increased susceptibility and risk of hamstring strain injury and players require several days to restore pre-match homeostasis. Despite this, it is not known how isometric hamstring strength and lower limb flexibility respond to a congested match period in professional development football players.

Chapter Six is a longitudinal cohort study that expands and incorporates findings from Chapters Four and Five. The manuscript is submitted for publication and currently under peer review. Clinical screening tests are commonplace and recommended for prevention of muscle injury in elite football. However, there is no documented evidence-based framework or concept published in the literature to guide clinicians in the implementation of clinical screening programs to prevent or reduce hamstring strain injury in elite football. The main objective of Chapter Six was to introduce a novel system that provides a framework for primary, secondary and tertiary prevention coupled with risk-factor based interventions of hamstring strain injury prevention in elite football. The main findings, possible clinical implications, strengths and limitations of this thesis are discussed in Chapter Seven. Directions for future research and overall conclusions of this thesis are also provided in Chapter Seven.
Chapter One: Introduction

Football is a very popular sport played by men, women and children around the world. Participation in the game provides players with a host of positive and tangible health benefits irrespective of age and gender (Krustrup et al., 2009, Bangsbo et al., 2014, Bangsbo et al., 2015, Krustrup et al., 2010). In the professional development phase (≥15 year-old players in elite full-time programs) and at the professional level, players are also exposed to significant injury risk, burden and incidence (Price et al., 2004, Cloke et al., 2012, Ekstrand et al., 2011a, Bahr et al., 2017, Hawkins and Fuller, 1999, Read et al., 2018). One third of all injuries in football are muscle injuries with over 90% of those affecting the lower limbs at the professional development and professional levels of the game (Ekstrand et al., 2011a, Cloke et al., 2012, Price et al., 2004, Read et al., 2018). Of these, the groin and hamstring regions are highly susceptible to injury in male professional development and professional football, accounting for over 50% of lower limb muscle injuries (Ekstrand et al., 2011a, Werner et al., 2009, Price et al., 2004, Cloke et al., 2012, Walden et al., 2015, Read et al., 2018). They are associated with high incidence and burden, recurrence rates, subsequent injury and underperformance (Hagglund et al., 2013, Bahr et al., 2017, Werner et al., 2009, Ekstrand et al., 2012, Ekstrand et al., 2011a, Werner et al., 2018). This absence from football due to injury has the potential to affect team success and player development (Cloke et al., 2012, Price et al., 2004, Le Gall et al., 2008, Hagglund et al., 2013). Consequently, groin problems and hamstring injuries are key issues to address at the elite levels of male football. Preventing groin and hamstring injuries and limiting the burden of these injuries is a priority for high performance support teams operating in the professional development and professional male football settings (Cloke et al., 2012, Price et al., 2004, Ekstrand et al., 2016, Bahr et al., 2017, Read et al., 2018).
1.1 Football physical demands

Physiological and musculoskeletal performance requirements are considerable on football players (Iaia et al., 2009, Dupré et al., 2018, Brophy et al., 2007, Charnock et al., 2009). The physical output varies between team positions and playing formations but at an individual level, nearly all players appear to exhaust their capacity from match play (Bangsbo et al., 2006, Mohr et al., 2003, Whiteley et al., 2017, Bangsbo, 2014, Buchheit et al., 2010, Di Salvo et al., 2007, Bradley et al., 2011, Carling et al., 2008). Football is an intermittent game that involves high variability and unpredictability for the players, who are required to perform significant volumes of high intensity efforts or ‘explosive actions’ spread over the duration of the match (Bangsbo, 2014). The relative workload, player actions and aerobic capacity in match play is similar between elite male youth and adult players (Stroyer et al., 2004).

A regular football match is played over 2 x 45 minutes halves separated by a 15-minute half-time break. Field dimensions are required to be 100-110 metres in length by 64-74 metres in width according to the laws of the game (Fédération et al., 1995). Each team starts the game with one goalkeeper and ten nomadic field players positioned in defence, mid-field and attack. A host of explosive player actions are required during match play (Bangsbo et al., 2006, Akenhead et al., 2013) including:

- Acceleration & decelerations
- Twisting & turning
- Changes of direction
- Running & sprinting
- Jumping & landing
- Tackling
- A variety of kicking actions

Explosive actions, high-speed running and sprinting are critical capabilities for top level football players (Bangsbo, 2014) and these physical demands have increased since the early 2000’s.
Top level players have been found to cover approximately 30-60% more high-speed running and sprinting volumes compared to professional players at a lesser level (Mohr et al., 2003). The performance of these high-intensity explosive actions have players operating near their anaerobic threshold coupled with high aerobic match demands (Bangsbo, 2014), evidenced by reports of mean player heart rates of 85% maximum and 75% of maximum oxygen uptake during match play (Bangsbo, 2014). In the last decade, training volumes have increased substantially in the corresponding professional development settings, presumably to reflect the increasing demands at the professional level (Read et al., 2018). In this time, injury incidence rates appear to have increased three-fold in the professional development system (Read et al., 2018). Linear sprinting is the most frequent player action involved in goal situations (Faude et al., 2012). It is important that players develop capability to perform repeated maximal football specific physical efforts through high-intensity aerobic and speed-endurance training (Iaia et al., 2009). At the professional development and professional levels of football, training occurs on most non-match days in the week.

1.1.2 Running

Players cover distances of 10-13km in match play involving walking, jogging and various running and sprint velocities (Bangsbo et al., 2006, Bradley et al., 2011). Distances up to 4.5km have been shown to involve high-intensity running when running (14.4-19.7 km/h), high-speed running (19.8-25.1 km/h) and sprinting (>25.1km/h) data are pooled (Bradley et al., 2009). Recent data, captured by semi-automatic computerised motion analysis systems, showed that repeat sprinting output from thirty German National team players over 19 matches was lower than previously estimated using different technology (Schimpchen et al., 2016). Pre-defined speed zones for high-intensity running (>21 km/h) and sprinting (>24km/h) were used to calculate individual sprinting thresholds (Schimpchen et al., 2016), which might contribute to the different findings between the studies. Sprinting, and the ability to perform repeated sprints throughout the match, is important in football. Acceleration is a powerful action involved in
Chapter 1: Introduction

Generating speed of movement for fast running and sprinting. Acceleration is a powerful action involved in generating speed of movement for fast running and sprinting. Power and speed ability features clearly within pivotal match situations in professional football and should be included in training (Faude et al., 2012). The number of accelerations per minute reduces significantly across the tournament in comparison to the first match (Arruda et al., 2015).

Longer sprints (>30m) require extended recovery time compared to shorter sprints of 10-15 metres (Bangsbo and Mohr, 2005). During and after matches, players demonstrate decreased capacity to maintain high speed running and acceleration/deceleration volumes (Akenhead et al., 2013, Mohr et al., 2003, Bradley et al., 2009). These reductions may be associated with dehydration and depletion of muscle glycogen concentrations acutely post-match and up to 48 hours later (Bangsbo et al., 2006, Nédélec et al., 2012). Total distances and high-speed running intensities seem to decline in the second half of matches with 20-40% reductions in high-speed running documented in the final 15 minutes of the second half (Mohr et al., 2003, Bradley et al., 2009, Di Salvo et al., 2009). In fact, the more explosive actions players perform in the first half, the greater the reductions in running are in the second half (Rampinini et al., 2007). The consequences of this may include reduced performance but can also increase players susceptibility to injury; particularly after high-intensity periods and during or after longer (>30m) sprints late in halves (Silva et al., 2018). Players with a previous hamstring injury seem to be most susceptible, since hamstring function declines faster in injured compared to non-injured hamstrings during repeated sprinting (Lord et al., 2018). It should be recognised that variation in match demands is a possibility and that internal and external variables could impact on both squad and individual players results between these match performance analysis studies (Carling, 2013).

1.1.3 Kicking and other skills

Other physical demands on players involve key skills such as kicking, passing and tackling. The frequency that players perform these skills can be influenced by pitch size and player numbers
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(Hodgson et al., 2014). Players passing and shooting volumes increase on a small pitch compared to a large pitch (Hodgson et al., 2014), which indicates that pitch size and player numbers should be considered when evaluating players readiness to train in regards to expected loading to the groin region. Kicking and change of direction involves significant hip adductor muscle activity and strength (Charnock et al., 2009, Brophy et al., 2007, Thorborg et al., 2011a). Even sub-maximal inside passes of the ball require substantial hip adductor forces (>200 Newtons [N]) and are associated with high adductor muscle stress (Dupré et al., 2018). The inside passing action involves hip abduction during the back-swing with increasing internal rotation of the hip to elevate the foot further during the leg-cocking and acceleration phases (Dupré et al., 2018). Hip adduction velocity during instep kicking does not differ between adults and youth players (Katis and Kellis, 2010).

A recent study investigating kicking characteristics in male professional players found that match related kicking demands varied between player positions (Whiteley et al., 2017). Players in external positions performed greater volumes and velocities of match related kicking compared to centrally positioned players, particularly central defenders and goalkeepers (Whiteley et al., 2017). Player interaction with the ball, short passes and accuracy thereof have been found to reduce after high-intensity periods during match play and in the second half of the game in young male football players (Rampinini et al., 2009, Rampinini et al., 2008). Short passing ability in professional male players might not be affected similarly to the demands of match play (Rampinini et al., 2011).

In addition to kicking demands, players perform a high number (1000-1500) of movements with and without the ball, performing 600-700 turns greater than 90° and 150-250 explosive actions in match play (Bangsbo, 2014, Bloomfield et al., 2007). The relative match related workload and activity patterns in elite youth football players at the end of puberty are similar to adult elite players (Stroyer et al., 2004). Recent research demonstrated that that professional development players in the U16-18 age can cover >8000 m of running in match play (Buchheit et al., 2010),
which is similar to total distances reported in professional players once walking and jogging activities are included (Bradley et al., 2011).

1.1.4 Positional and team formation variations

Positional differences in physical output and capacities during match play seem to exist for male youth, professional development and professional players (Bangsbo, 2014, Buchheit et al., 2010, Varley and Aughey, 2013, Schuth et al., 2016). In both youth and adult players, central defenders cover less total distance and, together with central midfield players, also appear to perform significantly less sprinting and high intensity running (Buchheit et al., 2010, Di Salvo et al., 2007). In contrast, male professional fullbacks and external attacking players perform significantly more sprints and high-speed running volumes (Carling et al., 2008, Di Salvo et al., 2007). Attacking male youth and professional development players have demonstrated higher volumes of high-speed running and sprinting compared to other positions (Buchheit et al., 2010). Additionally, attacking players in 4-3-3 team formations perform more high-speed running compared to attacking players in other formations (4-4-2 and 4-5-1) (Bradley et al., 2011). In Australian professional players, the number of maximal and sub-maximal accelerations during match play have been found to differ between playing positions with external full backs performing significantly more maximal and sub-maximal acceleration than any other position (Varley and Aughey, 2013). Together with forwards, external full backs also perform significantly more sprints (Varley and Aughey, 2013). Data from English professional players demonstrates that in-match positional interchange from central defender to external full back positions involve different physical demands (Schuth et al., 2016). An increase in total distance covered, including running, sprinting and high-intensity running with and without the ball was identified (Schuth et al., 2016).

1.1.5 Match induced groin and hamstring impairments

Match play induces muscle damage and fatigue through these high-intensity explosive actions, predominantly from eccentric muscle loading (Nédélec et al., 2012). The impairment is
distinguished by reductions in thigh strength and function due to central and peripheral fatigue mechanisms. Deficits can last several days post-match in both professional development and professional players (Thomas et al., 2017, Nedelec et al., 2014, Greig, 2008, Timmins et al., 2014, Thorpe and Sunderland, 2012, Thorlund et al., 2009, Rampinini et al., 2011, Ispirlidis et al., 2008). These physical changes have the potential to increase susceptibility for groin problems and hamstring strain injuries in-season by affecting intrinsic risk factors: low hip adductor and hamstring strength characteristics and hamstring strength asymmetry (Engebretsen et al., 2010a, Croisier et al., 2008, Timmins et al., 2016). Single and repeated sprint performances are also impaired during and after match play (Krstrup et al., 2006), and acute isometric knee flexor and extensor strength reductions post-match have been demonstrated using isokinetic dynamometry (Thorlund et al., 2009, Krstrup et al., 2011). Several studies using different match simulation protocols have demonstrated reduced strength of the hamstring complex with isometric (Greco et al., 2013, Marshall et al., 2014, Robineau et al., 2012), concentric (Greco et al., 2013, Robineau et al., 2012, Timmins et al., 2014) and eccentric contractions (Greco et al., 2013, Timmins et al., 2014, Greig and Siegler, 2009, Small et al., 2010). The magnitude of change is greater in isometric and eccentric hamstrings strength compared to concentric contractions and greater for the hamstring muscles compared to quadriceps post-match (Silva et al., 2018). Interestingly, the hamstring strength impairment is similar between isometric and eccentric contractions (Silva et al., 2018).

A recent report indicated that peripheral fatigue contributes more than central processes to post-match fatigue, likely due to the match induced muscle damage (Thomas et al., 2017). Central fatigue has been described as a reduced capacity of the central nervous system to stimulate skeletal muscle (Thomas et al., 2017). Central fatigue appears most prominent immediately post-match simulation with clear improvements at 24 hours and complete restoration at 48-hours (Thomas et al., 2017, Rampinini et al., 2011). Peripheral fatigue is also present acutely post-match without complete restoration noted at 72 hours in amateur and
elite male football players (Thomas et al., 2017, Ispirlidis et al., 2008). Another study investigating fatigue response to match play in young professional male players demonstrated knee extensor muscle function restoration 48 hours post-match (Rampinini et al., 2011). There is a possibility that highly conditioned male professional players might achieve complete restoration of peripheral fatigue 48 hours post-match (Rampinini et al., 2011). This highlights that players may be exposed to maximal or near maximal high-intensity football specific loading while still fatigued from match play. This has prompted monitoring of muscle function restoration to reduce muscle injury by facilitating timely individual player interventions in football (Thomas et al., 2017, Silva et al., 2018).

Kicking performance skills such as passing and shooting accuracy are also affected by fatigue with underprepared players demonstrating poorer precision (Rampinini et al., 2008, Maly et al., 2018). Other match induced physical changes include reduced range of knee extension and total hip range of motion (ROM), altered running kinematics, altered lower limb joint position sense, reduced hamstring activation patterns and inferior sprint and jump performances (Robineau et al., 2012, Timmins et al., 2014, Small et al., 2009).

1.2 Thigh injury in elite football: current state

On review of the physical demands of elite football it is unsurprising that thigh muscle injuries are the most common injuries in the sport. This situation has not improved over the last 25 years in both professional development and professional levels of male football (Hawkins and Fuller, 1999, Ekstrand et al., 2011a, Price et al., 2004, Read et al., 2018, Cloke et al., 2012). At the highest level of professional club football the occurrence of training related hamstring injuries has increased over the last decade (Ekstrand et al., 2016). At that level of professional football, average player availability (i.e. free of injury or illness) at training has been reported as 77% and 86% for match play (Hagglund et al., 2013). Injury burden and player match availability affects team success at this level and groin and hamstring injury are major contributors to this injury burden (Hagglund et al., 2013). At the professional development level, hamstring injuries
are reported in the top two most common muscle injuries (Price et al., 2004, Read et al., 2018, Cloke et al., 2012).

1.2.1 Groin problems in football

Historically groin injuries have been defined by time-loss. Recently it has become evident that players suffer from groin problems without missing matches, which suggests that time-loss does not capture the full extent of groin problems in football (Haroy et al., 2017). Groin problems are therefore considered a greater problem at professional development and professional levels than initially thought (Haroy et al., 2017, Bengtsson et al., 2017). Groin injury can occur as both acute muscle injuries and chronic presentations predominantly relating to the hip adductor muscle complex (Holmich et al., 2014, Serner et al., 2015, Werner et al., 2009, Werner et al., 2018).

Injury incidence and burden

Groin problems are common in football and affect male and female players across diverse age groups and levels of play (Holmich et al., 2014, Serner et al., 2015, Walden et al., 2015, Haroy et al., 2017). Kicking and changes of direction are the most common injury mechanisms, predominantly affecting the preferred kicking leg, in acute groin injuries (Serner et al., 2015, Hagglund et al., 2013). Chronic groin problems affect both legs more evenly (Werner et al., 2009). Most time-loss injuries develop gradually and are classified as overuse or chronic with most signs and symptoms being reported and diagnosed in relation to match play (Engebretsen et al., 2010a, Werner et al., 2009, Werner et al., 2018). The number of days between matches can influence the hip and groin muscle injury rate at the top level of professional club football. Twice the number of hip and groin injuries (190 versus 91) were reported if there were ≤5 days between matches compared to ≥6 days (Bengtsson et al., 2017).

On average, professional men’s teams sustain six to seven time-loss injuries per season with most resulting in moderate to severe time-loss (Werner et al., 2009, Werner et al., 2018). This represents 14% of all injuries over the last 15-years in professional football (Werner et al., 2009,
Werner et al., 2018). It has been reported that groin injuries account for 4-19% of the total injury rates in male football (Weir et al., 2015). Recently the clinical diagnosis of groin injury has been classified into regional anatomical entities (Weir et al., 2015). Adductor related groin problems are the most common groin problem in male football (Werner et al., 2018). They represent 63% of all hip and groin injuries, which is twice as many as other entities (Pubic, Iliopsoas, Inguinal and Hip related injury) in professional football (Weir et al., 2015). One in ten (11%) players with adductor related groin problem will suffer recurrences. Pubic and hip related entities demonstrate the largest proportion of recurrences, 30% and 25% respectively in male professional football (Werner et al., 2018). A quarter (25%) of players will sustain a subsequent groin injury other than adductor related in the same season as they suffered adductor related groin problems (Werner et al., 2018). Most (60%) adductor related groin problems defined by time-loss are classified moderate (8-28 days) or severe (>28 days) (Werner et al., 2018), which means that they are associated with substantial injury burden. In a recent study that investigated the prevalence of non-time loss and time-loss groin problems in football, the majority findings were non-time loss groin problems (67%) (Haroy et al., 2017). About one in five players sustain a time-loss groin injury every season at the professional level (Werner et al., 2009) but when non-time-loss injuries are considered, the injury rates are potentially much higher (Haroy et al., 2017). In elite and sub-elite male football it has been reported that 40% - 70% of players develop hip and groin pain each season (Thorborg et al., 2015). In congested match periods the majority of players may develop at least one groin problem with up to one in four players having substantial groin problems (Haroy et al., 2017). Nearly 30% of male football players may experience groin problems weekly in-season with six out of twenty players potentially having groin problems at any point in-season (Haroy et al., 2017). Most groin problems in football appear to be of gradual onset (Haroy et al., 2017) and the natural history of these problems are that they deteriorate over time (Thorborg et al., 2015). That considered, it is not surprising that most time-loss groin injuries in professional football are moderate to severe
Prevention, early detection and management of groin problems is clearly indicated and of high priority in elite football.

**Groin injury risk factors**

Injury risk factors are traditionally described as intrinsic or extrinsic (Hagglund et al., 2013). Intrinsic refers to internal player factors, whereas extrinsic risk factors relate to external variables associated with injury risk. Risk factors are also described as modifiable, e.g. strength, and non-modifiable, e.g. age. Risk factor studies commonly include data collected at a one-off test occasion in pre-season and then prospectively collect injury data in-season. There are methodological concerns with this approach since it excludes environmental influences that might dynamically affect players’ risk in-season. This should be considered when interpreting the clinical utility of many reported sports injury risk factors.

Reported intrinsic risk factors for groin problems in football include: previous time-loss groin injury (Whittaker et al., 2015, Engebretsen et al., 2010a, Hagglund et al., 2013), unilateral hip adductor strength deficits (Whittaker et al., 2015, Engebretsen et al., 2010a), and nomadic field players (compared to goalkeepers) (Hagglund et al., 2013). Potential extrinsic risk factors include: higher level of play (Whittaker et al., 2015), reduced sport specific training preparation (Whittaker et al., 2015, Lovell et al., 2006), match congestion (Bengtsson et al., 2013) and home matches (compared to away fixtures) (Hagglund et al., 2013).

The list of potential groin injury risk factors highlights the important relationship between previous groin injury (intrinsic, non-modifiable), hip adductor strength (intrinsic, modifiable) and football specific loading (extrinsic, modifiable). In a cohort of male football players (n=508) studied by Engebretsen et al. (2010a) a previous history of acute groin injury was linked to twice the risk of sustaining another groin injury. In Australian rules football (ARF), having sustained a groin injury as a junior player was a predictor for future time-loss related groin problems at the professional level (Gabbe et al., 2010). Football players with strength deficits on clinical testing of unilateral isometric hip adductor testing using a hand-held dynamometer, had four times
higher injury risk compared to players with appropriate strength (Engebretsen et al., 2010a). In addition, football players with current groin problems presents with lower isometric hip adduction/abduction strength ratios and eccentric adduction strength (Thorborg et al., 2011c, Thorborg et al., 2014). Furthermore, adductor strength reductions, on a short lever bilateral squeeze test, have been shown to precede the onset of groin pain in young ARF players (Crow et al., 2010).

Youth development football players that progress from part-time training backgrounds through an elite player pathway into full-time professional development programs may experience periods of rapidly increasing workloads and will be exposed to higher levels of match play. There is evidence that players with a lower training base before entering a full-time professional development football program have a higher risk of developing pubic related groin pain (Lovell et al., 2006). Players training ≤5 session per week at the level prior to (Australian state-level) entering a full-time program had approximately 70% probability of developing pubic groin pain compared to players who trained ≥6 weekly sessions at state level (Lovell et al., 2006). Four or less weekly training sessions were associated with a 80% probability of developing pubic related groin pain (Lovell et al., 2006). Consequently, this category of players can be considered high risk for developing groin problems, particularly if they have a previous history of time-loss groin injury and hip adductor strength deficits (Whittaker et al., 2015, Engebretsen et al., 2010a). The risk of developing or aggravating a current or previous groin problem may be even greater when players are exposed to accumulation of load from congested match periods (Bengtsson et al., 2013). An association between workload, defined by the acute to chronic workload ratio 1:3 and 1:4, and non-contact injury exists in male professional development and professional players (McCall et al., 2018, Malone et al., 2017, Bowen et al., 2017, Fanchini et al., 2018). Overall, it reinforces the importance of monitoring for groin problems to facilitate early clinical detection and management of groin problems in professional development football players.
1.2.2 Hamstring injury in football

*Injury details*

Hamstring injury is typically associated with high-speed running, sprinting and acceleration/deceleration during match play, particularly late in halves and during congested match periods (Beijsterveldt et al., 2013, Ekstrand et al., 2011a, Bengtsson et al., 2013, Price et al., 2004, Carling et al., 2016, Ekstrand et al., 2012, Cloke et al., 2012). The biceps femoris muscle is the most commonly affected of the hamstring muscles (>80%), followed by semimembranosus, with few semitendinosus injuries reported (Ekstrand et al., 2012, Timmins et al., 2016). The lateral hamstring (biceps femoris: long head or short head) is also more often involved in recurring hamstring strain injury (Ekstrand et al., 2012, Timmins et al., 2016). The long head of biceps femoris (BFllh) is believed to undergo peak strain during the late or terminal swing phase of the gait running cycle when the biomechanical loads increase resulting in peak knee flexion torque and muscle lengths (Thelen et al., 2005, Chumanov et al., 2012, Schache et al., 2011a). At this point in the cycle, the trunk/hip is flexed and knee is extending to outer range of approximately 30-45° off full knee extension. In addition, running speed influences loading of the lateral hamstring complex, highlighted by biomechanical modelling showing a linear increase in outer range lateral hamstring peak force and eccentric load with increased running speeds (Chumanov et al., 2007). Peak forces of the lateral hamstring complex increased by 44% when running at maximal speed compared to running at 80% of maximal speed (Chumanov et al., 2007).

*Injury incidence and burden*

Hamstring injuries are among the most common injuries in both professional development and professional football (Ekstrand et al., 2011a, Hagglund et al., 2013, Price et al., 2004, Cloke et al., 2012). Hamstring injuries account for up to 16% of all injuries in men’s football and the injury recurrence rates can be substantial at 16%-31% (Beijsterveldt et al., 2013, Ekstrand et al., 2012, Timmins et al., 2016, Hagglund et al., 2013, Woods et al., 2004). Most hamstring strain
Injuries are classified moderate and severe and consequently they are associated with the highest injury burden of all football related muscle injuries (Ekstrand et al., 2011a, Bahr et al., 2017, Hagglund et al., 2013, Cloke et al., 2012). On average a professional men’s team of 25 players can expect five time-loss injuries accumulating 80 time-loss days each season (Ekstrand et al., 2011a).

**Hamstring injury risk factors**

There is conflicting evidence regarding risk factors for hamstring injury in sport. One recent review included seven prospective cohort studies in men’s football; however univariate and multivariate analyses identified inconsistencies in findings (Beijsterveldt et al., 2013). Significant risk factors according to this review included: previous hamstring injury, increasing age (data limited to players of 22-26 years old), reduced hamstring flexibility (<90°), isokinetic eccentric strength assymmetries >15% and a leg length difference >1.8cm (Beijsterveldt et al., 2013).

Similar to groin injury risk factor identification, methodological concerns exists for identifying hamstring risk factors. The main limitation is that in-season external influences might affect players’ injury risk and susceptibility but are unaccounted for by one-off data collection session, particularly in the pre-season.

Workload is an established external injury risk factor in a multitude of sports, including football (Gabbett et al., 2014, Drew and Finch, 2016, Malone et al., 2017). In professional development football higher numbers of accelerations, and increased high-speed running (>20 km/h) distances performed by players with a low level of preparation resulted in increased injury rates, due to high acute to chronic workload ratios (Bowen et al., 2017). These findings suggest that rapid increases in football specific explosive actions and insufficient high-speed running volumes might increase injury risk in professional development players, due to reduced sport specific readiness. Similar findings are reported in professional male football where moderate exposure to high-speed running and sprinting are associated with the lowest rate of lower limb muscle injury when compared to lower and higher running and sprint loads in the preceding
three weeks (Malone et al., 2018). Rapid and extensive increases in high speed running (>24 km/h) above a player’s 2-year session average have also been found to increase the risk of hamstring strain injuries in Australian rules football (ARF) players (Duhig et al., 2016).

Interestingly, injuries were most likely in the 1-4 weeks, following exposure to spikes in high speed running, sprinting and accelerations (Duhig et al., 2016, Bowen et al., 2017, Malone et al., 2018). This lag in injury onset represents a latent period from exposure and biological onset to the development of symptoms.

Other factors shown to influence injury risk in professional development players includes sleep, nutrition and stress (Brink et al., 2010, Brink et al., 2012, von Rosen et al., 2017). Sleeping for more than 8 hours per night and meeting the required nutritional intake is associated with lower injury risk in elite youth athletes from a variety of sports, including football (von Rosen et al., 2017). Reduced scores on the recovery stress questionnaire for athletes (RESTQ-Sport) have been associated with injury in professional development football players (Brink et al., 2012). Interestingly a reduction in RESTQ-Sport scores were shown to precede clinical diagnosis by up to 2 months, which indicate a potential latency period from exposure and biological onset to development of a diagnosable health problem.

A host of additional potential risk factors are reported in relation to hamstring injury in football. Intrinsic risk factors include: nomadic field player (compared to goalkeeper) (Hagglund et al., 2013), uncorrected pre-season thigh strength asymmetries (Croisier et al., 2008), deficits in bilateral mean eccentric knee flexor peak force (Timmins et al., 2016), shorter BF1h fasicle length (Timmins et al., 2016), level of self-reported hamstring function as determined by the hamstring outcome score (Engebretsen et al., 2010b), active hip flexion range of motion (Henderson et al., 2010) and black ethnic origin (Woods et al., 2004).

Reported potential extrinsic risk factors for hamstring muscle injury in football are: home matches (compared to away fixtures) (Hagglund et al., 2013), congested match schedules (Bengtsson et al., 2013, Carling et al., 2016), in-season match play (compared to pre-season)
Muscle injury incidence is significantly higher during congested fixture periods when matches are separated by four or less days (Carling et al., 2016, Bengtsson et al., 2013). This is further supported by a recent 14-year multi-team study that reported increased muscle injury rates when games where separated by less than six days (Bengtsson et al., 2017).

A previous hamstring injury is the strongest established risk factor for sustaining another hamstring injury. A systematic review, which included five prospective cohort studies (mainly ARF and Athletics) of risk factors for recurrent hamstring injuries in sport reported limited evidence for the following three risk factors; 1) a grade one index hamstring injury, 2) a proportionally larger volume size trauma found on magnetic resonance imaging (54.5% versus 32.3%) of the index injury, and 3) previous knee anterior cruciate ligament reconstruction (ipsilaterally) (de Visser et al., 2012).

Other potential risk factors for hamstring injury recurrence include: higher number of past hamstring injuries, reduced active knee extension (AKE) ROM and isometric knee flexor strength deficit at outer range and tenderness on palpation of the hamstring just after returning to play (De Vos et al., 2014). In a population of mainly football players, larger AKE reductions and isometric knee flexor strength deficits 7 days after returning to sport were proposed to be independent predictors of future hamstring injury (De Vos et al., 2014). Further; fatigue, insufficient warm-up, inadequate rehabilitation, low sport specific fitness, lumbar and sacroiliac pain and dysfunction has been reported as potential risk factors for hamstring injury recurrence (Croisier, 2004).

Interestingly, a recent study of semi-professional male football players with previously injured hamstrings found they had lower capacity to handle the demands of football; demonstrated by faster decline in strength and function compared to non-injured hamstrings (Lord et al., 2018). They found greater strength reductions (16% versus 4%), in concentric peak knee flexion torque tested at 180°-s⁻¹ over 50 repetitions, in the previously injured versus non-injured leg. Even
greater strength reductions were reported between injured (96%) and non-injured (14%) legs in the previously injured player group when performing strength testing after repeat sprint efforts on a non-motorised treadmill (10 x 6 seconds maximal sprint efforts interspersed by 24 second of slow jogging) (Lord et al., 2018).

1.3 Prevention of groin problems and hamstring injury in football: current state
A range of interventions including exercise programs, education material and protective equipment have been utilised in an attempt to prevent injuries in football (van Beijsterveldt et al., 2013b). Exercise prevention programs appear the most common option in football at all levels, including elite youth and professional development levels (Read et al., 2017).

1.3.1 Groin injury prevention
Despite being one of the most common and debilitating injury problems in football, there is limited evidence to guide clinicians and high-performance support teams in the prevention or reduction of groin problems. Primary prevention exercise programs for groin injuries in football have, to date, been unsuccessful (Esteve et al., 2015). Two large randomised controlled trials (RCT) investigating exercise interventions to prevent groin injury in adult male football used similar exercises based on a successful rehabilitation program (Holmich et al., 2010, Engebretsen et al., 2008). One of these RCT’s evaluated Danish amateur male adult football players and included six exercises performed before every football training session (2-4/week) for an average duration of 13 minutes (Holmich et al., 2010). Exercises aimed to increase strength of the hip adductors, abductors and abdominal muscles while also incorporating single leg balance and hip flexibility exercises. The second study involved Norwegian elite male adult football players performing five exercises for 15 minutes three times per week (Engebretsen et al., 2008). Neither study was able to demonstrate significant reductions in groin injuries. Both studies reported issues with low compliance as the most plausible reason for the lack of efficacy (Engebretsen et al., 2008, Holmich et al., 2010). Other authors have suggested that the exercises, while appropriate for rehabilitation may not be of sufficient intensity for prevention
purposes (Serner et al., 2014). They advocate for the inclusion of three isolated hip adduction resistance exercises of higher eccentric intensity for prevention of groin injury (Serner et al., 2014). Considering the multi-factorial and complex interactions of intrinsic and extrinsic risk factors within the fluid context of elite football, addressing only one intrinsic risk factor (hip adductor weakness) may be insufficient to prevent groin injuries in football. Particularly when large proportions of players may already be playing with current groin problems (Thorborg et al., 2015, Haroy et al., 2017).

Alternative prevention strategies, other than exercise programs, have been proposed (Esteve et al., 2015). Suggestions includes regular screening of players and load monitoring (Esteve et al., 2015). This appears to more closely reflect the circumstances in professional development and professional football club environments (Read et al., 2017, McCall et al., 2015, Burgess, 2017).

1.3.2 Hamstring Injury Prevention

Considering the physical demands of football and match induced physical changes on players hamstring function, it is logical that current evidence supports eccentric and corrective strength training as a primary prevention approach (Croisier et al., 2008, Timmins et al., 2016, Petersen et al., 2011, Askling et al., 2003). A RCT involving 50 Danish male professional and amateur football teams investigated the preventative effect of the Nordic hamstring exercise (Petersen et al., 2011). In addition to their regular training, the intervention group performed 27 exercise sessions across a 10-week period of progressive eccentric hamstring strength training, followed by one weekly in-season maintenance session of 30 repetitions (12, 10, 8 repetitions) of Nordic hamstring exercise (Petersen et al., 2011). The program was based on a previous report that demonstrated greater effectiveness in developing eccentric and isometric hamstring strength from the Nordic hamstring exercise compared to bilateral concentric hamstring curls in Norwegian male football players (Mjolsnes et al., 2004). Results demonstrated a 70% reduction in hamstring injuries in the intervention group compared to the control group. Both index and recurring hamstring injuries were significantly reduced in the intervention group (Petersen et
al., 2011). Similar overall hamstring injury reduction rates have been reported after 10 weeks of different eccentric hamstring exercises, performed on a fly-wheel hamstring curl machine every four to five days (Askling et al., 2003). The results from the Askling et al. (2003) and Petersen et al. (2011) suggest that different types of knee-biased eccentric hamstring strength training can have similar injury reductive capacities on male football players.

Despite the potential value of these interventions, the incidence and burden of hamstring injury has not improved in elite male football and may even be increasing in male professional football (Ekstrand et al., 2016, Bahr et al., 2017, Price et al., 2004, Woods et al., 2004). This could be related to challenges around implementation and compliance with standard prevention exercises in the elite football setting (Bahr et al., 2015). Reports of unwanted post-exercise muscle soreness are also documented as a potential restriction to compliance (Goode et al., 2015). The reduced compliance of performing prevention exercise programs is the main explanation to the inconclusive evidence around the effectiveness of eccentric hamstring strength training to reduce hamstring injury in team sports (Goode et al., 2015). Interestingly, reports from high performance support staff at both the professional development and professional elite club environments suggest that eccentric hamstring strength training is a recognised injury prevention priority (Read et al., 2017, McCall et al., 2015) yet compliance appears to be a main issue in prevention research implementation. Low compliance with eccentric training using the Nordic hamstring exercise has been established at the professional level (Bahr et al., 2015). This highlights the importance of prevention strategies being accepted by coaches and players, the key stakeholders and beneficiaries, prior to and during implementation phases.

1.4 Alternative and complementary groin and hamstring prevention systems in football

Traditionally, risk factors such as a player’s strength has been evaluated as a one-off test at pre-season screening. However, it has been demonstrated that a one-off pre-season screening of
players hip adductor and hamstring strength is unable to predict who will develop a future time-loss groin problem or hamstring strain injury (Bahr, 2016, van Dyk et al., 2018, Mosler et al., 2018, Bakken et al., 2018). Injury causation is multi-factorial and influenced by the dynamic context of elite football (Bittencourt et al., 2016, Meeuwisse et al., 2007). The physical demands and player response, match scheduling, and potential other influences of less controllable external risk factors such as change of head coach, which may involve a change of leadership style, may affect injury causation (Ekstrand et al., 2017). It is clear that player injury risk and susceptibility can fluctuate in-season. In addition, considerations should be given to the impact of exposure to high-intensity explosive actions on the groin and hamstring regions during periods of impaired muscle function. Individual load management in the post-match recovery period has been recommended, guided by monitoring players hamstring strength through maximal voluntary isometric contractions (Silva et al., 2018). Similarly, monitoring player hip and groin strength for early detection and management of groin problems is advocated (Thorborg et al., 2015). It seems a systems approach to injury prevention that incorporates early detection and management of in-season impairments, susceptibility and risk, through regular in-season clinical screening, is more suited to the context of elite football compared to exercise interventions alone. However, the literature does not provide guidance or a framework of evidence-based systems and strategies around athlete monitoring to prevent or reduce groin problems and hamstring strain injury in football. A clear requirement exists to investigate potential new prevention concepts, systems and strategies using athlete monitoring in elite male football.

An alternative application to sports injury prevention has recently been recommended by Jacobsson and Timpka (2015). The authors introduced prevention classifications adjusted to the contemporary circumstances of today’s athletes based on frameworks provided by clinical epidemiology in conjunction with risk-factor based prevention. Combining these approaches allows for the integration of early preventative measures in both asymptomatic and
symptomatic health states (Jacobsson and Timpka, 2015). This proposed system has the potential to accommodate athlete monitoring as a prevention strategy in football. In health settings external to sport, such systems approaches are often standard practice and clinical epidemiology has employed this prevention concept for over 60 years (Jacobsson and Timpka, 2015, Fletcher et al., 2012). The prevention framework is based on the natural history of disease (or injury) and includes a pathology-based continuum that incorporates primary, secondary and tertiary prevention that can be combined with a risk-factor based prevention intervention system (Figure 1.1) (Fletcher et al., 2012).

![Figure 1.1 Prevention framework based on the Natural history of disease or injury and risk-factor based prevention measures.](image)

The natural history of disease (or injury) refers to the prognosis of a health impairment without intervention (Fletcher et al., 2012), when it runs its course uninterrupted. It is distinguished by: the healthy stage of susceptibility; subclinical and clinical phase; and stage of recovery, disability and recurrence. Central to the understanding of the natural history of disease (or injury) is the latency period and lead-time phenomena. The latency period refers to the time between exposure, the biological onset, and appearance of clinical symptoms (Fletcher et al., 2012). In this time clinical screenings may identify disease or injury before the appearance of clinical
symptoms, i.e. early detection. The period between early detection through clinical screening and the usual time of diagnosis is referred to as lead-time (Fletcher et al., 2012). The pathology-based prevention continuum is founded on clinical examination and may assist in early detection of injury, impairment or risk and susceptibility thereof, in the subclinical phase through secondary prevention strategies.

The risk-factor based concept of prevention involves interventions that are directed at different categories of risk, which allows for targeted injury prevention strategies (Jacobsson and Timpka, 2015). Risk categories involve population, subgroup and individual athlete levels and categorise risk as universal, selective and indicated (Jacobsson and Timpka, 2015). The aim is to facilitate an integrated performance health management structure in sport that is designed to prevent deterioration of player health by managing both pathology and injury risk or susceptibility early. It is recommended in a complete contemporary sports injury prevention systems approach that aims to limit the deterioration of health (Jacobsson and Timpka, 2015).

1.4.1 Prevention continuum: primary, secondary and tertiary

**Primary prevention**

Primary prevention aims to prevent injury from occurring by removing its causes in a healthy population in the stage of susceptibility (Fletcher et al., 2012, Jacobsson and Timpka, 2015). In the context of football it involves education, promotion and strategies to optimise personal and team health. Examples of primary prevention in football include optimisation of sleep, nutrition, training load, recruitment and compulsory use of shin guards (von Rosen et al., 2017, Bowen et al., 2017, Malone et al., 2018, Malone et al., 2017, Gabbett et al., 2014, Ekstrand et al., 2017, Ekstrand and Gillquist, 1983, Fédération et al., 1995). The substantial susceptibility of sustaining a groin problem and/or hamstring strain injury in-season warrants primary prevention. Evidence based interventions are limited but eccentric adductor and hamstring strength training have been shown to increase the strength of these commonly injured muscle regions, which is of
importance for both performance and prevention (Mjolsnes et al., 2004, Jensen et al., 2014). Eccentric training may be protective against hamstring strain injury by increasing muscle strength and fascicle length of BFh (Timmins et al., 2016). Improved hamstring strength may also improve running performance (Mendiguchia et al., 2015, Ishøi et al., 2017), a key performance skill in football. Similarly increasing hip adductor strength may improve kicking performance (accuracy under fatigue) and reduce susceptibility to sustaining an index or recurring groin injury or aggravating a current problem (Dupré et al., 2018). A lack of sport specific readiness or rapid fluctuations in football and running loads will increase player susceptibility to groin problems, hamstring strain injury and overall injury (Bowen et al., 2017, Malone et al., 2018, Malone et al., 2017, Gabbett et al., 2014). This strongly indicates that training load, sport specific readiness and player recruitment are required primary prevention targets in elite male football.

Secondary prevention

Secondary prevention is a two-step clinical process involving screening and follow up diagnostic examination (Fletcher et al., 2012). Screening is the clinical testing for the identification of a health impairment or risk factor that can be applied relatively quickly to individuals that might not yet have current clinical signs of injury. The clinical screening test does not need to be diagnostic itself due to the follow-up diagnostic examination (step two) (Fletcher et al., 2012). The aim is to detect a condition or impairment early, before it becomes symptomatic, and to minimise the chance of progression. It is distinguished by a subclinical and clinical phase. A latency in the onset of clinical symptoms from biological onset is demonstrated in the subclinical phase (Fletcher et al., 2012). In the context of elite football; strength based clinical screening tests are well placed to identify relevant impairments, susceptibility and modifiable risk factors. Evaluation of football induced groin and hamstring strength and associated pain presents an opportunity to identify impairments and increased risk or susceptibility to groin problems and hamstring strain injury in football in the days post-match. It provides an
opportunity to perform follow up examination to establish potential diagnoses and commence early management to limit time-loss and associated injury burden.

*Tertiary prevention*

Tertiary prevention involves the clinical management of a diagnosed health problem (Fletcher et al., 2012, Jacobsson and Timpka, 2015). It comprises the stage of recovery, disability and recurrence of injury or illness. The emphasis is on treatment, rehabilitation and management to restore function, improve or maintain current health status and avoiding recurring and subsequent health complications (Fletcher et al., 2012). It is indicated as an ongoing prevention strategy after a player has sustained an index injury, to avoid the common complication of injury recurrence or developing a subsequent injury (Toohey et al., 2017). It also includes regular in-season clinical screening to identify persisting or deteriorating impairments associated with the index injury. Tertiary prevention is ongoing, which reinforces the concept that prevention is a continuum. Hence, once a player is injured they should remain in the stage of tertiary prevention irrespective of whether they have returned to training, match play and top performance. Tertiary prevention also addresses risk factors of other related health problems (Fletcher et al., 2012). For example, a football player having had previous anterior cruciate ligament reconstructive surgery, will often return to sport with hamstring impairments and thus increased susceptibility of a hamstring strain injury (Toohey et al., 2017). In such cases, tertiary prevention of the knee injury will involve interventions that aim to correct the hamstring impairment and reduce the susceptibility of a subsequent injury to the ipsilateral hamstring. Such players should also undertake regular in-season hamstring strength testing as an indicated intervention that is part of clinical screening.

1.4.2 Risk-factor based prevention interventions

Risk indicators reflect the epidemiological concept of prevention relating to risk-factors. Risk-factor based interventions are described as universal, selective and indicated. These risk indicators reflect the specific population level of risk. It is a supported complement to the
pathology-based prevention continuum to deliver a framework for integrated contemporary prevention systems in sport (Jacobsson and Timpka, 2015).

**Universal**

Universal risk indicators and prevention measures are population-based and designed to target all football players. It involves the removal of risk that applies broadly to all players through participation. It has a natural fit in primary prevention. Education, promotion and optimisation of sleep, nutrition, training load, stress recovery, recruitment of players and staff and compulsory use of shin guards are examples of universal interventions beneficial to all football populations (von Rosen et al., 2017, Bowen et al., 2017, Malone et al., 2018, Malone et al., 2017, Gabbett et al., 2014, Ekstrand et al., 2017, Ekstrand and Gillquist, 1983, Fédération et al., 1995, Brink et al., 2012)

**Selective**

Selective interventions target subgroups within football specific risk or susceptibility and fits under primary prevention. It can be differentiated by age, gender or sport specific risk factors. In the context of elite football, interventions such as hip adductor and hamstring strength training, neuromuscular training and improving sport specific readiness are examples of selective preventative interventions.

**Indicated**

These interventions target individual players that demonstrate impairments causing higher than average risk or susceptibility of sustaining a future injury. Indicated interventions are naturally placed in secondary and tertiary prevention as they relate to the mechanisms of impairment. Indicated interventions are the product of the two-step process of clinical screening and follow-up clinical examination and typically include modifying further exposure to the causing factor and regular screening (Jacobsson and Timpka, 2015).
1.4.3 Athlete monitoring as a secondary prevention strategy

The standard approach to preventing (or reducing) these injuries in football has historically relied on information collected once in pre-season to ascertain individual player health and risk status. This approach fails to reflect the actual context that elite football players must perform in and it is therefore unsurprising that one-off pre-season screenings are unable to predict who will sustain a groin problem or hamstring strain injury in-season (Meeuwisse et al., 2007, Verhagen et al., 2018, Mosler et al., 2018, van Dyk et al., 2018). Further, sport specific fitness, strength and football readiness are typically at their lowest point at the start of pre-season (Caldwell and Peters, 2009, Jensen et al., 2014) when these one-off screenings occur. Pre-season screening cannot account for possible fluctuations in players hip/groin and hamstring health and function in-season and findings may be limited since they are captured out of context when players are not yet exposed to the biological onset of groin and hamstring impairments. Exposure to football match play demands represents the biological onset of injury, or risk and susceptibility thereof, through its associated physical changes, muscle damage and fatigue induced post-match impairments. In-season routine clinical screening in the form of athlete monitoring appears a logical complement to pre-season screening. Therefore, knowledge of normal responses and recovery time-frames to post match loads are required. This knowledge can inform high-performance staff of the most appropriate time to implement athlete monitoring at a group level as a secondary prevention strategy. Unfortunately, several of the most commonly used screening tests (e.g. overhead and single leg squat, hop and jump testing and postural evaluation) at the elite level of youth football have not yet been linked to injury or its risk factors (Read et al., 2017), which seems to be consistent with practices in professional football (McCall et al., 2015). Consequently, such tests have limited scope, based on current evidence, to inform high-performance staff in the two step clinical process of athlete monitoring as a secondary prevention strategy for groin and hamstring injury.
1.4.4 Clinical screening tests

The ability to monitor player’s health and function reliably, safely and efficiently in-season may provide important information to assist with clinical reasoning and risk assessment processes aligned with early detection and management strategies. Athlete monitoring as a secondary prevention strategy requires valid and reliable clinical screening tests that can be implemented with ease, at low cost and that are acceptable to the key stakeholders, i.e. coaches, players and clinicians. Hip and hamstring strength tests are indicated clinical screening tests to incorporate in athlete monitoring when implementing a secondary prevention strategy for groin problems and hamstring strain injury in elite male football. Safety, time required, and accessibility are also relevant considerations for clinicians.

This means that test selection is critical and call for reflections of the contextual requirements. Attention to the test’s precision through its absolute and relative reliability is required prior to implementation. Only tests that demonstrate acceptable measurement error to detect genuine test – retest change should be considered. Interpretation of what constitutes a genuine test – retest change relies on the test’s MDC_{95} which accounts for measurement error of both the test and retest results (Weir, 2005). Since athlete monitoring is aimed at detecting individual changes, MDC_{95} must be small enough to reliably detect clinically relevant changes on repeat testing. For example, if normal post-match hamstring strength reductions are known to be 15% the test’s MDC_{95} must be equal to or less than that.

The unilateral adductor and adductor:abductor (add:abd) strength ratio tests and the 5-second AST are suitable options for testing hip and groin strength health and function in football players. The tests are valid and reliable screening tools with suitable absolute and relative reliability for use in football (Light and Thorborg, 2016, Thorborg et al., 2010).

The unilateral hip adductor and add:abd strength test might be a more suitable option during the regular pre and in-season competition periods when there are less restraints on time. In addition to identifying unilateral adductor weakness the tests can establish low add:abd
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strength ratios that are associated with current hip and groin problems in football players (Thorborg et al., 2011a, Thorborg et al., 2014). These tests were applied in Chapter Two of this thesis during the regular pre and in-season domestic league periods. The reliability of the test components have been reported as: unilateral hip adductor ICC ranging from 0.89-0.93 with MDC\textsubscript{95} of 15.8% - 20.0%; hip abductor ICC ranged from 0.97-0.98 and MDC\textsubscript{95} of 6.8% - 8.1% whereas the add:abd strength ratio ICC were 0.76-0.81 with MDC\textsubscript{95} of 19.6% - 22.2% (Thorborg et al., 2010).

The elite football setting may at certain times require a very quick clinical screening test option, e.g. during a busy congested international tournament match schedule where the competing demands of players time is high. The 5-second AST is a suitable option that allows clinicians to quickly apply a valid and reliable hip and groin screening test in elite football (Light and Thorborg, 2016, Thorborg et al., 2017). It may also be a more feasible test option for screening a squad of players when there are few testers available. In this thesis we evaluated the 5-second AST in Chapter Three, since it is very quick and easy to apply in a hectic clinical environment. The test re-test reliability results ranges from ICC of 0.90-0.92 with a MDC\textsubscript{95} of 13.6% - 13.7% when testing elite football players (Light and Thorborg, 2016).

Clinical strength-based screening tests might also be supported by patient reported outcome measures of hip and groin health and function. The hip and groin outcome score (HAGOS) is a valid and reliable patient reported outcome score that can identify football players with current hip and groin problems (Mosler et al., 2015, Thorborg et al., 2017). This outcome measure is a potential athlete monitoring tool in a secondary prevention strategy in football. The reliability of the HAGOS ranges from ICC 0.82 – 0.91 with MDC\textsubscript{95} at group levels of 2.7 – 5.2 points and 17.7 – 33.8 points at an individual level across the six subscales (Thorborg et al., 2011b).

Similar to adductor strength testing, a simple isometric clinical hamstring strength test might be appropriate within the context of athlete monitoring as part of a secondary prevention strategy. A suitable position for such a strength test should involve 45° of hip flexion and 30-45° knee
flexion since it is associated with increased peak hamstring torque and mimics the terminal swing phase (Wollin et al., 2016, Guex et al., 2012). The magnitude of hamstring strength reductions post-match is similar between isometric and eccentric contractions (Silva et al., 2018) and therefore isometric test modes can be used with less chance of extending post-match muscle damage and might be more acceptable to players and coaches. Consequently, isometric contractions are recommended as a safer option to evaluate post-match hamstring function since they do not induce further muscle damage (Silva et al., 2018).

An externally fixed dynamometer system measuring unilateral hamstring strength with standardised hip flexion angle of 45˚ and knee flexion of 30˚ from full extension (0˚) was designed to mimic angles associated with the terminal swing phase and peak hamstring torque output. Its reliability was subsequently tested in professional development football players during the competitive season (Wollin et al., 2016). This was a preparatory study for the subsequent hamstring investigations reported in this thesis. The test methods and intra and inter-rater reliability have been published in detail (Wollin et al., 2016). Test – retest reliability of the externally fixed unilateral isometric hamstring strength test during the competitive in-season demonstrated good to high reliability, ICC = 0.86 (0.74-0.93) and MDC95 = 14.0% (Wollin et al., 2016). The test is quick, easy and safe to implement during the competitive in-season in elite male football (Wollin et al., 2016) and has the capacity to identify athletes with a previous hamstring strain injury up to three years post injury (Charlton et al., 2018). The Wollin et al. (2016) reliability paper is available in its full, peer reviewed and published, format in Appendix D.

Athlete monitoring to evaluate muscle function recovery post-match is supported (Thomas et al., 2017, Silva et al., 2018). Considering the injury incidence, burden and high-risk of recurring and ongoing problems to the groin and hamstrings in football, increasing the frequency of clinical screening appears an important part of a complete injury prevention strategy in elite male football. There is no available information in the literature to assist clinicians to implement
a framework of athlete monitoring as a secondary prevention strategy for groin problems and hamstring strain injuries in elite football. Consequently, the overall aim of this thesis was to introduce a novel injury prevention system based on primary, secondary and tertiary prevention, coupled with risk-factor based interventions, while investigating and highlighting the potential of athlete monitoring as a secondary prevention strategy in male professional development football. Underpinning this strategy is an understanding of the impact of the physical demands of football, particularly the effect of single and congested match play on groin and hamstring function.
Chapter Two: In-season monitoring of hip and groin strength, health and function in elite youth soccer: Implementing an early detection and management strategy over two consecutive seasons

Outline

Clinical screening of players is recommended for the prevention of groin problems in elite football, but there are no evidence-based published frameworks or concepts available to clinicians in the literature. Chapter Two presents the in-season monitoring system and strategies implemented to facilitate early detection and management of hip and groin strength, health and function over two consecutive seasons in male professional development players.

The primary aim of this Chapter was to describe a secondary prevention strategy; by implementing early detection and management, in the form of in-season monitoring of unilateral hip and groin (adductor and abductor) strength and hip and groin outcome scores (HAGOS).

The secondary aim was to compare unilateral hip adductor and abductor strength and HAGOS at pre-season screening prior to commencing football training with in-season test results.

Chapter Two (Paper 1) is presented in its peer reviewed and published format:

(Wollin et al., 2018c), In-season monitoring of hip and groin strength, health and function in elite youth soccer: Implementing an early detection and management strategy over two consecutive seasons. *Journal of Science and Medicine in Sport.*

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Original research

In-season monitoring of hip and groin strength, health and function in elite youth soccer: Implementing an early detection and management strategy over two consecutive seasons

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\textbf{A B S T R A C T}

\textbf{Objectives:} The primary purpose of this study was to describe an early detection and management strategy when monitoring in-season hip and groin strength, health and function in soccer. Secondly to compare pre-season to in-season test results.

\textbf{Design:} Longitudinal cohort study.

\textbf{Methods:} Twenty-seven elite male youth soccer players (age: 15.07 \pm 0.73 years) volunteered to participate in the study. Monitoring tests included: adductor strength, adductor/abductor strength ratio and hip and groin outcome scores (HAGOS). Data were recorded at pre-season and at 22 monthly intervals in-season. Thresholds for alerts to initiate further investigations were defined as any of the following: adductor strength reductions >15\%, adductor/abductor strength ratio <0.90, and HAGOS subscale scores <75 out of 100 in any of the six subscales.

\textbf{Results:} Overall, 105 alerts were detected involving 70\% of players. Strength related alerts comprised 40\% and remaining 60\% of alerts were related to HAGOS. Hip adductor strength and adductor/abductor strength ratio were lowest at pre-season testing and had increased significantly by month two (p < 0.01, mean difference 0.26, CI95\%: 0.12, 0.41 N/kg and p < 0.01, mean difference 0.09, CI95\%: 0.04, 0.13 respectively). HAGOS subscale scores were lowest at baseline with all, except Physical Activity, showing significant improvements at time-point one (p < 0.01). Most (87\%) time-loss were classified minimal or mild.

\textbf{Conclusions:} In-season monitoring aimed at early detection and management of hip and groin strength, health and function appears promising. Hip and groin strength, health and function improved quickly from pre-season to in-season in a high-risk population for ongoing hip and groin problems.

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1. Introduction

Groin injuries affect both youth and senior soccer players at various levels of the sport.\textsuperscript{1–3} On average, professional men’s teams sustain seven time-loss injuries per season with most resulting in moderate to severe time-loss\textsuperscript{3} and when non-time-loss injuries are included the injury rates may be even higher.\textsuperscript{3} Most groin problems in soccer appear to be of gradual onset\textsuperscript{1} and they seem to deteri-
onset of adductor strength reductions to development of clinical symptoms. Further, players with current groin problems and those with a groin injury in the previous season demonstrate significantly lower scores on all six subscales of the hip and groin outcome score (HAGOS).13,14 The HAGOS is a patient reported outcome measure that has been validated in soccer players and can differentiate between those with and without hip and groin problems.13,14 Its use has been supported to capture minor and/or overuse injuries.15

To date, primary groin injury prevention protocols have failed to demonstrate a significant effect, possibly due to challenges around implementation and compliance.16,17 Secondary prevention strategies may provide an alternative and/or complement primary prevention approaches in reducing the groin injury burden by limiting time-loss. Secondary prevention aims to identify signs of hip and groin health problems early, to allow for timely management in the subclinical phase to prevent deterioration of the problem by implementing indicated preventative measures.18 Indicated preventative measures are applied to individual players and includes load management and regular re-testing.18 This approach may enable clinicians to detect groin problems prior to players recognising or reporting them as an injury. Secondary prevention strategies require valid and reliable clinical screening tests that can detect players with or at risk of developing injury. Available evidence suggests that hip adductor strength, adductor/abductor strength ratio and HAGOS are appropriate to include in a secondary groin injury prevention strategy.2,10,16

The primary purpose of this study was to describe an early detection and management strategy when monitoring in-season hip adductor strength, adductor/abductor (add/abd) strength ratio and HAGOS, against thresholds related to groin problems in soccer. Secondly to compile pre-season (baseline) data with in-season results.

2. Methods

Twenty-seven male U17 Australian soccer players and their parents or legal guardian provided written informed consent to participate in the study. The players were selected from part-time training centres to commence full-time training at the football association’s centre of excellence program. All players volunteered to participate in this study, which was approved by the Australian Institute of Sport and La Trobe University Human Ethics Committees.

Prior to commencing training, players completed standardised screening including pre-season testing of hip adductor strength, add/abd strength ratio and HAGOS. Furthermore, anthropometric data and a record of past injury and training history were collected. Monthly in-season testing occurred, across 22 time-points, on the morning of the first regular training day back after a rest day (generally 40 h post-match). Each time-point involved testing ten criteria: hip adductor and add/abd strength ratio on each leg and HAGOS (6 subscales), meaning that a maximum of ten alerts could be triggered per player. Unilateral adductor and abductor strength was tested in supine based on a previous report.20 A ‘break’ test was used to introduce an eccentric component, since this can better capture minor and/or overuse injuries.15 Warm-up consisted of two repetitions (five seconds) separated by ten second rest. A twenty second rest period prior to a single maximal test was applied to realistically allow testing of a squad in an acceptable time. Reliability of strength testing was investigated in ten players without a history of groin injury. The inter-rater intra-class coefficient two-way random model results were: adduction 0.86, abduction 0.87 and add/abd strength ratio 0.76. Minimal detectable change (MDC = SEM × 1.96 × √2)21 results were: adduction 13.9%, abduction 14.6% and add/abd strength ratio 21%. Strength was recorded with a hand-held dynamometer (Micro FET2, Hoggan Health West Jordan UT, USA). Data were captured in Newtons and converted to N/Kg (peak force/body mass). Testing was performed by two male physiotherapists. A strength related alert included at least one of adductor strength reductions >15% and hip ratio <0.90. Mean (SD) hip ratio of 0.80 (±0.14) and 0.92 (±0.23) has been reported in soccer players with groin problems9,10 and recent normative eccentric add/abd strength ratio data in professional players ranged from 0.9 to 1.4.22

Players completed an electronic version of the HAGOS including all subscales at each time point. All questionnaires were answered in full. The HAGOS has six subscales; Pain, Symptoms, Activities of daily living (ADL), Sport & recreational activities (Sport), Participation in physical activity (PA) and Quality of living (QOL).13 Each subscale is scored 0–100 where higher scores indicate better hip and groin health.13 In this study HAGOS alerts were defined by a score <75 out of 100 in any of the subscales since it best fits the 95% reference range, across all subscales, in differentiating soccer players with or without groin problems.23 Clinical examination was conducted in accordance with the Doha consensus statement.24 Unrestored strength reductions at re-testing and after multi-modal interventions were considered subclinical presentations requiring load management as an indicated preventative measure. Time-loss was calculated for detected injuries and subclinical presentations requiring load management. Time-loss was classified as: minimal (1–3 days), mild (4–7 days), moderate (8–28 days) and severe (>28 days).2 The early detection and management process is outlined in Fig. 1.

Players declared themselves fit to commence training at pre-season testing. During the 22-month study period, the team played 87 matches involving two domestic competitions annually and international tournaments. The team completed 336 days of soccer training during the study period and there were no extended season breaks. Due to team logistics players were not available for strength testing in months 11, 12, 16 and 21.

Due to the study being performed in the applied soccer setting it required managing player findings and did not allow for a ‘wait and see’ approach. Consequently, players identified with alerts at pre-season and in-season testing proceeded per the outlined monitoring and clinical process (Fig. 1). Individual multi-modal management plans incorporated manual therapy, hip muscle activation and strength exercise programs to complete until strength reductions were restored. Exercise programs focused on simple, traditional weighted and elastic band resisted hip adduction and abduction that incorporated isometric, concentric and eccentric contraction modes known to activate the main hip muscle groups25 and improve adductor strength in soccer players.26 Injury rehabilitation comprised of contemporary groin management17 and aforementioned exercises.25,26 Additionally, the team performed 20 min of hip muscle activation, balance and pelvic stability exercises prior to training 1–2 times per week supervised by a physiotherapist. Exercises included lateral band walks, star excursion lunge with ball movement, banded hip bridging, isometric adduction, balance with football skills and jump/landing practices. A linear mixed model was used to investigate if the outcome measures changed from baseline at any of the 22 time-points. Normality of the strength data was confirmed by visually assessing the Q–Q plots of the residuals. The HAGOS variables demonstrated some deviation of normality in the tails of the distribution, however fixed effects estimates are known to be robust under heavy-tailed conditions.28 The dependent variables (HAGOS and strength) were treated as fixed variables and random intercept for subjects were included in the model to allow baseline values of the fixed variables to vary between subjects. The Welch’s t-test was used to investigate if there were any differences in time-loss between groin problems detected at pre-season screening compared to those identified in-
season. Effect size is reported as Hedges’ g. Descriptive data are reported as mean and standard deviation (SD) with significance level $p<0.05$.

3. Results

Twenty-seven elite male youth soccer players (age: $15.07 \pm 0.73$ years, height: $174.52 \pm 6.28$ cm, weight: $66.44 \pm 8.13$ kg, soccer years: $9.22 \pm 2.19$, pre-entry weekly training sessions: $4.44 \pm 1.53$, range: 3–10) volunteered to participate in the study as they transitioned into a full-time national program from part-time centres. The prevalence of a reported previous time-loss groin injury at pre-season screening were 52%. All reported past groin injuries had occurred within the previous three years and 64% in the season prior. Five players were released early from the program to join professional teams or return to state programs. Two players exited after five months, one each after 9, 19 and 20 months respectively. One of these player’s had a past history of groin injury. A new player entered the program at the 8-month mark and another two players commenced at the start of the 11th month. One player in this group reported a previous groin injury. Their respective data are included for the period in the program.

Overall, 105 alerts were detected involving 19 players (70% of cohort). Forty-two alerts (40%) were strength related (adductor and/or add/abd ratio) involving 19 players. Strength alerts were triggered on 14 of the time-points tested. The remaining 63 alerts (60%) were HAGOS related. They involved 16 players with alerts triggered on 19 of the time-points. The highest number of HAGOS alerts ($n=17$, 27%) at any time-point were found at pre-season screening. Over half (56%) of the players who triggered a HAGOS alert were identified at pre-season screening prior to commencing training. None of the players with HAGOS scores <75 out of 100 at baseline demonstrated a hip strength ratio <0.90.

Based on strength related alerts, time-loss was recorded on 11 occasions involving eight players. This resulted in 34 days lost ($3.09 \pm 5.05$: range 1–18 days), classified as minimal (82%), mild (9%) and moderate (9%). In-season HAGOS soccer related problems requiring rehabilitation were detected on four player occasions resulting in 31 time-loss days ($7.75 \pm 12.84$: range 1–27 days). In these four cases, time-loss was minimal (75%) and moderate (25%). In contrast, all HAGOS soccer related problems ($n=6$) detected...
Chapter 2: In-season Monitoring

Fig. 2. Hip strength outcome measures (mean and 95%CI) from baseline pre-season testing with monthly follow up over two consecutive seasons in elite male youth soccer players. A: Hip adductor/abductor strength ratio, B: hip adductor strength and C: hip abductor strength. 0 = baseline pre-season, 1–22 = follow up months. N = newton, kg = kilogram. *p < 0.05.
at pre-season testing where of moderate time-loss (8–28 days) resulting in a total of 85 days lost (14 ± 3; range 9–18 days). No severe time-loss events were detected in this study. The days lost in-season due to indicated preventative measures and rehabilitation were significantly less when compared to those detected at pre-season testing prior to commencing training (t (19) = −2.353, \( p = 0.03 \), mean difference \(-5.97, 95\% CI\ -11.27, -0.66, g = 0.80\). In-season strength results compared to pre-season are based on grouped (left and right) data and are presented in Fig. 2. Hip adductor strength changed significantly during the seasons (F(18, 759.551) = 19.105, \( p < 0.001 \)) and demonstrated significant improvements by month two compared to pre-season (\( p < 0.01 \), mean difference 0.26, CI95%: 0.12, 0.41 N/kg). The add/abd strength ratio also demonstrated significant in-season change compared to pre-season results (F(18, 760.666) = 2.512, \( p < 0.01 \)). It was smallest at the start of pre-season and had increased significantly (\( p < 0.01 \), mean difference 0.09, CI95%: 0.04, 0.13) at test-point two, mainly due to increased adductor strength. Similarly, HAGOS subscale scores changed significantly compared to pre-season and demonstrated significant improvements in all subscales within the first two months (Pain: F(22, 516) = 4.140, \( p < 0.001 \), Symptoms: F(22, 470.760) = 3.266, \( p < 0.001 \), ADL: F(22, 516) = 1.725, \( p < 0.05 \), Sport: F(22, 516) = 3.334, \( p < 0.001 \), PA: F(22, 516) = 1.876, \( p < 0.05 \), QOL: F(22, 516) = 1.816, \( p < 0.05 \)). HAGOS results are outlined in Fig. 3.

4. Discussion

The main aim of this study was to describe an early detection and management strategy when monitoring elite male youth soccer players for hip adductor strength reductions >15%, adductor/abductor strength ratio <0.90 and HAGOS subscale scores <75 out of 100 in-season. Secondly to compare pre-season hip and groin strength, health and function with in-season results.

This study involved a young cohort of elite male soccer players progressing to higher levels of play with a 52% prevalence of previous time-loss groin injury and HAGOS scores suggestive of ongoing problems when presenting for pre-season. This could be considered a high-risk population for ongoing hip and groin problems.\(^{19,29}\) The natural progression for such a cohort is likely to involve further deterioration of groin health and function, potentially leading to severe time-loss.\(^{4,19,27}\) Despite this, no severe time-loss were detected in this study and in-season hip strength and HAGOS scores improved significantly from pre-season scores. It is possible that the described secondary prevention approach contributed to these improvements and limited groin health deterioration commonly seen in soccer.\(^{4,12}\) In-season monitoring aims to identify groin problems early, in the subclinical phase, to initiate a cascade of clinical interventions aimed at restoring individual player’s strength, health and function to limit deterioration and time-loss. This study highlights the potential of in-season monitoring as a promising alternative and/or complement to primary prevention of groin problems in elite male youth soccer.

Hip strength was lowest at pre-season testing and gradually increased as players adapted to the new and higher training demands, with appropriate loading, management and modifications guided by results of in-season monitoring. The hip strength findings are similar to data from Danish sub-elite male football players that demonstrated lower hip strength after a mid-season break compared to results after two months of soccer training.\(^{26}\) This is in keeping with reports that soccer specific fitness, including strength and power, deteriorates after an off-season break\(^{20}\) and can improve with appropriate sports-specific loading. Regular monitoring of hip and groin strength, health and function may help to determine individual player’s response and readiness to loading.

The HAGOS scores suggest that hip and groin health and function were lowest at pre-season before commencing training. The pre-season HAGOS results in this study are similar to pre-season data in adult soccer players with groin problems in the previous season.\(^{4,12}\) Most (56%) of the players who triggered HAGOS alerts were identified at pre-season screening. These players did not demonstrate corresponding add/abd strength ratio issues during testing. This might be explained by the fact that the HAGOS
measures hip and groin health and function over the past week, while strength testing captures the present moment. This may explain why HAGOS and strength did not necessarily correspond. It highlights that clinicians should consider including objective and subjective measures when monitoring groin problems.

An advantage of this study is that it was conducted in the applied soccer setting during consecutive seasons. Conversely, we acknowledge that there are limitations in the present study associated with the inherent challenges of conducting research in this setting where individual management is required and the inclusion of matched control groups is unreasonable. Consequently, the results should be interpreted accordingly. In addition, the HAGOS is a retrospective self-report of an individual’s perceived hip and groin health and function over the last week and since scores were collected monthly, three weeks during each month were unaccounted for. Collecting all six subscales weekly may reduce compliance and reliability. Reducing the number of subscales used may allow for more frequent monitoring. Further, hip adductor strength reductions have been found to precede the onset of groin pain by two weeks in elite youth Australian rules football players. The optimal frequency of in-season strength testing is not established and it is likely to vary depending on contextual circumstances.

5. Conclusions

Hip and groin strength, health and function improved quickly in a high-risk population for ongoing hip and groin problems. Early detection and management of players groin health status in-season may assist in limiting further deterioration and time-loss. Such a proactive medical model appears a promising secondary injury prevention strategy as an alternative or to complement primary prevention methods in elite soccer. However, further research is required to confirm its effectiveness to reduce the burden of groin injury in the elite soccer setting.

Practical Implications

- In-season monitoring of hip and groin strength, health and function may assist in determining individual player’s response and readiness to loading.
- Athlete monitoring as a secondary groin injury prevention strategy appears promising in elite soccer.
- Clinicians should consider implementing both objective and subjective measures when monitoring soccer players groin health and function.

Acknowledgements

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References

Chapter Three: The effects of football match congestion in an International tournament on hip adductor squeeze strength and pain in elite youth players

Outline

This chapter investigates the effect of football match congestion, during an International tournament, on the 5-second adductor squeeze test. The Australian U17 National football team volunteered to participate in this study. Groin problems are common in elite male football and the risk and susceptibility of injury increases during match congestion. Hip adductor strength deficits are established intrinsic risk factors that may be affected by the accumulation of match play with limited recovery periods. Despite this, there are no published studies that investigate the effect of match congestion on hip adductor strength and groin pain in elite male football players. The aim of this study was to examine the effects of football match congestion on the 5-second hip adductor squeeze strength and pain response. (Wollin et al., 2018c)

Chapter Three (Paper 2) is presented in its peer reviewed and published format:

The effects of football match congestion in an international tournament on hip adductor squeeze strength and pain in elite youth players

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The effects of football match congestion in an international tournament on hip adductor squeeze strength and pain in elite youth players

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\textbf{ABSTRACT}

The purpose of this study was to investigate the effect of a congested international tournament match schedule on adductor strength and pain in elite youth football players. Twenty-two male players (age: 15.53 ± 0.48 years, height: 174.87 ± 7.59 cm, weight: 67.45 ± 7.40 kg) were included. The 5-second adductor squeeze strength was captured daily using a hand-held dynamometer during a 7-game international tournament. Pain during the squeeze test was recorded using numerical pain ratings (0–10) to quantify groin pain. Sessional rate of perceived exertion (sRPE) was collected during the tournament. Adductor strength changed significantly during the tournament in relation to time (F (14,294.94) = 1.89, p = 0.027) and cumulative sRPE (F(1,314) = 5.59, p = 0.019). Cumulative sRPE displayed a negative relationship with strength (B = −0.008, SE = 0.0032, 95%CI = −0.014,-0.002). The results indicate that for every 100 match sRPE arbitrary units the squeeze peak force reduced by 0.8N. Sixteen (72.7%) players demonstrated clinically meaningful strength reductions (>15%) during the tournament. Match congestion impacts on hip adductor squeeze strength in male youth football players. A negative relationship between match sRPE and adductor strength exists. Player monitoring involving the 5-second adductor squeeze test can be captured effectively and is suitable to include as part of secondary injury prevention during or immediately after a congested tournament.

\textbf{Introduction}

Groin injuries are common in football and affect diverse groups of players and levels of play (Holmich, Thorborg, Dehlendorff, Krosggaard, & Gruud, 2014; Serner et al., 2015; Walden, Hagglund, & Ekstrand, 2015). Acute muscle injuries and chronic presentations are prevalent with both predominantly relating to the hip adductor muscle complex (Holmich et al., 2014; Serner et al., 2015). The incidence of groin injury is highest during match play (Engebretsen, Myklebust, Holme, Engebretsen, & Bahr, 2010) with kicking and changes of direction the most common mechanisms and the preferred kicking leg the most frequently affected (Serner et al., 2015). Demands of match play can induce muscle damage and post-match fatigue lasting up to 72 hours (Ispirlidis et al., 2008; Nedelec et al., 2012). It is therefore not surprising that the rate of acute muscle and overuse injury is increased during congested match periods (Bengtsson, Ekstrand, & Hagglund, 2013; Carling, McCall, Le Gall, & Dupont, 2016; Dupont et al., 2010).

Monitoring of groin health, function and adductor strength restoration is advocated (Crow et al., 2010; Thorborg, Ratleff, Petersen, Branci, & Holmich, 2017) since isometric adductor strength reductions have been noted to precede the onset of groin injury (Crow et al., 2010) and playing football with such strength deficits is linked with increased injury risk (Engebretsen et al., 2010). The severity of groin injuries seems linked to the duration of time before it is detected and managed and this has prompted recommendations to closely monitor players in-season to facilitate early detection and management of groin problems (Thorborg et al., 2017). Monitoring of youth players may be of particular importance due to the greater susceptibility of pubic apophyseal injuries in the immature pelvis due to the late maturation of the pubic symphysis (Sailly et al., 2015). Additionally, data from youth Australian rules football (ARF) players indicate that players who sustained a groin injury in their junior years are 6 times more likely to suffer time-loss related groin injuries as a professional player compared to players without a previous injury (Gabbe et al., 2010).

Consequently, preventing groin injury in football is important. To date, primary prevention exercise programs have not yielded a significant effect in reducing these injuries (Esteve, Rathleff, Bagur-Calafat, Urrutia, & Thorborg, 2015). Therefore, secondary prevention strategies may have a place in reducing the incidence of groin injury in football generally and during match congestion specifically. The aim of secondary prevention is to identify signs of injury early to allow for timely management before the injury deteriorates (Jacobsson & Timpka, 2015). Secondary prevention strategies require quick, valid and reliable clinical screening tests that can detect players with or at risk of developing injury.

Recently a 5-second adductor squeeze test has demonstrated acceptable reliability and clinical utility to easily assess
football player adductor strength in-season (Light & Thorborg, 2016). Furthermore, numerical pain rating (0–10) during this test is a valid indicator of a player's football related hip and groin health and function (Thorborg, Branci, Nielsen, Langelund, & Hölmich, 2016) making this a suitable monitoring test to implement in a secondary prevention system. Further, high pain levels (>5 out of 10) when performing the test correlates with poor groin-related sports function (Thorborg et al., 2016). It has been proposed that players with such high reported pain should discontinue football until a clinical examination has confirmed their current groin health status in relation to continued football exposure (Thorborg et al., 2016).

Considering the number of football players affected by groin pain, the susceptibility in youth players and the increased rate of acute muscle and overuse injury during congested match fixtures there is a need to investigate the effect of match congestion on hip adductor squeeze strength and pain. This study aimed to examine the effects of a congested match schedule during an international tournament on the 5-second adductor squeeze strength and pain tests in male international youth football players.

Methods

Twenty-five international youth football players and their parents or legal guardian provided informed consent to participate in the study. The players performed a familiarity test session during a pre-tournament training camp prior to baseline testing. The players competed in an international U16 tournament in South East Asia and they arrived in the host city 7 days prior to the tournament start. Seven official matches were completed in 14 days. Players with no current injury that were eligible for match play were included in the study. Twelve of the players reported a history of previous time-loss groin injury (Werner, Hagglund, Walden, & Ekstrand, 2009). These players were included in the study to reflect the applied football setting where up to 70% of players may have groin problems during a season (Thorborg et al., 2017). This study was approved by the Australian Institute of Sport and La Trobe University Human Ethics Committees Human Ethics Committees.

Procedure

Baseline data were collected on the morning of tournament day one. Repeat testing followed each subsequent morning at the same time and place. The player test order was randomised initially and subsequently this order was followed at each time point. All testing was performed by the same male physiotherapist. Player’s self-reported rate of perceived exertion (RPE) was collected post-match, using a 10-point graded scale with zero equal to rest and ten representing maximal exertion (Impellizzeri, Rampinini, Coutts, Sassi, & Marcara, 2004). The session RPE (sRPE) scores (Duration x RPE) were calculated as an expression of individual match loads and reported as arbitrary units (AU).

5-second adductor squeeze testing

The players performed a standardised warm up protocol with a short lever squeeze effort into a standard size football placed between the knees in a flexed hip position of 45°. The warm-up squeeze consisted of 3 repetitions of 5-second sub-maximal efforts separated by a 10-second recovery period between repetitions.

The test protocol was implemented for maximal hip adduction strength testing based on a previous report (Light & Thorborg, 2016). The test was performed in 0° hip flexion where the tester fixed his forearm between the player’s ankles applying a handheld dynamometer (Micro FET2, Hoggan Health West Jordan UT, USA) 5 cm proximal to the medial malleolus of the preferred kicking leg. A single 5-second maximal voluntary contraction (MVC) was used to capture peak force in Newtons (N). To allow calculation of adductor torque (peak force x lever length/body mass), lever length was measured at baseline and defined as the distance between the anterior superior iliac spine to the point of dynamometer placement (Light & Thorborg, 2016). Body mass was measured daily prior to adductor squeeze testing. The reported minimal detectable change (MDC%) of a single MVC long lever 5-second adductor squeeze in elite football players is 13.6–13.7% (Light & Thorborg, 2016). Based on this, a strength reduction >15% compared to baseline was considered clinically meaningful. Players were blinded to their strength results throughout the study period. The associated groin pain levels were recorded using a 0–10 numerical rating scale (NRS), where 0 indicated no pain and 10 maximal pain (Thorborg et al., 2016). Thorborg et al. (2016) proposed a traffic-light approach based on the pain response to the 5-second adductor squeeze test in terms of football exposure: NRS 0–2 = green light or go ahead, 3–5 = yellow light or attention requiring a clinical examination to establish player’s current groin injury and ongoing football status. A NRS of 6–10 = red light or stop football exposure to commence injury management following clinical examination.

Match procedure

The initial match was played on tournament day one with matches 2–5 on days 3, 5, 7 and 9. Kick-off time was 15.30 except for match 5, which started at 18.30. The team was provided a rest day on day 10 before recommencing training on day 11. Match 6 and 7 were played on days 12 and 14 with kick-off at 18.30. During the tournament, players who completed ≥45 minutes of match play participated in 30 minutes of water based active movement and flexibility exercises in a swimming pool the following the day. The remaining players participated in football training. Cold water immersion baths were used by the match players post-match at an approximate temperature of 15°C for 8–10 min.

Statistical analysis

The force data were analysed with a General Linear Mixed Model (GLMM) using the R package lme4 (Bates, Mächler, Bolker, & Walker, 2015; Team, 2016). A random intercept
was included for each subject to account for the dependency of within-subject measurements. The fixed effect structure included a main effect for time (tournament day) as a categorical variable, a main effect for cumulative match sRPE and past groin injury (Yes/No). Sessional rate of perceived exertion variables were transformed into cumulative variables for each subject to account for their match history throughout the tournament. Significance tests were performed using Type II F Wald tests with Kenward-Rogers adjusted degrees of freedom and 95% confidence intervals (95%CI) were constructed using bootstrapping. The normality assumption was visually assessed by constructing normal QQ-plots from the model residuals. No obvious deviations from normality were detected. The pain data were heavily skewed towards 0, with 12 out of 22 subjects reporting no pain during the tournament. To accommodate this, pain data were analysed with a zero-inflated generalized linear mixed model with a log link function and allowing for over dispersion through the negative binomial distribution as implemented in the R package glmmADMB (Fournier et al., 2012; Skaug, Fournier, Bolker, Magnusson, & Nielsen, 2016). The fixed and random model structure was equal to the linear mixed model for the force data. Additionally, adductor peak force was included as a covariate in the model to investigate the relationship between adductor strength and pain. Pain results are reported as an odds ratio (OR) and descriptive statistics as mean ± standard deviation (SD). The level of significance set at p < 0.05.

Results

Three players were excluded from the study; two players did not get selected for the tournament and one sustained a knee injury prior to the tournament start. In total 22 players (3 goalkeepers, 6 defenders, 7 midfielders and 6 attackers) were included for final analysis (age: 15.53 ± 0.48 years, height: 174.87 ± 7.59 cm, weight: 67.45 ± 7.40 kg).

5-second hip adductor squeeze strength

The baseline peak adductor squeeze force for the squad were 256.50 ± 37.13 N and mean torque values were 3.43 ± 0.55 Nm/Kg (peak force x lever length/body mass) and 3.82 ± 0.64 N/kg (peak force/body mass). A significant main effect for both time (F(14,294.94) = 1.89, p = 0.027) and cumulative sRPE (F(1,314) = 5.59, p = 0.019) were demonstrated. Cumulative sRPE displayed a negative relationship with peak hip adductor squeeze force (B = −0.008, SE = 0.0032, 95%CI = −0.014,-0.002) (Figure 1). The results indicate that for every 100 arbitrary units of match sRPE, the squeeze peak force reduced by 0.8N. Individual player strength changes occurred during the tournament and most players demonstrated strength reductions compared to baseline (Figure 2). Sixteen players (72.7%) experienced an adductor strength reduction >15% during the tournament which was deemed clinically meaningful based on the previously reported MDC% (Light & Thorborg, 2016). There was no significant difference in adductor peak force between players with a past groin injury and those without (F(1,20) = 0.0098, p = 0.92) during this congested tournament.

5-second hip adductor squeeze pain ratings

During the tournament 45% of players reported groin pain. Four players (18%) reported pain ratings >2 on a total of 12 occasions (Figure 3). All of these ratings were 3 to 5 and no player reported pain above 5 out of 10. Pain changed in relation to time (F(14,308) = 1.84, p = 0.031), adductor peak force (F(1,308) = 4.06, p = 0.045) and past history of a groin injury (F(1,308) = 6.21, p = 0.013). There was limited reporting of pain but the results indicate that the higher adductor peak force the less likely players are to report groin pain during the 5-second adductor squeeze test (OR = 0.984, SE = 0.008, 95% CI = 0.969, 0.999). Additionally, players with a past history of
groin injury were more likely to report groin pain during this congested tournament (OR = 32.592, SE = 1.398, 95% CI = 2.105, 504).

Compared to baseline, players were less likely to report groin pain on adductor squeeze testing day 9 (OR = 0.078, SE = 1.08, 95%CI = 0.009, 0.644), day 12 (OR = 0.17, SE = 1.06, 95%CI = 0.022, 1.38) and day 14 (OR = 0.062, SE = 1.26, 95% CI = 0.005, 0.726). Interestingly, this coincided with the last group stage, semi-final and final match of the tournament being played on day 9, 12 and 14 respectively.

Discussion

This is the first study to investigate the effect of match congestion in an international tournament on football players’ hip adductor squeeze strength and associated groin pain. The findings showed that most (>70%) players demonstrated clinically meaningful strength reductions (>15%) during the tournament compared to baseline. This was linked to cumulative match sRPE arbitrary units (AU) and not previous history of groin injury. A negative relationship between cumulative match AU and the 5-second adductor squeeze peak force during football match congestion was demonstrated. The results indicated a force reduction of 0.8N for every 100 arbitrary units of match sRPE of match play. This has the potential to reduce adductor force by 7.2N per match or 50.4N (19.6%) compared to baseline over the 7 matches played in this congested match period.

The results suggest that hip adductor strength is dynamic in response to the demands of football match play. This is supported by data from youth rugby union players that demonstrated hip adductor strength reductions acutely post-match using a short lever squeeze test (Roe et al., 2016). An acute post-match isometric hip adductor strength change >12.5% has previously been reported to be clinically meaningful in youth football players (Paul et al., 2014) and the strength reductions associated with a current groin injury were approximately 12% (Crow et al., 2010). The threshold
used in the current study to indicate a clinically meaningful change is based on the reported minimal detectable change of the long lever 5-second adductor squeeze test (Light & Thorborg, 2016) and current evidence suggests that this is comparable to genuine post-match strength changes, but also of a magnitude that have been shown to precede groin injury in ARF. The number of individual changes in strength >15% in the present study are greater (16 players versus nil players) compared to the rugby data (Roe et al., 2016). This may be due to different demands on the adductor complex between football and rugby, the effect of a single match versus match congestion, or the potential difference in strength responses from a long and short lever squeeze test. The long lever adductor squeeze test where resistance is applied between the ankles creates larger adductor torques (Light & Thorborg, 2016; Lovell, Blanch, & Barnes, 2012) and targets the adductor longus muscle most efficiently compared to a short lever squeeze test where resistance is placed between the knees (Drew et al., 2016).

The pain response results demonstrated that no players rated their pain levels above 5 out of 10 during the 5-second adductor squeeze test and thus were not required to cease playing football as recommended by Thorborg et al. (2016) traffic-light approach. Pain ratings between 3–5/10 (yellow light) indicated that some players required clinical reviews and potential management during tournament play. Considering that these players had a past groin injury it highlights the importance of timely clinical examinations to assess their current groin health and function. A previous history of groin injury is an established risk factor for future groin injury (Whittaker, Small, Maffey, & Emery, 2015). In this study, it was the strongest indicator for reporting groin pain on long lever adductor squeeze testing. In fact, only those with a past history of groin injury reported pain. Additionally, reduced adductor strength might increase the odds of reporting pain, which seems in agreement with the findings in ARF players where adductor strength reductions preceded groin pain (Crow et al., 2010). However, the majority of players did not report any pain at all during the tournament and while we accounted for the over representation of non-pain (0) scores by allowing zero-inflation these results should be interpreted with caution given the relative low numbers of players reporting pain. Interestingly, the occasions that players were least likely to report pain on were the mornings of the last group stage, semi-final and final matches of the tournament. Players may opt to underreport pain on days of important matches due to the perception that it may influence their prospect of match selection. The addition of an objective strength measure to the 5-second adductor squeeze test may circumvent potential underreporting of pain and augment the clinical test outcomes in the applied football setting. We suggest that clinicians judiciously interpret the individual player’s context in relation to the suggested traffic-light approach around players football availability status. Applying a decision-making process guided by clinical findings, not pain ratings alone, with considerations around football demands, injury history and potential for under reporting of pain.

The present cohort is young and since complete maturation of the pubic symphysis cannot be expected before 21 years of age (Sailly et al., 2015) the results should not be extrapolated to adult players. The combination of delayed maturation of the pubic symphysis and high football loads may contribute to injury including clinical features of weakness and pain during the adductor squeeze test (Sailly et al., 2015). It highlights the importance of monitoring young elite football players groin health status regularly in-season, particularly around high load periods such as congested schedules. Particularly considering the continuation of playing football with a current groin problem appears to deteriorate and accentuate the problem further (Thorborg et al., 2017).

A potential limitation to the study is the lack of external load data. The ability to objectively analyse player’s external load could provide valuable information that might impact post-match physical changes to the adductor complex. In youth football, this technology may not be readily available and AU is a simple, reliable and established alternative (Impellizzeri et al., 2004). The present study involved one squad of 22 players competing in a single international tournament and accordingly the interpretation of the results should reflect the inherent limitations of a cohort study. Nonetheless, the results suggest that a severely congested match period has potential to induce an index, aggravate a current, and predispose players to future adductor related groin injury. Acute and cumulative fatigue may also have contributed to adductor strength reductions. Combined with available evidence that isometric adductor strength reductions increase groin injury risk (Engebretsen et al., 2010) and may precede the onset of groin injury (Crow et al., 2010), it highlights the importance of implementing secondary prevention strategies during congested tournament play in elite youth football players. It seems pertinent to provide extra attention to players with high cumulative match AU and history of time-loss groin injury. Early detection and management of players that demonstrate pain and/or significant adductor squeeze strength reductions could potentially reduce groin related problems obtained during or immediately after congested tournament play.

Conclusion

A congested football tournament match schedule impacts on hip adductor squeeze strength in international male youth football players. A negative relationship between match sRPE arbitrary units and isometric hip adductor strength exists and most players developed clinically meaningful isometric adductor strength reductions during match congestion. Player monitoring involving the 5-second adductor squeeze test can be captured effectively during official tournament play and appears a suitable strategy to include as part of a secondary injury prevention strategy during or immediately after football match congestion.

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References


Chapter Four: The acute effect of match play on hamstring strength and lower limb flexibility in elite youth players

Outline

Match play has the potential to affect player hamstring strength and hip, knee and ankle joint flexibility. These outcome measures have been associated with hamstring injury. Peak isometric hamstring strength (knee flexor force) can be captured easily, quickly and reliably with little expense in the elite football setting (Wollin et al., 2016). Lower limb flexibility testing is also a reliable and clinically applicable screening tool. Currently, most studies evaluating the impact of fatigue on hamstring function use match simulation protocols. Data from competitive matches is limited. There is no information on the acute effect of match play on the externally fixed dynamometry unilateral hamstring strength test and lower limb flexibility tests in professional development football players.

The purpose of this Chapter was to investigate the acute effect of competitive football league match play on isometric hamstring strength and lower limb flexibility at the hip, knee and ankle joints.

Chapter Four (Paper 3) is presented in its peer reviewed and published format:

The acute effect of match play on hamstring strength and lower limb flexibility in elite youth football players

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The aim of this study was to investigate the effect of competitive football match play on hamstring strength and lower limb flexibility. Fifteen male international youth football players were included. Hamstring strength and associated pain ratings, ankle dorsiflexion, hip extension, knee extension and flexion range of motion were evaluated immediately post-match and at intervals of 24, 48, and 72 h post-match. Strength significantly reduced post-match ($P < 0.01$), mean difference $-0.43$ (CI95: $-0.56$, $-0.30$) and 24 h post ($P < 0.05$) mean difference $-0.12$ Nm/kg (CI95: $-0.20$, $-0.04$). The associated pain scores significantly increased at the post-match ($P < 0.01$, ES = 0.61) and 24 h ($P < 0.01$, ES = 0.55) time intervals. At the 48 and 72 h post-match tests no significant difference was found for strength or pain ratings. No significant differences were detected for any of the range of motion measures. Competitive football match play has a significant acute and transient effect on isometric hamstring strength and associated pain levels during resisted knee flexion in male international youth players. Range of motion measures appear to remain relatively unaffected by match play. Isometric hamstring strength testing and associated pain levels might be considered for inclusion in-season to monitor player’s post-match hamstring recovery characteristics.

Football injury incidence and the resultant effect on player match availability rates have been associated with negative consequences on team success (Hagglund et al., 2013). Hamstring injury incidence, in particular, has received increased attention in the football medicine community as it is the most common injury in professional football (Ekstrand et al., 2011a). The incidence of these injuries in professional football does not appear to have decreased over time (Ekstrand et al., 2011b) and incidence in youth football resemble those in adult populations (Junge & Dvorak, 2004).

The cause of hamstring injury is believed to be multifactorial including both extrinsic and intrinsic risk factors. Hamstring strength imbalances, lower strength characteristics, and decreased range of motion (ROM) at the hip, knee, and ankle joints constitute previously reported intrinsic hamstring injury risk factors (Orchard et al., 1997; Witvrouw et al., 2003; Gabbe et al., 2006b; Bradley & Portas, 2007; Croisier et al., 2008; Henderson et al., 2010; Opar et al., 2015) that are all potentially modifiable. Bilateral hamstring strength asymmetries have been found to increase the risk of hamstring injury in professional football players (Croisier et al., 2008) and lower pre-season hamstring strength has been associated with a higher risk of hamstring injury during the competitive season in Australian rules football (Orchard et al., 1997; Opar et al., 2015). Additionally, decrements in isometric knee flexion force, after an acute hamstring injury, have been found to increase the risk of re-injury (De Vos et al., 2014).

A systematic review of potential hamstring injury risk factors in male football players identified reduced hamstring flexibility as a possible risk factor (van Beijsterveldt et al., 2013). Reduced hamstring flexibility during pre-season testing has been linked with an increased risk of hamstring injury in Belgian and English football players (Witvrouw et al., 2003; Bradley & Portas, 2007). Active knee extension (AKE) deficits at return to play after hamstring injury are associated with an increased risk of re-injury (De Vos et al., 2014) and a decreased hip extension ROM has been associated with an increased risk of hamstring injury in both football and Australian rules football players (Gabbe et al.,
In addition, reduced knee flexion and ankle dorsiflexion ROM has been proposed to elevate a player’s risk of hamstring injury in Australian rules football (Gabbe et al., 2005, 2006b).

Despite these findings, there are several inconsistencies in the identification of risk factors (Freckleton & Pizzari, 2013) and this may be attributed to the varied methodology of many studies (Mendiguchia et al., 2012) and that most authors examine musculo-skeletal characteristics only once, before the commencement of the season. This negates the ability to capture physical changes in-season that may precede the onset of injury and the capacity to identify the effects of match induced fatigue and the cumulative effects in-season on these musculo-skeletal parameters. Considering that in-season isometric hamstring and hip adduction strength reductions have been identified prior to onset of hamstring and groin injury, respectively (Crow et al., 2010; Schache et al., 2011), there may be potential to capture physical changes in-season that may impact on hamstring injury risk.

Football match play induces physical changes that could affect player’s intrinsic modifiable risk factors. Reductions in players physical performance, ability to maintain high speed running, and acceleration/deceleration distances have been demonstrated during and after match play (Mohr et al., 2003; Bradley et al., 2009; Akenhead et al., 2013). These reductions may be associated with depletion of muscle glycogen concentrations post-match and up to 48 h post-match (Bangsbo et al., 2006). In addition, match play produces transient muscle damage that may take up to 72 h to recover (Ispirlidis et al., 2008) probably due to the numerous eccentric muscle contractions performed by the players (Nedelec et al., 2012). Acute isometric knee flexor and extensor strength reductions post-match have been demonstrated using isokinetic dynamometry (Thorlund et al., 2009; Krustrup et al., 2011). Several studies using different match simulation protocols have demonstrated reduced strength of the hamstring complex with isometric (Robineau et al., 2012; Greco et al., 2013; Marshall et al., 2014), concentric (Robineau et al., 2012; Greco et al., 2013; Timmins et al., 2014), and eccentric (Greig & Siegler, 2009; Small et al., 2010; Greco et al., 2013; Timmins et al., 2014) contractions with isokinetic dynamometers. Other physical changes includes reduced range of knee extension and hip ROM (Small et al., 2009), altered running kinematics, lower limb joint position sense, hamstring activation patterns, and inferior sprint and jump performances (Small et al., 2009; Robineau et al., 2012; Timmins et al., 2014). This cascade of physical changes including transient muscle damage could increase the risk of hamstring injury at certain times in-season and at specific stages post-match play. This highlights the need for simple, precise and cost effective measures of physical characteristics that can be utilized in a realistic setup acceptable to coaches and players. Implementation of in-season player monitoring systems and strategies could potentially identify players at risk.

It is not known how hamstring strength and lower limb flexibility in football players respond to competitive match play over a 72-h follow-up period. To our knowledge, there is limited information in the literature that describes a normal response to competitive match play on isometric hamstring strength, hip, knee, and ankle ROM during the acute post-match recovery period to 72 h post. There is a need to establish players’ responses to competitive football match play on measurable intrinsic injury risk factors to inform the clinical reasoning and risk management process in player monitoring systems around the acute post-match periods.

The aims of this study were to investigate the acute effect of competitive football match play on clinically relevant measures of hamstring strength and associated pain on a numerical rating scale, ankle dorsiflexion, hip extension, knee extension, and flexion ROM prior to the match (PRE) and immediately post-match (POST) and at the subsequent 24, 48, and 72 h post-match intervals.

**Methods**

**Participants**

Fifteen male youth international football players from the national football association’s centre of excellence program recruited to represent Australia at the FIFA under-17 World Cup provided written informed consent to participate in the study. One defender was excluded due to a lower leg injury sustained during match play. Fourteen players (6 defenders, 4 midfielders, and 4 forwards) were included for final analysis of which 11 completed a full match and the remaining three played 82, 80, and 75 min, respectively (age = 16.72 ± 0.35 years, height = 175.66 ± 6.48 cm, weight = 66.24 ± 5.78 kg). All players were familiar with the tests as they have formed part of the team’s in-season monitoring routine for over 12 months. Player’s with no current injury, eligible to play a full match, and that played ≥75 min were included in the study. No previous hamstring strain injuries in the 12 months prior to the study were reported. One player reported a previous hamstring strain injury in the last 2 years. Match RPE was 8.29 ± 0.61 AU and the session RPE 725.79 ± 63.58 AU. The mean “load” for the week of match play was 2154.36 ± 368.90 AU and the last 4 weeks 7057.21 ± 1012.60 AU. This study was approved by the Australian Institute of Sport and La Trobe University Faculty Human Ethics Committees.

**Outcome measures**

**Hamstring strength test**

Hamstring strength testing was performed using a reliable method associated with small standard error of measure.
All testing was performed in the clinical area of the Department of Physical Therapies, Australian Institute of Sport. The hamstring maximal voluntary contraction (MVC) force was converted into peak torque defined as Nm/kg (Force × lever length/body-weight). The numerical pain rating score (0–10) was collected immediately after each test. Zero indicating no pain and 10 unbearable pain.

**Range of motion**

Ankle dorsiflexion was measured using the “knee-to-wall” method and hip extension ROM tested with a modified Thomas test in accordance with a previous report (Dennis et al., 2008). The AKE and passive knee flexion (PKB) ranges of motion were quantified with a bi-level inclinometer (Isomed Inc, Kirkland WA, USA) positioned on the midline of the tibia, 15 cm proximal to the distal tip of the lateral malleolus. The AKE was performed with the player in supine and test leg placed at 90° hip flexion by the tester. The player supported the posterior thigh in this position ensuring that no hip movement occurred during the test. The ankle was relaxed in a neutral position during the test and the player was instructed to extend the knee as far as possible. The PKB was performed with the player in prone with the distal half of the lower legs over the edge of the examination table. The tester passively moved the lower leg into knee flexion until the first point of restriction in ROM were registered at which point the measure was recorded. The same equipment was used throughout the study. Prior to this study, we investigated the intra- and inter-tester reliability for the AKE and PKB on 10 healthy active adults (6 men, 4 women) and demonstrated excellent results AKE: Intraclass coefficient (ICC) 0.91–92, MDC 5.2–10°, MDC 3.4–6.6°, PKB: ICC 0.89–0.94, MDC 3.9–7.4°, MDC 2.9–5.5°.

**Procedure**

All testing was performed in the clinical area of the Department of Physical Therapies, Australian Institute of Sport. The hamstring dynamometry testing was conducted by a senior sports physiotherapist having designed and used the test on a weekly basis for over 1 year. Range of motion tests were collected by senior physical therapy staff involved in performing the tests on a regular basis for more than 12 months. Player test order and selection of test leg was randomly selected prior to the pre-match test. This test sequence was followed at all subsequent test times. Height, weight, and lever length was recorded at pre-match testing. Player weight was recorded at each test occasion to allow for accurate torque (Nm/kg) conversions across the study period to account for possible fluctuations in weight, particularly post-match, that might have influenced strength results. The dynamometry test scores were blinded to both the assessor and subject, while the ROM results were blinded to the subjects only.

The tests were conducted around competitive home matches in the national under 21 competition and senior state league played at the Australian Institute of Sport. At completion of the match players walked approximately 300 m to the Physical Therapy department for post-match testing. Matches were played on a natural turf (rye-blend) pitch with field dimensions measuring 100 × 68 m. The weather conditions were dry with temperature at kick-off, 17.4 ± 6.5 °C. Player’s self-reported rate of perceived exertion (RPE) was collected at their post-match test, using a 10-graded scale, 10 representing maximal exertion (Impellizzeri et al., 2004). The session RPE score (Duration × RPE) were calculated as an expression of individual internal loads and reported as arbitrary units (AU). The players were familiar with the scale and process from their daily training routine.

Pre-match testing was performed 4 h prior to match play to accommodate for team logistics on match day. The mean time for post-match re-testing was 18.64 ± 5.53 min after the completion of the match. The outcome measures were tested in the following order (a) Hamstring dynamometry, (b) Ankle dorsiflexion, (c) Thomas test hip extension, (d) Active knee extension, (e) Prone knee bend ROM.

**Statistical analysis**

**Strength and range of motion**

The Shapiro–Wilk test was performed to evaluate normality of the data. Strength and ROM data were normally distributed. One-way repeated measures analysis of variance (ANOVA) tests were conducted for each outcome measure to compare mean differences between time points. Mauchly’s test of sphericity was used and the Greenhouse–Geisser correction applied if required. Where a significant time effect was identified, a Bonferroni post hoc analysis was conducted to determine which time points were different. The level of significance was set at P ≤ 0.05 and Bonferroni corrections applied as appropriate. For the time points with identified significant differences, effect sizes (ES) and 95% confidence intervals (CIs) were calculated using Exploratory Software for Confidence Intervals (ESCI, Geoff Cumming, Melbourne, Australia 2011) for paired sample data. The raw mean difference was used to represent the ES with average standard deviation between testing sessions used as the standardizer of the effect size equation (Cumming, 2013). Descriptive statistics are reported as mean ± standard deviation.

**Pain**

Numerical pain rating (0–10) data were examined with the Friedman test. Post hoc analysis with Wilcoxon signed-rank test was performed and the Bonferroni adjustment applied resulting in an alpha level of 0.0125. The effect size (ES) was calculated in accordance with the post hoc Wilcoxon signed-rank test setup. Reprinted from the Journal of Science and Medicine in Sport, doi:10.1016/j.jsams.2015.01.012, Wollin, M., Purdam, C., & Drew, M. K., Reliability of externally fixed dynamometry hamstring strength testing in elite youth football players. Copyright (2015), with permission from Elsevier Ltd.
rank test ($r = z/\sqrt{N_{\text{Total}}}$), where $z$ represents the $z$-score of the Wilcoxon calculation and $N$ the total number of observations (Rosenthal, 1991). An effect size of 0.2 was interpreted as small, 0.3 as medium and 0.5 as large (Cohen, 1992). Statistical analysis was performed using SPSS version 19 (SPSS Inc., Chicago, Illinois, USA).

**Results**

**Hamstring strength**

Isometric hamstring MVC was significantly different at the time intervals tested ($F(4, 52) = 20.1469$, $P < 0.01$). The pre- to post-match MVC decreased 17.6% ($P < 0.01$) demonstrating a mean difference of $-0.43$ (CI$_{95}$: $-0.56$, $-0.30$) Nm/kg. At the 24-h follow-up, MVC remained significantly lower to pre-match results ($P < 0.05$) with a mean difference of $-0.12$ (CI$_{95}$: $-0.20$, $-0.04$) Nm/kg. The results at 48 h indicated that hamstring strength had recovered and no statistically significant differences to pre-match were detected. The post-match results were significantly reduced compared to all other time points tested ($P < 0.01$). The results are presented in Table 1.

**Pain**

There was a statistically significant difference in perceived pain on isometric hamstring MVC depending on the time of testing ($\chi^2 (4) = 32.739$, $P < 0.01$). The median (IQR) pain score at PRE was 0.50 (0.00–1.00), which increased to 3.00 POST (1.00–4.00), 2.00 at 24 h (0.00–2.25), 1.00 at 48 h (0.00–2.00), and 1.00 at 72 h (0.00–1.00). There was a statistically significant increase in pain PRE to POST ($Z = -3.204$, $P = 0.001$, ES = 0.61), and PRE to 24 h post-match tests ($Z = -2.913$, $P = 0.006$, ES = 0.55). The associated pain levels during hamstring MVC at PRE to 48 and 72 h were not significantly different.

**Range of motion**

Ankle dorsiflexion and passive knee flexion ROM results were reduced from pre-match compared to the other test points but the changes were not statistically significant. POST passive knee flexion ROM demonstrated a trend toward significance ($P = 0.058$). The mean AKE ROM decreased up to 48 h post-match but not at a level of significance. Hip extension ROM remained essentially unchanged at all time points.

**Discussion**

This study examined the acute effect of match play on hamstring muscle strength and lower limb flexibility in male international youth football players up to 72 h post-match. The results indicate that competitive football match play results in an acute and transient reduction in hamstring strength. Significant strength reductions were present immediately after match play and at 24 h post-match. Conversely, associated pain during hamstring strength testing was significantly increased immediately after the game and 24 h post. Match play did not have a significant effect on the ROM measures included in this study.

This acute reduction in hamstring strength has been shown to occur following match simulation protocols (Greig & Siegler, 2009; Small et al., 2010; Robineau et al., 2012) using isokinetic dynamometry equipment. The percentage strength change in the current study is larger than reports from Danish youth football players (Thorlund et al., 2009) post match play and simulation protocols (Robineau et al., 2012). These previous studies tested knee flexion MVC, with players seated upright in an isokinetic dynamometer at a shorter knee angle. The amount of hip flexion during testing influence hamstring strength significantly (Guex et al., 2012) and the different hip and knee positions between the studies may have contributed to the differences in strength changes. The POST strength reduction in this study is similar to those observed from eccentric hamstring testing after football simulation protocols (Small et al., 2010; Timmins et al., 2014). Eccentric contractions are associated with higher hamstring peak torques than isometric contractions. In the acute post-match recovery period, eccentric contrac-

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>PRE</th>
<th>POST</th>
<th>24 h</th>
<th>48 h</th>
<th>72 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamstring torque (Nm/kg)</td>
<td>2.43 ± 0.32</td>
<td>2.00 ± 0.39$^*$</td>
<td>2.30 ± 0.28$^*$</td>
<td>2.39 ± 0.38</td>
<td>2.37 ± 0.33</td>
</tr>
<tr>
<td>Ankle DF (cm)</td>
<td>11.82 ± 1.92</td>
<td>11.07 ± 1.86</td>
<td>11.36 ± 1.55</td>
<td>10.86 ± 1.92</td>
<td>11.21 ± 1.85</td>
</tr>
<tr>
<td>Hip Ext (°)</td>
<td>17.36 ± 5.91</td>
<td>17.57 ± 6.78</td>
<td>18.00 ± 8.65</td>
<td>17.71 ± 7.77</td>
<td>16.86 ± 8.71</td>
</tr>
<tr>
<td>AKE (°)</td>
<td>169.14 ± 7.83</td>
<td>164.29 ± 7.64</td>
<td>167.14 ± 8.76</td>
<td>169.29 ± 7.59</td>
<td>168.71 ± 6.82</td>
</tr>
<tr>
<td>PKB (°)</td>
<td>133.71 ± 6.83</td>
<td>130.57 ± 5.89</td>
<td>131.86 ± 5.89</td>
<td>132.29 ± 6.41</td>
<td>133.43 ± 5.89</td>
</tr>
</tbody>
</table>

$^*P < 0.01$; $^5P < 0.05$.

AKE, active knee extension; DF, dorsiflexion; Hip Ext, hip extension (Thomas Test); PKB, prone knee bend; PRE, pre-match; POST, immediately post-match.
tions may not be well suited for implementation due to existing football-induced muscle damage. It may be that the current test position, designed to mimic hip and knee angles at the terminal swing phase in the running cycle, identifies physical changes to the hamstring complex at similar levels to eccentric contractions without inducing the same amount of hamstring strain.

Hamstring strength was restored at 48 h, which is in agreement with findings on knee extensor MVC post-match (Krustrup et al., 2011). This suggest that implementation of in-season player monitoring with isometric hamstring strength testing is suitable 48 h post-match. Significant strength reductions at ≥48 h may indicate incomplete recovery that should be considered for follow-up. Pain during isometric hamstring MVC can be expected to increase but remain at low levels acutely post-match and recover at 48 h. The ROM results indicate that we can anticipate these measures to remain reasonably stable in the post-match recovery period.

At the time of this study it was not permissible for players to wear global positioning system units during match play. The ability to objectively measure variables such as high speed running, acceleration and deceleration volumes might have provided valuable information on player’s external load that can have an impact on post-match physical changes to the hamstring complex. As research was conducted around competitive match play, we could not standardize player workload across the cohort and this is a limitation. Conversely, the ability to collect data in-season is a strength of the study design that allows for analyses of findings from competitive match play in its intended setting. The players self-reported RPE suggest that they exerted themselves at the higher end of the scale and that match play was of high intensity. The study cohort was limited to international male youth football players and as such the results may not directly transfer to other player cohorts or sports.

One of the aims of player monitoring systems is to quantify the individual player responses to both external and internal loads in-season and link them with performance and injury risk management strategies to optimize player availability rates. The ability to monitor player’s intrinsic risk factors reliably, safely, and efficiently in-season may provide important information to assist with the clinical reasoning and risk assessment processes leading in to match play. To do this, careful consideration of the tests relative and absolute reliability is required prior to implementation. Only tests that demonstrate small measurement error to detect true change should be considered for implementation. As player monitoring systems are aimed at detecting individual changes the MDC must be small enough to reliably detect true change that is clinically relevant for post-match monitoring. The relative and absolute reliability of the externally fixated hamstring dynamometry test in the present study is comparative to isokinetic dynamometry (Sole et al., 2007; Impellizzeri et al., 2008), which is considered the “gold standard”. This test detects hamstring strength changes that are clinically relevant to assess the effects of match play and has the ability to capture individual physical changes post-match and in-season. It can be utilized in a realistic setup at low cost and is accepted by coaches and players. Considering that isometric hamstring strength and AKE deficits are associated with increased risk of a hamstring re-injury (De Vos et al., 2014) having access to player in-season data may also prove beneficial during the return to play decision-making process after a hamstring injury.

In conclusion, competitive football match play has a significant acute and transient effect on isometric hamstring strength and associated pain during resisted knee flexion in male international youth players. This can be captured in-season, measured reliably with externally fixated dynamometry at low cost, and implemented in elite football settings with the acceptance of coaches and players. Hamstring strength and associated pain can be expected to recover 48 h post-match. Range of motion at the ankle, hip (extension) and knee are likely to remain relatively stable in response to match play. Inclusion of isometric hamstring strength testing and associated pain ratings might be considered for in-season monitoring of football player’s hamstring recovery characteristics.

**Perspectives**

This study highlights the ability to measure the effect of football match play on player’s hamstring strength and lower limb flexibility in-season. A single pre-season screening of players is not able to identify individual fluctuations on intrinsic injury risk factors due to in-season demands and player monitoring systems has this potential. Post-match player monitoring is suitable 48 h post and significant strength deficits identified ≥48 h may indicate insufficient recovery that should be explored further. The ability to capture such changes may assist in the clinical reasoning and risk management process around player preparation leading into upcoming match fixtures. A catalogue of player in-season data on these measures may also provide valuable information to assist with return to play decisions post hamstring injury. Further research is required to investigate if player monitoring during the season is an effective injury prevention strategy.

**Key words:** Soccer players, thigh, monitoring, in-season.
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References


Opar DA, Williams MD, Timmins RG, Hickey J, Duhig SJ, Shield AJ. Eccentric hamstring strength and hamstring injury risk in Australian


Chapter Five: Monitoring the effect of football match congestion on hamstring strength and lower limb flexibility: Potential for secondary injury prevention?

Outline

Football match congestion is associated with increased risk of hamstring strain injury. Player’s require several days to restore pre-match homeostasis. It was highlighted in Chapter Four that after a single match, professional development players require 48 hours to restore isometric hamstring strength levels to pre-match levels (Wollin et al., 2017). Lower limb flexibility appears unaffected after one competitive match. It is not known how isometric hamstring strength and lower limb flexibility respond to accumulation of load during a congested match period in professional development football players.

The objective of Chapter Five was to investigate the effects of competitive football league match congestion on hamstring strength and lower limb flexibility at the hip, knee and ankle joints.

Chapter Five (Paper 4) is presented in its peer reviewed and published format:

Original Research

Monitoring the effect of football match congestion on hamstring strength and lower limb flexibility: Potential for secondary injury prevention?

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Article info

Objectives: To investigate the effect of competitive football match congestion on hamstring strength and lower limb flexibility.
Setting: Elite male youth football.
Participants: Fifteen male elite youth football players from the national football association centre of excellence were included (age = 15.81 ±6.65 years, height = 171.95 ±6.89 cm, weight = 65.93 ±7.53 kg).
Main outcome measures: Hamstring strength and pain, ankle dorsiflexion, hip extension, knee extension and flexion range of motion.
Results: Hamstring strength was highest at baseline and significantly reduced at 24 (p = 0.001, mean difference = −0.19 Nm/Kg, CI95 −0.28, −0.1) and 48 h post-match 1 (p = 0.002, mean difference = −0.16 Nm/Kg, CI95 −0.25, −0.07). Strength recovered by match day 2 before significantly reducing again 24 h post-match 2 (p = 0.012, mean difference = −0.17 Nm/Kg, CI95 −0.20, −0.04). Pain was lowest at baseline and increased in the post-match periods (p < 0.05) with standardised effect sizes ranging from 0.07 to 0.42. Passive knee flexion range decreased post-match (p < 0.01) with mean differences of 1.5°−2.7°. The other flexibility measures remained unaffected by match play.
Conclusion: Isometric hamstring strength and pain can be considered for inclusion in-season to monitor player’s post-match hamstring recovery characteristics during congested match fixtures.

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1. Introduction

Hamstring injuries are common in football and the incidence is highest during match play (Ekstrand, Hagglund, & Walden, 2011), with the majority of hamstring injuries in football occurring during sprinting and high-speed running (Ekstrand et al., 2012). In men’s professional football, the hamstring injury rate increased annually over a 13 year study period (Ekstrand, Walden, & Hagglund, 2016). Congested fixture periods are considered high risk and associated with increased rates of muscle injury (Bengtsson, Ekstrand, & Hagglund, 2013; Carling, McCall, Le Gall, & Dupont, 2016; Dupont et al., 2010), with the hamstrings being the most commonly injured muscle during these periods (Carling et al., 2016).

Match play involves frequent explosive actions that require significant eccentric muscle loading such as change of direction and acceleration/decelerations (Akenhead, Hayes, Thompson, & French, 2013). These game specific requirements can induce muscle damage and post-match fatigue lasting up to 72 h (Nedelec et al., 2012, 2014). A recent report indicated that peripheral fatigue contributes more than central processes to post-match fatigue, likely due to the match induced muscle damage, that is associated with impaired muscle function (Thomas, Dent, Howatson, & Goodall, 2017). The relative match related workload and activity patterns in elite youth

With increased rates of
football players at the end of puberty are similar to adult elite players (Stroyer, Hansen, & Klausen, 2004). During congested tournament play in elite youth players, the number of accelerations/minute reduces significantly across the tournament in comparison to the first match (Arruda et al., 2015). Additionally, reductions in player’s ability to maintain high speed running and acceleration/deceleration distances have been demonstrated during and after match play (Akenhead et al., 2013; Mohr, Krustrup, & Bangsbo, 2003). These reductions may be associated with depletion of muscle glycogen concentrations post-match that can last up to 48 h (Krustrup et al., 2011). The effects of congested match play in senior players include reductions in repeated sprint performance and knee range of motion (ROM), elevated soreness and signs of muscle damage (Mohr et al., 2016). Furthermore, lower limb flexibility, specifically knee extension and hip ROM, is affected after match simulation protocols (Small, McNaughton, Greig, Lohkamp, & Lovell, 2009). The post-match cascade of physical changes resembles clinical features associated with hamstring injury and has potential to impact on known injury risk factors: hamstring strength imbalances (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008), lower strength characteristics (Opar et al., 2015; Timmins et al., 2016) and decreased range of motion at the hip, knee and ankle joints (Bradley & Portas, 2007; Gabbe, Bennett, Finch, Wajswelner, & Orchard, 2006; Henderson, Barnes, & Portas, 2010; Witvrouwen, Issa, & D’Haese, 2003). Monitoring these risk factors during a congested fixture period could provide valuable information for early detection and management of potential injury risk. Secondary prevention strategies involve regular monitoring of athletes with increased risk of injury (Jacobsson & Timpka, 2015). The aim of such strategies is to detect signs of injury early to permit appropriate interventions to prevent the condition from advancing (Jacobsson & Timpka, 2015). In-season tests of hamstring strength and other clinical tests associated with hamstring injury (Wollin, Thorborg, & Pizzari, 2017) serve as a potential secondary prevention strategy in youth football.

The effect of a single competitive elite youth football match on hamstring strength has demonstrated significant acute and transient strength reductions (Wollin et al., 2017). It is not known how hamstring strength and lower limb flexibility in youth football players respond to a competitive 2-match congested fixture over a 72-h follow up period. There is a need to establish youth players’ responses to competitive congested match periods on measurable intrinsic injury risk factors to inform the clinical reasoning and risk management process during these periods. The aim of this study was to investigate the effect of playing two competitive football matches in three days on clinically relevant hamstring outcome measures (hamstring strength and associated pain, ankle dorsiflexion, hip extension, knee extension and flexion ROM). We hypothesised that hamstring strength would decrease after each match and that strength reductions might be greater and take longer to recover post-match 2.

2. Methods

2.1. Participants

Thirty-three elite male youth football players representing the Australian U17 team and training full-time at the football association’s centre of excellence programme provided written informed consent to participate in the study. All participants were part of the match squads in two 2-match congested fixtures representing the football association’s centre of excellence programme. Players with no current injury, eligible to play a full match, and that played ≥75 min in match one and any minutes in match two were included in the study. Similar match exposure criteria have previously been used to define participation in 2-match congested fixture periods (Carling et al., 2016; Dupont et al., 2010). This study was approved by the Australian Institute of Sport and La Trobe University Human Ethics Committees.

2.2. Procedures

Data were collected from two congested periods that involved playing two matches in three days during official competitive home matches in the national under 21 competition and senior state league. The hamstring dynamometry testing was conducted by a senior sports physiotherapist experienced in using the test. Range of motion tests were collected by senior physical therapy staff involved in performing the tests on a regular basis. Player test order and selection of either right or left as the test leg was randomly selected prior to baseline testing. This test sequence was followed at the subsequent test times 24, 48 and 72 h post-match and on match day two. Height, weight and lever length were recorded during baseline testing. Player weight was recorded at each test occasion to allow for accurate torque (Nm/Kg) conversions across the study period to account for possible fluctuations in weight that might influence strength results. The dynamometry test scores were blinded to both the assessor and player while the ROM results were blinded to the player only.

All matches, except one, were played on a natural turf (rye-blend) pitch with field dimensions measuring 100 × 68 m. Due to heavy rain-fall the day prior, one match (Match day 1) was played on a synthetic pitch (Ligaturf RS + COOL Plus) of the same dimensions. Players were accustomed to training and match play on both surfaces. At kick-off, the weather conditions were dry with temperatures of 22.16°C (±10.32°C).

Immediate post-match recovery involved contrast water therapy, where players immersed the lower body in a hot bath (38°C for 3 min) followed by a cold bath (15°C for 4 min). The cycle was repeated twice. The day after a match, players performed an active recovery training session on a grass pitch, which included low intensity jogging (5 min) followed by lower limb flexibility exercises (5 min). The routine was repeated twice. Training resumed on day 2 post-match. Match 2 commenced 67 h after completion of match 1 on both occasions.

Players self-reported rating of perceived exertion (RPE) was collected post-match, using a 10-point graded scale with ten representing maximal exertion (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). The session RPE (sRPE) score (Duration x RPE) were calculated as an expression of individual match loads and reported as arbitrary units (AU). The players were familiar with the scale and process from their daily training routine. Pre-match testing was performed 4 h prior to match play to accommodate for team logistics on match day. The outcome measures were tested in the following order 1. Hamstring dynamometry 2. Ankle dorsiflexion 3. Thomas test hip extension 4. Active knee extension 5. Prone knee bend range of motion.

2.3. Outcome measures

The isometric hamstring strength test has demonstrated clinical utility to assess football player’s hamstring strength in-season with good intra and inter-tester reliability and small measurement error: intra-class coefficient with 95% confidence interval (CI95) 0.86 (0.74–0.93) and standard error of measurement 5% (Wollin, Purdham, & Drew, 2016). Testing was performed as previously reported (Wollin et al., 2017). Players were positioned in prone on a wedge at 45° hip flexion and 30° knee flexion applying force to a tethered externally fixed dynamometer. The load cell was...
calibrated prior to testing. The hamstring maximum voluntary isometric contraction (MVIC) force was converted into peak torque defined as Nm/Kg (Force x lever length/mass). The associated pain score was collected immediately after each test using a numerical rating scale (0–10), with zero indicating no pain and 10 unbearable pain.

Ankle dorsiflexion was measured using the ‘knee-to-wall’ method and quantified in centimetres (cm) with a fixed tape measure to record the distance between the great toe and wall (Dennis, Finch, Elliott, & Farhart, 2008). Hip extension range of motion was tested by a reliable method using the modified Thomas test (Dennis et al., 2008) and measured with a goniometer (Baseline Diagnostic and Measuring Instruments, USA). The axes were placed over the greater trochanter with the fixed arm pointing vertically and the moveable arm along the lateral thigh towards the lateral knee epicondyle. The active knee extension (AKE) and prone knee bend (PKB) ranges of motion were quantified with a bi-level inclinometer (Isomed Inc, Kirkland WA, USA). These tests demonstrate excellent intra and inter-tester reliability and the process followed previous reports (Wollin et al., 2017) and the same equipment was used throughout the study.

2.4. Statistical analysis

The data were inspected for normality with the Shapiro-Wilk test. To compare outcome measures at each time-point one-way repeated measures analysis of variance (ANOVA) was conducted for parametric data and the Friedman’s test for non-parametric data. Mauchly’s test of sphericity was used and the Greenhouse-Geisser correction applied if required. Where a significant time effect was identified, post-hoc analyses (LSD or Wilcoxon signed rank test) were conducted to determine which time points were different. Effect size (ES) and 95% confidence intervals (CI95) were calculated using Exploratory Software for Confidence Intervals (ESCI, Geoff Cumming, Melbourne, Australia 2011) for parametric paired-sample data. The raw mean difference was used to represent the ES with average standard deviation between testing sessions used as the standardiser of the effect size equation (Cumming, 2013). The effect size for non-parametric data was calculated in accordance with the post hoc Wilcoxon signed-rank test \( z = z/\sqrt{N(\text{Total})} \) where \( z \) represents the z-score of the Wilcoxon calculation and \( N \) the total number of observations. An ES value of 0.1 was interpreted as small, 0.3 as medium and 0.5 as large (Cohen, 1992). The Wilcoxon signed rank test was used to investigate the difference in sRPE between match 1 and 2. Statistical analysis was performed using SPSS version 19 (SPSS Inc., Chicago, IL, USA). The level of significance was set at \( p < 0.05 \). Descriptive statistics are reported as mean ± standard deviation (parametric) and median with interquartile range (non-parametric).

3. Results

Of the 33 players recruited for the study, 15 players (5 defenders, 4 midfielders and 6 attackers) were included for final analysis (age = 15.81 ±0.69 years, height = 171.95 ±6.89 cm, weight = 65.93 ±7.53 kg). None of the included players reported a previous history of hamstring strain injury. In match one, 13 played a full game and two completed 75 min. In match two, 10 played 90 min, and the remaining 5 players completed 80, 75, 70, 55 and 45 min respectively. Ten players completed both matches in full during the congested periods. The remaining players did not play sufficient match minutes and were subsequently excluded from the study. The preferred kicking leg (dominant) was tested in 60% of players.

The sum of the players match exposure during the congested fixture demonstrated a mean (SD) of 169.67 ± 16.63 (range 135.00–180.00) minutes. The average minutes played in match 1 was 88.00 (±5.28) and match 2: 81.67 (±14.47). The sum of the players sRPE over the two matches averaged 1346.67 ± 253.46 AU (range 630.00–1620.00). The sRPE for match 1 was 703.00 (±103.44) and match 2 643.67 (±169.73) AU. The sRPE for match 2 was lower compared to match 1, which demonstrated a trend towards significance (\( Z = -1.843, p = 0.065 \)) represented by a moderate effect size (ES = 0.34).

Hamstring strength was highest at baseline testing prior to the first match and hamstring MVIC differed significantly at the time intervals tested \( F(3, 42) = 5.299, p = 0.003 \). The hamstring strength compared to baseline was significantly reduced 24 (\( p = 0.001 \), mean difference −0.19 Nm/Kg, CI95 −0.28, −0.1, −8%) and 48 h post-match 1 (\( p = 0.002 \), mean difference 0.16 Nm/Kg, CI95 −0.25, −0.07, −7%). The hamstring strength was not significantly different between baseline and pre-match 2 (\( p > 0.05 \), mean difference −0.5 Nm/Kg, CI95 −0.12, 0.02, −2%) Hamstring strength reduced significantly again 24 h after match 2 compared to baseline (\( p = 0.012 \), mean difference −0.17 Nm/Kg, CI95 −0.29, −0.04, −7%). The hamstring strength did not change significantly (\( p > 0.05 \), mean difference −0.06 Nm/Kg, CI95 −0.02, 0.14, −2%) and 72 h (mean difference 0.04 Nm/Kg, CI95 −0.06, 0.14, −2%) post-match 2. The hamstring strength results are presented in Fig. 1.

There was a significant difference in perceived pain on isometric hamstring MVIC depending on the time of testing \( X^2(6) = 15.005, p = 0.02 \) (Fig. 2). Pain increased moderately 24 (\( p = 0.02 \), ES = 0.42) and 48 h (\( p = 0.036 \), ES = 0.38) post-match 1. There was no significant change in pain (\( p > 0.05 \)) on match day 2 (ES = 0.31) or at 24 (ES = 0.35), 48 (ES = 0.17) and 72 (ES = 0.07) hours post-match 2.

Baseline passive knee flexion (PKB) ROM was 132.4° (±5.2). PKB demonstrated statistically significant differences in relation to the times tested \( F(6, 84) = 3.325, p = 0.005 \). PKB was reduced by 2.7° (CI95 −4.21, −1.12, \( p = 0.002 \)) 24 h post-match 1 and by 2.1° (CI95 −3.88, −0.38, \( p = 0.02 \)) on match day 2. Reductions after match 2 were 1.5° (CI95 −2.88, −0.05, \( p = 0.044 \)) at 24 h and 2.7° (CI95 −4.91, −0.43, \( p = 0.023 \)) 48 h post. None of the other ROM outcome measures demonstrated a significant change during the 2-match congestion period.

4. Discussion

This is the first study to examine the effect of playing two competitive league matches in three days on hamstring muscle strength and lower limb flexibility in male elite youth football
players. The results indicate that congested competitive football match play produces a transient reduction in hamstring strength that may require >48 h to recover. At group level hamstring strength recovered by pre-match 2 testing. The associated pain during hamstring strength testing was elevated in the post-match periods compared to baseline. This was most pronounced 24–48 h post-match. A small reduction in passive knee flexion ROM was found at post-match testing compared to baseline, while active knee extension, hip extension and ankle dorsiflexion remained unaffected by this 2-match congested period.

Comparisons with the literature are limited since the only study to date that has included clinical outcomes during a congested fixture period evaluated adult football players and recorded the effects on running performance and inflammatory markers by blood analysis, repeat sprint ability, muscle soreness and knee ROM (Mohr et al., 2016). Although there is evidence of reductions in knee flexor (Nedelec et al., 2014; Wollin et al., 2017) and extensor (Krustrup et al., 2011) strength lasting up to 72 h from single match studies.

The pain results in the present study recovered earlier and were generally lower compared to the knee flexor soreness reported by the experimental group in Mohr et al. (Mohr et al., 2016). This may be due to differences in population age, timing of measurements and methodology between the studies. Mohr et al. (Mohr et al., 2016) evaluated post-match soreness after less recovery time, the morning after match play, using a 3-repetition full movement squat and palpation to reference knee flexor soreness.

Considering that the incidence of hamstring injury in professional football is not improving and may even be increasing (Ekstrand et al., 2016), the greater risk during congested fixtures (Bengtsson et al., 2013; Carling et al., 2016; Dupont et al., 2010) and that injury rates affect team success (Hagglund et al., 2013) alternative methods aimed at reducing hamstring injury in football are warranted. A proactive medical model based on the principle of early identification and management of players with impaired hamstring muscle function during congested match periods may assist the player preparation and risk management process in reducing hamstring injury.

The results of this study highlight that, at group level, the implementation of player monitoring with isometric hamstring strength testing during congested fixtures is suitable >48 h post-match. Significant individual player strength reductions on the day of match 2 may indicate incomplete recovery and restoration of hamstring muscle function that should be considered for follow up. Pain can be expected to peak 24–48 h post-match but remain at low levels. Range of motion results indicates a small, statistically significant reduction in knee flexion that is of no clinical relevance. Active knee extension, hip extension and ankle dorsiflexion remained unaffected by a 2-match congestion fixture which is in keeping with the acute response from single match play (Wollin et al., 2017). Based on this evidence, and in the absence of injury, there is no indication to monitor these ROM measures in the post-match period.

The ability to collect data in-season is a strength of the study design that allows for analyses of findings from official congested match play in its intended setting. Conversely, since research was conducted around official match play we could not standardise player’s workload and this is a limitation. Another potential limitation is that data were collected from two different levels of competition: a) national U21 league (youth professional players) and b) first team state league (semi-professional adult players). Post-match data from single match play in professional players suggest that muscle soreness and isometric hamstring strength recovery properties may be associated with the number of sprints <5 m and tackles performed (Nedelec et al., 2014). It is possible that the intensity at state league is lower involving less sprints <5 m and tackles compared to U21 national level players, which may have impacted on the post-match physical changes to the hamstring complex. At the time of this study it was not permissible for players to wear global positioning system (GPS) units during match play. The ability to objectively analyse player’s external load could provide valuable information that might impact post-match physical changes to the hamstring complex. In youth football this technology may not be readily available and sRPE is a simple, reliable and established alternative (Impellizzeri et al., 2004). Further, football sRPE is associated with GPS derived external load parameters including volume of accelerations, high-speed running and impacts (Gaudino et al., 2015).

Contrary to our hypothesis the strength reductions were not greater or longer lasting after match 2 compared to the match 1. This may be explained by the lower sRPE in the second match. The internal loads in match 2 were lower potentially due to reduced physical demands and subsequently less football induced muscle damage. Player rotation by coaching staff in match 2 may also have contributed to the quicker recovery seen after match 2. A potential confounding factor is the introduction of artificial pitch surface for one game (Match 1). However, hamstring strength and soreness recovery characteristics following a 90-min match simulation protocol on artificial pitch surface did not negatively influence hamstring strength and soreness compared to results on natural grass (Nedelec et al., 2013).

5. Conclusion

Competitive congested football match play produces a significant transient effect on isometric hamstring strength and associated pain during resisted knee flexion in male elite youth players. This can be captured effectively during match congestion and monitoring player’s individual match response on recovery. Restoration of hamstring muscle function may be considered for inclusion as a secondary prevention strategy during high risk periods such as congested football match play.

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Conflict of interest

None declared.
Chapter 5: Monitoring the effect of football match congestion on hamstring strength and flexibility

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Ethical approval
This study was approved by the Australian Institute of Sport and La Trobe University Human Ethics Committees. The participants provided informed consent to be part of this study.

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References
Chapter Six: Introducing a novel hamstring strain injury prevention system: highlighting secondary prevention in elite youth football

Outline

As shown in Chapters Four and Five isometric hamstring strength is reduced for several days post-match. This can be detected effectively and efficiently with an isometric strength test in the post-match periods of a single match and during congested match periods (Wollin et al., 2017, Wollin et al., 2018b). Individual load management guided by isometric hamstring strength testing post-match has been recommended (Silva et al., 2018). Clinical screening tests are commonplace and recommended for prevention of muscle injury in elite football (Read et al., 2017, McCall et al., 2015, Burgess, 2017, Price et al., 2004). Despite this, there is no documented evidence-based framework or concept published in the literature to guide clinicians in the implementation of clinical screening programs to prevent or reduce hamstring strain injury in elite football.

The main objective of Chapter Six was to introduce a novel hamstring strain injury prevention system and provide a framework for primary, secondary and tertiary prevention, coupled with risk-factor based interventions of this injury in elite football.

Chapter Six (Paper 5) is presented in its resubmitted format currently under peer review in the European Journal of Sport Science.
Introducing a novel hamstring strain injury prevention system: highlighting secondary prevention in elite youth football

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6.1 Abstract

This cohort study aims, firstly, to introduce a hamstring injury prevention system using a secondary prevention strategy. Secondly, to compare the occurrence and burden of hamstring strain injury between the secondary prevention strategy and standard practice (primary and tertiary prevention). Fifty-two elite male youth football players were included in an intervention group. Undertaking in-season hamstring strength monitoring as part of the secondary prevention strategy over a 4-year period of 115 matches. Data from another 22 players were used as control. The occurrence of hamstring strain injury was lower in the intervention group (z= -2.976, p=0.003, ES=0.35), who also had a 91% lower injury burden (1.3/1000h versus 14.2/1000h) and 94% lower incidence (0.05/1000h versus 0.8/1000h of total exposure) compared to the control. Consequently, the incidence rate ratio was greater in the control group (IRR=15.8, 95%CI 8.1, 30.9, p<0.001). The introduction of a novel prevention system using a secondary prevention strategy shows promise in reducing the occurrence and burden of hamstring strain injuries compared to standard practice in elite male youth football. Athlete monitoring in the context of an articulated and concomitant secondary prevention strategy that incorporates individual player interventions, highlights the potential for this complementary injury prevention approach in elite football.

Keywords: Soccer, posterior thigh, recovery, screening, athlete monitoring
6.1.1 Introduction

Despite the resources applied to the prevention of hamstring injuries in sport, the hamstring injury incidence and burden is not improving and may even be increasing in male professional football (Bahr et al., 2017, Ekstrand et al., 2016). Challenges around implementation and compliance with standard prevention exercises (Bahr et al., 2015), fluctuations in workload (Bowen et al., 2017, Malone et al., 2017, Malone et al., 2018), match congestion (Bengtson, Ekstrand, Walden & Hagglund., 2018), coaches leadership styles (Ekstrand et al., 2017) and the quality of communication between coach and medical teams (Ekstrand et al., 2018) have been purported explanations for the current hamstring muscle injury situation in elite male football.

Transformative change to the way hamstring injury prevention is viewed and implemented is needed to address the ongoing and potentially increasing incidence and burden of the condition. In this context, consideration of alternative and complementary prevention strategies are essential (Wollin et al., 2018b).

Jacobsson and Timpka (2015) recommended that contemporary sports injury prevention systems utilise an established public health management approach, by integrating pathology and risk factor based concepts, based in clinical epidemiology (Fletcher et al., 2012). Central to this framework are the three stages surrounding the natural history of disease (or injury) that involves a continuum of primary, secondary and tertiary prevention (Fletcher et al., 2012). Additionally, these stages are coupled with prevention strategies based on the target population (Jacobsson and Timpka, 2015). This allows for effective stratification of preventative interventions directed at populations (universal), subgroups (selective) and individual (indicated) levels. Figure 6.1 outlines the prevention continuum: primary, secondary and tertiary prevention coupled with universal, selective and indicated preventative interventions.
Primary prevention aims to remove causes or risk factors of a condition (Fletcher et al., 2012). It is promoted to players in the healthy stage of susceptibility and can include universal preventative interventions, e.g. sleep, nutrition and workload (Drew and Finch, 2016, Jacobsson and Timpka, 2015, von Rosen et al., 2017) and selective interventions specific to hamstring injury risk, such as hamstring eccentric strength training (Askling et al., 2003, Petersen et al., 2011, Timmins et al., 2016). Primary prevention most closely reflect current prospective hamstring prevention practices.

Secondary prevention is a two-step clinical process occurring in the subclinical stage of injury and involves clinical screening and follow up diagnostic assessments (Fletcher et al., 2012, Jacobsson and Timpka, 2015). It aims to evaluate health by detecting impairments, increased risk or susceptibility of injury soon after biological onset to facilitate early management to limit injury severity and time-loss. It is implemented at an individual player level through indicated preventative interventions. This includes modifying further exposure to the causing factor and
regular health evaluation screening (Jacobsson and Timpka, 2015). Secondary prevention for hamstrings may include regular monitoring of hamstring strength to detect impairments, since isometric strength reductions may precede the onset of HS injury (Schache et al., 2011b). Regular hamstring strength monitoring can confirm the restoration of hamstring muscle function following match play, prior to undertaking high training loads or another match. Early identification of a persistent impairment (subclinical stage) following muscle fatigue (Nédélec et al., 2012; Wollin, Thorborg, & Pizzari, 2017), and the subsequent early intervention to encourage restoration, could be a critical component of hamstring injury prevention.

Tertiary prevention involves, but is not limited to, the management and rehabilitation of a diagnosed injury. It aims to reduce consequences of injury by restoring function and performance, while preventing recurring or subsequent injury (Fletcher et al., 2012, Jacobsson and Timpka, 2015).

Player-responsive prevention and increased screening generally (Cloke et al., 2012, Price et al., 2004) as well as the introduction of post-match hamstring strength testing specifically (Silva et al., 2018) has been advocated in elite football. However, to date there are no frameworks or evidence-based guidelines available to assist clinicians in adopting a hamstring injury prevention approach that incorporates the pathology and risk factor based concepts of prevention.

The primary purpose of this study was to introduce a novel hamstring strain injury prevention system that incorporated a secondary prevention strategy in elite male youth football. Secondly to compare the occurrence and burden of hamstring strain injury in a cohort where secondary prevention was implemented in addition to standard practice (primary and tertiary prevention).

6.2 Methods

6.2.1 Study design

A cohort study was designed to assess the potential to reduce hamstring strain injuries in elite male youth football by introducing secondary prevention to standard practice. The sample
Chapter 6: Novel hamstring strain injury prevention system

consisted of Australian male U17 football players who commenced full-time training at the football association’s centre of excellence programme. Players from the programme during the period April 2014 – August 2017 formed the intervention group (INT) and undertook in-season hamstring strength monitoring as part of the secondary prevention strategy. Data, from a further 22 players in the immediately preceding cohort (December 2012 – March 2014), during their final month in year one and all of their second year in the programme, were included as a control group (CON). Player data were excluded from the study if they had no match exposure or incomplete injury records. All players (and parents or legal guardians) provided written informed consent to participate in the study and the study was approved by the Australian Institute of Sport and La Trobe University Human Ethics Committees.

6.2.2 Setting and context

The same coaching staff oversaw all player cohorts during the study period, playing a 4-3-3 formation utilising possession tactics and applying a high press when not in ball possession. The CON group performed strength and conditioning (S&C) training twice weekly, including Nordic hamstring exercise (NHE). The INT cohort did not have access to S&C training for the initial 15 months (out of 41) of the programme. The S&C programme, including NHE, were implemented at the discretion of the S&C coach twice weekly. Additional S&C exercises involving the hamstrings included lunges, deadlifts (single and double leg), hamstring bridges, hip thruster and sled pulling in both groups. In addition to the S&C programme, both groups performed the same 20 minute neuromuscular training programme prior to training 1-2 times per week supervised by a physiotherapist. Exercises included lateral band walks, star excursion lunges with ball movement, banded hip bridging, isometric adduction, balance with football skills and jump/landing practices. The cohorts competed in the national U21 (summer) and first team senior state league (winter) competitions each year. Matches were played in full format; 2 x 45 minutes halves.
6.2.3 Procedure

At intake to the programme, players completed standardised records of past injury and training history and measurement of anthropometric and hamstring strength data were taken. Hamstring strain (HS) injuries (dependent variable) were recorded prospectively and clinically diagnosed by a sports physician and/or sports physiotherapist. HS injury was defined by: i) sudden onset of posterior thigh pain and loss of function during football training or match play, leading to an inability to continue training/playing; ii) reduced isometric hamstring strength associated with pain on contraction; iii) tenderness on palpation and loss of hip flexion and knee extension ranges of motion (Askling et al., 2006).

6.2.4 Secondary prevention strategy

Secondary prevention strategies were introduced in April 2014 capturing the INT cohort over 115 matches and essentially incorporated regular post-match hamstring strength monitoring with resultant individual player interventions as indicated (Figure 6.2). In-season strength and injury data were collected for the domestic pre-season and in-season match periods. The HS injury count were logged weekly. Logistics of applied field research across a 4-year period resulted in hamstring strength testing being performed after 75 (65.2%) out of the 115 matches. Interruption in testing did not exceed two weeks.

6.2.5 Strength testing

Hamstring strength was tested on the morning of the first regular training day back after a rest day (≥40 hours post-match) to facilitate early detection of hamstring impairment. Players were positioned in prone on a wedge at 45° hip flexion and 30° knee flexion applying force to a tethered externally fixated dynamometer. Testing was performed in accordance with previous reports to capture unilateral maximal isometric peak hamstring force (Wollin et al., 2016). Five physiotherapists trained in applying the standardised test protocol where involved in the testing. Players identified with an alert defined by strength impairments greater than the minimal detectable change (MDC=14%) of the test (Wollin et al., 2016) returned for re-testing in
the afternoon and proceeded as per the outlined monitoring and clinical process (Figure 6.2).

The hamstring strength test is acceptable to players and coaches: it is quick and easy, inexpensive and is safe to apply to players during in-season post-match testing (Wollin et al., 2016, Wollin et al., 2017, Wollin et al., 2018b). Importantly, the test demonstrates good absolute and relative reliability to assess football player’s hamstring strength in-season with intraclass coefficient of 0.86 (95%CI 0.74-0.93) and standard error measure of 5% (Wollin et al., 2016).

6.2.6 Indicated (individual) interventions

Players with hamstring impairments on follow up testing were deemed to be in the subclinical stage and considered for indicated (individual) interventions. Indicated interventions always included team football training. The implemented indicated interventions were linked to HS injury mechanisms and reflective of load exposure to sprinting, high-speed running and explosive acceleration/deceleration activities based on the planned football training session. Individual player positions and workloads were also considered in consultation with the Coach. Examples of implemented indicated interventions included managing sprinting speed through individual running in lieu of competitive paired or small group sprint races. In match practice, during training, positional shifts of players were implemented. For example an externally placed full-back, while in the subclinical stage, could play centre-back to accommodate full training participation, since this position is associated with reduced exposure to sprinting and high-speed running (Buchheit et al., 2010, Di Salvo et al., 2007). In cases where positional shifts were not possible and overall player load could drop below coaches preferred level, supplementary individual sub-maximal running practice were implemented. Supplementary training using the arm ergometer were implemented in cases were further loading and additional high intensity exposure were required.
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6.3 Statistical analysis

The data were inspected for normality with the Kolmogorov-Smirnov test. Independent samples t-tests, equal variances not assumed, (parametric data: age, height and body-weight) and Mann-Whitney U tests (non-parametric data: previous HS injury, in-season HS injury, weekly training sessions, weekly matches and birth quarter) were used to investigate differences between the two groups at baseline. The Mann-Whitney U test were used to investigate if the dependent variable (HS injury) was significantly different between groups. Effect sizes (ES) were calculated using Hedges ‘g’ for parametric data and $r = z/\sqrt{N_{\text{Total}}}$ for non-parametric data.
where $z$ represents the z-score of the Mann-Whitney U calculation and $N$ the total number of observations. The magnitude of effect sizes for $g$ were interpreted as 0.2-0.5 = small, 0.5-0.8 = medium and >0.8 as large: a standardised ES value of 0.1 was interpreted as small, 0.3 as medium and 0.5 as large for non-parametric data (Cohen, 1992). A Poisson regression multivariate model was used to determine whether potential confounding independent variables had a statistically significant effect on the dependent variable. The investigated covariates included age, height, body-weight and previous HS injuries.

The incidence and burden of injury were calculated as the number of HS injuries/1000 hours of total exposure and number of time-loss days/1000 hours of total exposure respectively (Ekstrand et al., 2011a). Incidence rate ratio (IRR) were calculated by 2 x 2 tables accounting for total player time exposure. A case was defined as the occurrences of HS injuries in the total player time exposure period. Attributable fractions in the exposed (AFE) with 95% confidence intervals (95%CI) and attributable fractions in the population (AFP) were calculated (Rockhill et al., 1998). Attributable fractions are defined as the contribution of a risk factor to disease. This is the proportion of reduction in population disease that would occur if exposure to the risk factor was replaced with the alternative exposure option. The outcome is used to quantify the magnitude of change in cases, as a percentage, that would be prevented by using the intervention. The level of significance was set at $p<0.05$.

6.4 Results

In elite football, player movement within teams is common at varying times and for diverse reasons. In the CON group, one player left after the summer competition with another eight players joining the programme at the same time. In the INT cohort, 11 players exited the programme during or after their first year. Seven new players subsequently entered the programme to fill vacancies. Their respective data are included for the period in the programme. Data from three players were excluded (two in CON and one in the INT cohort) due to lack of match exposure or incomplete injury records resulting in fifty-two players being
included in the INT and 22 in the CON group. Thirteen (17.6%) of the player’s reported a past history of HS injury (Table 1). All past injuries had been sustained in the preceding three years. Three players had sustained a HS injury on more than one occasion. There was no significant difference in the number of players with a previous history of HS injury or number of previous HS injuries between groups (Table 1). The CON group were mainly studied in their final year of a two-year programme cycle, which meant they were significantly older, taller and heavier compared to INT (as first year players) who entered the study in the first year of the programme cycle. Only body-weight remained significantly higher in CON compared to INT in their second year. There was no significant difference between the groups in terms of which quarter of the year players were born (z= -1.755, p=0.079, ES=0.20) to explain this difference. The Poisson regression multi-variate model demonstrate that differences in HS injury between groups were not affected by potential confounding variables age (p=0.93), height (p=0.59), body-weight (p=0.23) and previous HS injury (p=0.07).

The occurrence of HS injury was significantly lower in the INT (n=1) group (z= -2.976, p=0.003, ES=0.35) compared to CON (n=5). The HS injury incidence was lower for INT (0.05/1000h) compared to CON (0.8/1000h) with resultant burdens of 1.3/1000h versus 14.2/1000h of total exposure respectively. Consequently, the IRR were significantly greater in CON (IRR=15.8, 95%CI 8.1, 30.9, p<0.001) with AFE=94% (95%CI 88, 97) and AFP=88%.
### Table 6.1 Comparative and descriptive data.

At each test occasion a maximum of two alerts (one per limb) could be triggered per player based on strength reductions greater than test MDC (>14%). In total 54 alerts were triggered involving 24 players (46.2% of INT) on 44 player occasions. More alerts (53.7%) were detected in the preferred kicking leg (dominant) compared to the non-dominant leg (46.3%). The majority of alerts were detected in attacking players (43.2%) followed by defenders (25.0%), midfield (22.7%) and goalkeepers (9.1%). In the attacking group, 84.2% of player occasions with detected alerts were found in externally positioned players on the wings. Most alerts (54.5%) from the defensive player occasions related to fullbacks with the remaining alerts (45.5%) detected in central defenders.

### 6.5 Discussion

This study demonstrated that complementing standard practice (primary and tertiary prevention) with a secondary prevention strategy shows promise for reducing the number and
impact of hamstring strain injuries in elite male football. In the current study there was a substantially higher occurrence and burden of HS injury in the standard practice group. Specifically, standard practice was associated with a 16-fold higher incidence with 94% of injuries in the INT potentially being prevented by the inclusion of secondary prevention strategies aimed at reducing hamstring strain injury. The burden of HS injury was 91% lower in INT compared to CON. There were no differences between groups in terms of previous HS injury history, weekly training volume, coaching staff or competition levels to explain the group differences.

In preparing football players for current and future demands of their sporting development it is important to optimise health and physical capacity, to provide organisations, technical staff and players the best opportunity to succeed. Reducing or maintaining low workloads constantly to avoid injury appears counterproductive to such aims (Malone et al., 2018, Malone et al., 2017). Equally, it is important to recognise that players will respond individually to the demands of football at varying times in-season and brief reductions of high-risk activities may be protective against HS injury (Bowen et al., 2017, Duhig et al., 2016, Malone et al., 2018). Elite male youth players can be expected to restore hamstring strength >24 to 48 hours post-match when using the test in this study (Wollin et al., 2017). Identifying individual players with hamstring impairments beyond this time-point appears promising as a secondary prevention method. This approach is supported by a recent systematic review in football that recommends individual load management in the fatigued post-match period guided by data from isometric post-match hamstring strength monitoring (Silva et al., 2018).

More hamstring strength test alerts were identified on the preferred (dominant) kicking leg, which is consistent with delayed restoration of kicking leg strength post-match shown previously in professional male football players (Nedelec et al., 2014). Number of tackles performed in a match is positively correlated with hamstring strength deficits (Nedelec et al, 2014), which might reflect players tackling more with the dominant leg and could help to
explain the greater number of alerts identified in the dominant leg in the present study. The
difference in kicking load during match play may also contribute to delayed restoration and
greater deficits in isometric hamstring strength of the preferred kicking leg compared to the
non-dominant leg post-match play. Match related kicking demands vary between player
positions (Whiteley et al., 2017), with players in external positions performing greater volumes
and velocities of match related kicking compared to centrally positioned players, particularly
central defenders and goalkeepers (Whiteley et al., 2017).

In the present study, most hamstring strength impairments identified post-match were found in
attacking players in external positions. Positional differences in physical output and capacities
during match play seem to exist for both elite male youth and professional players (Bangsbo,
2014, Buchheit et al., 2010). In both youth and adult players, central defenders cover less total
distance and, together with central midfield players, perform significantly less sprinting and high
intensity running (Buchheit et al., 2010, Di Salvo et al., 2007) in comparison to fullbacks and
external attacking players (Carling et al., 2008, Di Salvo et al., 2007). Attacking elite male youth
players have demonstrated higher volumes of high-speed running and sprinting compared to
other positions (Buchheit et al., 2010). Additionally, attacking players in 4-3-3 team formations
appear to perform more high-speed running compared to attacking players in other formations
(4-4-2 and 4-5-1) (Bradley et al., 2011). Combined, this may explain why most post-match
hamstring strength impairments were detected in attacking players.

A strength of this study is that it was conducted in the applied football setting over four
calendar years involving consecutive cohorts and the same coaches over a 115-match period.
Conversely, it is acknowledged that there are limitations associated with the inherent
challenges of conducting research in this setting where individual management is required, and
the inclusion of matched control groups is difficult. The application of generic (standardised)
load reductive interventions are unacceptable to coaches, players and support staff in elite
football. This removed the option of standardising the indicated interventions and introduced a
possible study limitation. The interventions in this study were therefore individual, consistent with secondary prevention principles and elite football requirements. Another potential limitation is that the Nordic hamstring exercise and broader S&C programme were not standardised between groups, however this reflects the applied elite football setting where injury prevention programmes are often modified to fit the contextual circumstances (O’Brien et al., 2017). In addition, post-match strength testing was not possible for all matches which is a possible limitation, although testing was not interrupted beyond two weeks. The optimal frequency of in-season strength testing appears to be linked with match play but is not yet established and is likely to vary depending on circumstances.

Another limitation of the present study is that available CON data were predominantly from year two of the programme, whereas INT data were included for the first and second years. Inevitably, the INT group were significantly younger, shorter and lighter during their initial year in the study. Contemporary data from elite male youth football players in full-time programmes indicate that there is no difference in overall injury occurrence and rates between 15 and 16 year-old players (Read et al., 2018). The potential confounding variables age, height, body-weight and previous HS injuries did not significantly affect the HS injury occurrence between the groups in the present study. That considered, and with the unique circumstance of U17 players competing against older age opponents at a higher level (U21 and adults), it is unlikely that being younger, shorter and lighter in the first year would lower the susceptibility of HS injury. Additionally, current evidence indicates that body-weight and height is not a risk factor for HS injury in male youth and adult football players (Emery et al., 2005, Hägglund et al., 2013, van Beijsterveldt et al., 2013a).

6.6 Conclusion

Introducing a prevention system to target hamstring strain injury in football by including a secondary prevention strategy while considering risk factors, appears promising in reducing the occurrence and burden of injury compared to standard practice in elite male youth football. This
systems approach suggests that prevention and performance are not at conflict with each other and should be considered one and the same within elite football. Athlete monitoring, in the context of secondary prevention, appears a promising complement to standard practice in reducing the occurrence and burden of hamstring strain injuries in elite football.

6.7 Acknowledgements

This work was supported by an Australian Government Research Training Program Scholarship.

6.8 Disclosure

The authors report no conflicts of interest.
Chapter 6: Novel hamstring strain injury prevention system

6.9 References


Fletcher, R. H., Fletcher, S. W., & Fletcher, G. S. (2012). *Clinical epidemiology: the essentials*: Lippincott Williams & Wilkins.


Chapter Seven

Grand Discussion and Conclusion

7.1 Discussion

The overall aim of this thesis was to introduce a novel prevention concept by incorporating primary, secondary and tertiary prevention, coupled with risk-factor based interventions, of groin problems and hamstring strain injury in elite football. Secondly, to highlight and investigate the potential of athlete monitoring as a secondary prevention strategy in professional development football. This was achieved by conducting a narrative review and a series of five original prospective and longitudinal cohort research studies.

The studies established the effect of the demands of football match play in-season and across seasons on valid and reliable clinical groin and hamstring tests including the unilateral supine hip adductor and add:abd strength test, the HAGOS, the 5-second AST, the externally fixed dynamometer unilateral isometric hamstring strength test and lower limb flexibility at the hip, knee and ankle.

Clinical screenings with the unilateral hip adductor strength, add:abd strength ratio tests and HAGOS can be used monthly in-season as the first step of two in secondary prevention. They can facilitate early detection and management of groin problems in elite football by measuring test results against pre-defined threshold alerts of early groin problems that required follow up with step two in the secondary prevention process. A key finding of Chapter Two was that hip and groin strength, health and function were at its lowest at pre-season prior to commencing training, can improve quickly in-season, and that groin problems in elite football players do not have to extend to severe time-loss.

Interestingly, half of this nationally selected cohort of professional development players had sustained a groin injury before the age of 15, most (64%) in the season prior, which raises
concerns of the potential effect on player and talent development success both in the short and long term. Despite hip and groin strength, health and function being lowest at arrival in pre-season, the data indicate that these characteristics can improve quickly if detected and managed appropriately. Regular in-season monitoring of hip and groin strength, health and function may assist in determining individual player response and readiness for the demands of elite football. Chapter Two demonstrates the potential of in-season athlete monitoring as a secondary prevention strategy in elite football. It highlights that clinicians should consider including both objective and subjective outcome measures to facilitate early detection and management of groin problems.

The main finding of the study in Chapter Three was that the accumulation of football match load has a negative effect on hip adductor squeeze peak force and that strength restoration cannot be assumed the following day. The 5-second AST peak force was reduced in most players during the tournament compared to baseline results, whereas pain responses were less commonly a problem. In fact, only players with a previous history of groin injury reported groin pain on testing. Congested tournament match play impacts on the established intrinsic groin injury risk factor: low hip adductor strength. It highlights the importance of athlete monitoring of hip adductor strength to facilitate early detection and management of groin problems during congested match play. The approach is accepted by coaches, players and clinicians and is suitable for inclusion in athlete monitoring as a secondary prevention strategy of groin problems during highly congested match periods.

Similar to adductor strength reductions, the physical demands of football match play also affect hamstring function shown by reduced isometric, concentric and eccentric strength post-match. Hamstring strength, using the standardised externally fixed dynamometer unilateral test, is significantly reduced acutely and 24 hours after a league match. Complete hamstring strength restoration can be expected 48 hours post-match. Associated hamstring pain on strength testing was significantly increased acutely and 24-hours post-match. Restoration of pain-free
status, at group level, was established 48 hours after match play. Interestingly, lower limb flexibility remained unaffected to the demands of competitive match play acutely and at 24, 48 and 72 hours post-match. This study (Chapter Four) highlights the clinical utility of testing hamstring strength in elite football players after competitive league matches in-season. The test is acceptable to coaches, players and clinicians and is suitable for clinical screening of hamstring strength post-match. Individual player management strategies for players with impaired strength and function 48 hours post-match is indicated as an early detection and management strategy aligned with secondary prevention.

Hamstring strength and associated pain and lower limb flexibility during and after match congestion in Chapter Five was relatively similar to that after one match in Chapter Four. Hamstring strength and pain had restored by the morning of the second match which was tested 63 hours after the first game. Lower limb flexibility was unaffected throughout the congested match period except for passive knee flexion (“Prone knee bend”). However, the reductions were small (1.5˚ - 2.7˚) and most likely clinically irrelevant. Based on the results of the studies reported in Chapters Four and Five the standardised externally fixed isometric hamstring strength test is indicated to capture post-match hamstring impairments. Collecting pain ratings from hamstring strength testing may not be required since secondary prevention is a two-step process where detected strength reductions in step one will lead to a follow up clinical examination (step two). Therefore, collecting pain ratings may be optional. There is no clinical indication to include any lower limb flexibility measures in athlete monitoring as a secondary prevention strategy in elite male football.

The final study (Chapter Six) was a longitudinal cohort study spanning four calendar years and 115 football matches designed to introduce a novel hamstring strain injury prevention system and to highlight athlete monitoring as secondary prevention strategy based on the study findings in Chapters Four and Five. The key findings of this study indicate that implementation of a novel and systematic hamstring strain injury prevention concept is possible and acceptable
to coaches, players and clinicians in elite football. It showed that the hamstring strain injury occurrence and burden can be very low in professional development football. The study showed that hamstring strain injury does not have to feature in the top two most common injuries in elite football. It is the first study to publish a prevention system incorporating primary, secondary and tertiary prevention continuum concepts coupled with risk-factor based interventions for hamstring strain injury in football.

7.1.1 Strengths and clinical implications of this thesis

This thesis has several strengths. The studies were conducted in the applied elite football setting. Data related to football players competing in official league matches and International tournaments. The investigations are connected to its intended environment with access to repeated measures longitudinal data over several seasons and involving high numbers of matches. The same coaching staff were in place throughout the study period ensuring consistency in coaching methods and leadership styles including the intervention and control groups. The clinical implications of this thesis are potentially substantial. These are the first collection of studies to introduce, describe and outline novel frameworks and concepts of a prevention system (continuum) surrounding groin problems and hamstring strain injury in male elite football. The system and strategies are acceptable to key stakeholders: coaches, players and clinicians. The prevention concept is simple, easy to implement and effective. The studies may assist clinicians when considering a paradigm shift towards a proactive medical performance systems approach to injury prevention (or reduction) in elite football. This prevention system demonstrates where evidence-based prevention and performance interventions are naturally placed within the continuum. Explicitly, it addresses human performance and prevention priorities in football simultaneously and shows that they are not at conflict with each other and should in fact be considered one and same. This highlights a proactive medical performance system, akin to a performance health management structure in elite football, rather than two separate operating systems of performance and prevention.
The studies in this thesis provide a resource that clearly describes and outlines athlete monitoring as a secondary prevention strategy for the two most common injury problems in male football. The studies enable clinicians to interpret and adapt the prevention systems and strategies to their specific requirements and environments. Prior to adapting and implementing the prevention system to their specific setting practitioners are advised to reflect on the ‘prevention paradox’ and the synthesis of emerging screening criteria (Andermann et al., 2008, Rose, 2001). Prevention is a product of aetiology and can be individual (indicated) and population (universal) based (Rose, 2001). The indicated based approach aims to identify ‘high-risk’, susceptible persons to offer them personalised interventions. The universal approach aims to control the determinants of incidence in the whole population rather than at the individual level (Rose, 2001). Both approaches have strengths and limitations often described as the prevention paradox.

The traditional medical approach to prevention is the ‘high-risk’ individual method (Rose, 2001). It is a reasonable practice since the sequence of treating a person’s health problem in the present to preventing another in the future is logical. In this setting screening is used to evaluate the person’s health or susceptibility in an attempt to mitigate incidence. This is akin to truncating the risk distribution which is associated with advantages and disadvantages. Advantages of the indicated approach includes that it is often acceptable to the individual, motivational to patient and practitioner, with the potential to be cost-effective and have a favourable benefit to risk ratio (Rose, 2001). Disadvantages to consider can include difficulties with screening and cost of screening. Screening aims to identify those of increased susceptibility but itself does not change underlying causes. Limitations might include weak predictive ability of tests and the inability to prescribe a level of absolute risk or danger (Rose, 2001).

The universal based strategy tries to control the determinants of incidence to reduce the average level of risk factors to the whole population. One of the advantages with this approach is that it aims to remove the cause or risk factors of disease. It has a great potential for the
whole population (Rose, 2001). The disadvantages with this approach are that it offers little
direct benefit to the individual, i.e. the prevention paradox. The prevention paradox is a
reflection that a preventative measure which has large benefits to the population offers little to
each participating individual (Viera, 2011).

An everyday life example of the prevention paradox is the legislation of compulsory use of seat
belt when travelling in cars. It offers great potential to reduce death or severe injury in car
accidents at a population level. However most participating individuals (those wearing seatbelts
each time they travel in a car) are unlikely be involved in a car accident (at least in the short
term) but are still required to wear a seatbelt to receive a prevention benefit (Viera, 2011). It is
an example of the universal strategy where ‘everyone’ participates but few benefits
immediately (Viera, 2011). This paradox can impact on individuals’ motivation to participate in
the preventative intervention, since most individual’s acts on immediate and substantial
rewards (Rose, 2001).

If we consider these strategies in the context of professional development and professional
football, we can clearly identify a requirement for integrating both approaches. At this level of
football, players are high level investments. The cost of player unavailability due to injury and
illness is substantial and misaligned with the aim of winning and developing future
professionals. In football, every player can be considered ‘high-risk’ since each individual is likely
to sustain an injury in any given season (Ekstrand et al., 2011b). A team of 25 players in the
European champions league can expect 15 muscle injuries per season with 5-7 of those being
represented in both the hamstring and groin injury categories respectively (Ekstrand et al.,
2016, Ekstrand et al., 2011a, Werner et al., 2009, Werner et al., 2018). Consequently, it is
unlikely that a player will never sustain a groin problem or hamstring strain injury during their
career. This suggests that individual strategies are highly indicated in the elite male football
setting. Such an approach, in theory, is likely to motivate players to participate in the screening
and intervention process since they might perceive an immediate and substantial personal
benefit. Players who have had to deal with the hardship of previous hamstring and groin injury, should be amenable to participation. The never injured player, who is uncommon at the elite level of football, might be less inclined to participate in either or both prevention approaches. Fortunately, most of these interventions are also performance enhancing and directly beneficial to player (individual) and team (population). This might improve stakeholder motivation to participate. However, the messaging and decision-making processes around these interventions from key influencers (e.g. club staff) could be important in enabling behavioural change.

Despite hamstring strain injury and groin problems being substantial population issues in elite male football, most players will not suffer an index or recurring hamstring injury every week. This might limit the utility of the indicated prevention approach. Similarly, it may affect participation ‘buy-in’ of the universal strategy in elite football. Examples of this include the reportedly low compliance or implementation uptake of the Nordic hamstring exercise and groin prevention exercise programs in elite male football (Bahr et al., 2015, Holmich et al., 2010, Engebretsen et al., 2008). If these exercises are introduced as injury prevention programs players might be disengaged due to the lack of immediate and substantial relevance to them. This could occur despite the high priority of the team (population) to reduce hamstring strains and groin problems. The outcome in both instances is potentially reduced compliance and implementation. It might also be that Nordic hamstring exercises and groin exercise programs are more effective across much larger populations. This would align with the limitation associated with universal based interventions where individuals will often have a small expectation of benefit (Rose 2001).

In this thesis an obvious example of a universal based approached would be to avoid exposing players to determinants of hamstring strain injury until ≥48 hours after match play demands. However, this approach is unrealistic in elite football where training occurs on most days and matches are played at least once weekly. Implementation of such intervention is not feasible, and alternatives are required. Elite football players will be exposed to the cause of disease
nearly daily, which is one reason they have rapid access to a range of medical services at training and match venues. The level of susceptibility is likely to fluctuate, depending on the extent of exposure to the determinants of incidence, i.e. football context, in relation to individual players rather than the whole population (team). Overall it supports a systems approach that integrates a player responsive (indicated) and team based (universal) strategy to optimise groin and hamstring health for football players to perform. The prevention continuum outlined in this thesis provides an evidence-based framework for indicated and universal based strategies directed at managing performance health.

Andermann et al. (2008) revisited the Wilson et al. (1968) ten ‘gold standard’ screening criteria to provide a more contemporary context and in response to the rapid growth in genetic screening. The article provides a synthesis of emerging screening criteria over the past 40 years since the Wilson et al. (1968) publication. The ten ‘new’ screening criteria that had emerged were:

1. The screening programme should respond to a recognized need
2. The objectives of screening should be defined at the outset
3. There should be a defined target population
4. There should be scientific evidence of screening programme effectiveness
5. The programme should integrate education, testing, clinical services and programme management
6. There should be quality assurance, with mechanisms to minimize potential risks of screening
7. The programme should ensure informed choice, confidentiality and respect for autonomy
8. The programme should promote equity and access to screening for the entire target population
9. Programme evaluation should be planned from the outset
10. The overall benefits of screening should outweigh the harm

If we consider each of these ten points against the context of integrating screening in athlete monitoring model as a secondary prevention strategy we have identified a clear need to include groin and hamstring screening. The incidence and burden of injury is substantial and impact negatively on this population. In this thesis we have presented the objectives of screening at the outset to optimise performance health by complementing a population method with individual based approach in this high-risk population. We have defined the population to professional development in this thesis and propose its potential to be extended to professional populations. We have provided emerging evidence of its effectiveness but recognise that additional and larger studies are required, which ideally should include different populations. The prevention continuum presented in this thesis clearly maps how universal, selective and indicated interventions integrate education, testing, clinical services and program management. The prevention continuum presented in the thesis adhered to a standardised approach, which included clinical examination by qualified and experienced health professionals to minimise potential risks of screening. The indicated interventions were all non-invasive, safe and common practice within contemporary football medicine practices. Participants were educated, able to opt out at any time, actively involved and consulted during the process. We enabled screening to every individual in the target population, promoting equity and access to all players. Studies designed to evaluate the program were planned at the outset with consent provided by key stakeholders and human ethics approval received. The clinical screening of a player was usually completed within five minutes. Testing methods were considered safe with clearly identified potential benefits outweighing the harm to player and team.

7.1.2 Limitations of this thesis and directions of future research

Cohort studies are associated with inherent limitations in terms of determining cause and effect. Small sample sizes can also be a limitation in cohort studies. This thesis may have benefited from larger size control groups and overall sample size. The addition of randomised
control groups would strengthen some of the conclusions in Chapters Two and Six. However, conducting research using matched control groups longitudinally in elite football is difficult, and often unacceptable to coaches and players. Future research directions should aim to include randomised control groups and larger sample sizes (e.g. multiple teams) to investigate the effectiveness of athlete monitoring as a secondary prevention strategy to reduce the incidence and burden of groin and hamstring injury in other professional development settings and at professional levels of elite football. Additionally, future research aiming to identify the optimal frequency of in-season strength and HAGOS testing would also be of benefit to clinicians implementing athlete monitoring.

The future direction around athlete monitoring in elite football is positioned to move away from a physical preparation and injury prevention focus in favour of a systems approach aimed at optimising performance (and) health. A recent cross sectional study in elite youth and professional English football found that coaches generally support load monitoring (Weston, 2018). In this survey coaches perceptions of the purpose of load monitoring were to maximise performance and reduce injury (Weston, 2018), i.e. performance health. The coaches reported different perceptions of traditional load monitoring methods compared to sport science practitioners in regards to blood lactate monitoring, views on training load, ratings of perceived exertion, heart rate monitoring and medical staff perceptions of load (Weston, 2018). It exposes the current sport science monitoring model to potential challenges with compliance and implementation success. The paradigm shift to a public health approach in elite football practice is inevitable, considering the limited success standard practice has had in tackling the burden of groin and hamstring injury and its associated performance issues over the last 20-30.

The attention to the process of performance health management is key and should precede debates around selecting tests or technologies. Once the performance health process, prevention continuum has been mapped the selection of tests and technology requirements will be much clearer to the stakeholders.
At the outset engagement with key stakeholders in the applied setting is critical to successful implementation. In the future this might involve Club owners, board of directors, chief executive officers, football directors and coaches. The future, based on this work, suggests that a much greater emphasis in both research, education and application will be on quality communication between coaches, support staff and players around performance health information rather than fatigue, recovery and injury or its prevention. To facilitate these directions the introduction of Performance Health Directors will be commonplace at the elite clubs. They will provide strategic directions and perform important roles as conduits between coaches and key stakeholders in managing the performance health processes and staff.

It is likely that supporting technology will evolve to provide palatable options for both research and applied practice. New technology will continually improve in the following domains: wearable, non-invasive, time effective, robust, reliable and relevant to performance health optimisation to meet sector demands. The technology will likely allow for sampling a range of data to provide responsive individual daily performance health evaluation status updates on players, coaches and support staff. Performance health management requires a move towards pattern recognition and management of performance health threats instead of focusing on injury risk factors.

7.1.3 Conclusion

Clinical screening and athlete monitoring have been recommended to prevent muscle injuries in elite football. The aim is to assess individual player risk, susceptibility, response and readiness to the demands of football at the professional development and professional football level throughout the season. This thesis introduced, outlined and investigated the potential of clinical screening and athlete monitoring in the applied elite football settings in-season. Athlete monitoring as a secondary prevention strategy is accepted by coaches, players and clinicians and can be implemented effectively. Consultation with key stakeholders is recommended prior to implementing athlete monitoring strategies. This should outline an articulated secondary
prevention strategy that clearly describes possible indicated interventions to provide stakeholders with insight to potential scenarios that can be expected in-season. Hip adductor, abductor and hamstring strength can be captured with simple, quick, inexpensive and safe test methods that demonstrate good absolute and relative reliability when testing elite football player’s strength in the applied competitive environment. Athlete monitoring as a secondary prevention strategy shows promise to complement primary and tertiary prevention in reducing the occurrence and burden of groin problems and hamstring strain injuries in elite football. There is no clinical indication to include lower limb flexibility testing in this process and the collection of numerical pain ratings during strength testing is optional. The novel prevention concept outlined in this thesis suggests that injury prevention and human performance enhancement are not at conflict with each other but rather one and same in elite football.
Bibliography


BENGTTSSON, H., EKSTRAND, J., WALDÉN, M. & HÄGGLUND, M. 2017. Muscle injury rate in professional football is higher in matches played within 5 days since the previous match: a 14-year prospective study with more than 130 000 match observations. *Br J Sports Med*, 52, 1116-1122.


FÉDÉRATION, INTERNATIONALE, DE, FOOTBALL & ASSOCIATION 1995. Laws of the game. FIFA.


TO: Martin Wollin
FROM: Ms Joanne Allen
SUBJECT: Approval from AIS Ethics Committee
DATE: 14\textsuperscript{th} August 2013

On the 13\textsuperscript{th} of August 2013, the AIS Ethics Committee gave consideration to your submission titled ‘Thigh and hip strength profiles, injury and training load in elite youth football players’. The Committee saw no ethical reason why your project should not proceed subject to:

- Including the listing of exclusions in the information to participants
- Including an explanation of ‘isokinetic test protocol’ which is user friendly

The approval number for this project: 20130808

It is a requirement of the AIS Ethics Committee that the Principal Researcher (you) advise all researchers involved in the study of Ethics Committee approval and any conditions of that approval. You are also required to advise the Ethics Committee immediately (via the Secretary) of:

- Any proposed changes to the research design;
- Any adverse events that may occur.

Researchers are required to submit annual status reports and final reports to the secretary of the AIS Ethics Committee. Details of status report requirements are contained in the “Guidelines” for ethics submissions.

Please note the approval for this submission expires on the 31 December 2016 after which time an extension will need to be sought.

If you have any questions regarding this matter, please don’t hesitate to contact me on (02) 6214 1577.

Sincerely
Joanne Allen
A/g Secretary, AIS EC (Acting)
On the 10th of December 2013, the AIS Ethics Committee gave consideration to your to vary your study titled “Thigh and hip strength profiles, injury training load in elite youth football players”. The Committee saw no ethical reason why your project should not proceed.

The approval number for this project: 20130808

It is a requirement of the AIS Ethics Committee that the Principal Researcher (you) advise all researchers involved in the study of Ethics Committee approval and any conditions of that approval. You are also required to advise the Ethics Committee immediately (via the Secretary) of:

- Any proposed changes to the research design,
- Any adverse events that may occur,

Researchers are required to submit annual status reports and final reports to the secretary of the AIS Ethics Committee. Details of status report requirements are contained in the “Guidelines” for ethics submissions.

If you have any questions regarding this matter, please don’t hesitate to contact me on (02) 6214 1577.

Sincerely
Joanne Allen
A/g Secretary, AIS EC (Acting)
MEMORANDUM

To: Dr Tania Pizzari, Rehabilitation Nutrition and Sport /Allied Health, SHE
Martin Wollin, Rehabilitation Nutrition and Sport /Allied Health, SHE

From: Executive Officer, La Trobe University Human Ethics Committee

Subject: UHEC acceptance of the Australian Institute of Sport (AIS) HREC approved project - 20130808

Title: Thigh and hip strength profiles, injury and training load in elite youth football players

Date: 5 February 2015

Thank you for submitting the above protocol to the University Human Ethics Committee (UHEC). Your material was forwarded to the UHEC Chair for consideration. Following evidence of a full review and subsequent final approval by the AIS HREC, the UHEC Chair agrees that the protocol complies with the National Health and Medical Research Council’s National Statement on Ethical Conduct in Human Research and is in accordance with La Trobe University’s Human Research Ethics Guidelines.

Endorsement is given for you to take part in this study in line with the conditions of final approval outlined by the AIS HREC.

Limit of Approval. La Trobe UHEC endorsement is limited strictly to the research protocol as approved by the AIS HREC.

Variation to Project. As a consequence of the previous condition, any subsequent modifications approved by the AIS HREC for the project should be notified formally to the UHEC.

Annual Progress Reports. Copies of all progress reports submitted to the AIS HREC must be forwarded to the UHEC. Failure to submit a progress report will mean that endorsement for your involvement this project will be rescinded. An audit related to your involvement in the study may be conducted by the UHEC at any time.

Final Report. A copy of the final report is to be forwarded to the UHEC within one month of it being submitted to the AIS HREC.
If you have any queries on the information above please e-mail: humanethics@latrobe.edu.au or contact me by phone.

On behalf of the La Trobe University Human Ethics Committee, best wishes with your research!

Kind regards,

Sara Paradowski
Senior Human Ethics Officer
Executive Officer – University Human Ethics Committee
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Appendix D:

Original research

Reliability of externally fixed dynamometry hamstring strength testing in elite youth football players

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A B S T R A C T

Objectives: To investigate inter and intra-tester reliability of an externally fixed dynamometry unilateral hamstring strength test, in the elite sports setting.

Design: Reliability study.

Methods: Sixteen, injury-free, elite male youth football players (age = 16.81 ± 0.54 years, height = 180.22 ± 5.29 cm, weight 73.88 ± 6.54 kg, BMI = 22.57 ± 1.42) gave written informed consent. Unilateral maximum isometric peak hamstring force was evaluated by externally fixed dynamometry for inter-tester, intra-day and intra-tester, inter-week reliability. The test position was standardised to correlate with the terminal swing phase of the gait running cycle.

Results: Inter and intra-tester values demonstrated good to high levels of reliability. The intra-class coefficient (ICC) for inter-tester, intra-day reliability was 0.87 (95% CI = 0.75–0.93) with standard error of measure percentage (SEM%) 4.7 and minimal detectable change percentage (MDC%) 12.9. Intra-tester, inter-week reliability results were ICC 0.86 (95% CI, 0.74–0.93), SEM% 5.0 and MDC% 14.0.

Conclusions: This study demonstrates good to high inter and intra-tester reliability of isometric externally fixed dynamometry unilateral hamstring strength testing in the regular elite sport setting involving elite male youth football players. The intra-class coefficient in association with the low standard error of measure and minimal detectable change percentages suggest that this procedure is appropriate for clinical and academic use as well as monitoring hamstring strength in the elite sport setting.

1. Introduction

Football is a popular sport played worldwide by men, women and children of all ages. Playing football is associated with both health benefits and injury risk.1,2 Hamstring injuries (HI) are the most common injury in male professional players, responsible for significant time loss and high recurrence rates.3–5 The long head of biceps femoris (LHBF) muscle demonstrates the highest incidence and recurrence rate of HI in football.6 Increasing age, past injury, match play and weekly match frequency are established risk factors for HI.1,3,4 Of the intrinsic, modifiable risk factors, strength deficits and imbalances are easy to quantify. Athletes with a previously injured hamstring can present with significant strength deficits compared to the non-injured side after returning to sport.7,8

Bilateral hamstring strength asymmetry has been identified as a potential risk factor for HI in football.9,10 Corrective strength training and re-testing of strength deficits and imbalances measured at pre-season in football players demonstrated reduced HI rates compared to players that did not correct strength imbalances.9 Statistically selected cut-offs included a bilateral hamstring strength asymmetry greater than 15%.9

The hamstrings are sensitive to football induced fatigue demonstrated by decreased isometric, concentric and eccentric strength after match play and repeated sprint efforts.11–13 Hamstring injuries frequently occur during fast speed running towards the late or terminal swing phase of the running gait cycle.14 The terminal swing phase involves hip flexion and approximately 30–45° knee flexion.15 During this phase of fast running the hamstring biomechanical loads appear to increase resulting in peak knee flexion torque and muscle lengths.15–17 In vivo measurements of the human LHBF propose that it primarily works on the plateau and descending arm of the length-tension curve, which involves 45–90° of hip flexion and 0–90° of knee flexion.18 The incorporation of 45°
of hip flexion has been suggested as a method to utilise a larger range of the muscle length–tension relationship during hamstring exercise.18

An objective physical measure of fatigue in the absence of injury to measure strength reductions is needed. The frequency of football actions during match play has been correlated with muscle damage and fatigue up to 72 h post-match.11,19 Typically, football training and occasionally match play resumes within 72 h post-match, which suggests that player fatigue is still prevalent in this period. A valid and reliable hamstring test that can be integrated efficiently and safely in the regular training environment may assist staff in the clinical reasoning and decision making process around HI and football induced fatigue. The majority of hamstring strength testing is performed seated, which is a non-functional position in relation to terminal swing of the running gait cycle. Acceptable inter-tester reliability of externally fixated dynamometry knee flexion strength has previously been demonstrated7,20,21; however, these studies were performed seated, prone or kneeling.

Isokinetic dynamometry remains the gold standard for strength testing. However, the use of hand held dynamometers for strength testing is increasing in popularity in elite sport programmes. Several reasons exist for the increased popularity of using hand held dynamometers such as time efficiency, cost of the device and results being available immediately. Prior to implementing dynamometry into the regular elite sport setting, the intra and inter-tester reliability as well as the standard error measure (SEM) and minimal detectable change (MDC) need to be established to make an informed decision on the best method for use in the clinic, player monitoring programmes and research.

The objectives of this study were (i) to investigate inter and intra-tester reliability of a hamstring strength test in a position associated with terminal swing in the elite sport setting of which it is to be applied (ii) to determine the SEM and (iii) to determine MDC.

2. Methods

Twenty-one male youth football players from a centralised national elite player development programme gave written informed consent to participate in the study. All players had one familiarisation session prior to data collection. For inclusion in the study players had to be free of any lower limb injury and involved in regular football training. This study was approved by the Australian Institute of Sport Ethics Committee.

Testing was performed in the clinical area of the Department of Physical Therapies, Australian Institute of Sport. The testing was conducted by a senior sports physiotherapist with 13 years of sport specific experience and a junior physiotherapist with 6 years of clinical experience. The testers were blinded from each other and performed the test procedure separately.

The setup and equipment included a calibrated load cell secured to the floor, an electronic examination table, a seatbelt and a portable 45° wedge (Fig. 1). Maximum voluntary isometric peak force was recorded on an electronic display (Omni Instruments AMLTR-150+RS232, product number TR150, United Kingdom) connected to a load cell (XTRAN S1W-9KN, Australia). Forces were converted to torque in accordance with published reports.22

Inter-tester, intra-day data was collected 10 min apart. Intra-tester, inter-week results were collected on the same day and time one week apart. Between testing sessions all participants were in the competitive season following their normal training and match cycle. The testing procedure was standardised and participants instructed to stabilise themselves on the inclined wedge, in prone, and holding on to its corners. The wedge design ensured that hip flexion was standardised to 45°. A fixed goniometer was used to set knee flexion at 30°. Axis of movement was taken on the lateral side of the knee with goniometer arms pointing towards the greater trochanter proximally and lateral malleolus distally. The seat belt was placed across the lower leg five centimetres (cm) proximal to the distal point of the lateral malleolus. Lever length was measured from the lateral joint line at the knee to 5 cm proximal to the lateral malleolus. The testing procedure involved two practice repetitions and one maximal test effort of each leg separately. Each repetition was 5 s in duration followed by 10 s rest between practices and 20 s rest between the final practice and the maximal test effort. Instructions of “go ahead, pull, pull, pull and relax” were given and vigorous verbal encouragement was provided during the maximal test. Less than 5 min was required to administer the test per player. Tester sequence was randomised for the inter-tester sessions. Leg testing order was randomised for both the intra and inter-tester sessions.

To assess the relative reliability intra-class correlation coefficients (ICC2,1) absolute agreement, single measure with corresponding 95% confidence intervals (95% CI) were utilised. The absolute reliability was examined and the SEM (SD × √1–ICC) and MDC (SEM × 1.96 × √2) were calculated utilising the same methodology as previous dynamometry studies23,24 and based on Weir.25 SEM% and MDC% were calculated by dividing their respective value with the related average of the test and retest values. The relative reliability was evaluated in accordance with previously defined criteria (poor = 0.60–0.69, fair = 0.70–0.79, good = 0.80–0.89, high = 0.90–0.99).26 Post hoc power calculations indicated that this study is adequately powered (α=0.05, β = 0.999). To compare left and right as well as dominant and non-dominant legs a two-sample t-test with unequal variances was utilised. All calculations were performed using SPSS version 19 (SPSS Inc., Chicago, IL, USA). Statistical significance was set at p < 0.05 for all calculations.

3. Results

Five players were excluded from the study, two due to a current lower limb injury and three due to incomplete data. In total, 16 players completed the study involving 32 lower limbs, age = 16.81 ± 0.54 years, height = 180.22 ± 5.29 cm, weight = 73.38 ± 6.54 kg, and BMI = 22.57 ± 1.42. The reliability of the hamstring strength results is presented in Tables 1 and 2. Inter and intra-tester values demonstrated good to high levels of reliability. ICC for combined inter-tester, intra-day reliability was 0.87 (95% CI = 0.75–0.93), SEM% 4.7 and MDC% 12.9 (Table 1). Combined intra-tester, inter-week reliability results were ICC 0.86 (95% CI = 0.74–0.93), SEM% 5.0 and MDC% 14.0 (Table 2). The distribution of player’s preferred kicking leg, defined as the dominant leg, was right, n = 11 and left, n = 5. The dominant limbs were significantly better at all time points with p < 0.05 for all calculations.
stronger than the non-dominant (p = 0.04). No significant difference (p = 0.22) was observed in the comparison of right and left legs. Testing did not interfere with players’ regular training routine and no participants were injured during testing or reported soreness in subsequent days. The mean knee flexion torque values for the right leg were 2.70 N m/kg (±0.40), left 2.62 N m/kg (±0.38) with a combined mean of 2.66 N m/kg (±0.39).

4. Discussion

This study demonstrates good to high levels of reliability of hamstring strength testing performed in a clinically relevant position to HI. Hamstring strength testing can be applied efficiently in the elite sport setting to assist with the clinical reasoning process around HI and playing induced fatigue. SEM% and MDC% provides valuable information that can be easily interpreted in clinical practice and during periodical monitoring of athletes in their daily training environment. The MDC% found in this study (11.1–15.9) allows for detection of strength change that correlates with football induced fatigue and bilateral asymmetries proposed to increase the risk of HI. The reliability results from the present study compares favourably with recent reports.7,21,27 The advantages of this test is that it is not portable as the load cell was attached to the floor and that it required a 45° wedge.

The study was performed on football players competing in their regular season without interference to team activities and did not cause player injury. It can be replicated in clinical and elite sport settings with little cost associated. The test process required less than 5 min per player to complete. Only two warm-up repetitions and one maximal test effort is required. This allows for practical implementation in periodical monitoring of player groups in the applied setting. Previous studies investigating the reliability of handheld dynamometry have included multiple maximal test efforts without interfering with the daily training environment or causing player injury.

The ability to detect strength changes at approximately 11–15% is clinically relevant as it correlates with previous reports that such strength change or imbalances are associated with football induced fatigue and increased risk of HI.9,13 It is unclear if isometric strength tests can identify football players with a previous HI or predict a future injury as the causation is multi-factorial. The extent to which isometric strength changes or bilateral asymmetries compare with similar findings obtained by isokinetic strength testing requires further investigation. Comparing player’s post-match strength levels against their baseline data may assist team medical staff in the clinical reasoning process around player management.

The literature is ambiguous to what extent isokinetic thigh muscle strength ratios influence hamstring injuries.9,28 Tol et al.29 reported that football players may have hamstring strength deficits when returning to play after hamstring injury without increased recurrence rates in the following two months. It may be more relevant to identify transient deficits to player’s baseline strength due to football induced fatigue in the context of in-season demands, rather than only assessing strength ratios in pre-season to determine its contribution to hamstring injuries in the upcoming season. This may be particularly pertinent during pre-season and intense and congested match periods especially in older players and those with previous hamstring injury. Isokinetic maximal strength testing is complicated, time consuming and probably unwise to implement for monitoring of players in the competitive season when players are fatigued. Isometric strength testing provides medical staff with a viable alternative for in-season player assessments without interfering with team activities or risking player injury.

5. Conclusion

Externally fixed unilateral isometric hamstring strength testing during the competitive season demonstrates good to high reliability in elite male youth football players and is able to detect strength changes of approximately 11–15% or greater. It can be applied time efficiently and safely, using a single maximal test effort reliably, without interfering with the daily training environment or causing player injury.

Practical implications

• This test demonstrates good to high reliability of isometric hamstring testing of young elite football players.
• The test application is quick to implement in the elite sport setting.
• The testing process is safe to use during the competitive season.

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References


Appendix E

Statement of Authorship: Paper 1

Statement from the authors confirming the authorship confirmation of the PhD candidate:

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We certify that Martin Wollin made the following contributions:

Conception and design of this study

Developed and executed the player recruitment and coaching staff endorsement

Education, supervision and training of research assistant

Analyses of outcome data

Writing the manuscript and response to reviewer comments”

Dr Kristian Thorborg Date: 29/04/2018

Dr Marijke Welvaert Date: 01/05/2018

Dr Tania Pizzari Date: 11/05/2018
Statement of Authorship: Paper 2

Statement from the authors confirming the authorship confirmation of the PhD candidate:

“As co-authors of the publication:


We certify that Martin Wollin made the following contributions:

Conception and design of this study

Developed and executed the player recruitment and coaching staff endorsement

Education and training of research assistant

Analyses of outcome data

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Statement of Authorship: Paper 3

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We certify that Martin Wollin made the following contributions:

Conception and design of this study

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Education, supervision and training of research assistants

Analyses of outcome data

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Introducing a novel hamstring strain injury prevention system: highlighting secondary prevention in elite youth football.

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Conception and design of this study

Developed and executed the player recruitment and coaching staff endorsement

Education, supervision and training of research assistants

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Dr Kristian Thorborg Date: 29/04/2018

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