CAN THE NATURAL TURF PITCH AFFECT INJURY RISK AND PERFORMANCE WITHIN ELITE FOOTBALL?

DAVID JOHN RENNIE

A thesis submitted in partial fulfilment of the

requirements of Liverpool John Moores University

for the degree of Doctor of Philosophy

April 2019

This research programme was funded by Leicester City Football Club.

Abstract

Historically, natural turf has been the pitch of choice within elite English football. However, its susceptibility to both climatic variation and footfall affecting its hardness, catalyzed the development of more robust, hybrid natural turf pitches. Despite such evolution, stakeholders continue to question the role hardness plays regarding injury on such natural turf. Unfortunately, the literature is scarce and lacks objective measures of pitch hardness providing no evidence to support or refute these concerns. Thus, the primary aim of this thesis was to question the role of natural turf hardness in both injury and performance in elite football.

The first study (Chapter 3) established that 87% of stakeholders within football perceived pitch hardness to be a major injury risk. Relative risk to specific tissues was perceived to be dependent upon the surface namely hard pitches affecting joint/tendons whilst soft pitches increased risk of ligamentous and ligament strains. The second study (chapter 4) developed the necessary methodological procedures for the objective evaluation of pitch hardness. The study proposed the use of a portable and practical objective measure of hardness (Clegg Hammer 2.25kg), evaluated its reliability and formulated a protocol for its use. This new protocol was then used within the remaining chapters to evaluate the pitch hardness. Chapter 5 established the temporal and spatial variation of natural turf, over eight football seasons, showing pitches have become harder. Such was the variation in hardness that over 23% of pitch exposures fell outside of UEFA's recommendations. It also established for the first time that the new hybrid natural turfs are significantly harder but less variable than native soil. The novel findings of chapter 6 showed that injury incidence, injury burden and

even the type of tissue at risk may be related to the hardness of the natural turf pitch. It also demonstrated that the type of hybrid pitches carry their own injury profile. The final pitch hardness manipulation study (chapter 7), the first of its kind, provided insight into how such surface hardness affects external and internal loads experienced by players.

In summary, this thesis has taken the first step towards exploring how the hardness of natural turf pitches could be viewed as a risk factor for injury within elite football. The novel design and methodology enabled detailed investigation of how natural turf pitches are changing and affecting both injury and performance. Profiles of injury, and technical and physical performance measures, were found to be dependent upon relative surface hardness. These findings provide clarity to those working within the applied setting enabling stakeholders to maximize player performance, whilst mitigating injury risk.

Acknowledgments

As in life, this thesis can be seen as a journey which has seen both massive highs and unthinkable lows. Its start was founded on relegation to League One, whilst its ending winning the Premier league perhaps dwarfs my progression, but in some way mirrors my emotional attachment to the learning process. Along the way I have had the privilege to meet, work and laugh with many people which I would like to acknowledge. Firstly, my director of studies Professor Barry Drust. Your understanding that working within the applied setting often requires an acceptance that pragmatism, is a skill needed to initiate and complete any given day, helped me considerably over this enduring process. Your patience and support gave me room to grow albeit at a very slow rate, into a more critical thinker within the workplace, thanks for understanding. Secondly, to my other two supervisors Associate Professor Jos Vanrenterghem and Dr. Martin Littlewood. Firstly, Jos despite your valiant escape bid to Belgium, your positivity, regarding my clumsy academic musings made for comments like “try to write it so it makes sense!” one of my favorites, and one with which I was in total agreement. Your love for concise writing means, I just need to say thanks. Martin, as both a supervisor, colleague and now friend, your support has been ever present. Your appreciation of the culture within which I work, but perhaps more importantly the stage of my journey enabled me to finally arrive at this destination. I will never forget the saxophonist at the Curzon, the cramp in your toes, or the warmth of your support for which I am eternally grateful.

I would like to thank all those I have worked with at Leicester City Football Club, it is a privileged but humbling experience working with such great people so a big thanks to all the players, coaches, and groundstaff. Continued applause for the medical and sports science team who have made this happen, and especially to Clare, for your support but more so, the coffee. Unfortunately, not everyone made it to the terminus at which I stand. My father in law John Turner, a special man, and one probably happy he won't need to pretend to read this, is sadly missed. Whilst my club owner Mr. Vichai Srivaddhanaprabha, "the possible man" also tragically died before completion of this thesis. Boss your funding of this study, but more your investment in me as a person made it possible for me to dream, I will never forget.

Thanks also to my family, Mum and Dad your eternal student is hopefully finished at University. To my unbelievably brilliant sons, Ollie and James for putting up my moods and me not always being there. If I can achieve this you can take on the world your own way, as always with a smile. Finally, to my wife Deanne, who on many occasions when I was falling apart, showed things were really just falling into place. Without your encouragement and support I would never be where I am today. You showed me that even in the darkest of times, the love and support of your family is the difference between success and failure, this thesis is testament to that.

Declaration

I declare that the work in this thesis, which I now submit for assessment on the program of study leading to the award of PhD, is entirely my own. Additionally, all attempts have been made to ensure that the work is original, and does not to the best of my knowledge breach any copyright laws, and has not been taken from the work of others, apart from work that has been fully acknowledged within the text of my work.

Publications and presented abstracts arising from this thesis:

Rennie D.J., Vanrenterghem, J., Littlewood, M., Drust B. (2016) Can the natural turf pitch be viewed as a risk factor for injury within Association Football? J*ournal of Science and Medicine in Sport* 19, 547-552.

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LIST OF ABBREVIATIONS

ASTM, American Society Testing Materials.

AFL, Australian Football League.

Clegg Hammer, Clegg Impact Surface Tester.

D-RPE, Differential Rating of Perceived Exertion.

D-RPE B, Differential Rating of Perceived Exertion for the demands on their breathing.

D-RPE L, Differential Rating of Perceived Exertion for the demands on their legs.

D-RPE T, Differential Rating of Perceived Exertion for technical difficulty.

GPS, Global Positioning System.

G, Gravitational force.

HD, High definition.

HR, Heart rate.

HSR, High speed running distance.

Hz, Hertz.

Kg, Kilogram.

M, meters.

m/s, meters per second

$m.min^{-1}$, meters per minute.

OSICS, Orchard sports injury classification.

PSI, Pounds per square inch.

RPE Session, Rate of Perceived Exertion for the total session.

SD, Standard deviation.

SSG, Small sided game.

UEFA, Union of European Football Associations.

V, Versus.

VHS, Very high speed running distance.

4V4 SSG, 4 versus 4 players small side game.

8V8 SSG, 8 versus 8 players small side game.

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CHAPTER 1

GENERAL INTRODUCTION

Natural turf pitch hardness:

The relationship to perceived injury risk,

injury prevalence and performance in elite

footballers.

1.0 Introduction

For the elite football player, injury rates are high with reported values in training between 1.5-7.6 injuries per 1,000hours exposure. This value increases in matches to 12-35 injuries per 1,000 hours (Rahnama 2011, Longo et al 2012). The majority of injuries are believed to occur when the acute and/or chronic stress applied to the tissue is greater than its capacity to 'absorb' the stress (McBain et al 2011). This overall load on the body is a result of the complex interactions between a large number of factors that impact upon the individual. Not surprisingly, many researchers have tried to attribute causality to the most prevalent injuries proposing numerous risk factors that may play a role in injury occurrence. Broadly, such factors can be classified as either intrinsic or extrinsic (Bahr and Holme, 2003). Intrinsic factors (those relating to the individual) may partly account for the potential of any player to be predisposed to injury. However, the act of participation exposes the individual and their inherent predispositions to extrinsic factors (those outside the player such as equipment, pitch conditions, and opposition). Meeuwisse and colleagues (2007) propose that the interaction between intrinsic and extrinsic risk will ultimately determine the possibility of players becoming injured. This relationship is not linear in nature but should be viewed as a more dynamic, recursive model where each exposure will result in a cumulative impact on all other risk factors (Meeuwisse et al 2007). Research has primarily focused on the intrinsic risk factors and their influence on injury despite the early work of Ekstrand and Gillquist (1984) illustrating the importance of extrinsic risk to injury incidence in football. Extrinsic factors identified in the literature include level of competition, shoe type, ankle bracing, stage of the season, climatic conditions, and the playing surface (Hawkins et al 2001, Orchard et al 2002, Murphy et al 2003).

Historically, natural turf has been the surface of choice for association football within England and the rest of Europe despite difficulties ensuring pitch quality, in a sport played across all climatic seasons. Attempts to drive pitch quality standards, through advancements in the construction and maintenance of natural turf has enabled production of robust ‘hybrid’ pitches which are more resistant to footfall and climatic variation. However, such changes have not gone unchallenged by users particularly regarding their perceived hardness and likelihood of injury (Ronkainen et al 2012, Roberts et al 2014, Mears et al 2018). Unfortunately, the natural turf playing surface as an apparent extrinsic risk factor to which all players are exposed in both training and matches has been poorly researched and its potential role within the injury paradigm remains unclear (Rennie et al 2016). Most knowledge is indirect in origin being mainly inferred through reported seasonal trends of injuries associated with harder drier pitches (Hawkins and Fuller, 1999, Walden et al 2005, Ekstrand et al 2011, Ekstrand et al 2013) or through comparative studies on artificial pitches (Ekstrand et al 2006, Fuller et al 2007, Soligard et al 2010, Williams et al 2011).

Within other sports, pitch hardness has been suggested to influence the players’ performance, movement patterns, and sprinting speed (Norton et al 2001, Twomey et al 2014). Furthermore, research has also shown pitch hardness can affect ball bounce and roll (Stiles et al 2009). It would therefore seem conceivable that the hardness of the playing surface may affect the performance of players, and the way in which they interact with the ball within football (Anderson et al 2008). These factors may in turn, influence their potential risk of injury. Whilst equipment to objectively assess the pitch hardness reported within the literature is both reliable and readily available, the methodology for its use is underdeveloped and lacks clarity. Clearly, the temporal and spatial characteristics of the natural turf pitch mean that its hardness will vary markedly in relation to both footfall and climatic conditions (Caple et al 2012). Despite this knowledge no research to date has objectively, measured the hardness of the natural turf pitch relating it to prospective injury or performance data, in an attempt to establish the effect that such natural surfaces may have on injury risk (Rennie et al, 2016).

The overall aim of this thesis was to objectively examine the relative hardness of the natural turf pitches within elite association football. It will broadly address the hardness of natural turf and how this impacts perceptions, performance and injury risk within elite professional football. It will also tackle the methodological limitations of previous research objectifying pitch hardness to develop a practical, reliable protocol for testing pitch hardness within football. The thesis aimed to significantly add to the literature providing a better understanding of natural turf pitch hardness and how this can contribute to injury or performance within elite football.

1.1 Objectives

1. To explore perceptions of key stakeholders within professional football about the hardness of the natural turf pitch, how it could be considered a potential injury risk, and how it affects both the performance of the player and the ball.

2. To develop a practical methodological approach to objectively test pitch hardness.

3. To prospectively examine the relative hardness of new hybrid natural turf pitches used within elite football.

4. To examine relationships between prospectively collected injuries and objective pitch hardness.

5. To evaluate the acute influence of pitch hardness variation on player load and performance.

CHAPTER 2

LITERATURE REVIEW:

Can the natural turf pitch

be considered an injury risk factor for injury

within elite football?

2.0 Introduction

Football remains the highest participation sport in the United Kingdom (UK) with 8.2 million adults and 3.35 million children participating within 119,000 teams (Snow 2015). As one of the most popular sports using natural turf surfaces in the UK, 5% of the population participate in football at least twice a week (Sport England, 2017). Within the English Premier League, costs incurred as a result of absence through injury showed a 21% increase from the £176.7 million seen over the 2016-17 season. This equates to every club in the premier league, losing an average of £440,000 in wages to injury, per player over the season (Fraser, 2017). This chapter considers one extrinsic risk factor which may contribute to such injuries and one to which all players are exposed, namely the pitch on which the game is played. Historically, grass pitches have been the playing surface in football for both training and matches. Quality standards have been published for the management of natural turf football pitches within England to enhance pitch safety and performance (Bell and Holmes 1988, Canaway et al 1990, Baker and Canaway, 1993, Baker et al 2007, UEFA, 2018). Despite recognition that the natural turf pitch can be a factor for injury (Adkison et al 1974, Alles et al 1979, Keene et al 1980, Stevenson and Anderson 1981) there has been little in the way of scientific evaluation of its risk value to the players. The subsequent sections of this literature review aim to outline the historical development of natural turf pitches within elite football, discuss and critique the available means for testing the hardness of such natural turf, establish the current level of evidence linking natural turf with injury and discuss methodological concerns associated with research into pitch hardness. It summarises by proposing a conceptual model of pitch hardness and injury risk within football that will provide a framework to guide future research and the direction of this thesis.

2.1 Historical development of the natural turf pitch within association football.

Natural turf sports pitches are used globally as a surface for team sports such as football (soccer). The administration of these surfaces is limited by the financial and management resources available to each club, with the aim of surface provision arguably determined by these components. Below the elite level, where resources are often limited, the principal aim of pitch management is to provide a hard wearing (durable) surface that maximises a player's enjoyment of the game, but minimises the risk of injury (Baker and Canaway, 1993). The focus of this thesis is on the relative hardness of such natural turf pitches. Surface hardness has been defined as 'the ability of the surface to absorb the impact energy created by any object striking that surface' (Rogers, 1988). Hardness is known to affect both the bounce and roll of the ball as well as the perceptions of those exposed to such surfaces (Ronkainen 2012, Roberts et al 2014).

At the elite level, income and expenditure in football is substantial. The English Premier League was the runaway market leader in comparison to other European leagues over the 2017-18 season, with a record revenue £4.5 billion; players' wages increased 9% on the previous year to a total of £2.5 billion (Deloitte, 2018). The marketing of the Premier League has developed a world-wide audience, and the clubs which comprise it are actively encouraged to invest in the brand. As such, over £395 million was invested over the 2017-18 season by Premier League clubs in their stadia, with only five clubs investing less than £1 million, indicating commitment to improving stadia and match day experience (Deloitte, 2018). Whilst management of the pitch is not a priority in comparison to players' wages, the surface needs to withstand high intensity use whilst maintaining the aesthetic requirements that TV coverage demands; as a judgement on the quality of the surface is often based on appearance (Adams and Gibbs, 1994, James 2011). However, the aim of pitch management is not to simply produce a pitch that is attractive; the pitch must support play through a UK winter, characterised by cold and wet weather, while simultaneously supporting grass growth and enabling damaged grass to recover. A poor quality pitch is not only damaging to the reputation of the Groundsmen in charge, it could harm the brand of the Premier League, but most pertinently could be the cause of injuries to players (Jennings-Temple, 2005). Injury rates in football have been cited as three times higher than those in defined high-risk occupations demonstrating the risk that participation brings (Hawkins and Fuller, 1999), the natural turf pitch is the workplace for those involved in the elite game and as such provides a unique setting for health and safety management in the workplace. The Health and Safety at Work Act of 1974 (HMSO, 1974) requires employers to control as far as is reasonably practicable, risks to the health, safety, and welfare of employees. Provision for such legislation is difficult within football, as every player reacts uniquely to the surface based on their intrinsic risks factors and past experiences. Furthermore, the pitch quality standards for performance of natural turf sports pitches are recommendations, and as such, are not enforceable, whilst the determination of whether the pitch is fit to play remains the decision of the match referee.

The nature and properties of natural turf are fundamental to the playing characteristics of soccer. Unlike other sports such as cricket, where temporal and spatial variation may be desirable, in football such temporal and spatial variation is undesirable, and as a consequence, has seen an increasing use of sand based materials to construct surfaces (James, 2011). However, the demand for hard wearing surfaces that do not increase injury risk has resulted in a significant change in mechanical properties, in particular increased stiffness and shear strength (Caple, 2011). Thus, over the past 30 years there has been a significant change in the development and maintenance of natural turf football pitches. New natural turf meets the requirements of the players for faster, higher traction surfaces, reflecting the increased fitness, strength and speed and more advanced technique developed over the same time period. With increased surface stiffness, player energy cost is reduced. Furthermore, increased uniformity of surface quality allows improved technique development as ball/equipment behaviour becomes more predictable (Stiles et al 2009).

The construction profile of natural turf football pitches can have many variations. The grass plant within elite football is generally cut to between 25-28mm, the roots of which are the primary stabilisers surface (UEFA, 2018). However, it is the medium in which the grass grows, also known as 'root zone', which dictates the mechanical properties of the soil. As such, the native soil pitches of the past, or those used within the amateur game are often clay-rich and exhibit poor mechanical properties. For example, in winter their poor drainage reduces the stability of the surface and they are at risk of water-logging, whilst in summer they can become extremely hard. These traits affect the performance of the players, the ball and detract from the spectacle of the game as a whole (James et al, 2010, James et al 2011, Stiles et al 2009).

To improve pitch playability and durability, higher sand content constructions (>90%) have been introduced at the elite level. The sand root zones aid drainage but they inherently lack cohesive properties which necessitates their reinforcement to ensure stability of the root zone is maintained (Spring and Baker 2006, James et al, 2010, Anderson et al 2018). The reinforcement of the sand growing medium has led to the development of 'Hybrid natural turf pitches', which are more wear resistant than native soils pitches. It has been estimated that a clay based pitch with its poor drainage capacity can support less than 50 exposures per season, whereas those with sand root zones are considered able to withstand 180 exposures (Baker et al 1992).

Many differing materials from shredded carpets, to shredded running shoes have been utilized in an attempt to reinforce sand root zones (McNitt and Landschoot, 2003). Whilst many have led to an improvement in the playing surface quality through greater surface stability, many have led to significant increases in surface hardness (Baker, 1997, McNitt and Landschoot, 2003). This was a concern for some researchers who reported harder surfaces were a danger to athletes (Rogers and Waddington, 1990).

Figure 2.1 Illustrating the sand rootzone of a fibre sand pitch.

Currently, favored sand root zone reinforcement generally follow two options: firstly, thin polypropylene fibres, 35mm in length are mixed into the sand before being laid and over seeded (Fibre-sand or Fibrelastic, see Figure 2.1). Secondly, where the turf is reinforced directly, such as the Desso Grassmaster system, which injects or 'stitches' synthetic turf fibres 200mm into the natural turf root zone to reinforce the turf (see Figure 2.2).

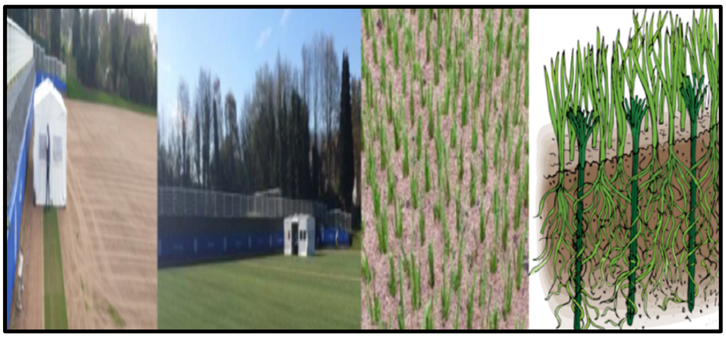


Figure 2.2 Installation of a Desso Grassmaster pitch, supported with schematic image taken from Thomson and Rennie 2016.

In additon to rootzone reinforcement, the modern natural turf pitches require significant investment to ensure their surface quality remains throughout the football season. A number of technological advances have increased the quality and durability of natural turf surfaces including: drainage, irrigation, agrochemicals, turfgrass breeding, turf reinforcement, supplementary lighting, ventilation and advanced stadium architecture (see Figure 2.3). The modern stadium natural turf pitch can be considered the sports surface equivalent of hydroponics, whereby growth of the grass plant is supported in a sub-optimal soil for plant growth by supplementary irrigation, fertilizer and lighting (James et al, 2010, Thomson and Rennie 2016).

Figure 2.3 Advancing technology such as pop up irrigation sprinklers and artificial growing light ensure year round growth of the natural turf pitch.

2.2 Testing natural turf pitches for their relative hardness

To ensure the quality of natural turf pitches over such a transitional period, researchers have utilized objective tests to promote and measure pitch quality. Whilst objective means for testing natural turf pitches have been developed (Clegg Hammer, Penetrometer and the Berlin/Stuttgart Athletes) and standards for recommended levels of hardness have been proposed (UEFA 2018); these have remained only recommendations and are not enforced in the same way as those for the artificial pitches (Stiles et al 2009). Consequently, no links between objective tests of hardness and the injury potential of a surface have thus far been made (Rennie et al., 2016).

Early researchers utilised subjective measures, such as ‘degrees of squelchiness’ (Thornton 1973) or the heel test to assess surface resilience or hardness. Inter-tester reliability was problematic and rating hardness along a ten-point scale, where a score of seven was indicative of a surface appropriate for football, was difficult and prone to error (van Wijk, 1980). In order to determine the contribution of pitch hardness to the risk of injury within football, the integration of reliable and objective means for measuring ground hardness was therefore required. Since the 1980’s, research into football pitch construction has focused on delivering set quality standards to ensure a playing surface that is both hard wearing and cost effective (Holmes and Bell, 1986, Baker & Issac 1987, Baker & Cannaway 1991, Baker et al 2007, Stiles et al 2009). The pitch standards must also simultaneously provide a platform for the enjoyment of players and spectators alike, on which the risk of injury is minimised (Baker and Canaway, 1993).

Originally designed to measure road compaction, the Clegg Hammer (Clegg, 1976) became a pragmatic means of assessing the hardness of any given football pitch (Bell and Holmes 1988, Baker and Cannaway 1993, Baker and Wheater 2007). Initially researchers favoured the use of the 0.5kg Clegg hammer, but this gave way to the heavier 2.25kg hammer when research discovered the reliability of the 0.5kg hammer was affected by the amount of grass coverage and cut height (McNitt & Landschoot, 2004; Miller, 2004). It is easy to use, provides reliable objective readings and does not adversely affect the pitch surface prohibiting its use prior to training or matches (Twomey et al., 2011). Furthermore, it has been shown to relate well to the players’ perceptions of hardness (Canaway, 1994).

The relationship between pitch or surface hardness (as measured using the Clegg hammer) and the soil moisture content at the time of the test, has only been considered in a few studies. Generally, hardness decreased as moisture content increased, although Baker and Isaac (1987) argued that this was more pronounced in root zone mixtures containing native soil. Sand based root zones did not exhibit such a marked decline in hardness through the playing season (Holmes and Bell 1986, Bell and Holmes 1988, Baker 1989, McNitt et al 2004). When one considers pitch hardness in relation to pitch construction, evidence is somewhat mixed. In that sense, Holmes and Bell (1986) demonstrated that sand root zone pitches gave almost identical hardness readings to native soil pitches; however, the native soil exhibited greater variability across the pitch. A more recent study by Caple et al (2012) demonstrated differences were evident particularly over the winter with native soil being significantly softer than sand root zone pitches. Whilst the Clegg hammer is the most frequently used objective measure of hardness, unfortunately the protocol for its use is unclear, making comparisons between studies difficult. How many consecutive drops and indeed the pattern of drops over the pitch required to establish a true representation of pitch hardness are not agreed upon within the literature (Stiles et al 2009).

Whilst perhaps intuitive, linking the relative pitch hardness obtained from devices such as the Clegg Hammer with injury risk has not been accepted by all researchers. Nigg and Yeadon (1987) stated that such impact tests are in essence material tests, and should not be used to predict the potential of a surface to cause an injury. A comparison of the Clegg hammer with the ground reaction forces experienced by humans on a force plate, researchers discovered that only low correlations (r=0.2) were evident, concluding that discriminating surface hardness was not reflective of the loads experienced on the human (Saunders et al, 2011). Consequently, larger, more robust and often more expensive equipment was designed to address such issues. The Stuttgart Artificial Athlete which later developed into the Berlin Artificial Athlete, and even penetrometers (Orchard, 2001) have been used to test pitches. Devices such as the artificial athletes have rarely been used on natural turf due to prohibitive costs and the large surface deformations that can be produced on testing. Some authors question whether even the most expensive tools can add clarity to the load/hardness debate, especially when one considers that the human body is almost intuitive in its lower limb adaptation to surface hardness (Ford, 2013). Young and Fleming (2007) summarised testing of natural turf pitches. They concluded that whilst testing with devices such as the Clegg hammer may not simulate player loading well, they are a useful way of indexing the hardness of such surfaces, and as such, the Clegg hammer could be a useful monitoring tool for such surfaces.

Within elite level professional football, the hardness of the natural turf pitch has been benchmarked using the Clegg Hammer (UEFA, 2018). Consequently, a professional natural turf pitch should fall between 70-90G, with acceptable limits between 60-100G, and anything above 100G or below 60G being deemed unacceptable (UEFA, 2018). Such extremes of pitch hardness lead to less favourable ball surface interaction and or increased risk of injury (Twomey et al 2014, Stiles et al 2015). However, despite the availability of such objective measures and guidelines, no scientific papers have utilised the device to quantify pitch hardness and relate this to the problem injuries within professional football (Rennie et al, 2016). One explanation may be found in the methodological approach that has been used by researchers to assess pitch hardness (Petrass and Twomey, 2013). Uniformity in the testing protocols adopted, drop heights and hammer weights makes comparison of data between studies difficult. Such methodological uncertainty does not provide the necessary rigor, for meaningful questions to be asked regarding natural turf hardness and how it affects injury and performance.

2.3 Current evidence that natural turf pitches affect injury incidence within association football.

An extensive review across all football codes reports that links between ground conditions and injury were mostly intuitive. From the available research papers (N=79) only five studies objectively measured pitches, with none reporting strong associations between pitch hardness and an increased risk of injury (Petrass & Twomey, 2013). The majority of studies have instead adopted subjective means of pitch assessment, were poorly standardised and lacking sufficient definition. This makes it difficult to draw firm conclusions regarding the relationship between pitch hardness and injury (Twomey et al 2014).

The paucity of research specifically related to association football is apparent as three studies were reported within this sport (Petrass and Twomey, 2013). All of the available data used subjective assessments of pitch conditions reporting associations of 24% (Ekstrand and Gillquist, 1983) and 21% (Chomiak et al, 2000) between pitches and injury.

It is unclear whether subjective measures provide a true reflection of pitch hardness and linking them to injury is difficult. Twomey et al (2014) showed only 50-60% concordance between subjective and objective assessment of pitch hardness. The failure to denote a more comprehensive relationship between these approaches makes it questionable if subjective assessment is sufficiently robust to establish links between injury and pitch hardness, which represents a major limitation in the available data sets within the academic literature.

Within football, objective measures of pitch hardness derived from devices such as the Clegg hammer (Bell and Holmes 1988, Baker and Canaway, 1993, Baker et al 2007) have been reported, but no studies have linked the values to the incidence of injuries. Other sports have used equipment such as the Clegg Hammer (Twomey et al 2011, Twomey et al 2012, Twomey et al 2014), or the Penetrometer (Twomey et al 2011, Orchard, 2001) to gain objective measurements of hardness; though a lack of consistency with respect to the equipment and protocols used impacts on transferability and applicability (Twomey et al 2011). Consequently, the available research may not have; (a) effectively determined a true representation of the pitch hardness, or (b) evaluated how this variable may directly influence the risk of injury. Therefore, there seems to be little available research that effectively and directly investigates the impact of pitch surface on injury in elite football. This would seem to be an important omission for both our theoretical understanding of injury mechanisms and practical approaches to injury prevention for those involved in the day-to-day interactions with elite players in the industry. Indirect evidence that pitch hardness may adversely affect injury has been drawn from research that (a) compares injury incidence between artificial and natural turf pitches; (b) proposes a seasonal bias for injuries; or (c) critically interprets how the pitch may impact factors that can lead to injury such as biomechanical load, speed of the game and player movement.

2.3.1 Pitch hardness: Injury incidence on artificial versus natural turf

The majority of research in football relating pitches to injury focuses on comparative studies outlining the incidence of injury on artificial or natural grass surfaces (Adkison et al 1974, Alles et al 1979, Keene et al 1980, Stevenson and Anderson 1981, Williams et al 2011). First Generation artificial turf pitches in the 1970's with their short nylon fibres were reported as being hard (Dragoo and Braun, 2010, Geyer et al 2003). This made the playing characteristics different from natural grass pitches with many studies reporting a significant increase in the incidence of injuries, particularly abrasions and sprains (Adkison et al 1974, Alles et al 1979, Keene et al 1980, Stevenson and Anderson 1981). The artificial pitches of today are more representative of their grass counterparts with longer fibres and rubber granular infill promoting more acceptable levels of hardness (Williams et al 2011). Such are the improvements in artificial surfaces that many studies report no significant differences in injury incidence between them and the natural turf pitch (Williams et al 2011, Dragoo and Braun, 2010, Geyer et al 2003, Soligard et al 2010). Nevertheless, evidence remains indicating persistent differences between injuries sustained on the two different surfaces (Ekstrand et al 2006, Fuller et al 2007, Fuller et al 2007, Kristenson et al 2013, Almutawa et al 2014).

To date, no studies reported what characteristics of the playing surface were directly attributable for the injury rates witnessed, nor did they objectively scrutinise the pitches. This suggests an inherent assumption amongst some researchers that pitches remain constant over time. This however is not the case, as even artificial pitches demonstrate large degrees of temporal and spatial variation (Forrester and Tsui, 2014). Natural turf pitches are living things and will exhibit greater temporal and spatial variation than their artificial counterparts. Research using 'natural turf' as an undefined variable in injury studies may mask the variation within and among such surfaces. This observation could be highly significant in investigations of this nature (Stiles et al 2009).

2.3.2 Seasonal bias, pitch hardness and injuries

In England, one of the largest epidemiological studies in football reported evidence for an early season bias for injury. The study reported peaks in training injuries in July, while match injuries seemed to be at their highest in August (Hawkins and Fuller 1999). Surface dryness (hardness) over the pre-season period was associated with 70% of injuries, a value which fell to 51% during the season. Wet or muddy pitches were recorded in 40% of all in season injuries, whereas they were only noted in 8% of those injuries sustained in pre-season. These findings were supported by the results from the UEFA Champions League study which prospectively tracked injury data from 27 top clubs, across ten European countries between 2001 and 2012 (Ekstrand et al 2013). This longitudinal approach corroborating the findings of Hawkins and Fuller (1999) highlights the apparent robustness of an increase in injury during the early season period when pitches are frequently reported as being harder (Walden et al 2005, Ekstrand et al 2011).

Such relationships are also noted in the Australian Football League (AFL) where the prevailing climatic conditions in the northern territories of Australia lead to drier, harder pitches. These conditions were associated with a 2.8-fold increase in rates of Anterior Cruciate Ligament (ACL) injuries than the softer wetter pitches of the southern regions (Orchard et al 1999). Variable climatic conditions were also highlighted in the Champions League study (Walden et al 2013), where geographically regionalised injury differences were reported. This may suggest that the prevailing climatic conditions of varied countries and therefore their pitch conditions (hard or soft) may influence the injury rates recorded. However, unlike the AFL study (Orchard et al 1999), the Champions League study did not evaluate the pitch conditions at time of injury (Walden et al 2013). In that sense, some caution must be exercised when attempting to make causal attributions regarding seasonal bias for injury and pitch hardness. Reduced early seasonal fitness levels, changes in footwear and the high exposure to training loads over the pre-season period may also contribute to the increased risk of injury (Woods et al 2002). Consequently, reduction in injury rates over the season may be more attributable to the physiological adaptations associated with match/training exposure than any change in pitch hardness accountable to seasonal change.

Thus far, researchers have attempted to establish direct links between injury risk, and pitch hardness, through subjective reporting of pitch conditions. The failure to match objective pitch hardness measurements with the precise injury location on the pitch makes conclusions somewhat erroneous (Petrass and Twomey 2013). Adopting a more integrated approach, incorporating an engineering and biomechanical analysis of natural turf and its effect on human movement, may promote better understanding of the processes by which the pitch may underpin injury within football (Stiles et al 2009).

2.3.3 Pitch hardness and Biomechanics.

As objective information on pitch hardness within the literature is sparse, it may be prudent to examine laboratory based studies that have collected biomechanical data investigating the effect that the surface has on the individual. This data may support inferences linking pitch hardness and injury. Any surface on which a player runs will affect them kinetically, through the forces to which they are exposed and kinematically, in the way they adapt their movement to accommodate such forces. Consequently, an understanding of how the body adapts to such loading may provide the cornerstone of any rationale as to how the pitch may influence injury within football. Few biomechanical studies have been performed using a natural grass surface. The tools required for such objective testing are considered difficult to apply within a field based setting as complicating extraneous variables negatively impacting the objective data recorded. Some researchers have, however, attempted to analyse the effect of different natural turf constructions and hardness, on kinetic data within the laboratory setting (Stiles et al 2011, Smith et al 2004, Kaila 2007, Geyer et al 2003). These researchers cultivated grass within trays which were used to form a runway overlaying a force platform permitting ground reaction force data to be obtained. Such research suggests that significant differences are evident in rates of loading between different experimental turf hardness conditions. Ground reaction forces in both running and turning movements were noted as being surface dependent. More specifically, harder surfaces resulted in increased loading values when compared to softer counterparts (Stiles et al 2011). This data is however limited in its ability to generalize insights into injury mechanisms and/or injury risk in elite players, due to small subject numbers (n=8), the population used (university students) and the speed at which the trials were executed (3.83m/sec). These speeds are substantially slower than those observed in games (5.5m/sec - 6.9m/s = high speed run and over 7 m/s = sprint). Despite its limitations, such research suggests that the surface hardness of natural turf may affect the loads and movement adopted by the players. An examination of the literature surrounding 'running gait' corroborates this, highlighting that runners adjust the stiffness of their leg to accommodate the surface stiffness beneath their foot (Geyer et al., 2003). Additionally, whilst running, the individual will co-ordinate the actions of many muscles, tendons and ligaments so that the leg behaves like a single mechanical spring during the ground contact (Ferris et al 1999, Hardin et al 2004). Ferris (1999) concluded that such adaptation to the relative surface compliance is regulated within the first step on the surface. Runners show a decreased leg stiffness of 29% between the last step on a soft surface and the first step on the hard surface. The ability to change leg stiffness quickly allows the individual to maintain dynamic stability when running on varied and unpredictable terrain. This is pertinent within football as pitch construction varies resulting in non-uniform surface hardness with respect to the prevailing climatic conditions. Consequently, there is marked variability between pitches and within the same pitch. The ability of players to adapt quickly to changes in hardness is therefore an asset, but may incur a cost, namely increased energy expenditure, which in turn may predispose players to fatigue (Geyer et al 2003, Ferris et al 1999, Hardin et al 2004). Within amateur football, players' running speeds and the metabolic energy costs were studied on natural grass, artificial surface or asphalted track (Sassi et al 2011). No differences were found in running speed for the players', however a significant main effect for surface was noted, with the natural and artificial turf being of similar compliance resulting in similar levels of energy expenditure. However, the use of amateur players and running speeds between 2.72 and 3.33m/s may not be reflective of elite players as higher running speeds result in higher energy costs (Pinnington and Dawson 2001). Increases in surface dependent energy expenditure singularly may not appear significant however, utilising Meeuwisse's et al (2007) model of injury risk and once considered collectively over a football-season, the cumulative effects may predispose the player to fatigue/overload induced injuries. The relative hardness or softness of the pitch therefore determines how hard the players have to work during any given match or training session. The players still achieve the requirements of the task, namely to complete the match or training session, but the energy required to do so may be enough to make them susceptible to injury in the near future (Geyer et al 2003, Ferris et al 1999, Hardin et al 2004).

2.3.4 Pitch hardness affects game speed and injury

As research and development into artificial pitches has progressed, so too have developments and innovation associated with grass surfaces. Such developments may have been an attempt to answer user requirements for faster, harder, higher traction pitches. They may also be attributable to media/spectator expectations for a more consistent playing surface. Such surfaces provide the platform upon which the modern player can exploit their strength, power, and speed (Stiles et al 2009). Research by

Norton et al (2001) offers a link between pitch hardness and its effect on the game and the individual. They examined the effect of pitch hardness on the speed of the game, concluding that pitch hardness was significantly correlated with game speed within the AFL. They noted hard pitches witnessed faster play, more scoring shots and significantly longer stoppages in play than games played on softer pitches. Collision rates were also increased which coupled with the increased mean player speed led to a higher incidence of injuries on the harder surfaces. If indeed harder pitches promote quicker speeds, players may spend a greater proportion of any game within high intensity or sprint zones, which may have a twofold effect on the player. Firstly, they may experience higher levels of fatigue and thereby increase their likelihood of becoming injured in the later stages of games. Secondly, exposing the players to excessive or prolonged loading at such speeds may overload the musculoskeletal system, increasing their susceptibility to potential injury (Gregson et al., 2010). Unfortunately, as there have been no studies in football regarding the hardness of pitches and their effect on match speed or fatigue, any assumptions are purely hypothetical, but warrant research in the future.

2.4 Pitch Hardness: Methodological concerns

Undoubtedly, methodological issues are important factors that impact the quality of the evidence available. Knowledge of the mechanisms by which the pitch may affect injury rates is limited by our current understanding of the pitch, exposure rates of players, the loading experienced by players and by the means for reporting and recording mechanism for injuries. Evidence supporting the pitch's involvement in injury within football thus far, lies within epidemiological studies from which, one can draw no direct link to the proposed models of injury risk.

Currently, the evidence that natural turf pitches can be viewed as a risk factor for injury in Association Football is constrained by the subjective methodology adopted. A major limitation is that pitch conditions are open to interpretation and are likely to be an amalgam of a number of variables such as hardness, traction, grass cover and moisture (Twomey et al., 2012). The subjective nature of classifications such as wet/soft or dry/hard lack detailed descriptions of whether this truly reflects the entire surface or the area in which the injury occurred. Furthermore, the use of retrospective recall and the absence of reported reliability for both the subjective tests used and of the assessors performing them, makes their reported findings questionable and generalisation difficult. Unquestionably, technical difficulties are evident when it comes to testing pitch hardness. Equipment costs, portability, reliability, validity and availability are all potential obstacles. Nevertheless, to evaluate such surfaces and investigate their role within football injuries, researchers will need to adopt, develop and improve objective measures to evaluate the surface. These must then be incorporated into longitudinal studies and compared prospectively with incidence of injury data collated in line with universally agreed definitions of injury and corroborated with time exposure data (Plaza-Carmona et al., 2014).

A further confounding methodological reason why the literature does not support an associated rise in injury with increased pitch hardness may be found in the theory of 'modifiable risk', which sees individual players modify their behaviour in accordance with the demands of the situation or their past experiences (McIntosh, 2005). Such behaviour modification was reported in a comparative study of Swedish elite footballers during competitive games on artificial turf and grass (Bloomfield et al 2007). No differences were observed between players on artificial turf and natural grass in terms of total distance covered, high intensity running, number of sprints, standing tackles or headers per game. However, there were statistically significant fewer sliding tackles on artificial turf than grass. This may be indicative of modifiable risk on the part of the players. Additionally, behaviour modification was noted in the passing strategies adopted, with more short and midfield-to-midfield passes on the artificial turf than grass. The players' perception was also affected by the surface with the male players reporting a negative overall impression, poorer ball control, and greater physical effort on the artificial turf. This behaviour modification may in part account for the stability in injury incidence within professional soccer when surfaces are compared. It is possible the player self regulates their activity or behaviour on any given pitch so as to minimise their risk of injury. Such behaviour modification may therefore make any interpretation of pitch hardness or injury incidence data and research difficult.

Perhaps researchers in the applied setting need to take a more pragmatic approach which provides reliable, objective data about the pitch without adversely affecting the playing surface. This will allow testing to be performed close enough to the match or training session to allow inference to be drawn at the appropriate time to both exposure and injury surveillance data. This would enable a more accurate real time reflection of the interaction of pitches and their effect on the player and their risk of injury.

2.5 A conceptual framework for the natural turf pitch and its influence on risk of injury.

To conceptualise a model for the football pitch and how it may influence injury necessitates recognition of methodological limitations within available research, coupled with an awareness of the factors affecting human locomotion. Thus far, research has focused on the pitch as a primary risk factor where exposure results in injury. Clearly this is limited, as not all players who encountered the surface on that day were injured. Perhaps researchers need to consider the dynamic, recursive nature of player-pitch interaction investigating how single and cumulative exposures to varied hardness's of pitches affect injury risk. Such an approach supports a conceptual model founded upon the work of Meeuwisse (2007).

Analysis of player movement patterns has enabled researchers to determine the physiological demands of such movement (Bloomfield et al 2007, Iaia et al 2009, Gregson et al 2010). Consequently, football can be viewed as an intermittent sport punctuated by bouts of repeated high intensity exercise (Gregson et al 2010). Players continually change direction and speed, adopting unorthodox movement patterns enabling them to execute the technical skills required to outperform their opponents (Bloomfield et al 2007, Gregson et al 2010). Such movement profiles may affect the energy expenditure, musculo-skeletal load, fatigue and injuries seen in professional football. Additionally, as surface compliance is known to affect both energy expenditure (Geyer et al 2003, Ferris et al 1991, Hardin et al 2004, Pinnington and Dawson 2001, Sassi et al 2011, Plaza-Carmona et al 2014) and musculo-skeletal load (Stiles et al 2011), one may consider the impact of the natural turf pitch conditions on such physiological demands. The relative hardness of any natural turf pitch being transient and affected by extraneous variables such as the weather, will change throughout the season, thereby altering the demands of any given pitch-player interaction.

The conceptual model in Figure 2.5 addresses the extrinsic risk that pitch hardness may play within football injuries. It highlights how interactions between the player and the pitch can alter the 'intrinsic' make-up of the player, subsequently affecting how susceptible the player is to future injury. To aid understanding of the proposed model, a number of examples of how the natural turf pitch could affect physiological demands, and thereby the potential for injury are highlighted below.

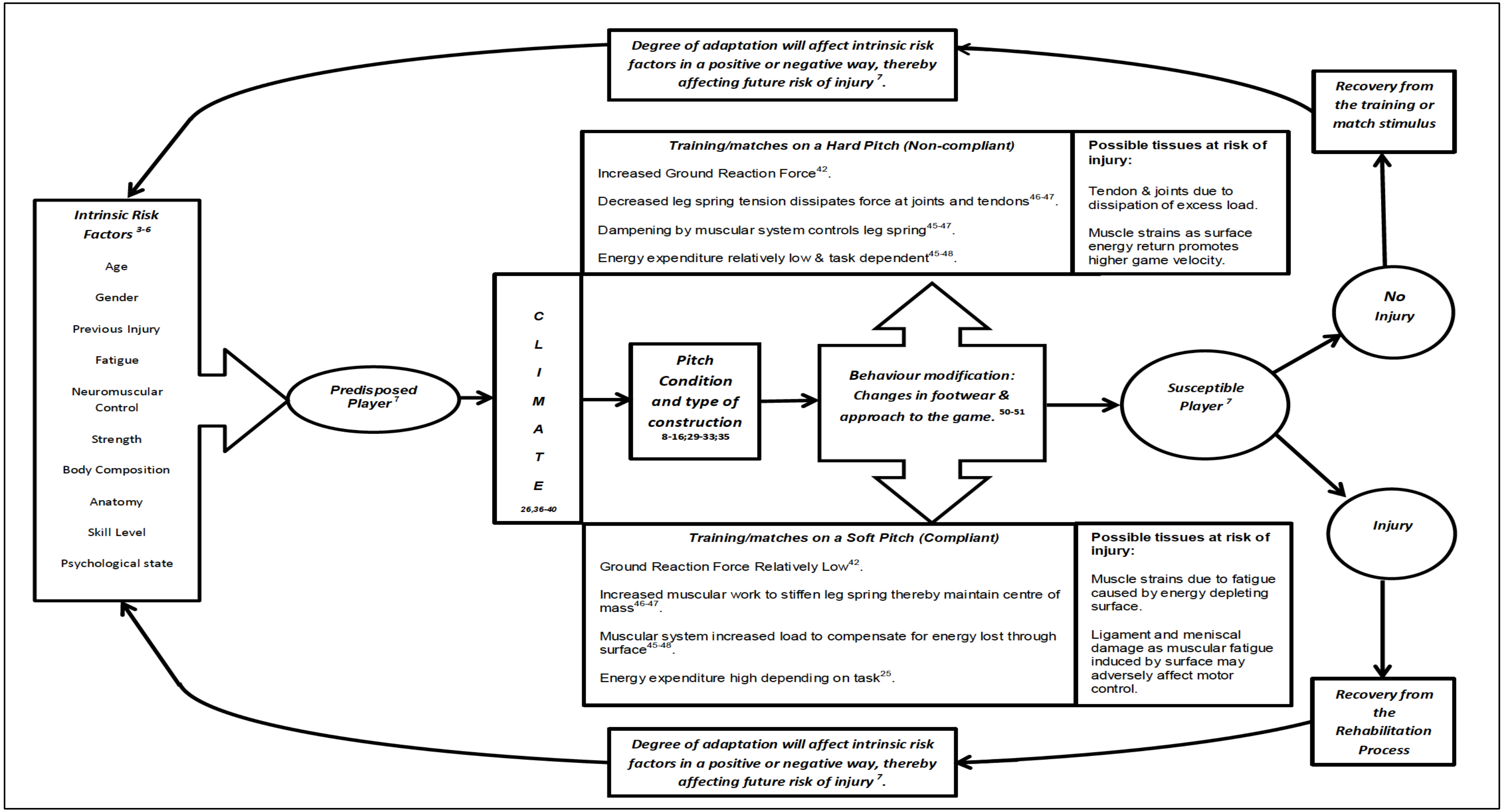


Figure 2.4 A conceptual framework for the natural turf pitch and how it may influence a footballer's risk of injury (Rennie et al 2016).

For any given task, an appropriate degree of muscle contraction is required to achieve the desired displacements and velocities of the body on the pitch (Ferris et al 1998). Additionally, the player's muscles must; (1) generate additional force to compensate for the inevitable energy dissipated through surface compliance, (2) modify the required force according to the level of strain development in the tendons, and (3) minimise the peak impact forces experienced by their joints during loading of the stance leg (Geyer et al 2003, Ferris et al 1998, Ferris et al 1999, Hardin et al 2004). Consequently, a player running on a compliant (soft) pitch expends more energy for any given running velocity when compared to running on a less compliant (hard) pitch in order to compensate for energy dissipated through the surface (Pinnington and Dawson 2001). Soft pitches negatively affect the ability of the muscles to utilise the elastic properties of their tendons leading to an over dependence on the muscles to maintain performance leading to fatigue. This has been confirmed through demonstration of a negative relationship between surface compliance, oxygen consumption and muscle performance testing on real sports surfaces. (Katkat et al 2009). Testing elite basketball players vertical jumping and leg strength on artificial and natural turf demonstrated as compliance increased performance decreased (Katkat et al 2009). However, compliance testing with medicine ball drop may not be truly reflective of the surfaces tested. Nevertheless, it was apparent the muscles needed to work harder due to the energy depleting nature of the surface. Therefore, considered in isolation, playing on more compliant surfaces may induce localised muscle fatigue. Over a more cumulative time frame the additional muscular effort may cause an increased risk of muscle strains. Conversely, the player running on a hard pitch will experience increased loading through joints and tendons due to increases in impact forces (Stiles et al 2011, Smith et al 2004, Kaila 2007, Geyer et al 2003). The musculoskeletal system 'dampens' this by reducing leg stiffness, effectively cushioning each step. In the short term, these excessive ground reaction forces may be dissipated through the aforementioned spring system (Geyer et al 2003, Ferris et al 1991, Hardin et al 2004, Ferris et al 1998), though the efficacy of this would decrease the more fatigued the players became. Consequently, the pitch can affect the musculoskeletal system of players in both an acute and chronic manner. Previous injury, repetitive impacts or insufficient adaptation/recovery between exposures would reduce the load required to initiate tissue breakdown and resulting injury.

This proposed model suggests the pitch can play a significant factor in the physiological and biomechanical demands of any given task. Thus, the relative hardness or softness of a pitch may influence the loads and fatigue experienced by the musculo-skeletal system (Smith et al 2004, Kaila 2007, Katkat et al 2009). Failure to provide players with sufficient time for musculoskeletal adaption following pitch exposure could increase their risk of injury. This could be acute, causing immediate injury, or through repeated exposure result in more chronic overuse injury (Meeuwisse et al 2007) (Figure. 2.4).

2.6 Summary

The literature regarding natural grass pitches and injury within football has largely been unable to confirm the contention that the pitch hardness can be considered a significant extrinsic risk factor in injury. The adoption of comparative studies, where the natural turf pitch is compared with its artificial counterpart, has limited research into the effects of the grass surface and its influence on injury. Such research masks the variation within and among such natural turf surfaces. Anecdotal evidence for the effects that grass football pitches have on injury has been reported (Hawkins et al,1999, Woods et al 2002) but no studies have included objective measurement. Although biomechanical analysis of natural turf is difficult, there are trends suggesting researchers are realising the importance of such work and commencing studies to address the need for such data (Stiles et al 2011). Perhaps most pertinently, the literature outlines a negative relationship between surface compliance and energy expenditure (Pinnington and Dawson 2001, Sassi et al 2011) suggesting that the pitch affects the physiological demands of any given training session or match. This may be one link in the chain between pitch hardness and the relative injury risk of each player. It is hoped with increased use of objective pitch testing, a better understanding of how the player and pitch interact will help us to understand how relative pitch hardness contributes to injury risk.

CHAPTER 3

Within elite football,

how does the relative hardness of natural turf

football pitches affect the key stakeholders'

perceptions of injury, performance and shared

accountability?

3.1 Introduction

Historically the natural turf pitch has been the platform for Association Football however, its susceptibility to both traffic (footfall) and prevailing climatic conditions (Baker et al 2007) has promoted the development and use of artificial pitches (Fuller et al, 2007). Perhaps driven by the increased use of artificial pitches, the media spotlight, demands of the fans, or those involved in the management of the game, the natural turf pitch has evolved over recent years to provide a platform which is more consistent and robust (Baker et al 2007, Caple et al 2012, Thomson and Rennie, 2016). This affords players the opportunity to perform to the maximum of their physical capability, and express themselves on a surface which permits performance and rewards skill (Stiles et al 2009). However, injury rates within football remain high with incidences reported between 1.5-7.6 (training) and 12-35 (match) injuries per 1000 hours exposure (Rahnama 2011, Lungo et al 2012). Furthermore, such injury rates appear resistant to change; a factor reflected by a longitudinal study of teams with the Champions League competition, where no significant reduction in injuries were witnessed over an eleven-year period (Ekstrand et al 2013). This has led many researchers attempting to quantify relative risk so as to attribute causality to either intrinsic or extrinsic factors. In their ‘dynamic model of injury etiology Meeuwisse et al (2007) concluded that intrinsic risk factors only become relevant once the player is exposed to the extrinsic environment of either training or matches. One extrinsic factor which all players are exposed to is the pitch upon which the game is played.

Quality standards have been published for the management of natural turf football pitches within England to enhance pitch safety and performance (Baker et al 2007) however, these are broader and not enforced in the same manner as those for the artificial surface (Mears et al 2018). Consequently, there is no minimum performance quality standard for a Premiership natural turf pitch, and as such, suitability of play is determined by the match officials (Bartlett et al 2009). Remarkably, despite recognition that the natural turf pitch could be a factor for injury, there has been little in the way of scientific evaluation of its risk to the players. To date, subjective or comparative studies reporting injury rates on artificial versus natural turf whilst interesting, promote a flawed research model conceptually, which has done little to inform the the scientific community and/or practitioners in the field. As such, the question remains; have such pitch improvements come at the cost of an ever increasing level of injury risk?

Pitches have been shown to affect both the individual, speed of the game and the performance of the team, not only the ball (Norton et al 2001). Recently, comparisons between artificial and natural turf pitches have reported player activity profiles (distance/intensity), injury prevalence and technical measures of performance were unaffected by surface type (Dragoo and Braun 2010, Soligard et al 2010, Williams et al 2011). Nevertheless, differences remain between artificial and natural turf pitches regarding accuracy and kinematics of shooting, site of injury, passing strategy, slide tackle frequency and the perception of fatigue (Ekstrand et al 2006, Fuller et al 2007, Anderson et al 2008, Kristenson et al 2013). Perhaps most importantly, perceptions of artificial pitches by their users are often negative (Ronkainen et al, 2012), which may in part, explain why the natural turf pitch remains the dominant surface of choice within

Association Football. However, what is not apparent within the literature is how the natural turf pitch and its susceptibility to change is itself perceived.

In an attempt to address this, Ronkainen et al (2012) examined players' perceptions regarding their exposure to football pitches, be they artificial or natural turf. Three main themes emerged; namely the surface condition, the player, and the ball interaction. However, no inferences were made regarding how such surface conditions such as relative hardness, traction, grass coverage or surface stability contributed to players' perceptions of injury risk, style of play, movement patterns or indeed ball interaction. Roberts et al (2014) used this work to develop a questionnaire examining perceptions of surface properties comparing natural and artificial football turf pitches. They concluded that players perceived artificial turf to be harder, faster and more abrasive, have less grip and thinner grass coverage than natural turf. Unfortunately, it was unknown whether such perceptual differences were viewed positively or negatively by the players and no links were established to the relative risk of injury. Studies by Poulos et al (2014) and latterly by Mears et al (2018) concluded that 90 and 91% respectively of players believed the type or condition of the playing surface could contribute to an increased risk of injury. Furthermore, Mears et al (2018) reported player's perceptions stating that natural turf often showed a wider variation of pitch conditions than artificial counterparts. Interestingly, both hard and soft natural turf pitches were found to be statistically significant predictors of muscle strains, which they suggested meant neither surface was suitable (Mears et al 2018). This lack of clarity regarding natural turf pitches within the literature necessitates more detailed investigation.

The primary stage of research into natural turf pitches and their implied role within injury and performance must focus upon the perceptions of the key users of the natural turf pitch. This provides a better understanding of questions to be answered, and the necessary robust methodology to investigate natural turf hardness injury and performance. Ronkainen et al (2012) stated data obtained from elite professional players should be viewed as 'information rich'. However, this research must extend beyond the players and include all key stakeholders, incorporating views of managers, coaches, physiotherapists, sports scientists and those taxed with the preparation of the surfaces, namely the groundstaff. Undoubtedly, this will provide a better understanding of where any potential conflicts or concerns lie. Once established, such perceptions may form a framework for prospective studies, utilising objective measurement techniques and accurate injury surveillance strategies to address the concerns of those using such pitches.

This is the first study to focus purely on the natural turf pitch, its relative hardness, and how the key stakeholders perceive that it is affected in relation to the likelihood of injury, their effect on the ball, the individual or their team. The chapter will be divided into two parts to aid the clarity of presentation. Part A will focus on the natural turf pitch, its relative hardness and how it is perceived to affect injury. The associated objectives were to (1) explore whether the pitch is perceived as a potential injury risk factor by those working in professional football, and (2) investigate if and how a hard or soft natural turf pitch is perceived to affect specific tissues and their likelihood of injury differently. Part B, explores the perceptions of key stakeholders that the relative hardness of the natural turf pitch can affect the performance of the ball, the individual and/or their team's approach to the game. Furthermore, it will examine who they perceive to be accountable and/or responsible for the pitches upon which the game is played.

3.2 Methodology

Professional football within England is spread across four divisions and encompasses some 92 teams. To gain a true reflection of the research question regarding natural turf pitches the perceptions of those who work, or play across all levels must be explored. Such a geographically dispersed sample necessitated a questionnaire based study which examined the opinions of key stakeholders within the professional game; namely players, managers, coaches, physiotherapists, sports scientists and groundstaff (Gratton and Jones 2010). Their perceptions of the natural turf pitch were explored in relation to surface hardness and how in their experience, it affected the likelihood of injury, the performance of the ball and how they approached any given game or training exposure using a questionnaire. This broad data participant profile hopefully moves some way to establishing a consensus regarding the perceptions of the natural turf pitch and its importance amongst key stakeholders in the sport (Gratton and Jones 2010).

3.2.1 Questionnaire Design

This study utilised a cross-sectional questionnaire designed to examine the perceptions of key stakeholders within English professional football clubs regarding natural turf pitches, their role in injury and the effects they may have upon performance (see Appendix 10.2 for sample questionnaire). The questionnaire was deductively developed in line with the previous works of Ronkainen et al (2012) and Roberts et al (2014) utilising their structured approach, conceptual framework and their reported findings. The underlying difference in this questionnaire in comparison to Ronkainen et al (2012) and Roberts et al (2014) was that it solely focused upon the natural turf pitch, rather than its artificial counterpart making this an original and novel research design. The appropriateness, validity and clarity of the questions created were optimised through a substantial pilot process. The group of individuals that took part in the pilot consisted of professional players from the Under 23 teams at three separate clubs. These individuals did not take any part in the actual survey itself. The pilot process helped refine the language used, replacing words like compliance with more recognisable terms such as soft. Furthermore, frequently missing data within the piloted returns, was attributed to questions where participants did not perceive the question to be relevant to them personally. As a result, a 6^{th} option was added to the Likert scale, that of 'not applicable' to address these concerns. With limited academic literature relating to natural turf pitches and their role in injury and performance, this group and the pilot process were fundamental in the review of the appropriateness of the questions selected.

The majority of data were ordinal in nature as it was collated through a 5 point Likert scale. This scale extended from 'strongly agree' through to 'strongly disagree'. The addition of a 6^{th} point was included for the participant if they felt the question/answer was not applicable or that it was not relevant to them specifically. The questionnaire was comprised of 18 questions that were sub-divided into five broad categories. The first section collected demographic information such as gender, age, ethnicity, occupation and number of years of experience. The second section explored general perceptions about natural turf pitches and whether they may be viewed as a risk factor in injury. The third section examined perceived differences between hard and soft pitches in relation to specific tissues and their prospect of injury as a result of exposure to such a surface, whilst the fourth focussed upon perceptions of pitch hardness and its effect on the ball, the individual or their team's performance. The final section examined the accountability/relationships between key stakeholders with that of the groundstaff.

3.2.2 Procedure

In order to administer the questionnaire, the Head Physiotherapists at all professional clubs, comprising the Premiership (n=20), Championship (n=24), and Football Leagues 1 (n=24) and 2 (n=24) were contacted via email to request their support. They were provided with a covering letter, participant information sheet explaining the study and a copy of the questionnaire (Appendix 10.2). Over the 2014-2016 seasons each Head Physiotherapist was requested to provide a copy of the questionnaire to their club's manager, coaches, physiotherapists, sports scientists and groundstaff working within the first team environment inviting them to participate. Additionally, players who had played at first team professional levels within the leagues in question were also invited to participate via the Head Physiotherapist at the club. Completion and return of the questionnaire was taken as consent for inclusion within the study with assurances given that all data would be fully anonymised. The study met the requirements, and was approved, by the local university ethics committee.

3.2.3 Participant Demographics

As evidenced in Appendix 10.2, a total of 419 questionnaires were completed and returned with the largest proportion comprising those completed by players, followed by physiotherapists, sports scientists, managers or coaches and finally the smallest occupational sub-group being the Groundstaff. Response rates for the players was based upon an average first-team squad of 25 players (92 Clubs; N=2300), whilst it is difficult to know the exact first-team staffing levels at all 92 clubs' elite clubs within England a safe estimate would be an average of three staff per position giving a total of 276 for each profession. This equates to an estimated return rate of Players 11%, Managers/Coaches 9.5%, Physiotherapists 29%, Sports Scientists 12% and Groundstaff 8%.

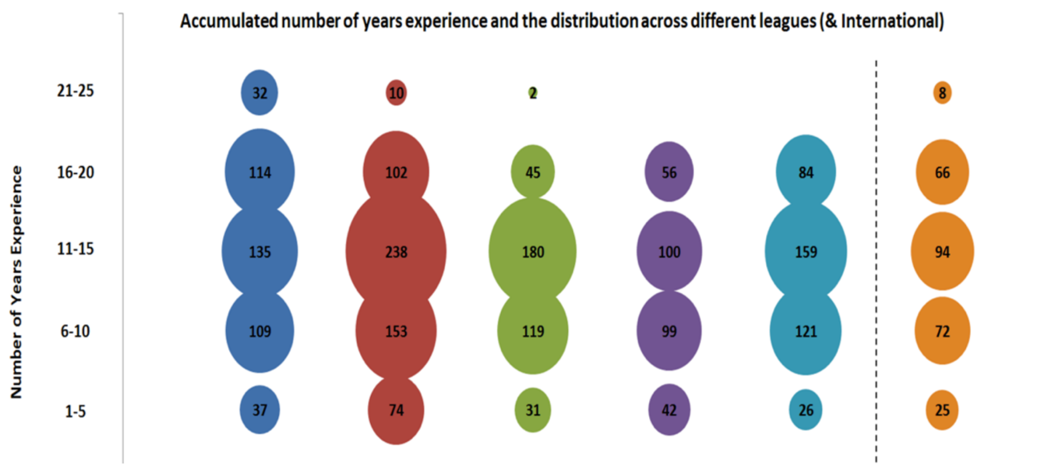
Tables 3.1-3.2, and Figure 3.1 illustrate the age and football experience of the sampled population. Generally, the players were a younger cohort than the other occupations in the study but varied widely regarding their age. Perhaps not surprisingly, managers or coaches were both the oldest (one was aged between 66 and 75 years) and showed the longest experience within the game (with nine having more than twenty-six years' experience). Figure 3.1 shows the experience of key stakeholders was spread evenly across all divisions.

Table 3.1: Occupational sub-groups shown through age categorisation.

Years of age	16-25 years	26-15 years	36-45 years	46-55 years	56-65 years	66-75 years	Total
Player	123	121	9	0	0	0	253
Manager or Coach	1	2	14	9	2	1	29
Physiotherapist	12	37	22	10	0	0	81
Sports scientist	13	15	4	2	0	0	34
Groundstaff	6	6	6	4	0	0	22
Total	155	181	55	25	2	1	419

Table 3.2: The experience within the game of each occupational sub-group.

Years involved in professional football	0-5 years	6-10 years	11-15 years	16-20 years	21-25 years	26 + years	Total
Player	83	68	73	24	4	1	253
Manager or Coach	2	1	2	2	13	9	29
Physiotherapist	30	21	13	10	6	1	81
Sports Scientist	23	7	4	0	0	0	34
Groundstaff	4	4	5	4	2	3	22
Total	142	101	97	40	25	14	419



	Total Playing Years	Premier League	Championship	League 1	League 2	Other	International
Total years	558	427	577	377	297	390	265
Mean years	2.22	3.42	3.59	3.12	3.20	4.76	4.28
S.Dev	1.08	3.79	2.60	2.29	2.84	3.80	3.66

Figure 3.1: Bubble graph illustrating the participants' collective working years' experience across all divisions within football.

Table 3.3: Classification of the subject's ethnic profile.

Ethnicity	White	Mixed white	Black African	Black Caribbean	Black British	Asian	Arabic	Other	Total
Player	181	18	19	28	1	2	1	3	253
Manager or Coach	28	0	0	1	0	0	0	0	29
Physiotherapist	80	0	0	0	0	1	0	0	81
Sports Scientist	34	0	0	0	0	0	0	0	34
Groundstaff	22	0	0	0	0	0	0	0	22
Total	345	18	19	29	1	3	1	3	419

Regarding ethnic profiles (Table 3.3), the sample group were predominantly white (345, 83%) with only 72 (17%), from a total of 419 respondents, reporting their race as non-white. 18 players reported their ethnicity as mixed white, 19 Black African, 28 Black Caribbean, 2 Asian, 1 Black British, 1 Arabic and 3 recorded their race as 'other'. Furthermore, only one Black Manager and one Asian physiotherapist were recorded within the sample population. Primarily, the largest sub-group of players were that of midfielders (N=87, 34.4%), strikers (N=58, 22.9%), followed by centre backs (N=49, 11.9%), full backs (N=41, 9.6%) and finally goalkeepers (N=18, 4.2%) completed the questionnaire (see Figure 3.2).

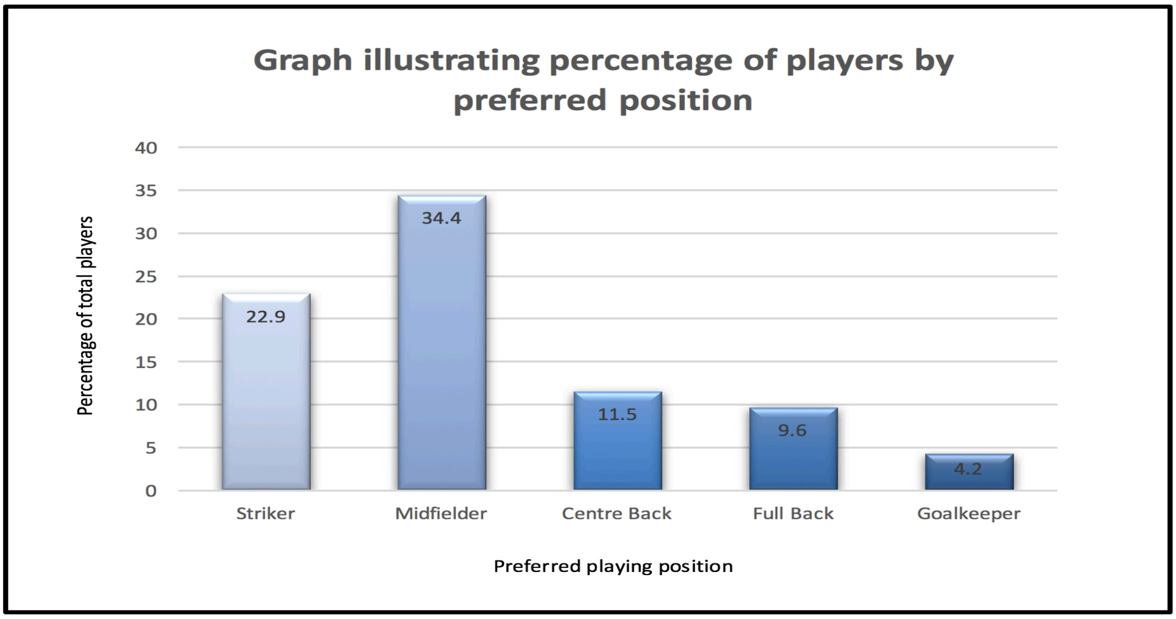


Figure 3.2: Percentage breakdown of players by preferred playing position.

3.2.4 Statistical Analysis

Data was analysed using a segmental approach; this was in keeping with the design of the questionnaire. Primarily, descriptive statistics were generated for the sample group as a whole, providing an overview of the participants as a collective group. Secondary, more analytical statistical testing examined the role of occupation on the perceptions of key stakeholders regarding natural turf pitches utilising Kruskal Wallis and Chi squared tests with statistical significance set at $p<0.05$. A comparison of the occupational median scores, was utilised to highlight any significant differences between occupational sub-groups.

3.3 Results

The results are divided into two distinct sections namely;

Part A: (1) explores whether the pitch is perceived as a potential injury risk factor by those working in professional football, (2) investigate if and how a hard or soft natural turf pitch is perceived to affect specific tissues and their likelihood of injury differently.

Part B: (1) explores the perceptions of key stakeholders that the relative hardness of the natural turf pitch can affect the performance of the ball, the individual and/or their teams approach to the game (2) examine who they perceive to be accountable and/or responsible for the pitches upon which the game is played.

3.3.1 Results Part A: (1) Is the natural turf pitch perceived as a potential injury risk factor by those working in professional football?

When the population of participants is addressed as a whole (Table 3.4), the data suggests that there is a perception that pitches can be a significant risk factor for injury, with 87% either agreeing or strongly agreeing with the statement. Only 10% of the group expressed a neutral view regarding the question while 3% disagree with the statement.

Table 3.4 The collective samples perception that pitches may be viewed as risk factors for injury.

Question	Collective response of all key stakeholders						Total
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A	Total
I believe that the pitch may be a risk factor for injury	165 (39.4%)	201 (48.0%)	42 (10.0%)	9 (2.1%)	2 (0.5%)	0 (0%)	419 (100%)
I have experienced an injury I blamed on the pitch.	123 (29.4%)	123 (29.4%)	67 (16.0%)	25 (6.0%)	19 (4.5%)	62 (14.8%)	419 (100%)
I have seen others get injuries I put down to the pitch.	136 (32.5%)	199 (47.5%)	58 (13.8%)	10 (2.4%)	7 (1.7%)	9 (2.1%)	419 (100%)
I believe variability of hardness/softness across a pitch is a problem which may cause injuries.	24.3%	45.6%	21.7%	5.7%	1.9%	0.7%	419 (100%)

Some 59% of participants reported having experienced an injury themselves which they believed to be attributable to the pitch, whilst over 80% attribute injuries they have witnessed in others to the pitch surface. One factor highlighted as a major area of concern for injuries by over 69% of the population, was the degree of variability in the relative surface hardness across any given pitch. Nearly three quarters of those questioned reported that hardness of the pitches had changed over their time in the game (74%), with over 82% perceiving pitches were getting harder.

Perceptions regarding a seasonal bias between pitch hardness and likelihood for injuries clearly divided opinion with participants. Approximately 48% of respondents were in agreement that seasonal biases were evident, whereas 52% opposed these views. Figure 3.3 shows a more detailed breakdown of the responses to this question for the respondents. Interestingly, of those who do perceive a seasonal bias to relative pitch hardness (blue), there is an apparent 'bi-modal' temporal distribution. This would indicate that injuries are perceived to be greatest, between August/September and between December/January. The perceived risks over the remaining months of the season appear to be perceived as relatively lower and uniform.

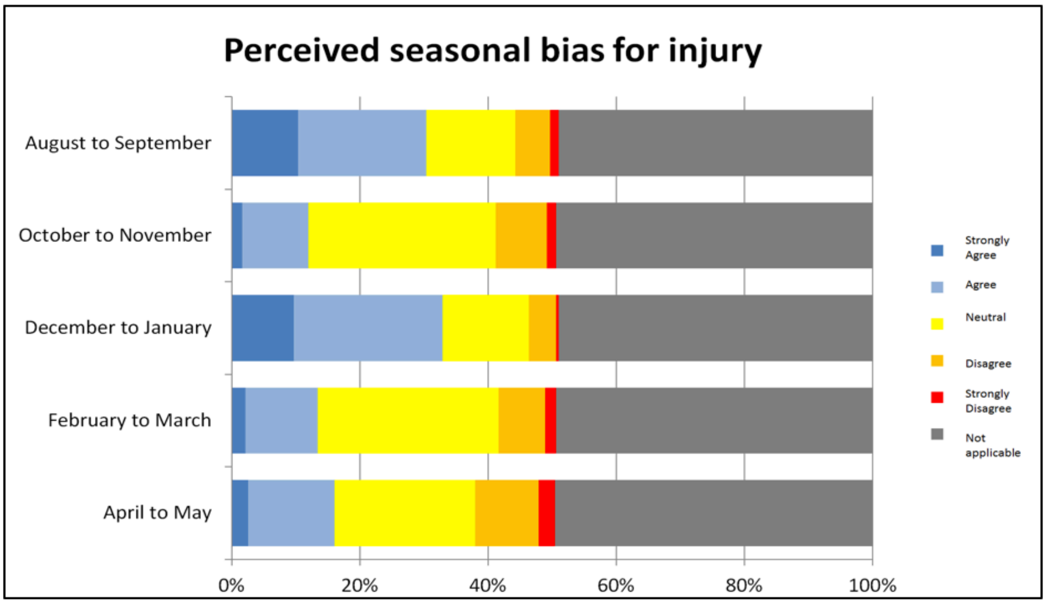


Figure 3.3: Graphical illustration of collective perceptions regarding seasonal bias for injury within football.

Table 3.5 Perceptions that the pitch may be a risk factor for injury defined by occupation.

Occupational Group	I believe that the pitch may be a risk factor for injury						Total
	Str. Agree	Agree	Neutral	Disagree	Str. Disagree	N/A	
Player	83 (32.81%)	129 (50.99%)	33 (13.04%)	7 (2.77%)	1 (0.40%)	0 (0%)	253
Manager or Coach	12 (41.38%)	16 (55.17%)	1 (3.45%)	0 (0%)	0 (0%)	0 (0%)	29
Physiotherapist	50 (61.73%)	29 (35.80%)	2 (2.47%)	0 (0%)	0 (0%)	0 (0%)	81
Sports Scientist	11 (32.35%)	20 (58.82%)	2 (5.88%)	1 (2.94%)	0 (0%)	0 (0%)	34
Groundstaff	9 (40.91%)	7 (31.82%)	4 (18.18%)	1 (4.55%)	1 (4.55%)	0 (0%)	22
Total	165 (39.4%)	201 (48.0%)	42 (10.0%)	9 (2.1%)	2 (0.5%)	0 (0%)	419 (100%)

Perceptions that natural turf pitches can cause injury were reported by over 96% of physiotherapists, managers/coaches (96%), and sports scientists (91%). Interestingly, groundstaff reported less agreement (72%). Only one player (0.4%) and one member of groundstaff (4.5%) strongly disagreed with the perception that pitches can cause injury (Table 3.5).

Whilst the collective perceptions of the participants suggest that pitches should be viewed as a risk factor, a further analysis of the sample based on occupation illustrated statistically significant differences between occupations χ^2 (4, n=419) =26.39; p<0.01. Physiotherapists reported the strongest levels of agreement whereas other key stakeholders agreed that natural turf pitches should be viewed as a risk factor. Perhaps the physiotherapist role in injury prevention or their past experiences of injuries which may have been attributed to the pitch hardness may have added to their collective occupational response. Other significant differences were evident between the occupational sub-groups regarding the view that the variability of hardness/softness across a pitch may cause injuries, (χ^2 (4, n=419) =35.48, $p<0.01$). If the respondents had seen others get injuries that they attributed to the pitch χ^2 (5, n=419) =13.44; $p<0.05$ and also whether they had experienced an injury which they believed was due to the pitch χ^2 (5, n=419) =12.42; $p<0.05$ (Appendix 10.2).

3.3.2 Results Part A: (2) General perceptions of how hard or soft natural turf pitches are perceived to affect specific tissues and/or injury.

Perception of Hard Pitches

Taken collectively, over 66% of participants perceived hard pitches were likely to cause injury, with 27% expressing neutral views and a mere 7% in disagreement. Figure 3.4, provides a deeper understanding of the specific tissues and injuries that are perceived to be most at risk when a player is exposed to a hard natural turf pitch. The most prevalent perceived risks were to the joints with soreness/pain linked to surface hardness by 93% of respondents. Cuts and abrasions (68%) and tendon damage (54%) were also highly linked to surface hardness by participants. The risk of muscle strains (44%) and ligamentous injuries were however considered less (41%) related to the harder surface. Participants reported the least risk of injury on hard pitches for risk of bone fractures, concussion, or bruising/dead legs.

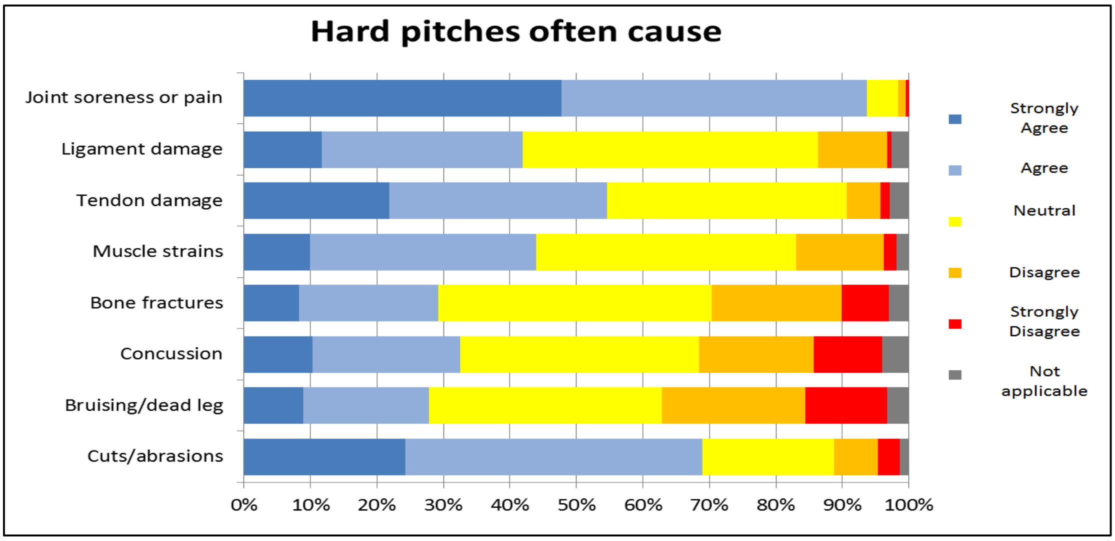


Figure 3.4. General perceptions of how hard natural turf pitches are perceived to affect specific tissues and/or injury.

Interestingly, participants perceptions regarding hard pitches resulting in more injuries was statistically dependent upon occupation χ^2 (4, n=419) =21.27; p<0.01. Furthermore, specific tissues were deemed to be more or less at risk depending upon the occupation of the participant. Significant differences were evident between the occupational groups perceptions of the relationship between the pitch hardness and ligamentous damage χ^2 (4, n=419) =22.92; p<0.01, cuts and abrasions χ^2 (4, n=419) =21.40; p<0.01, muscle strains χ^2 (5, n=419) =9.94; p<0.05, joint soreness χ^2 (5, n=419) =14.33; p<0.01 and tendon damage χ^2 (5, n=419) =12.27; p<0.05 (Appendix 10.2). The perceived risk of ligamentous injury and concussion was more of a concern to the groundstaff compared to other groups. Players, managers and coaches perceived a greater likelihood of joint soreness/pain, than other occupational groups. Perceptions of likely tendon damage on hard pitches was also impacted by occupational sub-group with players, physiotherapists, managers and coaches reporting most concern, followed by the sports scientists. The groundstaff evidenced more neutral perceptions regarding hard pitches and the likelihood of perceived tendon injury (Appendix 10.2).

Perceptions of Soft Pitches

Collectively, over 40% of participants agreed that when natural turf pitches are soft, they pose a heightened risk of injury, while 38% were neutral and 21% disagreeing with this statement. Figure 3.5 highlights the specific tissues and injuries perceived to be most at risk when a player is exposed to a soft natural turf pitch. The most prevalent perceived risk of injury on soft pitches was linked to muscle strains (60%) and ligamentous damage (42%). Notably, the lowest perceptions of risk on soft pitches was linked to injuries such as bruising/dead leg (5%), concussion (6%), cuts/abrasion (12%) and bone fractures (8%).

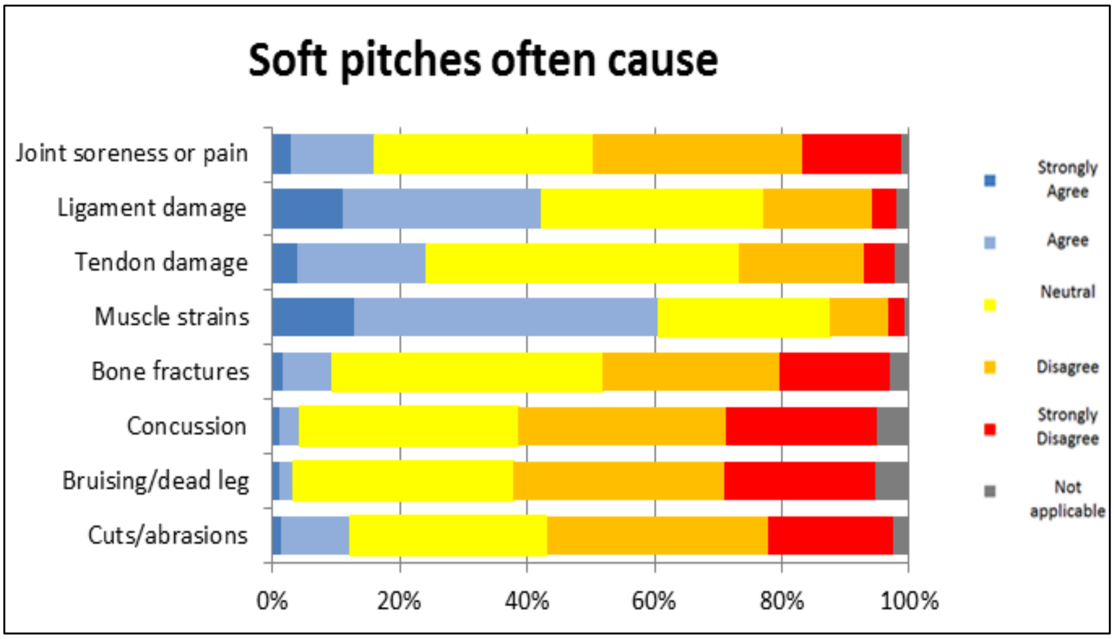


Figure 3.5. General perceptions of how soft natural turf pitches are perceived to affect specific tissues and/or injury.

When occupational difference in the participants responses were examined in relation to the likelihood of injury on soft pitches, statistically significant differences were evident χ^2 (4, n=425) =16.69; p<0.01. Specifically differences were noted between occupational groups for specific injury classifications namely, bone fracture χ^2 (4, n=419) =16.97; where players were seen to disagree, whilst groundstaff perceived moderate agreement that the soft pitches could result in such injury. Physiotherapists and sports scientists expressed more neutral views. The perceived risk of tendon damage found mostly neutral perceptions regarding risk with the exception of sports scientists who expressed slight disagreement that soft pitches are likely risk factor for tendon injury, p<0.01, χ^2 (4, n=419) =12.47. Perceptions of likely joint soreness also differed significantly; p<0.05, χ^2 (4, n=419) =10.65, with players/managers disagreeing with other stakeholders who were more neutral. The groundstaff perceived soft pitches to be a likely risk for ligamentous injury in comparison to other occupations; p<0.05 and ligamentous damage χ^2 (4, n=419) =9.86; p<0.05 (Appendix 10.2).

3.3.3 Results Part B: (1) Perceptions of key stakeholders that the relative hardness of the natural turf pitch can affect the performance of the ball, the individual and/or their teams approach to the game.

The data in Figure 3.6 illustrates the perceptions of participants regarding the ball and its interaction with the relative hardness/softness of any natural turf pitch. This figure clearly shows that soft or hard pitches are thought to affect the performance of the ball differently. In general, very hard/hard pitches were considered to affect the bounce height and roll of the ball. Over 90% perceived the ball to bounce higher, and roll further (over 75%) on this type of surface compared to very soft/soft pitches. Extremes of both hardness or softness were generally interpreted negatively by respondents, with many identifying a "medium" hardness for a better consistency of bounce (50%), ease of dribbling (50%) and ball striking ability (60%). The ball was also perceived to remain in play longer on soft surfaces (30%) in comparison to harder surfaces (10%).

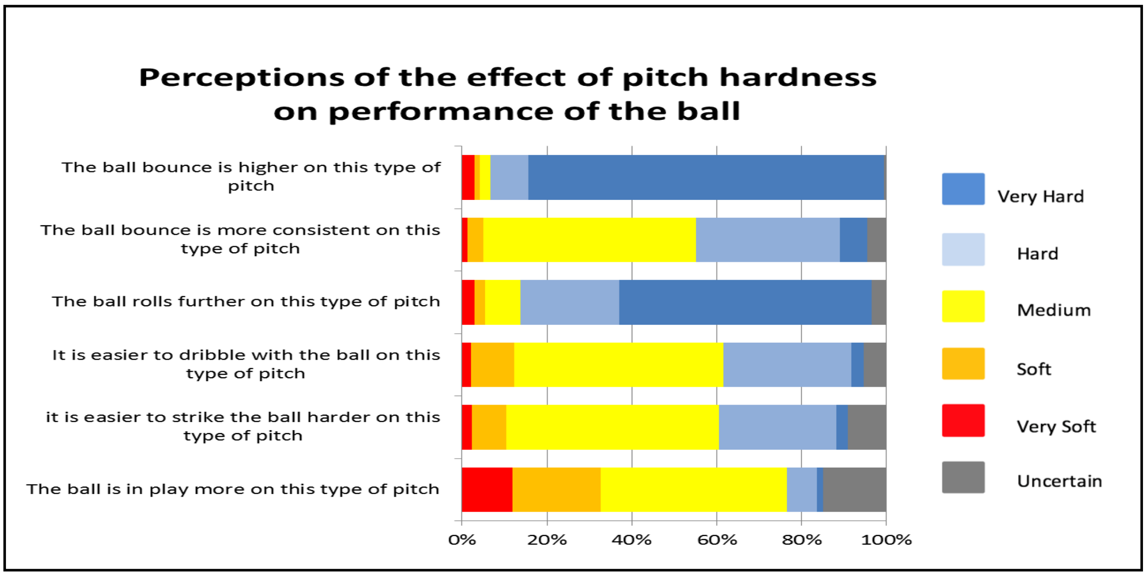


Figure 3.6: All key stakeholders' perceptions concerning the effect of pitch hardness on the performance of the ball.

How the relative pitch hardness affects the perceptions of individuals on recovery and performance, the passing strategies that are employed in the game, and the speed of the game are shown in Figure 3.7. Exposure to very soft/soft pitches resulted in players (over 81%) reporting that such pitches left them feeling very "leggy" or tired (defined as having a reduced perceived power, energy or fatigue). The surface was also perceived to impact physical performances such as the ability to perform high intensity running/sprinting. The performance of such actions was considered optimal on pitches of medium hardness (44%) with hard pitches (39%), very hard pitches (8%), soft (5%) and very soft surfaces (1%) considered less advantageous to these actions. Similar trends were also noticeable in the perceptions around the ability to accelerate, decelerate, stop and change direction (Appendix 10.2).

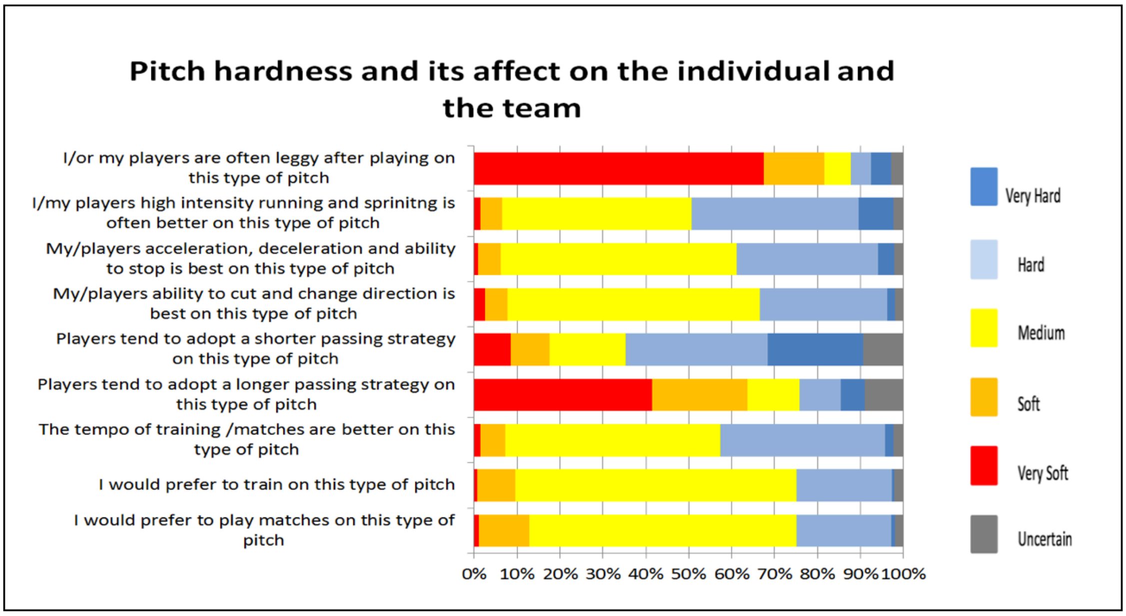


Figure 3.7: Illustrating perceptions concerning the effect of pitch hardness on the individual and the team.

Perceived pitch hardness also seemed to affect the perceptions of passing strategies, with shorter passing strategies being more seen as being appropriate on hard (33%) and very hard (22%) pitches. Conversely, on very soft pitches (41%) and soft (22%) pitches, players felt that longer passing strategies were more frequently needed. The pace or tempo of both training and matches was also thought to be affected by the surface with medium hardness pitches (50%) deemed to promote a better "tempo" than soft (38%) or very soft (2%) surfaces. Extremes of hardness/softness were not preferred for either training or matches with the majority of players preferring a medium hardness in both training (65%) and matches (62%). Behaviour was reportedly adapted as a function of the perception of the surface with 77% changing their footwear to accommodate harder pitches. Approximately 66% indicated that they also offered advice to others regarding choice of footwear. While this general advice seemed common (two thirds of the sample), only 24% reportedly had prevented others from playing because of the relative hardness of any given pitch.

No significant differences were found between the occupational sub-groups regarding the perception of the ability of players to perform high intensity running and sprinting (p=.242), accelerate/decelerate (p=.956), in the tempo of the game in both training and games (p=.704) and the preference for training pitch type (p=.287). These outcomes suggest some homogeneity in responses across differing occupational groups in the impact of the surface on performance related variables. There were however statistically significant occupational differences for the preference of pitch type to play matches upon χ^2 (4, n=419) =60.112; p<0.001. Other occupational differences were found in the perception of the type of pitch that resulted in feeling tired or leggy χ^2 (4, n=419) =50.202; p<0.001, the ability to cut and change direction χ^2 (4, n=419) =12.95; p<0.05 and how the pitch impacted longer passing strategy χ^2 (4, n=419) =22.184; p<0.001 (Appendix 3.7.2 Table 13). Interestingly, differences were especially notable between groundstaff and other key stakeholders in relation to which pitch type made players tired or leggy, perceived preference for match day pitch type, the ability to cut or change direction, and for adopting a longer passing strategy in relation to the surface hardness (Appendix 10.2).

3.3.4 Results Part B: (2) Who stakeholders perceive to be accountable/responsible for the natural turf pitches upon which the game is played.

This section focuses upon the key stakeholders' perceptions of accountability or responsibility for the natural turf pitches. It is clear from Figure 3.8, that many of the key stakeholders feel little in the way of responsibility for the pitches upon which they play. Approximately 70% did not feel it was applicable to discuss how they wanted the pitch to be prepared with the groundstaff before the commencement of the season. Only 10% of those questioned admitted to giving the groundstaff any specific instructions as to how they wanted the pitches prepared. This was also noticeable regarding pitch preparation, for both daily training and the home matches.

The key stakeholders also seemed largely unsure regarding their role in decisions around pitch management. This can be illustrated by observations such as uncertainty around the surface where they trained, the nature of any specific watering strategies to be used and the length of the grass they required on their pitches. Less than 15% of key stakeholders felt they had a close working relationship with their groundstaff, so perhaps not surprisingly the overall ratings of satisfaction with the surface was generally low (just over 40% were satisfied with their training and 58% their match pitches). Despite such relatively poor satisfaction, nearly 70% of those questioned believed that the pitch could significantly influence the performance of their team. Perhaps of most interest, was that despite perceptions that the pitch can significantly influence the performance of the team, over 60% perceived having a good relationship between keys stakeholders and the groundstaff as not being important.

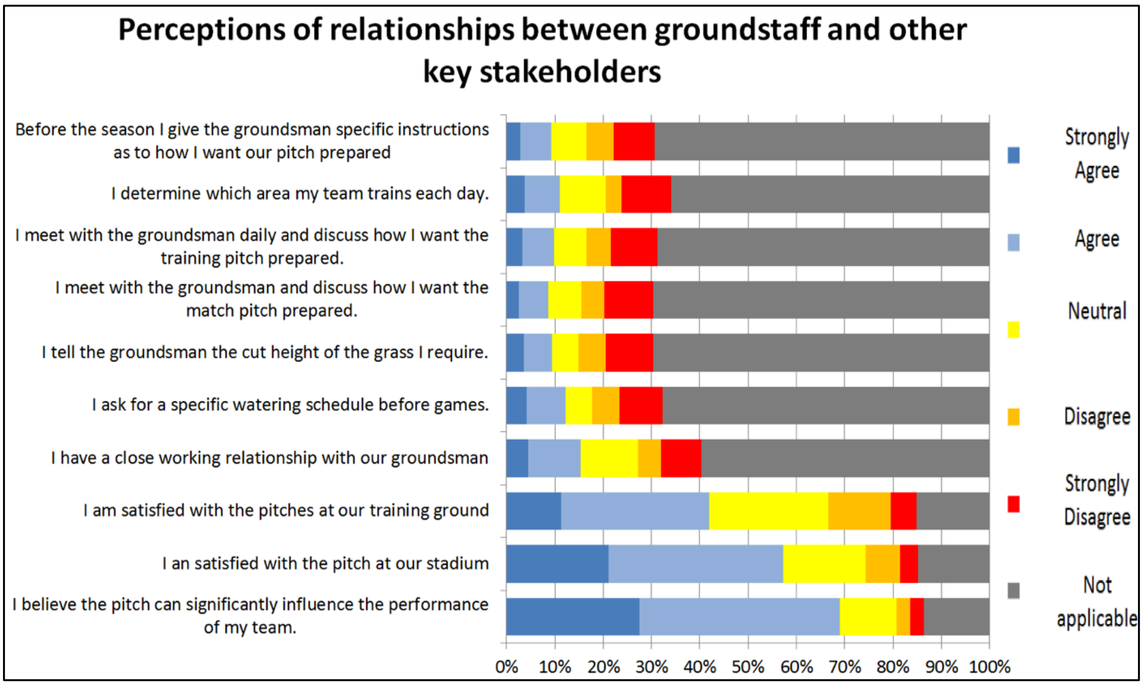


Figure 3.8. Illustrating perceptions concerning the effect of pitch hardness on the individual and the team.

No significant differences were found in perceptions between any of the different occupational sub-groups regarding their satisfaction with training pitches (p=.566) and match pitches (p=.502). There was also no significant difference in relation to whether the pitch was thought to influence the performance of the team (p=.163). Responses were however found to be different pending occupational groups for the all other remaining questions with the largest difference between occupations being whether key stakeholders felt they had a good working relationship with their groundstaff χ^2 (4, n=397) =61.715; p<0.001. What is apparent is that neither the players', physiotherapists' nor sports scientists' perceive they have any role in the preparation or maintenance of the pitches upon which they play. Furthermore, the players did not perceive it necessary to develop any relationship with the groundstaff; a view which was reinforced by the physiotherapists and to a lesser extent by sports scientists. In contrast, managers and coaches reported neutral views regarding their relationship with the groundstaff (Appendix 10.2).

Whether they met daily with the groundstaff to discuss preparation of either the training pitch, χ^2 (4, n=397) =26.120; p<0.001, or the match pitch was also different, χ^2 (4, n=397) =19.168; p<0.001. The views on the preparation and maintenance of pitches also differed by occupation. If key stakeholders gave specific instructions as to how they wanted pitches prepared for pre-season, χ^2 (4, n=397) =16.701; p<0.001, the length of cut height of grass, χ^2 (4, n=397) =19.332; p<0.001 or indeed the specific watering schedule prior to games, χ^2 (4, n=397) =23.593; p<0.001. Further, differences were found between whether they determine where they train, χ^2 (4, n=397) =40.391; p<0.001. Neutral views were reported by managers and coaches in relation to where they train. Managers/coaches, however, showed little regard for the preparation and maintenance of pitches, with little accountability evidenced for giving specific instruction on pitch preparations prior to the start of the season, having daily discussion about training pitches or indeed the match pitch, the cut height of grass, or the watering schedule before games.

3.4 Discussion

This is the first study to focus purely on the natural turf pitch, its relative hardness and how it is perceived to affect key stakeholders in relation to the likelihood of injury, the effect on the ball, individual or team. The results highlight that natural turf pitches are perceived to be a significant risk factor for injury within elite professional football. Furthermore, the key stakeholders were able to differentiate subtle differences between the relative hardness of the pitch and the specific soft tissues which they perceived to be more at risk. Pitch hardness was also perceived to effect the performance of the ball, the individual and/or their teams approach to the game. However, the results of the study were not uniform, being affected by occupational difference. Finally, the research discovered a fractured working relationship between key stakeholders and the groundstaff which may be a contributory factor to many of the perceptions raised within this study.

3.4.1. General perceptions that natural turf pitches can be viewed as risk factors for injury?

Natural turf pitches, their construction and maintenance, have undoubtedly changed over the years culminating in the pitches of today, which are generally considered more robust, maintain better grass coverage and are more resistant to both traffic and the prevailing climatic conditions (Stiles et al 2009, Caple et al 2012, Thomson and Rennie 2016). Despite such developments the perceptions of these new surfaces amongst key stakeholders is largely unknown. This is the first study of its kind to focus purely on the natural turf pitch, its relative hardness and how it is perceived to affect the key stakeholders in relation to the likelihood of injury, the performance of the ball, the individual or their team. The first research objective was to explore the general perceptions of those working within professional football, as to whether the pitch can be viewed as a potential injury risk factor. From the findings presented, it is clearly evident that the key stakeholders perceive pitches to be a significant risk factor for injury. Many participants described having experienced an injury themselves, or indeed, attributed injuries seen in others, to the pitch surface. This reinforces the previous findings of Mears et al (2018), Poulos et al (2014), Roberts et al (2014), and Ronkainen (2012), regarding such concerns of injury risk on natural turf surfaces. However, whilst the results were similar, the design of previous studies may have detracted from the impact of their findings. This study, unlike those cited within the literature (Mears et al 2018, Poulos et al 2014, Roberts et al 2014, Ronkainen 2012), focused purely on the natural turf pitch and did not draw comparisons with other pitch types which may have diluted or polarised perceptions. Other novel markers of the current inquiry involve the inclusion of all key stakeholders, promoted a more focussed data set, adopting a more holistic approach to the question of injury risk and the natural turf pitch. As a result, it is considered that the current research has found more subtle nuances regarding the natural turf pitch than previous inquiry. Whilst perceptual links remain between natural turf pitch hardness and injury, these have been found to be non-uniform, being affected by occupation. Furthermore, perceptions regarding natural turf pitch hardness demonstrated specificity, whereby certain tissues were perceived to be more at risk of injury on differing levels of pitch hardness.

The key stakeholder's occupation highlighted significant differences between their perceptions of injury risk. For instance, the perceptions that natural turf pitches could be associated with an increased risk of injury was viewed with significantly more concern by all occupational groups (91-96% agreement) than the groundstaff (76% agreement). This in itself is a highly pertinent finding, as such a disparity may be the foundation for such perceived differences in injury risk. It is possible that this apparent reduction in either awareness or concern about other user's perceptions, is reflected in how the groundstaff prepare or maintain such surfaces.

Key stakeholders were able to report subtle differences in their perceptions of natural turf pitches with over 73% perceiving that pitches had changed over their time in the game, and 82% stating that pitches were getting significantly harder. This finding is probably a reflection on how the natural turf pitch has developed over recent years to one which is more robust and resistant to both climatic variation and footfall over the season (Bartlett et al 2009, Caple et al 2012). Advances in technology, such a 'lighting rigs' augments both growth and grass cover throughout the season, whilst developments in construction with re-enforced root zones has aided the durability of pitches (Caple et al 2012, Thomson and Rennie 2016). Whilst these links appear logical, unfortunately they are not supported within the literature by objective, longitudinal studies exploring such perceived changes in natural turf pitch hardness (Stiles et al 2009). This lack of evidence needs to be addressed by researchers in order to understand the potential driver for such perceptions, especially as hard pitches themselves were perceived to carry a higher relative risk of injury (67% agreement) than soft (40.3% agreement). Interestingly, the lack of homogeneity, with notable occupational differences was especially evident regarding the groundstaffs' perception of an increased risk of injury on softer pitches than other occupations. As the groundstaff are tasked with the preparation and maintenance of the pitches, perhaps their perception that soft pitches may carry a higher injury risk may go some way to explaining why pitches are perceived as getting significantly harder by other stakeholders. Why such perceptions are prevalent, what drives or informs them, and indeed why occupational differences exist is unknown and to date there is no available literature.

3.4.2. How are hard or soft pitches perceived to affect specific tissues and likely injury?

What was evident from the data, was the apparent clarity with which stakeholders perceive variable levels of risk depending on the relative hardness of the pitch. None more so than when considering which specific tissues or indeed injuries are perceived to be most at risk. The most prevalent perceived risk on hard pitches was joint soreness or pain (93% agreement), followed by cuts and abrasions (68% agreement) and tendon damage (54% agreement). In contrast, soft pitches were perceived to affect specific tissues or injuries, in a different way to their harder counterparts. The perceived risk of joint soreness/pain fell dramatically by 77%, cuts and abrasions by 50% and tendon damage by 30% between the two differing surfaces. The soft natural turf pitch most perceived risk being muscle strains (60% agreement). This finding both supports, and differs from those proposed by Mears et al (2018), whose qualitative based study of elite players' perceptions of four differing playing surfaces (artificial, gravel, indoor sports surface and natural turf) concluded both hard and soft natural turf pitches were statistically significant predictors of muscular injury. The reasoning behind such perceptions are not supported by objective data linking surface with injury likelihood as no prospective studies objectively comparing pitch hardness to injury have been conducted (Rennie et al 2016).

Clearly, the data presented thus far establishes a general consensus within key stakeholders that the pitch can be viewed as a significant risk factor for injury. Why this is the case remains unclear, perhaps the regular, repeated exposure of key stakeholders to such surfaces enables them to differentiate or 'chunk' relative hardness and how it makes them feel, thereby developing and adapting their perception of risk based upon their experiential learning. Furthermore, extremes of hardness and softness are perceived to affect specific tissues and their likelihood of injury in a very specific manner. This new knowledge must be utilised and promote prospective research, utilising objective measurements of pitch hardness, coupled with recognised injury surveillance and reporting methods in order to address the concerns of those exposed to such surfaces.

One proposed link within the literature supporting the idea that hard pitches may indeed be viewed as a significant extrinsic risk factor is founded within seasonal bias for injuries (Hawkins and Fuller 1999, Orchard et al 2002, Ekstrand et al 2013). Both Hawkins et al (1999) and Ekstrand et al (2013) reported injury incidence in football to be highest in the months of July and August when pitches are frequently reported as harder. Their observations contrast with the perceptual findings of this study, which offered a more mixed response, with less than half of the sample suggesting injuries followed a seasonal pattern. Interestingly, those who perceived seasonal bias did report a 'bi-modal' temporal distribution, with greatest risk between August/September and again between December/January. It is plausible to suggest that the 'bi-modal' distribution may reflect a seasonal variation in pitch hardness, due to the prevailing climatic change across the season. For example, the drier months of August/September may lead to harder pitches, than seen in the wetter December and January period. This would support the participants feelings around the relative timing of injury risk with surface and time of year. Alternatively, the perception that injuries peak in December/January as a result of the natural turf pitch may be attributed to the variability in pitch hardness caused by freezing/thawing of the surface at that time of year. This view may be supported within this study, where 69% of key stakeholders reported concerns regarding variability of surface hardness and injury risk. Variable climatic conditions were also highlighted within a study of teams within the Champions League (Walden et al 2013) where geographically regionalised injury differences were noted. Inferences were drawn that such climatic variation would in turn affect pitch hardness and thereby injury, however the links were more theoretical in nature as pitch hardness was not measured within the study. Nevertheless, these studies offer some insight behind this study's findings regarding key stakeholders' perceptions of seasonal bias in relation to injury and pitch hardness level.

The underlying mechanisms behind perceptual differences between hard or soft natural turf pitches and injury risk are unclear and warrant further investigation. The interface between biomechanical and physiological load may contribute further to understanding the findings established in this study. It is well known that in order to stimulate improvements in training and performance, the intensity and volume of internal loads needs to be sufficiently high enough to trigger adaptation, yet not too high to avoid overload, tissue breakdown and subsequent injury. This process is well recognised and validated by the literature regarding internal or physiological response to exercise (Wallace et al 2014). Whilst biomechanical data concerning the resultant forces acting on players on differing pitch hardness is scarce, it is recognised that different rates of loading exist between various experimental turf hardness conditions (Stiles et al 2011). This laboratory based study concluded the ground reaction forces in both running and turning were surface dependent, with harder natural turf resulting in higher ground reaction forces. This may provide some foundation for the key stakeholders perceptions that a hard pitch can cause injury to bone or tendon, as such tissues have been reported susceptible to injury from such a repetitive or excessive over-loading (Plaza-Carmona et al 2014).

In contrast, soft pitches were perceived to affect specific tissues or injuries, in a different way to their harder pitches, with the most prevalent risk perceived to be muscle strains. The reasoning behind such perceptions are not explained by the current literature as no prospective studies objectively comparing pitch hardness to injury have been conducted. Researchers have proposed that fatigue may have a role to play in the process, as injuries are frequently prevalent in the last fifteen minutes of the first half and are at their most prevalent in the final fifteen minutes of any match (Hawkins and Fuller, 1999). Whether the compliance (hardness) level of any given pitch can affect fatigue and thereby perceptions of relative injury risk, has not been established. Nevertheless, there is evidence within the literature which could suggest conceptual links between the compliance of the natural turf pitch, and how this may account for participants perceived risk of injury (Rennie et al, 2016). As surface compliance is known to affect both energy expenditure (Pinnington and Dawson 2001, Katkat et al 2009, Sassi et al 2011) and musculo-skeletal load (Stiles et al 2011, Plaza-Carmona et al 2014), one may consider the impact of the relative hardness of natural turf pitches on such physiological demands. Consequently, the concerns of participants within this study regarding joint soreness/pain on hard pitches could be attributed to elevated loading through joints and tendons due to increases in impact forces (Ferris et al 1999). Conversely, the soft pitch with its associated perceived risk for muscle strains may indeed be due to the increased demand placed on the muscle as a result of the energy sapping and depleting nature of the surface (Pinnington & Dawson, 2001; Sassi et al 2011).

The relative risk of ligamentous injury was also perceived to be of concern by 42% of participants on soft natural turf pitches. It is recognised that hardness of natural turf is a balance between the 'soils' moisture content and the compaction of its particles (Baker et al, 2007, Caple et al, 2012). Increases in moisture content and/or decompaction of the soil results in softer pitches. Such soft pitches may also demonstrate a reduction in the surfaces traction coefficient (grip), thereby reducing a player's stability (Baker et al 2007). One could argue the soft pitch with its reduced stability and traction underpins why participants perceive ligaments injury to be more prevalent on such pitches. However, such links require caution as the questionnaire within this study was designed to question hardness and did not explore participants' perceptions of traction.

3.4.3 General perceptions of whether the relative hardness of the natural turf pitch affects the performance of the ball, the individual, or their team.

Whilst pitch quality standards for natural turf make recommendations upon preferred levels of hardness (Canaway et al 1990, Institute of Groundsmanship 2001, Football Association, 2004, UEFA, 2018), no current literature addresses how the relative hardness of the natural turf pitch affect the bounce and roll of the ball, how it enables or hinders the movement of the players. Nor does it examine the effect on the team in relation to the style of play they adopt to counter such surfaces. This is the first study of its kind to examine the perceptions of key stakeholders to the natural turf pitch regarding such matters. The results clearly demonstrate that extremes of either hardness or softness were interpreted negatively, with key stakeholders preferring pitches of a more medium relative hardness in both training and matches. This was particularly noticeable with favourable responses regarding the consistency of bounce, and the ease of which it is to both dribble and strike a ball. Furthermore, the key stakeholders perceived that pitches with medium relative hardness enable the ball to remain in play more. Participants perceived very hard/hard pitches to promote the ball to bounce higher and roll further when compared to very soft/soft pitch a response supported by the literature (Stiles et al 2009). This supports the views of Roberts et al (2014) who concluded that the consequence of exposure to a variety of surface over their careers, makes players very adept at interpreting subtle differences in surfaces and how these may affect the way the game is played. These perceptions are seemingly operationalised in the practical strategies used by players to perform, as players describe a need to adapt their approach to the game according to the surface. Players reported the need for accommodating such ball-surface interactions through modification of their preferred passing strategies. Key stakeholders reported utilising shorter passes on harder pitches, in contrast to softer pitches where longer passing strategies were needed. This supports the findings of Andersson et al (2008), who reported players who perceived artificial pitches to be harder also adopted a shorter passing strategy on such surfaces. Perhaps such attempts to gain more control over the speed and roll of the ball explains why participants perceived that the pace or tempo of both training and matches were also affected by the perceived relative pitch hardness. Medium to hard pitches were deemed to promote a better tempo than soft or very soft. These observations suggest that playing on varying hardness's of natural turf pitches may necessitate a change in the style of play (Andersson et al 2008).

Through exploration of stakeholders' perceptions, it is clear that the relative hardness of the natural turf pitch not only affects the ball, but also has a marked effect upon the individuals and the performance of their teams. Exposure to very soft/soft pitches resulted in over 81% of the players reporting that the pitch left them feeling very "leggy" or tired. This contrasts the literature which reports no significant difference in physical performance when data from subjectively perceived harder (artificial pitches) and softer (natural turf pitches) are compared (Dragoo et al 2010, Soligard et al 2010, Williams et al 2011). Perhaps by focusing on extremes of hard or soft, this study may have highlighted the nuances in natural turf. This may have enabled participants to interpret or perceive natural turf with more clarity, a factor which has limited comparative studies of perceptions between natural and artificial turf. A plausible reason when a player runs on a compliant (soft) pitch, is that they expend more energy for any given running velocity, in order to compensate for energy dissipated through the surface. This has been confirmed through demonstration of a negative relationship between surface compliance and oxygen consumption (Sassi et al, 2011). This increased energy expenditure on such soft pitches may potentially increase fatigue levels in players leading to the tired or leggy perceptions reported by over 81% of players. Interestingly, there was a notable occupational difference between perceptions by the groundstaff and other key stakeholders for which pitch type made players “tired or leggy”. The groundstaff adopted a more neutral stance in relation to soft pitches compared with that of the other key stakeholders who strongly agreed that soft and very soft pitches led to such negative feelings of fatigue. Whilst the groundsmen have no input to training or match loads, they are taxed with the preparation of the surface. Indeed, a greater understanding of the perceptions of the other key stakeholders as to how such pitches lead to fatigue may help reduce this potential problem.

The relationship between the ground reaction force and energy return may explain why soft pitches were viewed as poor surfaces to perform certain movements (Pinnington et al 2001, Hardin et al 2004, Sassi et al 2011), whereas hard pitches were perceived by participants to be the best surface on which to accelerate, decelerate, stop and change direction. It was not surprising to note then, that in an attempt to accommodate for such differing pitch hardness and the potential impact on these on movements, 77% of participants modified their behaviour through footwear changes. Optimum stud penetration is of paramount importance to achieving maximum traction whilst reducing plantar pressure points on the foot. Surface hardness therefore affects both traction and comfort which necessitates behavioural change from the players regarding footwear (Thomson and Rennie, 2016). This appears to be an attempt by players to mitigate any negative perceptions of the surface, in order to maximise their movement performance, a factor that can be founded within the theory of modifiable risk (McIntosh, 2005).

3.4.4. Who do the key stakeholders perceive to be accountable/responsible for the natural turf pitches upon which the game is played?

Clearly given the choice, key stakeholders would prefer to train and play on natural turf pitches of a medium hardness. However, despite this and the fact that nearly three quarters of the participants perceived the pitch could significantly affect the performance of their team, only 58% were satisfied with their match pitch, compared to 40% with their training pitches. Why such disparity exists is perhaps more apparent when the accountability for such pitches was examined between the key stakeholders and the groundstaff. Clearly, many key stakeholders feel little in the way of responsibility for the pitches upon which they train and play with the majority not feeling a need to discuss how they wanted the groundstaff to prepare the pitch before the commencement of the season and only 10% admitting to giving the groundstaff specific instructions. Such approaches were also notable regarding decisions on how the groundstaff were to prepare the pitches for both daily training and even matches. Key stakeholders were also seemingly ambivalent in their decisions regarding where they trained on a daily basis, any specific watering strategies, and even on the length of the grass they required on their pitches. Perhaps it was not surprising that less than 15% felt they had a close working relationship with their groundstaff, while over 60%

did not perceive such a relationship as important. It is well recognised that a team's collective efficacy is often the mediator between cohesion and performance outcome (Carron et al 2002). The conclusions from this study that key stakeholders were not satisfied with the natural turf pitches in either training or at their stadia, coupled with a lack of responsibility for the preparation and maintenance of such pitches is highly significant. Role clarity, and a shared acceptance of one another's roles are of paramount importance to successful team work. Clearly such poor team working, communication and support for one another's roles may have a pivotal part to play in the apparent disconnect between key stakeholders and those taxed with preparing the pitches upon which the game is played, namely the groundstaff. This may be viewed as a key factor in the perceptions of participants' within this study.

3.5 Limitations

Undoubtedly, the greatest limitation with this study was how the participants were recruited. The challenge for researchers working within the hard to reach population of elite level professional football is that access to key stakeholders, in particular the players, is often viewed with suspicion even with the promise of anonymity. Consequently, access is often via 'gatekeepers', who control to a large extent, how such requests are dealt with internally with their organisations. In this instance, the gatekeepers being the head physiotherapists at each club, determined who, how and when any questionnaires were completed. Although the participants within this study showed a broad range of experience, and appear a representative group; it is impossible to report the true response rate of the questionnaire, as no record of the number of questionnaires distributed by the head physiotherapist at the clubs were made. Secondly, perceptions can often be swayed by audience effects; it is unclear whether the questionnaires returned from the clubs were completed in isolation or in the presence of others. As a result, such audience bias is not known and needs to be acknowledged. Thirdly, the ethnic profile of participants indicated that the majority were white in origin, with only 74 (18%) from 419, reporting their race as non-white. Since the questionnaires were administered by a third party, it makes it difficult to interpret whether more non-white subjects declined to complete a questionnaire, or whether they were not provided with the opportunity to do so. Fourthly, the lack of redress to some of the perceptions raised particularly by the groundstaff limits the understanding of how their perceptions may shape their approach to the preparation and maintenance of the pitches. Finally, the number of groundstaff sampled was relatively low in comparison to all other occupational groups, which makes the interpretation of their responses more difficult than other stakeholders.

3.6 Conclusion

This chapter has revealed that key stakeholders perceive hardness of natural turf pitches to affect both performance and injury risk. Such concerns were echoed by ex-player and now television pundit Pat Nevin (2017) in an interview for BBC sport.

"*In the simplest terms, modern pitches look fantastic; they are beautifully flat and can cope with huge wear and tear. The groundsmen make them look beautiful for the TV, but when the changeover was happening did anyone ask the players, the managers or the medics what was needed?"* (Braidwood, 2017).

A conceptual model has been proposed within the literature review illustratrated how the extrinsic risk factor, the natural turf pitch could influence a footballer's risk of injury. By detailing the perceptions of key stakeholders within football, part 1 of this study has outlined the perceptions that natural turf pitches can be viewed as a risk factor for injury. It has demonstrated how perceptions of hard or soft natural turf pitches affect specific tissues and their risk of injury, in a surface dependent manner. Expanding upon this, Part 2 highlighted how pitch hardness was perceived to affect the bounce and roll of the ball, the player and their team, through the adaptation of passing and running performance strategies. Furthermore, it also demonstrates how perceptions of relative fatigue and the tempo of the game is likely affected by the surface hardness. Finally, in closing with an examination of relationships between key stakeholders and their groundstaff, the study has demonstrated an apparent lack of accountability and a disjointed workplace, where collaboration between key stakeholders and groundstaff appeared extremely limited. Such poor working practices may be viewed as a major contributing factor to many of the perceptions reported within this study.

However, despite perceptual data showing concern; it does not provide a specific surface hardness that was considered effective for both the performance of the ball, the player and the team. Neither, does it reflect a specific hardness, which does not adversely affect the likelihood of injury as a result of exposure. Consequently, researchers need to establish pitch quality standards which reflect those of the key stakeholders, namely to enhance performance whilst minimising the risk of injury. This must be in collaboration with all those working within the game, as clearly the data presented highlights that there are occupational differences underpinning such perceptions. Furthermore, future research needs to be performed in a prospective manner, utilising objective measurement techniques and accurate injury surveillance strategies in order to address the concerns, of those using such pitches.

CHAPTER 4

Pitch hardness within association football:

The development of methodological

procedures for the objective evaluation of the

natural turf football pitch.

4.0 Chapter prelude

The literature review (Chapter 2) highlighted the lack of objectivity within natural turf football pitch testing. Available studies, adopting objective means for evaluating surface hardness, did not share a common methodology; consequently, knowledge is limited by the methodological variances within the available research. Researchers wanting to measure pitch hardness have to make multiple decisions on how to approach the measurement of pitch hardness for example, tools, protocols, and frequency of sampling. The following chapter addresses three independent methodological problems highlighted by the current literature (4.1-4.3). This approach developed a protocol which was accurate, reliable and pragmatic enough to enable researchers to assess the hardness of natural turf football pitches.

4.1 Introduction

Since the 1980's research into football pitch construction has focused on delivering set quality standards to ensure a playing surface that is both hard wearing and cost effective (Baker et al 2007, Stiles et al 2009). The pitch standards must also simultaneously provide a platform for the enjoyment of players and spectators alike, on which the risk of injury is minimised (Baker and Canaway, 1993). In order to determine the contribution of pitch hardness to the risk of injury within football, the integration of reliable and objective means for measuring ground hardness is needed. Early researchers utilised subjective measures such as 'degrees of squelchiness' (Thornton 1973) or the heel test to assess surface resilience or hardness. Inter-tester reliability was problematic and rating hardness along a ten-point scale, where a score of seven was indicative of a surface appropriate for football was difficult and prone to error (van Wijk 1980). Researchers have also experimented with different objective measures for hardness such as the Stuttgart athlete (Bell et al 1985) and even penetrometers (Orchard, 2001). Originally designed to measure road compaction, the Clegg Hammer (Clegg, 1973) became a pragmatic means of assessing the hardness of any given football pitch. It is easy to use, provides reliable objective readings and does not adversely affect the pitch surface prohibiting its use prior to training or matches (Twomey et al 2011). Furthermore, it has been shown to relate well to the players' perceptions of hardness (Canaway, 1994).

Within football, the hardness of the natural turf has been benchmarked using the Clegg Hammer (UEFA, 2018). Consequently, a professional natural turf pitch should fall between 70-90G, with acceptable limits between 60-100G, and anything above 100G or below 60G being deemed unacceptable (UEFA, 2018). Despite the availability of such objective measures and guidelines, no scientific papers have utilised the device to quantify pitch hardness and relate this to the problem injuries within professional football (Rennie et al, 2016). One explanation may be found in methodology used by researchers to assess pitch hardness (Petrass and Twomey, 2013). Uniformity in the testing protocols adopted, drop heights and hammer weights makes comparison of data between studies difficult. This chapter will address these issues, in particular reliability of the testing process focusing on three main concerns. Firstly, the number of recommended consecutive drops of the Clegg Hammer (2.25kg). Secondly, the optimal pattern with which the hammer is dropped onto the pitch surface. Finally, assessing the inter or intra-tester reliability of such a device on natural turf football pitches. These concerns will be addressed through the independent studies outlined below.

4.1.1 How many consecutive drops of the Clegg Hammer reflect the natural turf pitch hardness?

The literature appears somewhat confusing regarding the optimum number of drops required to establish a representative value for the surface hardness being tested. Early studies evaluating natural turf with the Clegg hammer, recommended that the hammer be dropped consecutively onto a surface until readings became stable which was noted as generally occurring on the fourth drop (Clegg 1976). This contrasts the views of The American Society for Testing and Materials (ASTM, 2000) standard which recommends using one single drop of the Clegg Hammer based on the premise that it replicates player movement more closely. Other researchers reported using the first, third or fourth drop as a reflection of the surface hardness (ASTM, 2000, Chivers et al, 2003, Caple et al 2012). Indeed, for many authors, the most notable being those who founded the pitch quality standards used today, fail even to report how many drops of the Clegg Hammer they used within their studies (Baker et al 2007).

Clearly the adoption of repeated consecutive drops as recommended by Clegg (1976) produces the greatest surface compaction by the hammer with the first drop. After which further deformation with each subsequent hammer drop is reduced. However, research by Twomey et al (2014) demonstrated that hardness figures with further consecutive drops continue to increase with significant differences being reported between the first and second drops, but not between the third and fourth on community-level Australian Football pitches. Findings such as these, demonstrate that decisions regarding the number of drops recorded needs careful consideration as conclusions regarding the performance of the pitch, or the association with injury risk, may vary considerably depending on the number of drops made (Twomey et al 2014). Thus far no research has been published regarding the relationships between consecutive drops of the Clegg Hammer on a natural turf football pitch.

The aim of this study was to determine whether significant differences exist between five consecutive Clegg Hammer drops on a natural turf football pitch. This information will promote better understanding of previous protocols and how they affect the pitch hardness results reported. Furthermore, it may develop methodology which is both time and resource efficient in determining values for surface hardness.

4.1.2 What drop pattern for the Clegg hammer should be adopted to reflect the hardness level of any natural turf pitches?

Natural turf pitches are known to demonstrate both temporal (over the course of a season) and spatial variation (within one given pitch) in their relative hardness. Consequently, they rarely reflect a uniform pattern of hardness across their entire surface (Baker et al 1991, Bartlett et al 2009, Caple, et al, 2012; Straw et al 2018). In order to gain a truer understanding of how the natural turf pitch hardness may affect performance or injury, testing needs to reflect where the players move during the game (Caple et al, 2012). Thus far, researchers have adopted numerous hammer drop protocols (Figure 4.1) which appear based on ease of testing or in order to answer a specific research question (Baker 1995). The adoption of such a variety of drop patterns makes comparison between studies difficult.

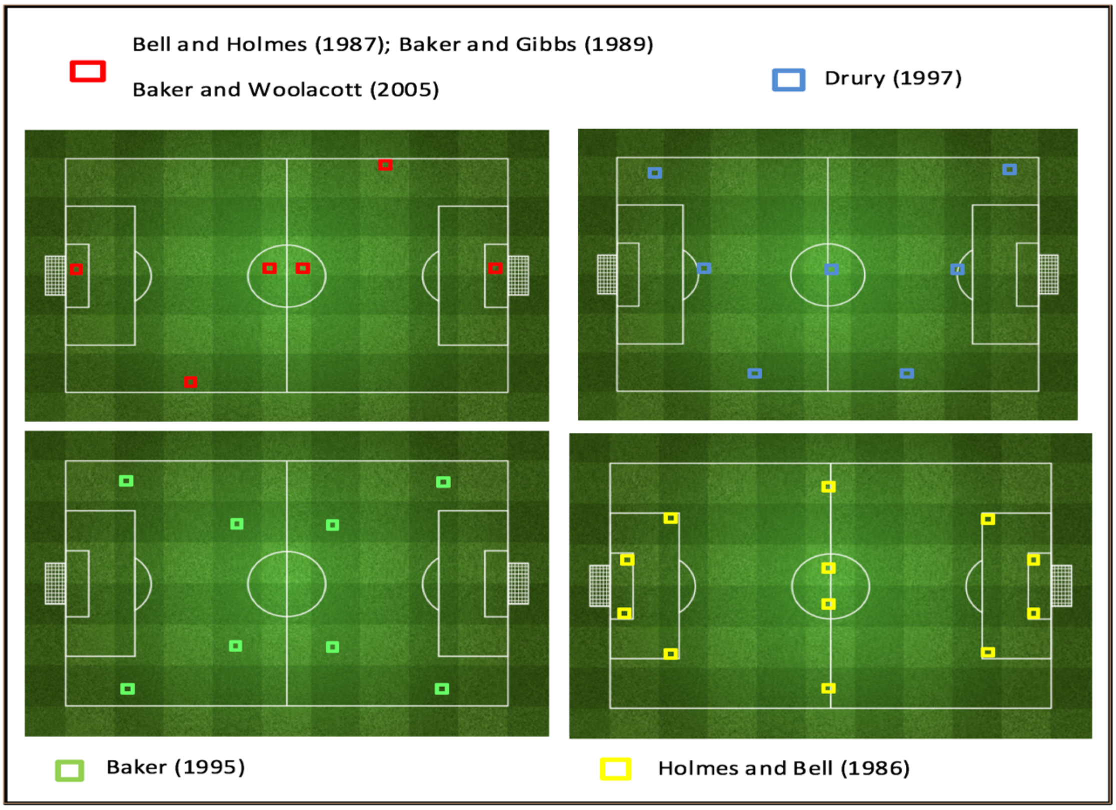


Figure 4.1 Illustrates a variety of 'drop pattern' protocols used for the Clegg Hammer within the literature.

The concentration of footfall as indicated by the recognised wear profile of the natural turf pitch has been used previously to establish testing protocols for pitch hardness (Adams and Gibbs, 1994). It is generally accepted that the wear pattern on a soccer pitch follows a diamond shape extending outward from the goalmouth to the touch line at half way before narrowing once again to terminate at the opposing goalmouth (Adams and Gibbs, 1994). However, at an elite level, wear patterns of pitches may appear less apparent as improvements in pitch construction, maintenance and the use of lighting rigs promoting year round growth (Thomson and Rennie, 2016). Nevertheless, the compaction of the surface attributed to footfall arguably could be higher, as players' physical performance and distances covered have increased significantly (Barnes et al 2014).

Figure 4.2, an 'Opta heat-map' illustrates the total ball contacts, by one team over 90 minutes in a Championship Football League game. The more intense the colour, the greater number of touches the team had within that area of the pitch. The data has been normalised to a single direction of play from left to right and overlain with the diamond wear pattern proposed by Adams and Gibbs (1994). It is reasonable to assume that the opposition will adopt defensive positons in relation to these ball contacts and as such players interact across almost the entirety of the pitch, frequently working outside of the diamond proposed by Adams and Gibbs (1994).

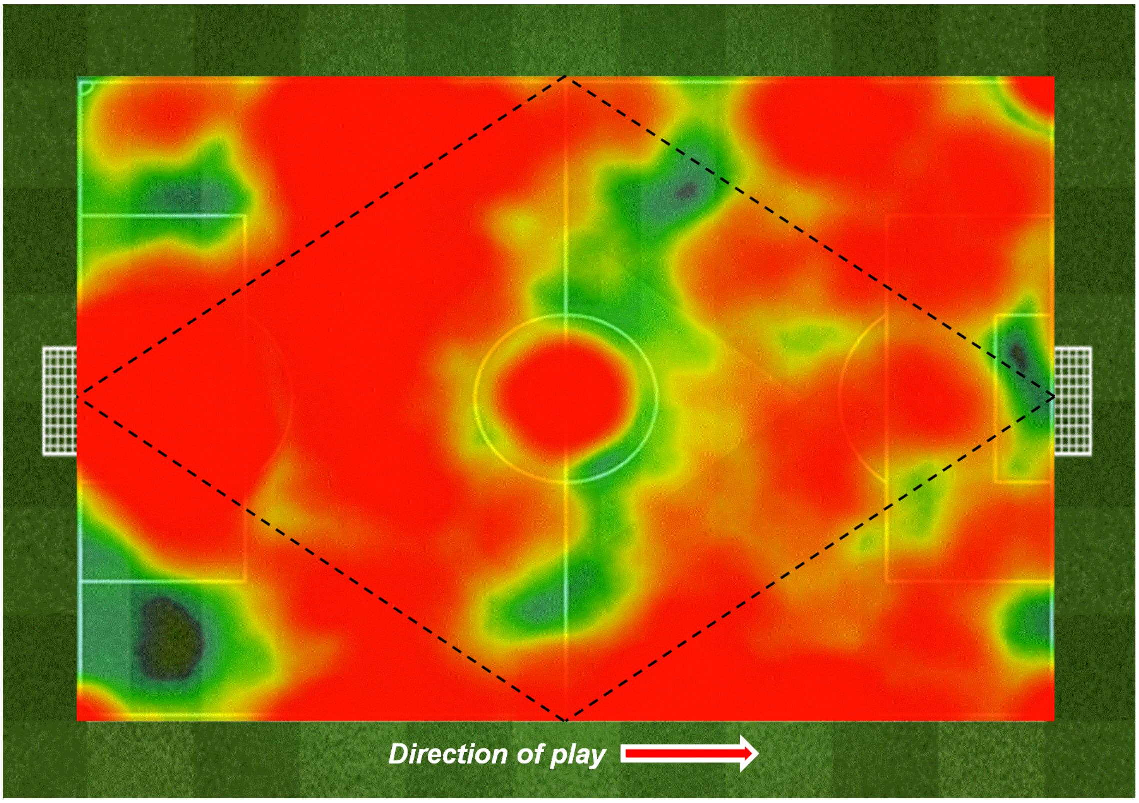


Figure 4.2 Opta Heat Map illustrating a team's total ball contacts during a Championship match within the Football League.

It is also apparent that if the drop patterns of previous researchers (Figure 4.1) are also overlain onto the Opta heat-map (Figure 4.2) there is a disparity between areas of wear/footfall, and where pitch hardness would have been measured. Consequently, research to date may not have gleaned a true reflection of the pitch hardness. This coupled with the seasonal nature of the game, prevailing climatic conditions, height of the spectators' stands and restricted airflow across the surface make it imperative when addressing pitch hardness to ensure a representative sample of the pitch has been analysed (James, 2011, Petrass and Twomey, 2013).

Thus far, no research has been published regarding the relationships between differing drop patterns of the Clegg Hammer on a natural turf football pitch. The aim of this study was twofold, firstly to establish a protocol for football which promotes a representative sample of the pitch hardness, adopting positions which are more reflective of playing position, wear patterns and the footfall of the elite players demonstrated in figure 4.3. Whilst secondly, to determine whether significant differences exist between the new 15-drop protocol and the four differing Clegg Hammer drop protocols highlighted in Figure 4.1. This information will aid a better understanding of the previous protocols and how they affect the pitch hardness results reported. Furthermore, it may develop a methodology which is both time and resource efficient.

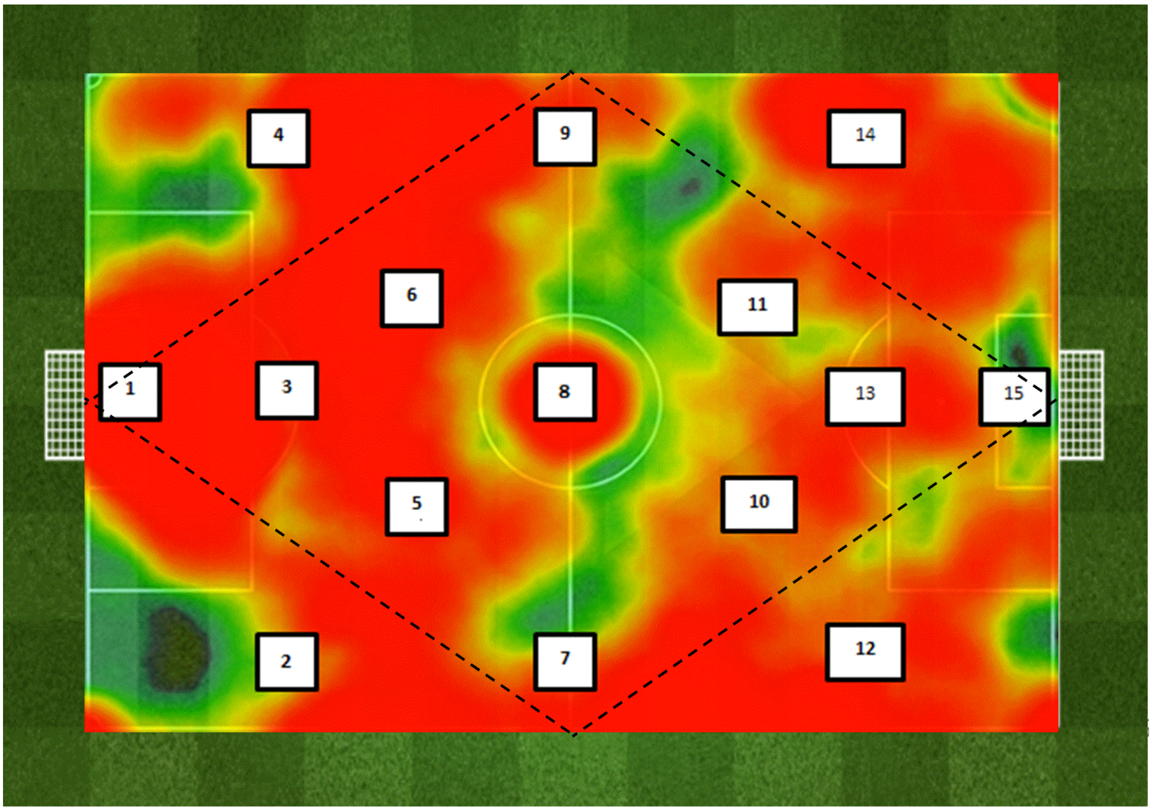


Figure 4.3 Opta heat map overlain with the diamond wear pattern and the proposed 15 drops Clegg Hammer protocol.

4.1.3 Does the users level of experience affect readings of the Clegg hammer? Inter and intra-tester reliability of the Clegg Hammer on a natural turf football pitch.

Within the controlled research setting it is often commonplace for one individual to perform all testing procedures thereby minimising potential bias or sampling error. However, within the applied sport setting, it is far less likely and resources may necessitate multiple-testers to ensure data is collected appropriately. When one or more testers are involved within a methodology it is often difficult to quantify exactly how any individual bias, or testing errors may affect the data collated (Gratton and Jones 2010). Consequently, it is important to have an understanding of intra and inter-tester reliability of the Clegg Hammer and its testing protocol. Available literature rarely cites how many testers were used in the collection of the Clegg Hammer data, nor does it state their level of experience or competence. In fact, only one study to date has examined the inter-rater reliability of the Clegg Hammer, reporting it to be robust enough for multiple-testers use as they demonstrated no significant differences between experienced or novice testers (Twomey et al, 2011). This study will examine Clegg hammer reliability as determined by the level of experience of the testers (experienced versus novice) performing the data collection.

4.2 Methodology

To aid clarity the methodology and result section will be contained in three parts, after which the most salient findings will be discussed collectively. Part A: explores the optimal number of consecutive drops that should constitute at Clegg Hammer Protocol. Part B: (1) develops an optimal 15-drop pattern for the Clegg Hammer, testing its reliability and (2) compares this new protocol with previously published drop patterns. Part C: addresses the inter and intra-tester reliability of the Clegg Hammer on a natural turf football pitch. For reference, the general cut length for elite pitches is between 22-25 mm, this was not recorded within this chapter as the 2.25kg Clegg hammer has previously been reported to be valid for such pitch preparations (McNitt & Landschoot, 2004; Miller, 2004).

4.2.1 Part A: How many consecutive drops of the hammer reflect the natural turf pitch hardness?

The surface hardness of one football pitch was sampled using a 2.25kg Clegg Hammer (Figure 4.4). It comprised an impact hammer (Missile) fitted with an accelerometer that measures its' deceleration impact in gravities (G). The hammer was dropped from a clearly marked drop height of 45 cm through a guide tube. The harder the surface the more rapidly the hammer decelerates on impact resulting in higher readings.

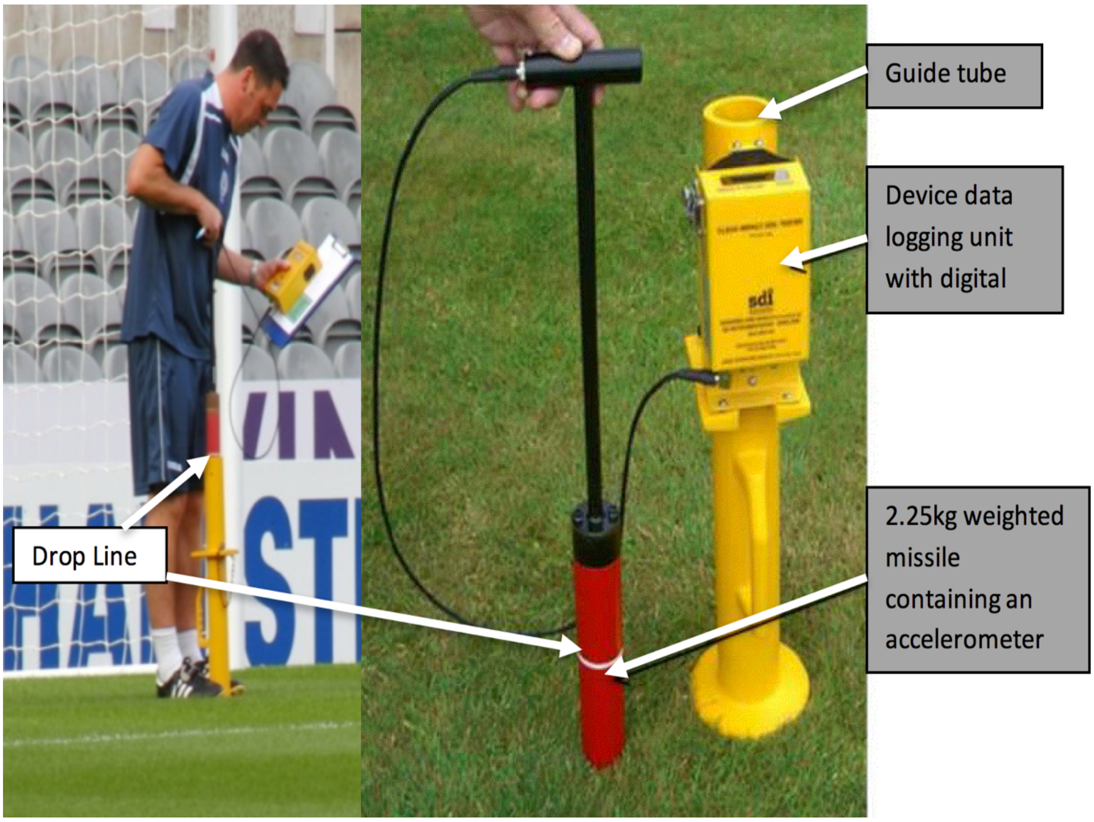


Figure 4.4 An illustration of the 2.25kg Clegg Impact Hammer tester during testing.

A repeated, consecutive five drop protocol was used to measure the pitch hardness with the Clegg Hammer. The pitch was tested across 15 different sites which were pre-selected and were deemed to reflect generalised team shape positions namely, goalkeeper, right/left full back, centre half, right/left centre midfield, right/left wing and a central striker. The shape was then mirrored on the opposite half of the pitch (Figure 4.5). Once in the recognised drop zone the tester took five consecutive readings without moving the base of the testing device, each drop of the hammer was recorded so that the same spot was repeatedly impacted and tested.

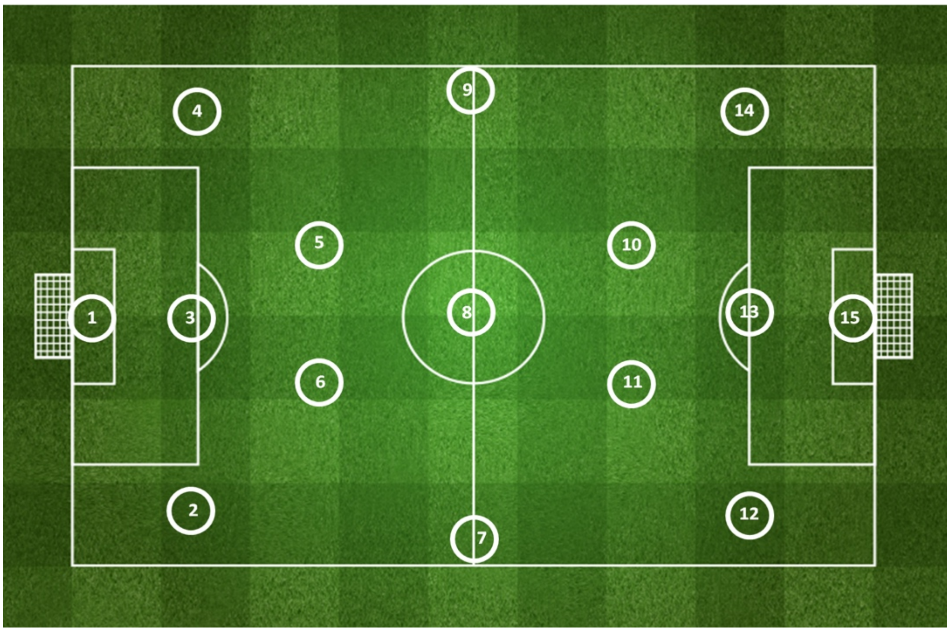


Figure 4.5 A schematic diagram illustrating the 15 pre-determined drop zones where hardness measures were taken.

The readings were collected in drop zone order (1-15) by one single experienced tester dropping the hammer consecutively five times. The pitch was sampled between 1400 and 1500 hours on the day of testing to allow air and soil temperatures to stabilise. Weather conditions remained dry, with a stable temperature of 12^{o} C throughout the testing period.

4.2.2 Statistical Analysis

All data were double entered in Microsoft Excel, checked and edited before being transferred and analysed in SPSS Version 24 (SPSS Inc., Chicago, Illinois). Descriptive statistics in the form of means, standard deviation, 95% confidence intervals and percentage increase for pitch hardness were calculated for the pitch on all 5 drops recorded at each of the 15 separate drop zones. As the data were normally distributed a repeated-measures analysis of variance (ANOVA) was undertaken to examine whether significant differences existed between the pitch hardness measurements. The data did not assume sphericity under Mauchly's Test of Sphericity therefore Huyn-Feldt adjustment was applied. Levels of Statistical significance were accepted at a $P < 0.05$. The use of correlation alone as a measure of reliability in sports medicine has received criticism in the literature (Atkinson and Nevill, 1998) and therefore it is recommended that additional measures are used to assess for reliability and agreement. Coefficient of Variance (CV) is one measure that can be used to assess the degree of variance which allows comparison between data.

4.2.3 Results

Table 4.2 Descriptive statistics of five consecutive Clegg hammer drops over 15 sites on a natural turf football pitch.

Hammer drop number	Mean (G)	Std. Deviation	Confidence interval (0.05)	Hardness Percentage increase
Hammer drop 1	89.200	5.7346	2.90	N/A
Hammer drop 2	106.867	8.3740	4.23	19.80
Hammer drop 3	112.467	8.1492	4.12	5.32
Hammer drop 4	116.067	9.9101	5.01	3.14
Hammer drop 5	118.733	10.9965	5.56	2.27

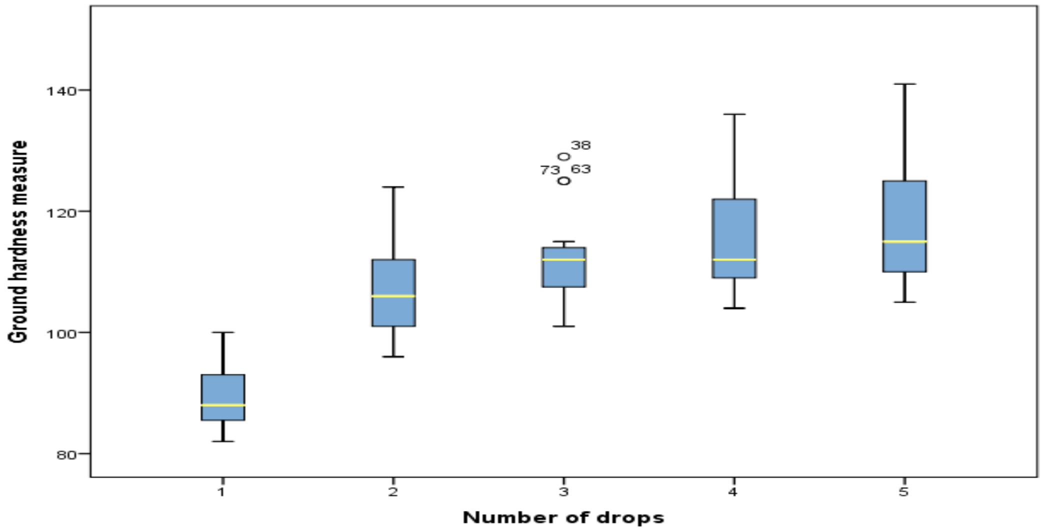


Figure 4.6 Box plots illustrating the effect of five consecutive drops of the Clegg Hammer over a natural turf football pitch.

The F test with Huynh-Feldt adjustment showed consecutive drops measurements were significantly different over the 5 drop measures F (1.277,6.384) =186.8, p=0.03 indicating that with subsequent drops the hardness value reported by the Clegg Hammer differ significantly from one another. Post-hoc testing found significant differences between each drop such that drops 1 and 2, and drop 2 and 3 (P<0.05), between the third and fourth drop there was no significant difference P=0.051. The fourth and fifth drop were also statistically different to one another however (P<0.05). It appears that increasing the number of consecutive drops within a given area there is an associated increase in the hardness measured which remains significant, but reduced, even after five drops.

4.2.4 Part B (1): The reliability of a 15-drop football specific Clegg Hammer drop pattern.

4.2.5 Methodology

The surface hardness of one football pitch was sampled using a 2.25kg Clegg Hammer (Figure 4). The 15-drop protocol adopted in 4.2.1 (Part A), was also used for this study. This protocol had 11 measures within the diamond of wear reported by Adams and Gibbs, (1994). In addition, the 4 drops which fall outside of the wear pattern, help to address the movement profiles seen on the Opta Heat map (Figure 4.3). It was hypothesised that this will promote a more representative sample of the pitches hardness as the 15-drop protocol adopts positions which are more representative of playing position and are more reflective of the wear patterns outlined by Adams and Gibbs (1994).

In line with the findings of the previous study (Part A: 4.2.1), the standard one drop protocol as advised by the ASTM (2000) was adopted to measure the pitch hardness. This process was repeated ten times in drop zone order (1-15) to evaluate the reliability of the measure. Consequently, 150 measures of pitch hardness were obtained (1 single drop at 15 drop zones x 10 repetitions N= 150). The test protocol was sampled between 1400 and 1500 hours on the day of testing to allow air and soil temperatures to stabilise. Weather conditions remained dry, with a stable temperature of 12^{o} C throughout the testing period.

4.2.6 Statistical analysis

All data were double entered in Microsoft Excel, checked and edited before being transferred and analysed in SPSS Version 24 (SPSS Inc., Chicago, Illinois). Means, standard deviations and 95% confidence intervals were calculated for the pitch on all ten occasions of testing. The data was checked for normal distribution using the Jarque Berra test. As the data were normally distributed the F Test was undertaken to examine whether significant differences existed between the pitch hardness measurements both as a total pitch and by the constituent individual drop zone.

Intra-class correlation coefficients (ICCs) were used to assess reliability of total scores between each full pitch measure. Intra Class Correlation measures how strongly the measurements resemble each other. Statistical significance was accepted at a *P* value of <0.05. To determine the intra-rater reliability, intra-class correlation coefficients (ICCs) were calculated. In order to classify the ICCs, the Landis-Koch classification was used to rate the level of agreement: 0.00-0.20, slight; 0.21-0.40, fair; 0.41-0.60, moderate; 0.61-0.80, substantial; 0.81-1.00, almost perfect.

4.2.7 Results: B (1) The reliability of a 15-drop football specific Clegg Hammer drop pattern.

Data were tested for the assumptions of normality which was achieved. The Mauchly's Test of sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(9) = 11.111$, $p = 0.999$. The scores for the 15 drop zones were averaged, with standard deviations and confidence intervals being calculated to create a representation or overall score for the relative total/whole pitch hardness. This was repeated a further nine times. Taken as a whole the ten repeated tests measures' for mean hardness were found to be 89.1 (SD, 1.168; C.I. 0.77). The stability or consistency of the repeated measures for pitch hardness measured is clearly visible in Table 4.3. Both the range within the data set and the confidence intervals are small suggestive of highly reliable measures.

Intra-class correlation for the ten repeated measures of whole pitch hardness demonstrated in Table 4.4, indicates almost perfect intra-class reliability (Landis-Koch) demonstrating the test-retest reliability for the pitch as measured with the 2.25kg Clegg hammer across 15 pre-determined drop zones was highly reliable ($p<0.001$).

Table 4.3 Intra-class correlation coefficients for the ten repeated measures of whole pitch hardness.

Intra-class Correlation [b]	95% Confidence Interval		F Test with **True Value 0**			
	Lower Bound	Upper Bound	Value	df1	df2	Sig
.926[c]	.854	.971	13.472	14	126	**.000**

These results support the concept that it is possible to obtain a reliable total pitch hardness score using the clegg hammer in 15 zones. Further evaluation of the variability in measures within each of the individual 15 drop zones was carried out using the F Test. Mauchly's test of sphericity was applied (not gained) consequently, Huynh-Feldt adjustment was employed resulting in a no significant difference being noted ($F=1.494$; $p=0.222$*).* The F test shows there is no significant difference amongst the measurements, this result is considered with the limited sphericity measured by the test. Therefore, the pitch hardness measures within each of the 15 identified drop zones showed no statistical difference. Consequently, the reliability of the repeated measures is not only demonstrated across total 15 drops on the pitch but also within each of the 15 single drop zones.

Table 4.4 Coefficient of Variance (%) for Repeated Measures of Pitch Hardness

Test	1	2	3	4	5	6	7	8	9	10
Mean	90	89.06	89.27	90.33	89.13	89.20	86.93	89.73	87.13	90.2
SD	5.54	3.90	3.55	5.89	5.5	5.73	6.94	4.89	7.30	5.71
%CV	6%	4%	3%	6%	6%	6%	7%	5%	8%	6%

4.2.8 Part B (2): A comparison of the 15-drop Clegg Hammer protocol with previous research.

In order to establish which protocols were the most representative of the pitch's relative hardness the 15-drop method was compared with those noted within the literature. The surface hardness of one football pitch was sampled using a 2.25kg Clegg Hammer (Figure 4.4). In line with the findings of the previous study (Part B: 4.2.5), the standard one drop protocol as advised by the ASTM (2000) was adopted to measure the pitch hardness. Each of the five differing drop protocols (i.e. 6 drops, 7 drops, 8 drops, 12 drops or 15-drops per pitch, Figures 4.1 and 4.5) was repeated five times across the surface of the pitch. The readings were collected by one single experienced Clegg Hammer user. The pitch was sampled between 1400 and 1600 hours on the day of testing to allow air and soil temperatures to stabilise. Weather conditions remained dry, with a stable temperature of 10^{o} C throughout the testing period.

4.2.9 Statistical Analysis

All data were double entered in Microsoft Excel, checked and edited before being transferred and analysed in SPSS Version 24 (SPSS Inc., Chicago, Illinois). Descriptive statistics in the form of means, standard deviation, 95% confidence intervals and were calculated for the pitch on all recorded drops within each of the five different protocols. The coefficient of variance (CV) was also calculated for the respective drop patterns.

4.2.10 Results

Table 4.5 Comparisons of data from differing Clegg Hammer drop protocols.

Drop protocol	Number of drops over five repeated tests	Minimum hardness (G)	Maximum hardness (G)	Mean hardness (G)	SD	CV (%)
15drop ■	75	53	72	63.27	3.743	5.92
12drop ■	60	48	77	60.67	5.736	9.45
8drop ■	40	53	70	59.63	3.364	5.64
7drop ■	35	51	76	61.11	5.069	8.29
6drop ■	30	49	68	59.63	5.236	8.78

The sample sizes over the study show marked differences with the 15 drop protocol obtaining an additional 45 measures of surface hardness in comparison to the 6 drop protocol. It was also noticeable that the 15 drop protocol resulted in the highest mean score for pitch hardness (63.3G) whereas the 8 and 6 drop protocols reported the pitch to be the softest (59.6G). Interestingly the highest degree of variation within the pitch measures taken by drop number was shown by the 12 drop protocol (CV, 9.45) which was also reflected in the largest data range of 29G.

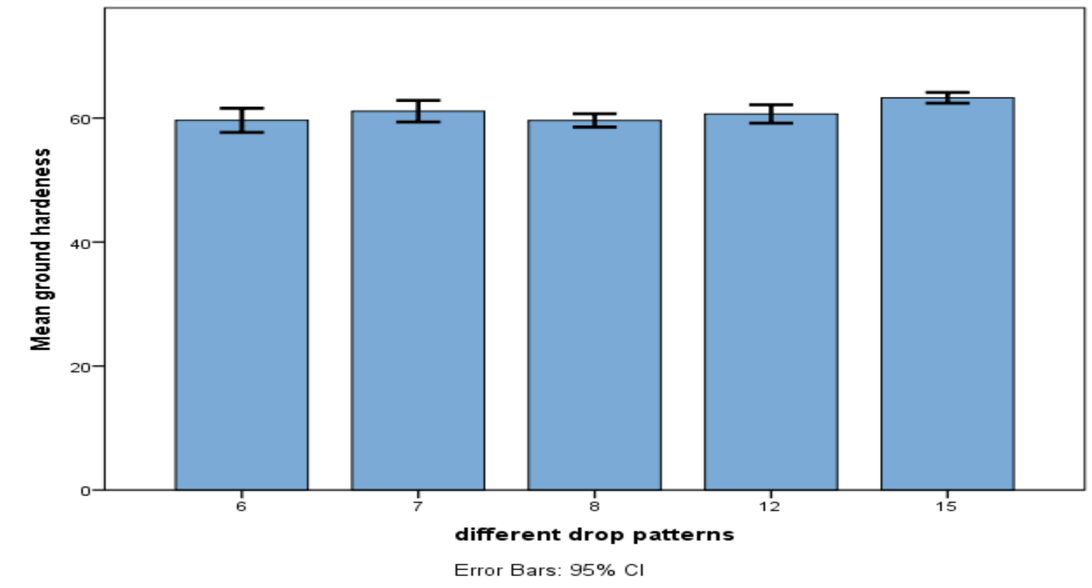


Figure 4.7 Bar chart illustrating mean hardness in relation to drop patterns with associated error bars

The bar graph illustrates how the mean data appear very similar however; the error bars are notably smallest within the 15-drop protocol which maybe suggestive of a more representative sample.

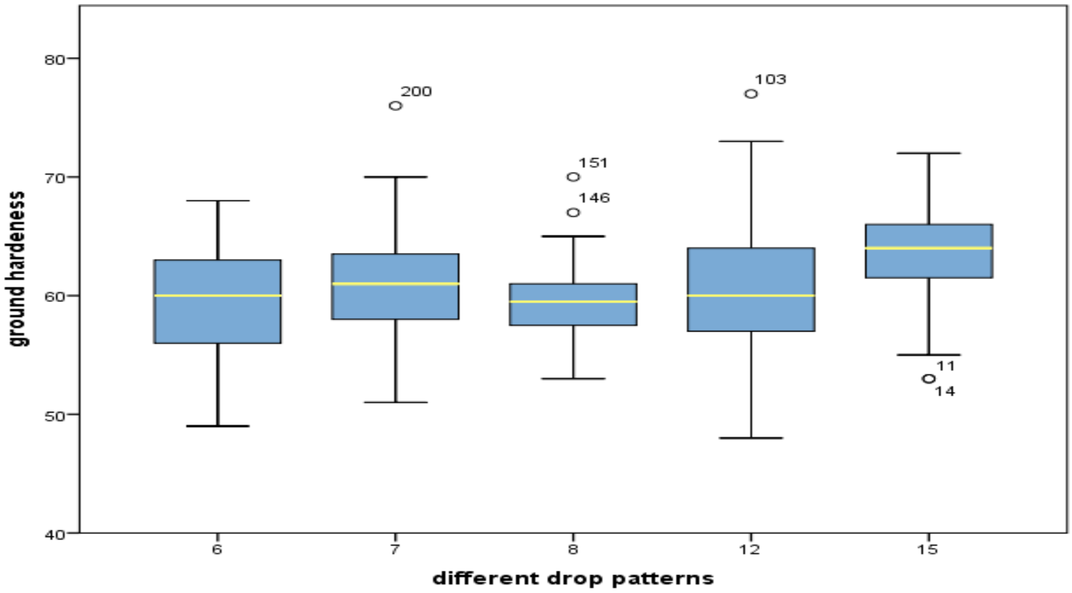


Figure 4.8 Box plots of the varied drop patterns in relation to pitch hardness (G).

4.2.11 Does the users level of experience affect readings of the Clegg hammer? Inter and intra-tester reliability on a natural turf football pitch.

4.2.12 Methodology

The surface hardness of one football pitch was sampled using a 2.25kg Clegg Hammer. The standard one drop protocol as advised by the ASTM (2000) was used to measure the pitch hardness over 15 pre-determined drop zones. The readings were collected in drop zone order (1-15) by two experienced and two novice testers. Experienced testers had over one year's practise of using the Clegg hammer whereas, novice testers used the device for the first time on the day of testing. Novice testers were given a basic demonstration of the Clegg Hammer, were provided with a recording sheet for their scores and were not informed of the likely level of pitch hardness. The four testers performed the pitch assessment in isolation and were blinded to the results of the other testers to eliminate any potential bias. Each tester sampled the pitch five times between 1400 and 1600 hours on the day of testing to allow air and soil temperatures to stabilise. Weather conditions remained dry, with a stable temperature of 12^{o} C throughout the testing period.

4.2.13 Statistical Analysis

All data were double entered in Microsoft Excel, checked and edited before being transferred and analysed in SPSS Version 24 (SPSS Inc., Chicago, Illinois). Means, standard deviations and 95% confidence intervals were calculated for each testers pitch hardness scores on all five occasions of testing. As the data were normally distributed a repeated-measures analysis of variance (ANOVA) was undertaken to examine whether significant differences existed between the pitch hardness measurements. To determine the inter-rater and intra-rater reliability, intra-class correlation coefficients (ICCs) were calculated. In order to classify the ICCs, the Landis-Koch classification was used to rate the level of agreement: 0.00-0.20, slight; 0.21-0.40, fair; 0.41-0.60, moderate; 0.61-0.80, substantial; 0.81-1.00, almost perfect. Given the data were derived of a normal distribution, Bland-Altman plots were created in order to compare the level of agreement between the experienced and novice testers (Altman and Bland, 1983: Bland and Altman 1986).

4.2.14 Results

Table 4.6 Descriptive statistics illustrating intra-tester differences in Clegg Hammer readings based on level of experience.

Level of experience	Mean	Standard Deviation	N
Experienced 1	63.27	3.743	75
Experienced 2	62.79	3.743	75
Novice 1	60.16	4.430	75
Novice 2	61.17	4.154	75

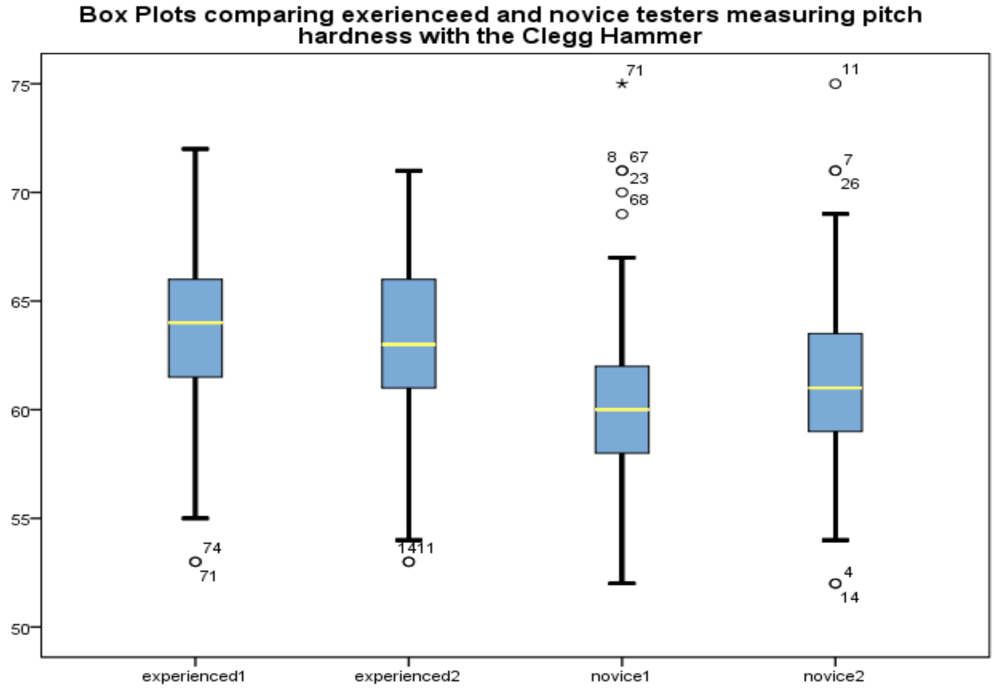


Figure 4.9 Box plots demonstrating variability in testing scores when comparing the experienced and novice testers.

The descriptive data in Table 4.6 shows marginally higher mean scores recorded for the experienced testers rather than the novice testers. There is also a noticeably reduced standard deviation for the experienced testers possibly indicating less variability in the measures.

In addition to increasing variance associated with larger standard deviation for novice testers, the box plots clearly indicate that their data is less consistently controlled than that of the experienced testers as they demonstrate many more ‘outliers’. It is particularly noticeable that the majority of outliers within the novices’ data fall above the upper limits of the inter-quartile range. Both experienced testers were very similar in their resulting data. Interestingly the two experienced testers’ recorded two outliers each both located beneath the lower interquartile range were recorded in two identical drop zones (11 and 14).

Calculation of the inter-tester reliability utilising ICCs (presented in Table 4.7) revealed there to be noticeable difference between the pitch hardness scores obtained and the level of experience of the tester. Taken collectively the experienced and novice testers showed moderate levels of reliability (ICC, 0.362; p=0.004). However, comparison between experienced and novice testers where no reliability was evident. Substantial reliability (ICC, 0.664; p<0.001) was found between the two experienced tester whereas moderate levels were found between the two novices (ICC, 0.567; p=0.002).

Table 4.7 Demonstrates the Intra-class correlations between the four Clegg Hammer testers.

	ICC	95% CI Lower Bound	95% CI Upper Bound	Sig	Classification
Between all four testers	0.357	.106	.556	0.004	Moderate
Experienced 1 v Experienced 2	.664	-.470	.728	0.000	Substantial
Experienced 1 v Novice 1	.068[c]	-.314	.362	0.350	No reliability
Experienced 1 v Novice 2	.031[c]	-.439	.361	0.440	No reliability
Experienced 2 v novice 1	-.095[c]	-.672	.291	0.775	No reliability
Experienced 2 v Novice 2	-.160[c]	-.691	.226	0.662	No reliability
Novice 1 v Novice 2	.567[c]	.321	.725	0.002	Moderate

Test-retest reliability was high for all four testers regardless of experience with the two experienced testers showed almost perfect re-test reliability (Experienced 1, ICC, p<0.002; Experienced 2, ICC, p<0.001). The novice testers also showed almost perfect re-test reliability (Novice 1, ICC 0.969 P<.0001; Novice 2, ICC0.916, p<0.001).

Figures 4.10-4.15 display Bland-Altman plots for the level of agreement between expert and novice assessors. The lowest level of bias is found between the two expert measures where the bias is set at 0.48 and lower and upper levels of agreement are 7.8 and -6.7 respectively. There are two outliers sitting on the upper level of agreement and one below the lower level however the remaining data is within +- 2 standard deviations of the bias around the mean. The lowest level of agreement is between Expert 1 and Novice 1 with a bias of 3.1 with levels of agreement being 14.2-8.0 for upper and lower levels respectively.

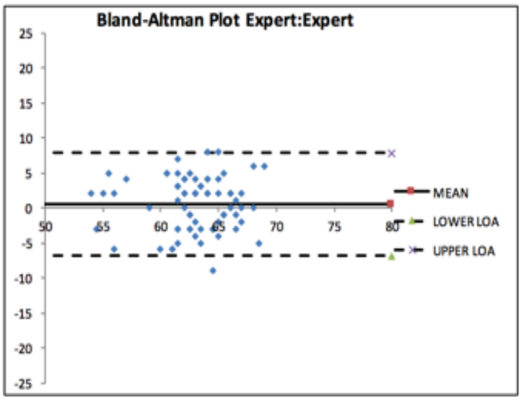


Figure 4.10 ExpertVExpert

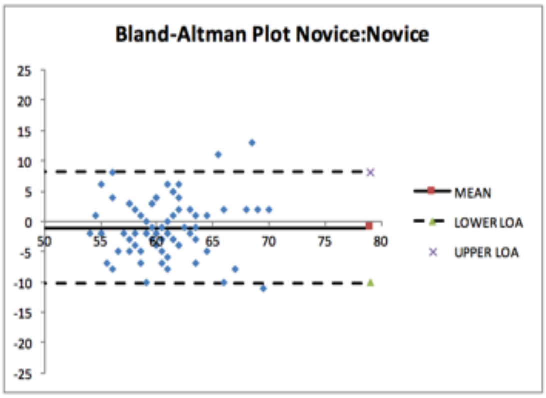


Figure 4.11 NoviceVNovice

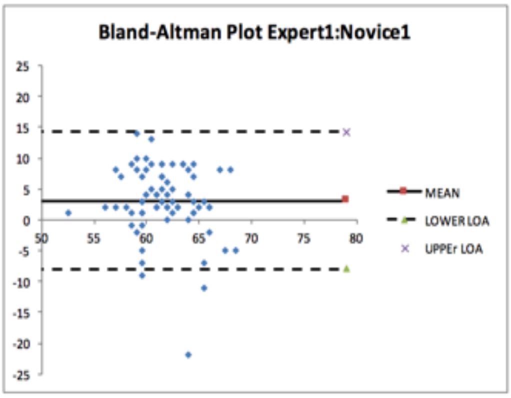


Figure 4.12Expert1VNovice1

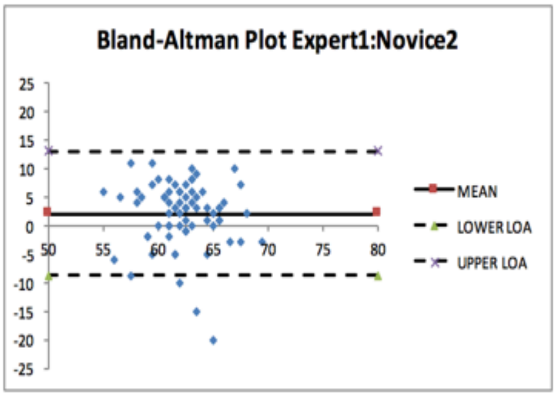


Figure 4.13Expert1VNovice2

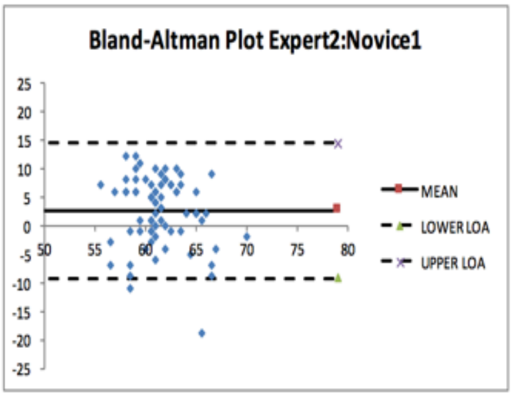


Figure 4.14 Expert2VNovice1

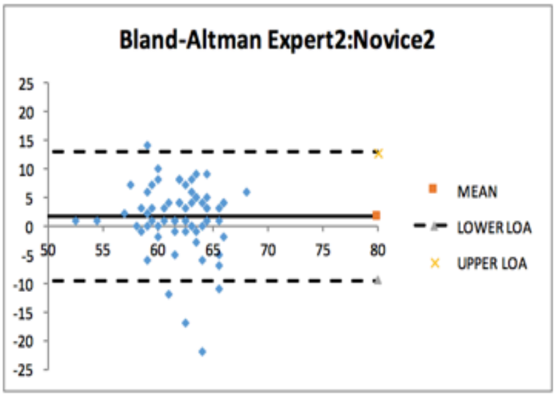


Figure 4.15Expert2VNovice2

Figures 4.10-4.15: Bland-Altman plots for the level of agreement between expert and novice assessors.

4.3 Discussion

This chapter has evaluated an objective means for evaluating the hardness of natural turf namely, the Clegg Hammer (2.25kg). Adopting a logical, robust process, the studies have provided clarity regarding such testing within elite football. As such the first drop recommended by the ASTM (2000) was confirmed as the preferred choice. The development of a football specific 15-drop protocol was compared with those of previous researchers finding it to be more reliable and reflective of the positions/movement patterns of players. Finally, the effect of user experience regarding the Clegg Hammer was clarified. Collectively, these result provide a standardisation of methodology for researchers to investigate how such pitch hardness affects injury and performance.

Within the literature the only available study concerning the effects of repeated consecutive Clegg Hammer drops was performed on community level Australian football fields. Twomey et al (2014) concluded that surface hardness as reported by the Clegg Hammer is dependent upon the number of times it is dropped on the surface of the pitch. Significant differences were found between the first and second drop (14.0% change; $P<0.001$) but not between the third and fourth drop (2.1% change;($P<0.57$) (Twomey et al, 2014). This differs from the data shown within this study (4.2.1) which reports significant differences in pitch hardness are noted even after a fifth drop has been made. This may be attributable to the standard of pitches examined being community Australian Football League (AFL) rather than a higher standard football pitch. The range between drops in Twomey's study (75.4 drop 1 - 91.4 on drop 4) was less than this current study (89.2 drop 1 - 116 on drop 4) which may be indicative of their underlying construction with the sand based football pitch having larger propensity for surface deformation and thereby a larger available range for compaction.

What is clearly evident within the data of Twomey et al (2014) is the trend for a graduated increase in subsequent mean hardness coupled with a reduction in the percentage change with each subsequent hammer drop. This corroborates the findings of this study where the mean hardness rises form 89.2G to 118G over the 5 drops whereas the percentage change in the mean falls from 19.8% to 2.27% by the fifth drop. This is likely to be attributable to the increasing surface compaction with each subsequent drop.

However, despite the increasing compaction of the surface reported within this study the spread of the data appears to increase with subsequent drops, a factor which is also reflected by the increasing confidence intervals noted in Table 4.2. Such is the increase that by the fifth drop the spread is approximately 40G, compared with the 15G witnessed between drop 1 and drop 2. This may in itself be a pertinent finding for researchers as dispersion within data may affect their ability to draw inferences or predictions regarding other measures.

Collectively the results of both Twomey et al (2014) and this study demonstrate that decisions regarding the number of Clegg Hammer drops requires careful consideration especially if data is being used to investigate injury or performance in football. Injuries within community level AFL and junior cricket in Australia have utilised the first drop as their preferred method in line with the ASTM (2000) recommendations. What is apparent is that if any of the other consecutive drops had been used the reported hardness values would have been significantly higher and therefore the conclusions drawn would have been different.

More practically, during the consecutive drop testing it was noted that surface deformation with the hammer was marked particularly on areas where grass coverage was sparse or wear patterns were high. Clearly with increasing consecutive drops of the Clegg Hammer (circled 1-5) the resulting soil compaction leaves a deeper indent in the pitches surface. Researchers within the applied setting need to strike a balance which provides testing protocols whilst being accurate, informative and reliable are also amenable to administration as close to pitch use as possible. This should enable access and acceptance by those who use and those who prepare the natural turf pitch.

Figure 4.16. A photograph of the pitch surface following a test of; 1, 2, 3, 4, or 5 consecutively repeated drops.

The findings of this study that repeated, consecutive drops of the Clegg Hammer on a natural turf football pitch, produce increases in hardness values with each subsequent drop is crucial. Researchers need clarity regarding which drop was used in order to fully understand the relative hardness of the reported surface hardness. It is imperative any future work clearly states the number of hammer drops used in order for results to be accurately interpreted and valid comparisons drawn. The recommendation of this work is to use one drop only at each site in line with the the ASTM (2000) recommendations. The second study within this chapter (study 4.2.4) shows that the 2.25 kg Clegg hammer as a means to assess the hardness of a natural turf pitch is a highly reliable objective measure. This is an important finding as the need for objectivity in the testing of pitch hardness is paramount, if researchers are to investigate the potential role that the pitch may play within injury in football (Twomey et al, 2014).

Whilst the construction of today's football natural turf pitch is designed to be consistent between each interaction, by virtue they are a living thing, affected by footfall and climatic conditions they can never be 100% uniform (Stiles et al 2009; Caple et al, 2012). The spatial variability of pitch hardness witnessed in the repeatability testing was small. This is demonstrated clearly in Figure 4.7, where small fluctuations about the mean hardness and variations in the error bars show that even when testing a pitch in quick succession on a climatically stable dry day the measures obtained will fluctuate. The coefficient of variance which is <10% across all repeated measures provides further evidence for the reliability of the tool and the drop zone pattern. The 15-drop zones were not definitive markings on the pitch, rather the pattern of drops were regarded as a practical, pragmatic approach to obtaining an objective reflection of pitch hardness which could be readily used within the applied setting. Consequently, the exact point within any given zone where the tester determined to drop the Clegg Hammer was open to interpretation, a factor which may affect the variability seen. However, as there was no evidence of statistically significant difference found between the individual drop zones it would suggest that it was an appropriate means of evaluating the pitch.

In comparing this study with the works of Twomey et al (2011) it is noticeable that ICCs were significantly higher, 0.926 compared with 0.77. This is probably attributable to the differing nature, preparation and competitive standard of the pitches. Twomey evaluated the reliability of the Clegg Hammer on community level Australian Football League pitches, whereas this study examined a training ground pitch at an English Premiership League Club. The mean value for first drop hardness was noted within their work as being significantly higher at 123G compared with this study where pitch hardness averaged 89G. The construction of the surfaces in question will also undoubtedly lead to potential differences in the spatial variation of the scores obtained with comparisons between a professional clubs training and community based pitches making a true comparison difficult. Nevertheless, both studies confirm the Clegg hammer is a reliable means by which to assess pitch hardness.

A possible limitation of this study is that it was conducted only on one natural turf football pitch. However, the pitch conditions were deemed to be representative of what the training pitch should be at the stage of the season. Furthermore, restricting testing to a single day enabled greater control over climatic variables such as temperature and rainfall. Testing was performed in the afternoon and restricted to a single hour testing duration as this permitted climatic variation to be minimised as much as possible.

Whilst the findings that the Clegg Hammer was reliable is an important finding in itself, what remains unclear within the literature is how researchers should obtain a representative sample of the pitch. Consequently, numerous protocols have been proposed but no studies to date have examined how reliable or representative they actually are. Part B (2) of the chapter (4.2.8) addressed this in elite football demonstrating that the reported pitch hardness is dependent upon the protocol adopted for testing. It is clearly evident that although measures were taken sequentially on the same pitch and on the same day, with the same calibrated Clegg Hammer, by the same experienced user, there were significant differences in the reported pitch hardness dependent upon the protocol used.

Previously researchers appear to have used drop patterns to answer more specific questions rather than provide a general overview of the representative hardness of any given pitch (Baker et al 2007). Given the recognised wear pattern proposed by Adams and Gibbs (1994) it is unclear whether we have a valid understanding of pitch hardness, or one more reflective of where previous research decided to drop the Clegg Hammer. It is clear that all of the drop patterns illustrated in Figure 4.1 have limitations and many areas of the pitch are not assessed. Even where 12-drops across the pitch were proposed, large areas remain untested for instance, the midfield area (Bell and Holmes, 1986).

Notable differences in the average hardness for the pitch were seen with the example of 6-drop (mean 61.1G) and 8-drop (mean 59.6G) showing the pitch to be softer comparatively to that proposed by the more extensive 15-drop protocol (mean 63.2G). When one looks at the range of values it is clear that by limiting the number of drops some of the more extreme scores were missed. Examining more closely, the drop patterns with the lowest coefficient of variances notably the 8 drop and 15 drop patterns with box plots (Figure 4.8) it is clear that although the 8 drop pattern has tight spread of data, and the smallest inter-quartile range, it is also noted to have a number of outlying data points. One would expect the error measurements to be greater for the 8 drop patterns simply due to number of observations, 40 as compared to 75 with the 15 drop pattern. The additional drops appeared to enrich the data set, reducing the effect of the outliers enabling better conclusions to be drawn. Confidence intervals shows the narrowest in relation to the 15 drop pattern. Consequently, the 15 drop pattern has the lowest variance with respect to the number of measurements, thereby representing a truer reflection of the pitch hardness.

The results of the study also demonstrated the reported spatial variability known to exist within natural turf pitches. Recorded levels of hardness ranged from 49G to 77G across the surface of the same pitch. The 15-drop and 8-drop protocols recorded the lowest standard deviations of all those tested. This is an important finding as the large stadia of today's football have been reported to affect the shade, air-flow and growing capacity of the grass (James, 2011). If the testing area does not capture this data, then the reported values may prove ineffectual when propositions are made regarding how playable such surfaces are perceived to be. Further it will be difficult to evaluate how the pitch affects the performance of the ball, the individual or the teams approach to the game. If links are to be made between the relative hardness of such pitches and important variables such as injury risk, or performance then the data recorded must be a true reflection of the pitch hardness.

Researchers need a protocol for testing the pitch which reflects the demands that the game or training puts on the pitch. The 15-drop protocol proposed within this study was found to exhibit the lowest variance and is deemed the most likely of those tested, to provide an accurate measure of the relative hardness of the natural turf pitch. Furthermore, it helps develop methodology which is both time and resource efficient in determining values for surface hardness.

Research within the applied setting faces a number of differing challenges than that within academia. One such challenge, is maximising resources to enable adequate and regular data capture, as such it is often more commonplace that multiple testers are used within the applied setting. This study highlights that such an approach does not come without its potential problems as the data captured, can be dependent upon the level of experience of those have capturing it.

Clearly, despite the Clegg Hammer being shown to be a highly reliable measure for recording the surface hardness of a football pitch, it appears dependent upon the level of experience of its user. The inter-class correlation between the two experienced testers demonstrates the substantial reliability however; no such association was noted between the experienced testing score and those of the novice testers. Data collected by novice testers reflected lower average scores than their experienced counterparts. Furthermore, the number of outliers in excess of the upper interquartile range was high.

Perhaps one reason for this may be the design of the Clegg Hammer itself as the release height is dependent upon the tester accurately locating the mark on the drop tube. In this instance it appears novice testers may have over-estimated dropping the hammer from a height marginally higher than the actual mark, resulting in an increased acceleration of the hammer and consequently higher scores for pitch hardness. Alternatively, the novice tester may have inadvertently been pushing the hammer on release, resulting in the higher number of outliers above the inter-quartile range.

Test re-test reliability was high for all four testers regardless of experience with the two experienced testers showed almost perfect re-test reliability (Experienced 1, ICC, $p=0.002$; Experienced 2, ICC, $p<0.001$). The novice testers also showed almost perfect re-test reliability (Novice 1, ICC 0.969 $P<.0001$; Novice 2, ICC0.916, $p<0.001$). It was interesting to note however that both of the novice testers correlated well with one another suggesting that the difference between experienced and novice testers was on interpretation and execution of the testing task. Despite the evident differences between experienced and novice testers the differences between the two groups were consistent suggesting that reliability of the device is good even when used by novices. The significant inter-group differences between experienced and novice testers within this study highlight the need for research to inform readers of the levels of experience of those within their studies. This will enable a better comparison to be made between studies. This has implications for future research into pitch hardness especially when the data is to be used for predictive purposes regarding injury or performance within team sports.

Inter-rater reliability within Twomey et al (2011) work showed almost perfect relationships between novice and experienced testers which reduced minimally to a rating classification of substantial when examined against level of experience. Twomey's test retest reliability was not as good as this study with experienced tester scoring 0.77, 0.66 and 0.66 which was probably a reflection on the quality of the surfaces being measured (community versus professional). Interestingly, the novice testers scores varied between 0.70, 0.56 and 0.18 for the first Clegg Hammer drop. These values and those recorded within this study suggest that an ICC reliability level of 0.70 (substantial) should be adopted to confirm that a tester has demonstrated an adequate level of reliability prior to them participating in trials.

Twomey et al (2011) used intra class correlations for the measurement of reliability. Correlations whilst useful do not account for the degree of bias thus cannot be relied upon as a true measure of agreement (Atkinson and Nevill, 1998). The Bland-Altman plots provide greater insight into the agreement and the difference between the assessors. The plots demonstrate that there is the highest level of agreement for the expert testers, with an approximate 95% probability that the difference between any 2 tests lie within the limits of agreement and has the lowest level of bias.

Whilst it is encouraging that the Clegg hammer has been shown to be a reliable device, researchers must be aware of the potential for altered values dependent upon the user's level of experience. These findings reflect those of Twomey et al (2011) who also reported differences between experienced and novice testers with the Clegg Hammer. Their study also found novice testers under-reported/scored than their experienced counterparts with average 1st drop hardness of 116 compared with 120 (F value 0.88; *P<0.50).*

4.4 Conclusion

The findings of this study that repeated, consecutive drops of the Clegg Hammer on a natural turf football pitch, produce significant increases in hardness values with each subsequent drop is crucial. Researchers need clarity regarding which drop was used in order to fully understand the relative hardness of the reported surface hardness. The recommendation as a result of this work is to use one drop only at each site in line with the ASTM recommendations (2000). The 2.25kg Clegg Hammer was shown to be a portable and highly pragmatic means of testing natural turf pitch hardness. The standardisation of individual drops is good with the clearly marked drop position, the guide tube and digital display making data collection easy, whilst minimising any likely user error. The use of single drops inflicted no apparent damage to pitch surface making it amenable to being used close to training or match times. However, it must be noted that mechanical testing with the Clegg Hammer whilst providing objective measures of hardness, cannot be viewed as a reflection of the loads to which the players are exposed (Young and Flemming, 2007, Saunders et al 2011).

Researchers need a protocol for testing the pitch which reflects the demands that the game or training puts on the pitch. Such data needs to be sufficiently reflective of what is going on but not so constrained and time consuming that those employed in the applied setting forgo its collection. Furthermore, the results of this study highlight the potential variability that can exist between users, consequently, studies need to familiarise testers fully with the equipment being used to record hardness. It also suggests that if multiple testers are used that the reliability of their data be demonstrated to enable better comparisons with other published studies. It is apparent that methodological issues may have diluted the effects that pitch hardness may have had upon injuries in professional soccer. Future work is required to prospectively analyse, in a longitudinal manner how the hardness of the natural turf pitch varies temporally. Additionally, research needs to explore how the construction of the natural turf pitch affects both the temporal and spatial variation of such pitches. These research questions need to be answered in both the training and match situations, utilising the proposed 15-drop protocol whilst adopting one drop at each site, in line with the American Society for testing and materials (ASTM) recommendations. This data should then be correlated with prospective data pertaining to injury incidence and performance, in order that a truer understanding of the effects that surface hardness may have on the injury incidence of professional soccer players.

CHAPTER 5

The temporal and spatial variation within natural turf pitches: An 8-year longitudinal study in elite football.

5.1 Introduction

Chapter 3 portrayed a detailed analysis into the effects of pitch hardness on perceptions of injury. The findings showed overwhelmingly that those working within the professional game, believe there are questions to be answered regarding the hardness of the natural turf pitch and its role in both performance and injury. However, it is not apparent from the available literature why such perceptions exist. Biomechanical studies have reported surface hardness to affect the mechanics of running (Ferris et al 1999, Stiles et al 2012) and energy expenditure (Sassi et al 2011), whist within professional Association Football, only speculative links have been made regarding natural turf pitch hardness and injury (Rennie et al 2016). In order to develop a better understanding of pitch hardness, a more objective approach to the collection of data is necessary. Consequently, Chapter 4 described a validated protocol to enable researchers to measure pitch hardness such that this association can be explored objectively. The studies contained within Chapter 4 have focussed upon spatial reliability/variability over a single pitch, on a single day, to help assess the validity and reliability of such a protocol. Understanding both the spatial and temporal variation of hardness within natural turf pitches may prove important for both optimisation of the pitch performance and mitigating injury risk. As natural turf pitches are known to demonstrate temporal variation in accordance with the prevailing climatic conditions or footfall, a more expansive longitudinal approach is required (Straw et al 2018).

The work of Caple et al (2012), demonstrated the surface construction and maintenance of natural turf resulted in differing degrees of spatial and temporal variation. Their work examined the hardness of two differing natural turf football pitches (Fibre sand or Desso Grassmaster) over the course of one season. Fibre sand consists of polypropylene fibres (25mm in length) being mixed into the sand before the rootzone is installed, whereas Desso Grassmaster has synthetic fibres stitched vertically into the surface to a depth of 200mm. Testing was performed on average every three weeks with a 2.25kg Clegg Hammer, recording the third consecutive drop as the measure of hardness. These pitches were then compared to two 'native soil' rugby pitches. The results showed that the sand rootzone pitches showed less variability and exhibited greater impact hardness than native soil, especially in winter. Of particular note was the hardness of sand rootzone pitches tested within football, as they were found to exceed those reported in pitch quality standards (Bell and Holmes, 1988; McClements and Baker, 1994; Baker et al 2007). However, testing being restricted to every third week may have limited a true understanding of the temporal variation evident. Furthermore, comparison between football and rugby pitches may not accurately reflect the pitches; as maintenance, usage and funding vary widely across these two football codes.

A further study by Forrester et al (2014) explored the temporal and spatial variation within an artificial pitch over the course of a full season. Their results highlighted that spatial variability exceeded that of temporal. One would expect that if the relatively inert, stable artificial surface demonstrates such temporal and spatial variability that the natural turf pitch, would vary far greater with this regard. If this is indeed proven, then testing of such pitch hardness would need to be performed close to exposure in order to extrapolate any relationship or association between the relative pitch hardness, performance or indeed relative injury risk.

Key stakeholders perceived the hardness of natural turf pitches to be increasing; a matter of concern as harder pitches were also perceived to increase the likelihood of injury (Figure 3.4-3.5, Chapter 3). A better understanding of spatial and temporal variation in pitch hardness is pertinent as it will advise maintenance strategies for groundstaff, thus optimising the performance of such playing surfaces. Perhaps more importantly, it will inform researchers on the frequency with which such surfaces need testing in relation to their expected rate of change. In order to address these concerns and questions, this study examined the temporal and spatial variability in hardness of natural turf pitches prior to every exposure (training session and match). To enhance the originality and novelty of the study, the research was conducted longitudinally over eight full competitive playing seasons within elite level English professional football. The objectives of the study were fourfold:

1. To examine whether natural turf pitches demonstrate temporal and spatial variability of their hardness.
2. To evaluate the extent to which the hardness of natural turf pitches change across the season.
3. To determine if there is a significant difference between the hardness of training and match pitches.
4. To determine if the construction (hybrid/native soil) of the natural turf pitch affects its relative hardness.

5.2. Methodology

5.2.1 Participants

One professional elite football club was studied over the course of eight full seasons (2008-2016), with data being recorded before every first team training session, first team home or away match, played on natural turf pitch. Data collection commenced in the final week of pre-season (August) and extended until the final match or training session (May). Over the period of study, the team played in three different leagues; namely League 1 (2008-09), the Championship (2009-14) and the Premier League (2014-16). Further pitch hardness data was collected from the domestic cup competitions, specifically the League Cup and the Football Association Cup.

5.2.2 Procedure for testing pitch hardness.

Ground hardness was objectively measured in gravities, by one experienced tester using a 2.25kg Clegg Impact Soil Tester (CIST; Clegg 1976) prior to every every first team training session and match over the course of the 2008-2016 seasons. The testing protocol adopted was in line with that of study 4.2, utilising the 15-drop protocol. The 15 drop zones were deemed to reflect generalised team shape positions, namely goalkeeper, right/left full back, centre half, right/left centre midfield, right/left wing and a central striker (Figure5.1). One drop of the Clegg Hammer, as advised by the American Society for Testing Materials (ASTM F1702 standard for assessing impact absorption for natural turf in the USA, 2000) was adopted to measure the pitch hardness at the 15 pre-determined locations across the surface of the pitch. The specific construction type of the pitch namely, native soil, fibre sand, Desso or Fibrelastic, was also recorded prior to testing following confirmation from the appropriate head groundsman. For reference, the general cut length for elite pitches is between 22-25 mm, this was not recorded within this chapter as the 2.25kg Clegg hammer has previously been reported to be unaffected by such cut heights (McNitt & Landschoot, 2004; Miller, 2004).

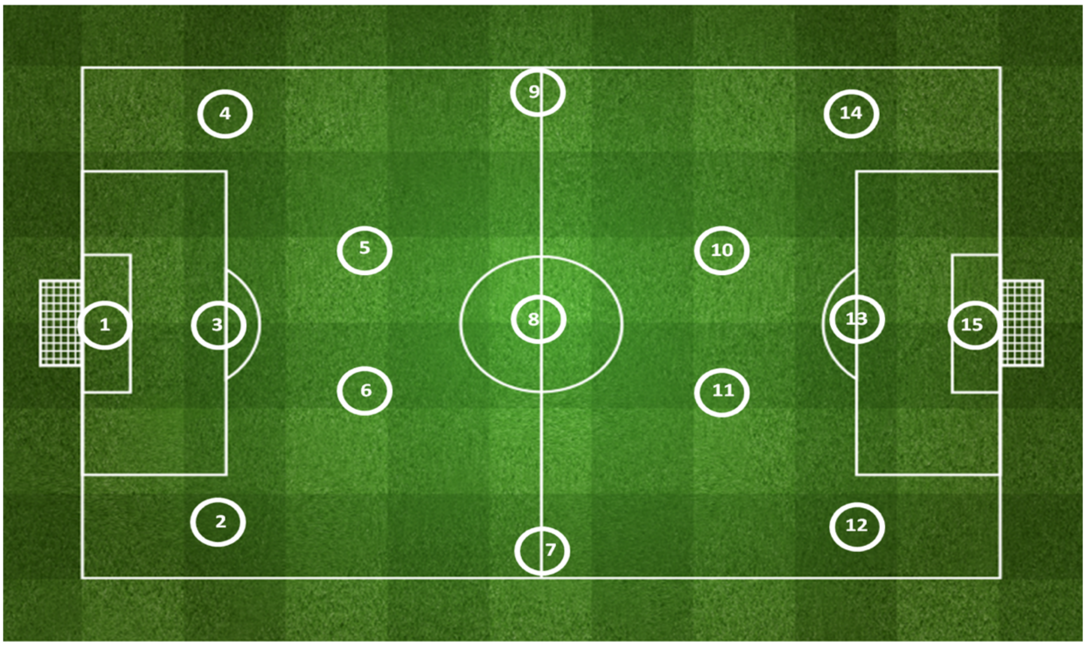


Figure 5.1. A schematic diagram illustrating the 15 pre-determined drop zones where hardness measures were taken.

5.3 Statistical Analysis

The mean, standard deviation and coefficient of variance of the 15-drop protocol was used as a reflection the current pitch hardness with each given exposure, be it in training or match. These were collated and comparisons drawn over the eight-year study period to demonstrate temporal and spatial variation in pitch hardness. Variance in the relative pitch hardness was demonstrated for match/training pitches, as well as the type of pitch construction through box plots. The Shapiro-Wilk test of normality was not achieved for match versus training pitch hardness, as a result Mann Whitney U test for independent samples was utilised to establish any apparent difference. Finally, the Kruskal-Wallis test was used to determine differences in pitch hardness regarding the type of pitch construction. Pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons to reduce the likelihood of a Type 1 Error.

5.4 Results

5.4.1 Exposure

Over the course of the study, 1497 total exposures of first team players, to natural turf pitches were recorded. 74% (N=1109) of these were within training sessions whilst 26% were on match-day (N=388) producing an average seasonal exposure to natural turf pitches of 187 times (training:138.5 and match: 48.5). The need to address pitch quality standards advanced developments in both the construction and maintenance of the natural turf pitch. Consequently, over the study, players were exposed to four different natural turf pitches; namely native soil, fibre sand, desso and fibrelastic.

Table 5.1. Illustrates the exposure of first team players in training and matches by season and pitch construction.

Season	Total exposures	Training exposures	Match exposures	Native Soil	Fibre Sand	Desso	Fibrelastic
2008-09	156	103	52	115	39	2	0
2009-10	195	143	52	148	38	8	1
2010-11	201	151	50	152	38	10	1
2011-12	199	150	49	2	167	29	1
2012-13	185	136	49	3	152	29	1
2013-14	174	122	52	4	139	30	1
2014-15	190	148	42	0	3	186	1
2015-16	197	155	42	0	3	193	1
Total	1497	1108	388	424	578	487	7

The reduced number of training exposures seen in 2013-14 season was due to world cup preparation periods afforded to international teams.

5.4.2 Temporal and spatial variation of pitch hardness over eight football full seasons.

Table 5.2 demonstrates temporal and spatial variability within natural turf pitches. With the exception of one particularly soft year (2011-12), where the average hardness was 77.35G, and a further season which was particularly hard (2013-14), the data appear to show a general trend for an annual increase in pitch hardness extending from 82.10G (2008-09) to over 85G in (2015-16). Whilst the 2011-12 season was undoubtedly the softest of those tested, it also demonstrated the highest levels of variability with average

Coefficients of Variance 8.75 and a range of 6.2-10.85. Interestingly, variability within the data set is notably reduced over the final two seasons in comparison to previous years suggesting that such pitches were of a more uniform hardness than those tested earlier in the study.

Table 5.2: Table Illustrating monthly variance in pitch hardness over eight seasons.

Year	August	September	October	November	December	January	February	March	April	May	Season Average
2008/09											
Mean	84.6	87.85	92.18	81.66	82.63	79.99	70.87	74.37	80.84	95.98	82.10
S. Dev	5.22	5.14	5.32	5.04	4.84	5.99	5.64	6.40	7.31	2.90	5.57
CV	6.18	5.91	5.85	6.42	5.85	7.49	8.26	8.79	9.10	3.02	6.96
2009/10											
Mean	84.55	91.10	89.82	81.27	81.21	80.66	78.41	78.79	78.33	86.21	82.76
S. Dev	7.16	7.43	8.38	6.07	4.66	5.32	6.51	5.59	8.52	6.55	6.59
CV	8.53	8.16	9.39	7.60	5.86	6.68	7.95	7.19	11.03	7.58	7.96
2010/11											
Mean	81.91	88.55	89.49	82.04	82.16	74.46	77.91	78.95	84.68	91.07	82.33
S. Dev	7.08	6.70	5.88	5.83	6.01	5.89	4.86	6.75	7.15	12.34	6.38
CV	8.64	7.56	6.64	7.11	7.30	8.22	6.28	8.59	8.47	6.27	7.79
2011/12											
Mean	78.55	82.05	80.05	73.86	68.85	70.52	76.64	81.23	82.64	No Exposures	77.35
S. Dev	8.47	7.33	8.14	6.76	6.28	7.25	4.80	5.73	5.10		6.74
CV	10.85	9.00	10.12	8.92	9.04	10.32	6.38	7.06	6.20		8.75
2012/13											
Mean	84.30	86.07	82.33	82.86	82.88	82.94	82.01	83.07	85.76	87.48	83.84
S. Dev	3.64	4.77	5.22	4.32	4.65	4.50	4.85	5.31	4.32	3.63	4.54
CV	4.32	5.53	6.30	5.23	5.32	5.43	5.95	6.45	5.05	4.15	5.41
2013/14											
Mean	93.10	95.07	90.03	92.42	92.24	80.92	81.74	88.72	97.37	102.25	90.62
S. Dev	6.44	7.44	6.62	7.92	5.56	3.07	7.87	7.62	8.81	7.08	6.85
CV	6.97	7.90	7.34	8.68	6.03	3.79	9.71	8.54	8.87	6.68	7.53
2014/15											
Mean	87.21	86.37	85.28	84.37	84.66	81.65	80.85	84.49	92.91	86.67	85.46
S. Dev	8.01	3.64	3.39	3.13	3.36	4.22	3.81	5.27	6.09	4.15	4.57
CV	9.15	4.21	3.88	3.69	3.96	5.18	4.73	6.30	6.52	4.83	5.32
2015/16											
Mean	84.99	85.36	83.75	85.64	83.88	84.76	83.95	85.97	86.57	87.50	85.07
S. Dev	3.89	4.78	5.07	3.93	4.32	4.25	5.02	4.47	3.99	3.64	4.37
CV	4.61	5.61	6.07	4.60	5.15	5.05	6.00	5.22	4.62	4.16	5.16

The process of averaging such data may mask the true temporal variation with each exposure to the natural turf pitch. Consequently, a truer representation, showing large fluctuations in the relative hardness between each exposure is shown in Figure 5.2. The average pitch hardness over the course of the study was 83.61G, with the softest recording 51G, extending to the hardest pitch recording a value of just over 128G.

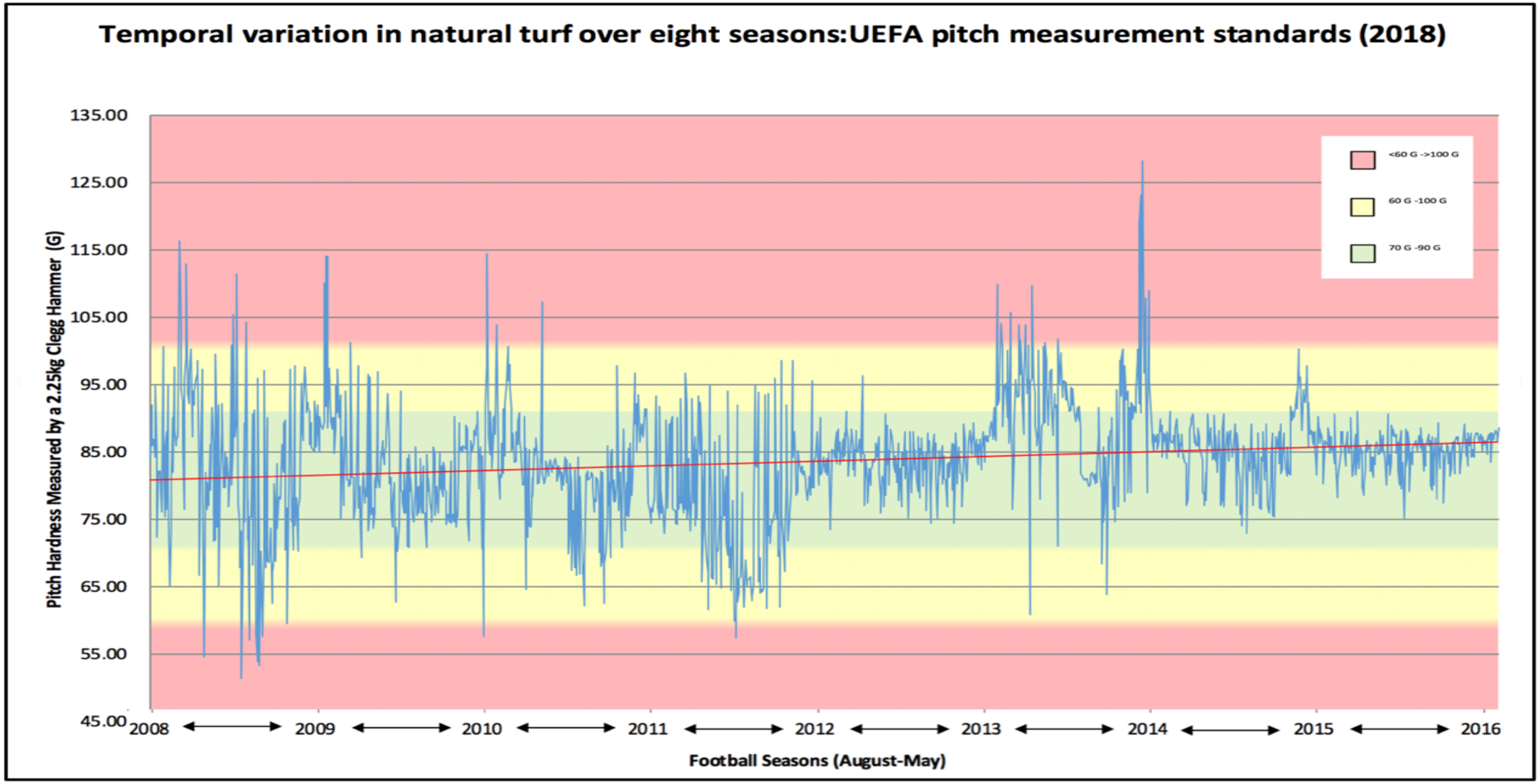


Figure 5.2 A comparison of the UEFA natural turf pitch quality standards (2018) and longitudinal natural turf pitch hardness data over eight years in elite level English professional football.

The line of best fit in Figure 5.2 suggests that pitches over the eight-year study appear to be getting harder. However, caution is urged as the high degree of variation may affect such an assumption. When the longitudinal data is compared with recognised pitch quality standards, it becomes apparent that on numerous occasions the temporal variability falls outside of the recommended range. To demonstrate this, UEFA's (2018) guidelines were transposed over the data set, within Figure 5.2. The central green belt (70-90G) is the recommended target range, acceptable levels of hardness are shown by amber colours, whilst the red zone is proposed to be unacceptable. Players were exposed to unacceptable levels on pitch hardness on 51 occasions (4%) over the period of this study, with 1,152 (77%) of total exposures falling within the recommended target range.

5.4.3 Changes in natural turf pitch hardness over the season.

When the data set are collated monthly across the eight years, it is apparent that the hardness of natural turf pitches follows a distinctive pattern, an almost sinusoidal curve (Figure 5.3). There is a smooth periodic oscillation where average pitch hardness increases from August (84.9G) to September (87.8G), before falling gradually to its lowest point in February (79G). After which it climbs towards a peak value in May of 91G. The largest standard deviations noted were in December (6.43), April (6.17) and May (6.02), whereas the remaining months appeared relatively uniform (range 3.94-4.69).

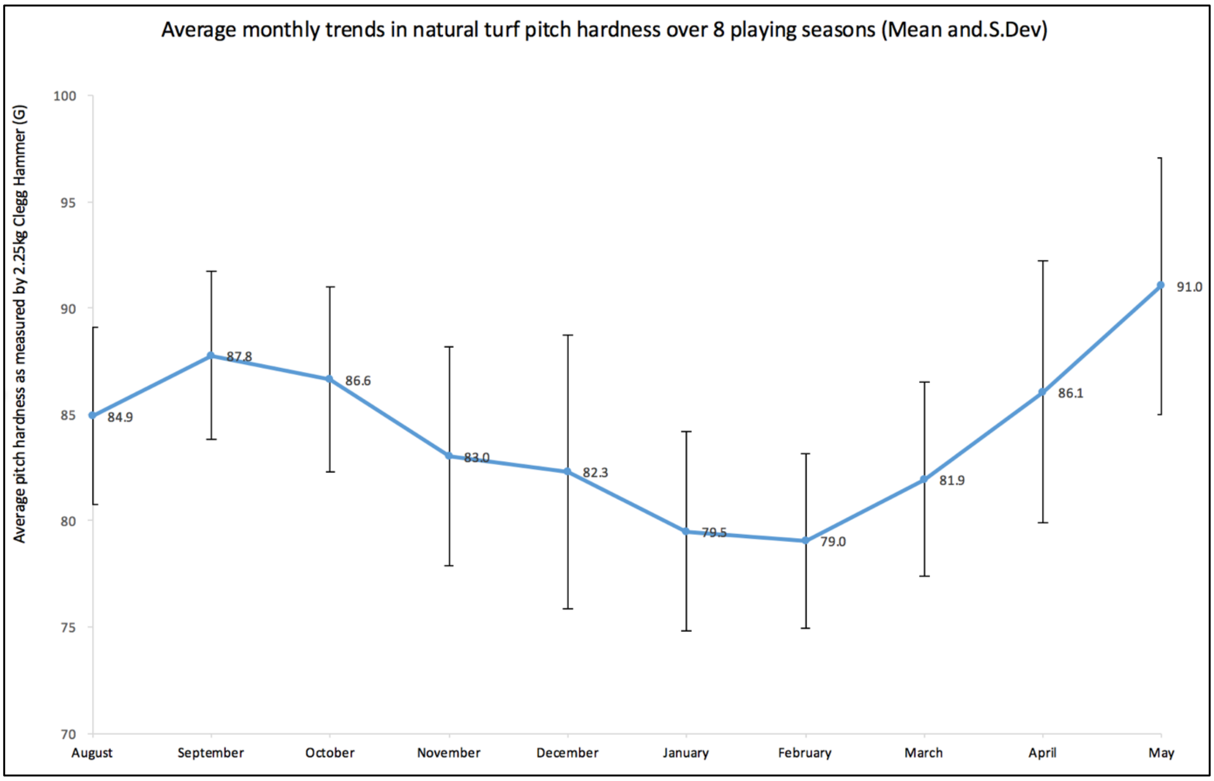


Figure 5.3. Average monthly trends in natural pitch hardness over 8 playing seasons in elite football.

5.4.4 Does the hardness of training and match natural turf pitches differ?

Within the literature incidence of injuries reportedly differs between the training and match setting. The data contained within table 5.3 provides a comparison of the average relative hardness of training and match pitches to which players were exposed over the 8-year study period.

Table 5.3. A comparison of the relative hardness of natural turf training and match pitches.

	Mean	**Range**	**Standard deviation**
Training Pitch hardness	82.75G	(53.16 G - 128.20 G)	5.91 G
Match Pitch hardness	86.05G	(51.39 G - 114.0 G)	5.12 G

Independent samples Mann-Whitney U test demonstrated a significant difference in the hardness recorded for training or match pitches (Training: t= -6.725; p<.001, Match: t=-6.628; p<0.001). Whilst the match pitches are significantly harder than training pitches, the difference is not uniform in presentation (Figure 5.4). Training pitches show a wider spread of recorded data 75G, compared to the match pitch data of 63G (Table 5.3, Figure 5.4). Suggesting that they are less consistent regarding their relative hardness. This is particularly noticeable when the pitch becomes harder than 100G.

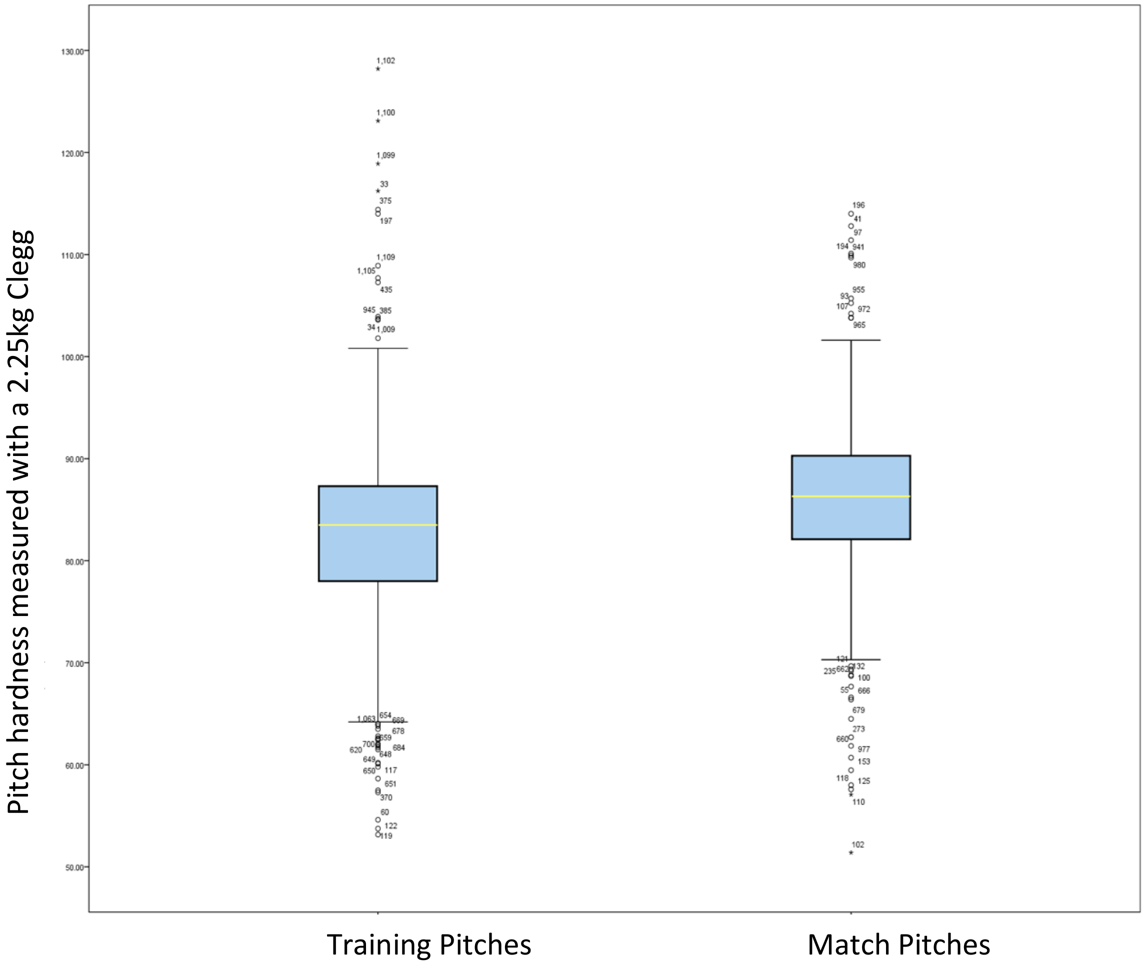


Figure 5.4, Box plots demonstrating the variability of natural turf pitch hardness in either training or match setting over an eight-year period.

5.4.5 Does the construction of the natural turf pitch determine its relative hardness?

Table 5.4 illustrates a graduated move away from the native soil pitch towards those with reinforced sand as their growing medium for natural turf. Over the study period the sampled data set can almost be divided into three distinct sections where there were preferred construction types. The first period demonstrates a predominant exposure to Native soil pitches (2008-11), followed by Fibre sand (2011-14) which then gave way to Desso Grassmaster system (2014-16). Exposure to the fourth pitch type, Fibrelastic was limited as it was only employed at two stadia. The dominance of pitch type may have been a reflection of the respective league in which the team was playing namely League 1 (2008-09), the Championship (2009-14) and the Premier League (2014-16).

Table 5.4. Frequency of training and match exposures of the four different natural turf pitches.

Year	Native Soil		Fibre sand		Desso		Fibrelastic	
Exposure	Training	Match	Training	Match	Training	Match	Training	Match
2008-09	103	12	1	38	0	2	0	0
2009-10	143	5	0	38	0	8	0	1
2010-11	151	1	0	38	0	10	0	1
2011-12	0	2	150	17	0	29	0	1
2012-13	0	3	134	18	2	27	0	1
2013-14	0	4	122	17	0	30	0	1
2014-15	0	0	1	1	146	40	0	1
2015-16	0	0	1	2	154	39	0	1
Total exposure	397	27	410	169	302	185	0	7
Percentage exposure	36%	7%	37%	43%	27%	48%	0%	2%

Table 5.5. Average hardness of natural turf pitches over an eight-year period within Elite football defined by pitch construction type.

	Native Soil (N=424)	**Fibre Sand (N=579)**	**Desso Grassmaster (N= 487)**	**Fibrelastic (N=7)**
Mean	81.09G (51.39-116.23)	83.55G (57.3-128.20)	85.85G (57.59-109.70)	85.29G (74.90-95.30)
Standard deviation	9.18	9.52	5.12	6.03
Coefficient of Variance	11.32	11.40	5.97	7.07

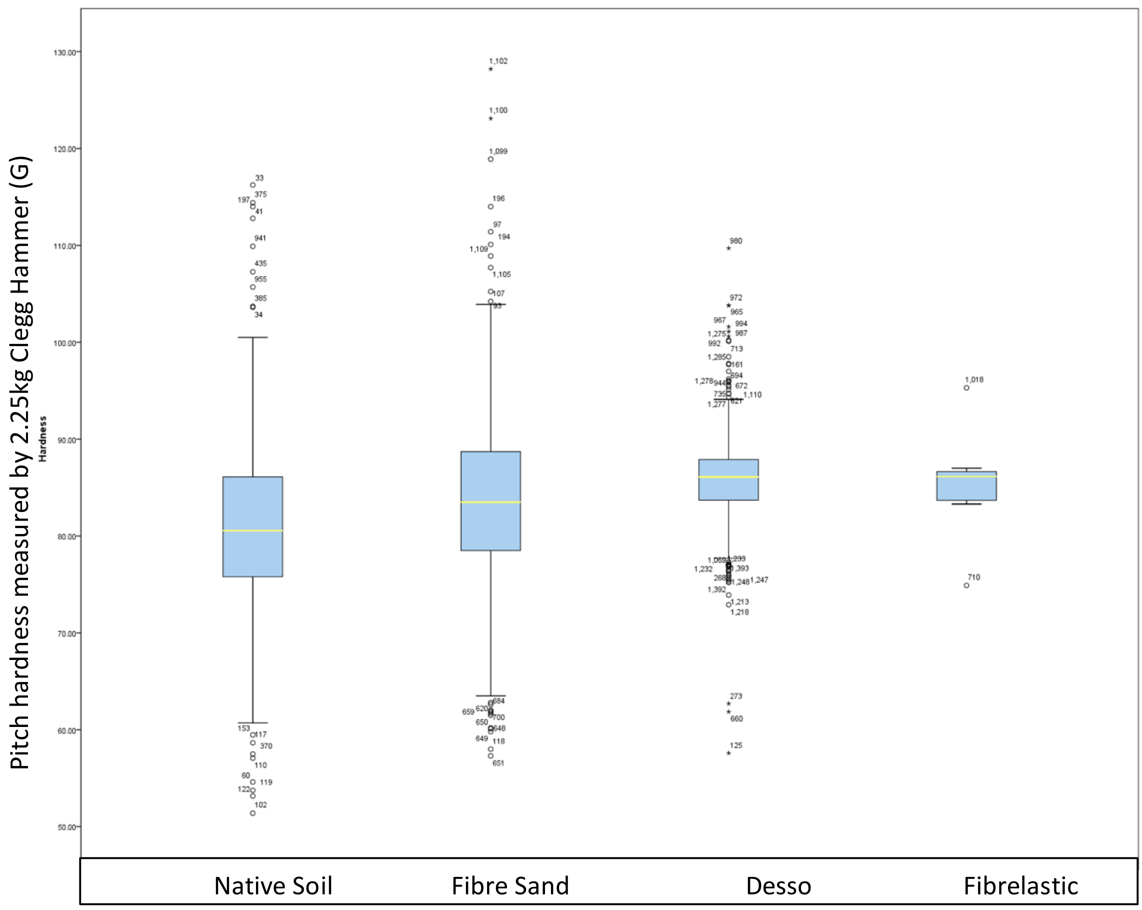


Figure 5.5, Box plots demonstrating the variability of natural turf pitch hardness in relation to their construction type.

Table 5.5, together with Figures 5.5 and 5.6 demonstrate how pitch construction has influenced the relative hardness over time with very idiosyncratic patterns becoming apparent. Native soil and Fibre sand pitches appear to demonstrate the most variability (CV 11.32 and 11.4 respectively) whereas, the Desso Grassmaster pitches appear to have a more concentrated levels of hardness (CV 5.97).

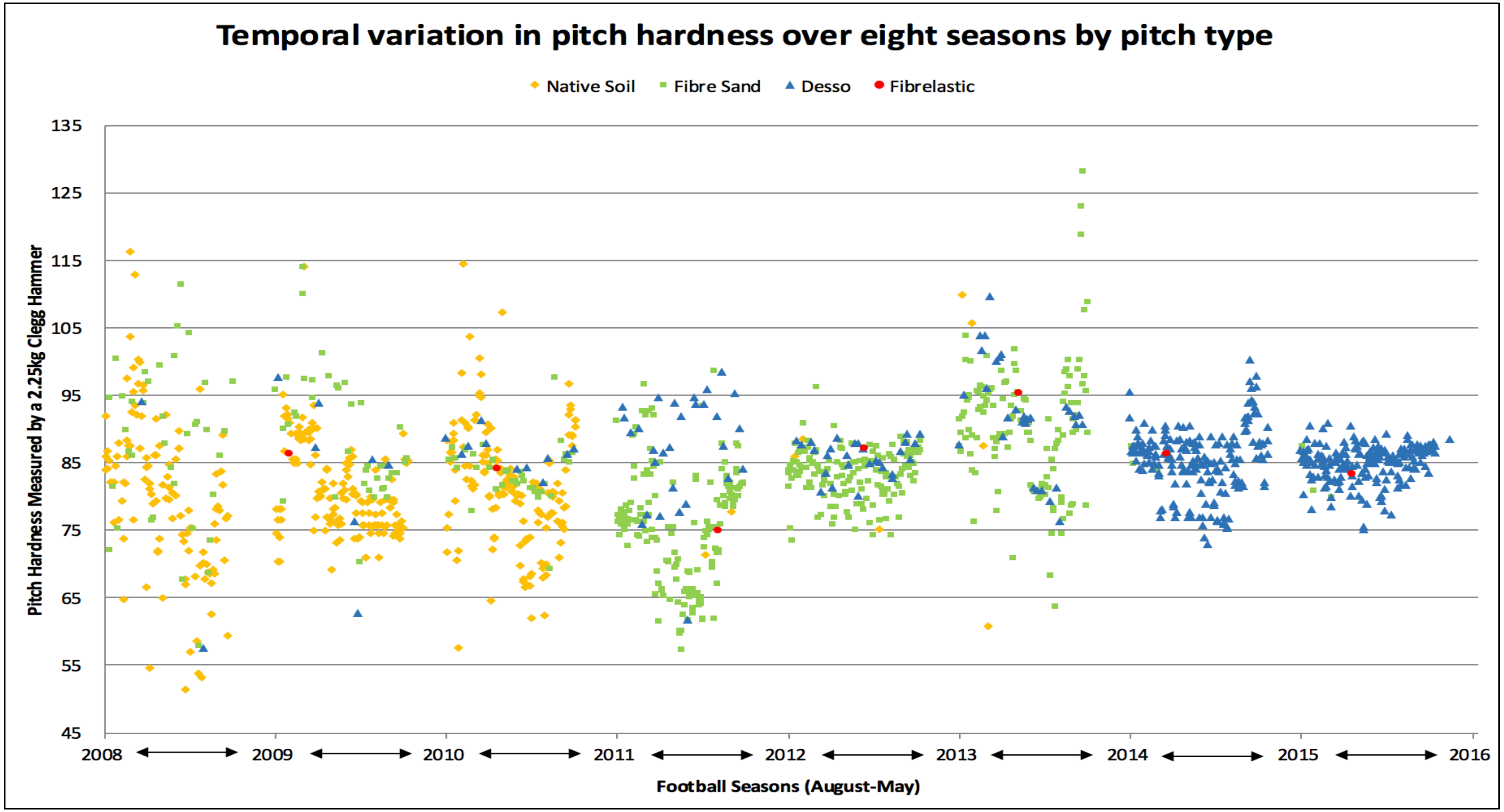


Figure 5.6: Temporal variation of natural turf pitch hardness in relation to pitch construction.

A Kruskal-Wallis test was conducted to determine if there were differences in pitch hardness between the four pitch types. Distributions of pitch hardness scores were not similar for all pitches, as assessed by visual inspection of the pitch type box plots (Figure 5.5) thus violating the assumption of homogeneity of variance and requiring comparison of ranked means. The distribution of pitch hardness scores was statistically significantly different across the four types of pitches, $\chi^2(3) = 107.61$, $p < 0.001$. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed statistically significant differences in pitch hardness scores between Native Soil (mean rank 599.21) and Fibre Sand pitches (mean rank 734.5) ($p < 0.001$), This was also true between Native soil and Desso, (mean rank =895.25) ($p < 0.001$) and also between Fibre Sand and Desso ($p < 0.001$). However, no statistical differences were found between the Fibrelastic pitch and the other three pitches. The low sample size (n=7) in comparison to the other pitches sampled may have impacted on the power of testing and therefore the results for Fibrelastic should be treated with caution.

5.5 Discussion

This is the first empirical study within the academic literature to longitudinally examine elite level association football pitch hardness prior to every exposure of players in both training and matches in one football club. It has shown that natural turf pitches have changed regarding their relative hardness over the eight-year period, becoming both harder and less variable in nature. Match pitches were significantly harder than their training counterparts, whilst collectively, their relative hardness showed seasonal variability, being softest over the winter months. Interestingly, the study's novel design revealed that by increasing the frequency of testing, the true extent of temporal variation became evident, demonstrating a need for researchers to objectify such surfaces as close to player exposure as possible. Finally, the chapter has shown how modern advancements in pitch construction significantly affects both the hardness and variability of the natural turf pitch. Collectively this demonstrates an extrinsic risk factor which is changing in relation to season and through advances in its construction. This variability requires further investigation regarding its affect upon injury risk and performance at an elite level.

This study is an example of how natural turf pitches within association football and their relative hardness change across seasons and longitudinally over time. It is clear that such variation is not simply spatial, that is within any one given pitch, rather it is also temporal in nature. This reinforces the work of both Caple et al (2012) and Forester et al (2014) who demonstrated temporal and spatial variability in both natural turf and artificial pitches. However, the longitudinal nature and increased frequency of testing, prior to each player exposure within the current data set, enables a richer understanding of the magnitude of such temporal and spatial variation. For example, whilst Caple et al (2012) showed that sand root zone pitch constructions such as Fibre sand and Desso Grassmaster were harder than native soil pitches especially over the winter. This study goes further demonstrating the differences between native soil and the other individual, engineered root zone surfaces. Furthermore, Forester et al (2014) concluded spatial variation was greater than temporal regarding an artificial pitch this was not the case within this study where temporal variation was prevalent. This difference between artificial and natural turf highlights the methodological flaws of previous comparative works reporting on injury rates between natural and artificial turf. These are unique surfaces which react to climate, footfall and maintenance in an idiosyncratic manner making comparison with more inert artificial pitches impractical.

Within the literature it has been recognised that the relative hardness of the pitch will affect the bounce and roll of the ball (Baker et al, 2007, Stiles et al 2009). Furthermore, biomechanical studies have shown it to affect running mechanics and energy expenditure (Ferris et al 1999, Stiles et al 2012, Sassi et al 2011). However, less is known about how players adapt to the repeated cumulative effects of such variations in relative hardness. Interestingly, perceptions of pitch hardness remain associated with injury risk (Ronkainen et al 2012, Roberts et al 2014, Ames 2018), despite a lack of objective assessment of such surface hardness (Rennie et al, 2016). Chapter 3 demonstrated that key stakeholders are not simply concerned with hardness, but also with the variability of natural turf hardness across time. Perhaps the large fluctuations in the relative pitch hardness within this study provides foundation for such user's perceptions. Despite these pitches being of an elite level and having large investment in both their construction and maintenance, many fell outside of the recommended guidelines proposed by UEFA (2018). Furthermore, the variability witnessed from one exposure to the next, may make adaptation and recovery between exposures difficult for the player, affecting their subsequent performance and likelihood of injury (Meeuwisse et al 2007, Anderson et al 2008).

Primarily, whilst the demands of football in both training and matches remain the same, the platform upon which players are exposed alters in relation to the prevailing climatic conditions and footfall (Baker et al 2007, Bartlett et al 2009). The extent of seasonal variation in natural turf was marked with a reported range in hardness of 77G across the season (51G-128G). It is notable that during the first two-month period (August-September) pitches generally become harder, increasing to over 87G. As the climatic seasons changes through autumn to winter (November-February) the hardness falls to 79G, before it once more begins to gradually harden to an end season value of 91G (March-May). Such seasonal variation, offers some support for the bi-modal perceptions of a seasonal bias and injury in relation to pitch hardness reported by the key stakeholders in Chapter 3. Perhaps it is these extremes, or indeed changes from soft to hard pitches or vice versa, which may unsettle the players' adaptation process, and provide the foundation for many of the negative perceptions reported around such variability.

The variation over each season reinforces the need for researchers and their protocols to adopt regular testing patterns (Table 5.2). Chapter 4 demonstrated that spatial variability within a repeated measure task over a single of pitch to be low (5.7%). In comparison, over the course of the longitudinal study, such measures show increasing variance to an average of 6.82%. However, as to be expected, this is not uniform and varies accordingly with an annual range of 5.16-8.75. One proposed link within the literature supporting the idea that hard pitches may indeed be viewed as a significant extrinsic risk factor is often founded within seasonal bias for injuries (Hawkins and Fuller 1999, Orchard et al 2002, Ekstrand et al 2013). Both Hawkins et al (1999) and Ekstrand et al (2013) reported injury incidence to be highest in the months of July and August when pitches are frequently reported as harder. Variable climatic conditions were also highlighted within a study of teams within the Champions League (Walden et al 2013), where geographically regionalised injury differences were noted. Interestingly, those who perceived seasonal bias within Chapter 3 reported a 'bi-modal' temporal distribution, with greatest risk between August/September and again between December/January. Perhaps this perceived 'bi-modal' distribution may reflect such seasonal variation in natural turf pitch hardness, which to a large extent was reinforced by this study. This would support the participants' feelings around the relative timing of injury risk with surface and time of year. Thus, understanding the spatial and temporal variation regarding hardness in natural turf pitches may prove to be important for both optimisation of the pitch performance and mitigating injury risk to those exposed to such surfaces.

Within the literature, it is well recognised that injury incidence within professional football is between 6.7 and 12.3 times higher in competitive matches than in the training setting (Ekstrand et al 2011(b), Morgan and Oberlander 2001, Noya Salces et al 2014). In part, these differences may occur because of the greater intensity of competition or indeed the relative 'risk and reward' behaviour of participants in the competitive setting. However, as the natural turf pitch is known to affect the behaviour of the ball and perceptions of key stakeholders regarding their approach to the game, an understanding of differences between the hardness of training and match pitches would be of value to researchers. This is the first study within the literature to examine the differences in training and match pitch hardness longitudinally over a number of seasons.

Interestingly, whilst both pitches showed similar levels of spatial variation, they differed significantly regarding their relative hardness. Training pitches were significantly softer and showed a greater range than match pitches, probably a factor of the investments both financially and with regards manpower. Intuitively, one would expect groundstaffs budget and maintenance schedule to favour the more show-piece match pitch. Specialised irrigation and drainage systems together with growing lights ensure that grass coverage throughout the season at many stadia. The harder match pitch re-affirms the key stakeholders' perceptions that harder pitches are more likely to cause injury when considered in relation to injury incidences of 6.7-12.3 times that of the softer training pitches.

At an elite level, the natural turf pitch has evolved over recent years to provide a platform which is more consistent and robust (Baker et al 2007, Caple et al 2012, Thomson and Rennie, 2016). This affords players the opportunity to perform to the maximum of their physical capability and express themselves on a surface which permits performance and rewards skill (Stiles et al 2009). Perhaps the largest contributory factor has been developments in soil technology, which has seen the native soil pitch gradually superseded by Fibre sand, Desso Grassmaster and Fibrelastic type of natural turf pitches. The reinforced nature of the root zones in such pitch construction has aided pitch quality standards making natural turf more resilient (James 2011).

Over the course of this study, particularly training pitches have transitioned from native soil to the same construction modality as the match pitch, probably in an attempt to aid preparation and familiarity of players (Table 5.4). However, there is no literature available which outlines the effect of such transition on the natural turfs pitch hardness. When the relative hardness of pitches is objectively analysed it is clear that the process for pitch quality improvement, may indeed have been a success. The original native soil pitches were the softest of the pitches players were exposed to with a mean hardness of 81.09G and high Coefficient of Variance 11.32, followed by Fibre sand constructions (83.55G, CV 11.40). The high degree of variability with this type may have been in the preparation, as it is difficult to maintain a consistent mix of the polypropylene fibres within the sand. As a result, some areas can become more or less concentrated thereby demonstrating increased variability. Perhaps the most significant change occurred with the Desso Grassmaster pitches who were both significantly harder and much less variable in when tested (85.85G, CV 5.97).

Whilst such changes in the relative hardness, variability and provision of match equivalent surfaces to train upon may aid preparation and familiarity this may come at a cost. Figure 5.6 shows clearly how the variation and pitch types have changed resulting in a narrower range of exposure for the players. Referring to the consequences of exposure to sports participation and injury risk, Meeuwisse et al (2007) concluded that adaptations occur that alter risk and affect aetiology of injury in a dynamic and recursive fashion. As a result of exposure to a variety of surfaces players learn to adapt their behaviour in accordance (Anderson et al 2008), creating an almost functional plasticity (Liu-Ambrose et al 2012). Motor learning through subsequent success or failure informs future decisions and performance, leading to a more adaptable and robust system (Milton et al, 2007). The ability to make and modify responses under a broad spectrum of conditions is central to effective sporting performance and injury prevention (Glasgow et al, 2013). Reducing the 'bandwidth' of the natural turf pitch (hardness/variability) may reduce the ability of players to cope when exposed to a pitch that falls outside of their normative values. Thus impacting on their robustness and ability to adapt whilst increasing the likelihood of poor performance and risk of injury.

Generally, the focus of researchers has been on the acute link between any given pitch and the likelihood it will cause injury. Players are known to be able to adapt to changes in relative surface hardness within one step (Ferris et al 1999). Furthermore, at an elite level such players can accommodate for changes in both the bounce and roll of the ball. There needs to be a recognition that the pitch conditions (variability of hardness) may indeed play a role in the development of overuse injuries as well (Milburn and Barry, 1998, Twomey et al 2014, Rennie et al 2016, Straw et al 2018). This is an important consideration as the testing of such pitch hardness would need to be performed close to exposure in order to extrapolate any relationship or association between the relative pitch hardness and variables of interest such as injury risk.

5.6 Conclusion

The primary aim of this study was to examine and report upon the spatial and temporal variability in hardness of natural turf pitches in an elite football team encountered longitudinally across eight seasons, both in training and in matches. It has shown that natural turf pitches have become progressively harder but less variable, a factor probably attributable to developments in construction and maintenance. Match pitches have a significantly harder profile than their training counterparts whilst collectively, their relative hardness showed seasonal variability, being softest over the winter months. Interestingly, the increased frequency of testing highlighted the true extent of temporal variation, demonstrating a need for researchers to objectify such surfaces as close to player exposure as possible. Finally, the chapter has shown how modern advancements in pitch construction significantly affects both the hardness and variability of the natural turf pitch.

A better understanding of the degree of temporal variation in pitch hardness is pertinent as it advises maintenance strategies for groundstaff to optimise the performance of such a playing surface. Perhaps most importantly it informs researchers that the frequency of testing must reflect the research question. In the future, researchers need to utilise the objective measures close to player exposure, linking this with prospective injury data collection. This may enable a truer understanding of the role such natural turf pitches may play within injury risk in professional football.

CHAPTER 6

An exploratory study of natural turf pitches:

Can they really be viewed as

a risk factor for injury

within elite football?

6.1 Introduction

Injuries are a major factor within professional football and have been shown to negatively affect the performance and success of elite teams in both league and European cup competition (Hagglund et al 2013). Furthermore, injuries have been shown to not only affect the individual in terms of lost playing time, future earnings and contracts (Ekstrand et al 2013) but also their reported mental health, with many reporting anxiety, sleep disturbance and depression (Gouttebarge et al 2015). In order to prevent injury, an understanding of the extent of the problem and how injuries present themselves is necessary (Bahr and Holme 2003). However, before 2005 the literature detailing such injuries was fraught with inconsistencies, and difficult to interpret as it lacked both a clear definition and framework for reporting. The advent of consensus statements enabled researchers a shared terminology and framework to record such injuries (Hagglund et al 2005, Fuller et al 2006). This has enabled a better understanding of both the incidence and severity of injuries within the professional game (Bahr et al 2018). Longitudinal studies conducted by UEFA over an 11-year period reported an incidence of injury of 7.6/1000h, however such incidence was situation dependent being almost seven times higher in the match setting than that of training (26.7 vs 4.0/1000h) (Ekstrand et al 2013). These figures remain striking despite major investment in medical and sports science within the elite game. In essence they equate to a constant 14% absence over the season within a 25-man squad, as such it was predicted that each player was likely to sustain two injuries per season (Ekstrand et al 2013).

Whilst epidemiological studies provide us with the incidence and burden of injuries within football they do not provide us with the underlying reason or cause for such injuries. As a consequence, a number of researchers have proposed theoretical models regarding such causation of injury often focusing upon intrinsic or extrinsic risk factors (van Mechelen et al 1992, Meeuwisse et al 2007). Whilst intrinsic risk factors are often resistant to change such as age, race and previous medical history, more recently, some studies have investigated the extrinsic risk factors as they are perceived to be more modifiable in nature (Bahr et al 2003). Extrinsic risk factors such as training and match load (Gabbett and Ullah 2012, Gabbett 2016, Rossi et al 2018), fatigue (Mohr et al 2005, Ispirlidis et al 2008), and the number of games per week (Dupont et al 2010, Bengtsson et al 2013), have been associated with injury. The pitch upon which the game is played has also been purported to be an extrinsic risk factor (Hawkins et al 2001, Woods et al 2002, Walden et al 2013, Bianchi et al 2018). However, thus far investigations into the role that the natural turf pitch may have upon the injuries within professional football has not been objectively examined (Rennie et al 2016). Instead, intuitive links have been proposed via comparisons of injuries sustained on either natural or artificial turf (Ekstrand et al 2006, Fuller et al 2007, Williams et al 2011, Kristenson et al 2013, Bianchi et al 2018), inferred through studies of climatic variability (Walden et al, 2013) or simply via anecdotal inference that more injuries were noted early in the season on harder pitches (Hawkins and Fuller 1999, Hawkins et al 2001, Woods et al 2002). Despite such speculation no studies have objectively measured the hardness of such pitches and furthermore, none have prospectively examined such data in line with accurate injury surveillance data. The literature is also lacking regarding the recent evolution of natural turf pitch. Technological advancements in growing lights and root zone reinforcement has heralded the ‘hybrid’ natural turf pitch as an accepted surface for the elite game (Thomson and Rennie 2016). However, no research is available to show how such a transition from native soil to reinforced hybrid turfs like Fibre-sand and Desso has affected injury rate or burden within the elite game. Thus any link between the hardness of the natural turf pitch and injury risk within elite football remains unclear and lacks empirical evidence.

This study aimed to address this by objectively measuring natural turf pitch hardness prior to player exposure be that in training or matches. This data was synchronized with the injury surveillance data recorded after each exposure to the natural turf pitch. Records of both pitch hardness, pitch construction and injury status of the first team squad were maintained over 8 consecutive season at an elite football club. It was hoped that the design of the study would enable a better understanding of the natural turf pitch and its possible links to injury within elite football. The objectives of the study were threefold; 1. To critically examine the injury rates and injury burden at one professional elite football club over eight consecutive seasons, 2. To explore how differing levels of pitch hardness affect such injuries and 3. To investigate how differing natural turf pitch construction affects injury.

6.2. Methodology

This was a longitudinal study of one elite football club, which extended across 8 consecutive seasons (2008-2016) playing in England with data being collected under the pretext of the authors employment, as Head Physiotherapist. The study design adheres to the consensus statement on injury definitions and data collection procedures in football (Hagglund et al 2005, Fuller et al 2006). In addition to injury surveillance data, objective pitch hardness data was obtained with a 2.25kg Clegg hammer prior to each pitch exposure, (training or match), adopting the 15-drop protocol validated in Chapter 4. Prior to data collection at the commencement of each season all first team players were fully informed of the study and provided signed consent in line with ethical approval. The groundstaff of the club were also consented at the beginning of each season, thereby ensuring available access in order to test the hardness of the natural turf pitch ahead of player exposure. For any away game the opposition Groundsman was contacted in advance, was sent a copy of the study protocol and provided signed consent. Both the players and all groundstaff were assured that all data would be anonymized and stored in a secure manner.

In accordance with the football consensus statement and injury definition, only time loss injuries were included within the analysis (Hagglund et al 2005, Fuller et al 2006). An injury was defined as any physical complaint that occurred while participating in a football match or a training session that led to an inability to participate in a future training session or match (i.e. a time-loss injury). Players remained injured until the club's medical staff allowed full participation in training and released the player for match selection (Hagglund et al 2005, Fuller et al 2006). If a player was transferred to another club during the study period his data was still included within the data set, thus no data was lost. Regarding calculation of match related exposure the figures were calculated on 11 players, with no additional substitution data included. The exposure data for any player receiving a red card was included.

6.2.1 Inclusion criteria and definitions

All players belonging to the first team squad representing the studied team were eligible for inclusion. The general operational definitions are listed in table 6.1 for injuries and table 6.2 for the natural turf pitch. Players were considered injured until the Head Physiotherapist of the club allowed full participation in training and availability for match selection. The return to play decision was established collaboratively between the medical and sports science team. In order to be considered ready for return the player was deemed to be asymptomatic from a clinical perspective, had achieved all objective discharge test criteria including speed/volume thresholds, functional/positional specific testing and they were psychologically ready to return to play.

Table 6.1 Operational definitions of injury used within the study.

Operational definitions of injury used in the study	
Training session	Team training that involved physical activity under the supervision of the coaching staff
Match	Competitive match played against another team within the English football league or cup competitions.
Natural turf pitch	The traditionally accepted surface for playing football which is covered predominantly with natural grass (generally perennial rye grass within England).
Injury	Any physical complaint sustained by a player that resulted from match or training exposure on natural turf pitch and led to the player being unable to take part in the next training or match exposure.
Slight injury	Injury causing 1-3 days lay off
Mild injury	Injury causing 4-7 days lay off
Moderate injury	Injury causing 8-28 days lay off
Severe injury	Injury causing more than 28 days lay off
Injury rate	Number of injuries per 1000 player hours ((Σ injuries/Σ exposure – hours) x 1000)
Injury Burden	Number of lay off days per 1000 player-hours ((Σ lay off days/Σ exposure-hours) x 1000)

Table 6.2 Operational definitions of natural turf pitches used within the study.

Operational definitions for natural turf pitches used in the study	
Native Sand Soil Pitch	A natural turf grass pitch grown in native soil with no additional root zone reinforcement.
Fibre Sand Pitch	Hybrid natural turf pitch whose sand root zone is reinforced with thin polypropylene fibers, approximately 35mm in length before being laid and over seeded.
Desso Pitch	Hybrid natural turf pitch which is reinforced directly, by 'injecting or stitching' synthetic turf fibers 200mm into the natural turf root zone to reinforce the turf.
Fibrelastic Pitch	Hybrid natural turf pitch whose sand root zone is reinforced with with polypropylene and elastin fibers before being laid and over seeded.
Hard pitch (UEFA 2018)	>90G measured with a 2.25kg Clegg Hammer
Recommended pitch hardness (UEFA 2018)	70-90G measured with a 2.25kg Clegg Hammer
Soft pitch (UEFA 2018)	<70G measured with a 2.25kg Clegg Hammer

6.2.2 Data collection

Injury data was collected in line with previous epidemiological studies within professional football (Ekstrand et al 2011, Ekstrand et al 2013). Across the study period the Head Physiotherapist of the football club recorded four main data streams:

1. The relative pitch hardness with a 2.25kg Clegg Hammer prior to any exposure using the 15-drop protocol validated within chapter 4.2.8.
2. The construction type of the pitch players to which players were exposed to namely Native soil, Fibre sand, Desso or Fibrelastic.
3. The first team's exposure in minutes to any natural turf pitch in either training or match play.
4. Prospective injury surveillance data which was coded according to the modified version of the Orchard Sports Injury Classification System (OSICS) 2.0 (Orchard et al 2010). To aid clarity, and enable comparison with the perception study of chapter 3 within this thesis, the injuries were globalized into injury types for example ligament, muscle, joint, tendon, nerve, concussion and soft tissue. (For a complete list of injuries included in each category, see Appendix 10.3).

6.2.3 Analysis of data

Within elite football it is difficult to establish causality because of the multi-factorial nature of such injuries. Consequently, this exploratory study focused upon a detailed descriptive analysis of the question whether the natural turf pitch may be considered a risk factor for injury within the elite game? Injury data was collated as a collective sample over the eight-year longitudinal study and reported utilizing descriptive statistics. Both injury incidence (number of injuries) and injury burden (number of days lost to injury) within both training and match play were calculated and reported as the number of injuries per 1000 hours with corresponding mean, and standard deviation. This was represented as a collective figure for the total data set and more specifically regarding injury type such as muscle, ligament, joint, and tendon. Pitch hardness data (in gravities) was presented as a mean and standard deviation. For reference, the general cut length for elite pitches is between 22-25 mm, this was not recorded within this chapter as the 2.25kg Clegg hammer has previously been reported to be valid for such pitch preparations (McNitt & Landschoot, 2004; Miller, 2004).

6.3 Results

6.3.1 Collective pitch hardness and injury data extending over 8-seasons.

Natural turf pitch exposure

Over the course of the 8-year study players were exposed to natural turf pitches on 1497 occasions with an average pitch hardness of 83.61G (SD 5.7). Training pitch exposure (N=1109, 41 ,588 hours) recorded an average hardness of 82.75G (SD 5.9), whilst match pitches (N=388, 6,402 hours) had a mean pitch hardness of 86.05G (SD5.12). Figure 6.1 below illustrates that 76.7% of the exposure fell within the recommended levels of hardness proposed by UEFA (2018). However, 17% of players' exposure to natural turf was harder than the that recommended with 6.3% being softer.

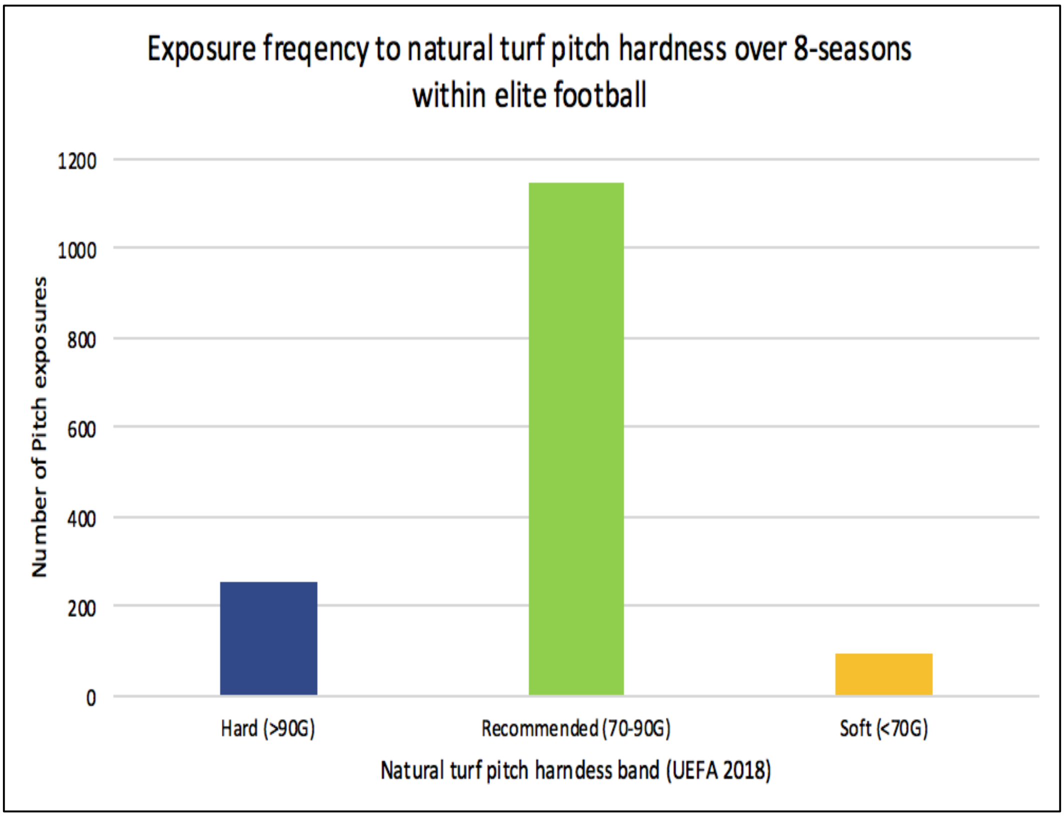


Figure 6.1 Exposure frequency in relation to UEFA recommended hardness over 8 seasons in elite football.

6.3.2 Injury rates and burden in training and matches over 8-seasons.

Table 6.3 Illustrates injuries in training and matches in relation to tissue type.

(Injury rate expressed as number of injuries/1000h. Injury burden expressed as number of injury days absent/1000h).

	Total	Muscle	Ligament	Joint	Tendon	Nerve	Soft tissue	Concussion
Training (N=1109)	286	70	36	87	28	13	51	1
Mean Pitch Hardness 82.75G SD 8.24	3116 days missed	727 days missed	674 days missed	1486 days missed	72 days missed	41 days missed	114 days missed	2 days missed
	Injury Rate 6.88	**Injury Rate 1.68**	**Injury Rate 0.87**	**Injury Rate 2.09**	**Injury Rate 0.67**	**Injury Rate 0.31**	**Injury Rate 1.23**	**Injury Rate 0.02**
41,588 exposure hours	**Injury Burden 74.92**	**Injury Burden 17.48**	**Injury Burden 16.21**	**Injury Burden 35.3**	**Injury Burden 1.73**	**Injury Burden 0.99**	**Injury Burden 2.74**	**Injury Burden 0.05**
Match (N=388)	205	46	24	45	11	6	71	2
Mean Pitch Hardness 86.05G SD 8.49	2546 days missed	600 days missed	917 days missed	726 days missed	153 days missed	10 days missed	134 days missed	6 days missed
6,402 exposure hours	**Injury Rate 32.02**	**Injury Rate 7.19**	**Injury Rate 3.75**	**Injury Rate 7.03**	**Injury Rate 1.72**	**Injury Rate 0.94**	**Injury Rate 11.09**	**Injury Rate 0.31**
	Injury Burden 397.69	**Injury Burden 93.72**	**Injury Burden 143.24**	**Injury Burden 113.4**	**Injury Burden 23.9**	**Injury Burden 1.56**	**Injury Burden 20.93**	**Injury Burden 0.94**

In total, 491 injuries were recorded (286 training: 58%, 205 match play: 42%) resulting in an absence of 5662 days (training 3116: 55%, match play 2546: 45%). The collective injury rate was 8.74 injuries/1000 hours, with a training rate of 6.88 injuries/1000 hours and match rate of 32.02 injuries/1000 hours. Injury burden used to highlight the severity of recorded injuries showed an overall burden of days lost 100.68/1000 hours, whilst in training 74.92 days lost/1000 hours and match play 397.69 days lost/1000 hours. The relative risk of injury to exposure within training was 1 to 3.9, with an average time loss to injury of 2.81 days. Match play risks were comparatively higher being 1 to 1.9 exposures with an average time loss to injury of 6.56 days.

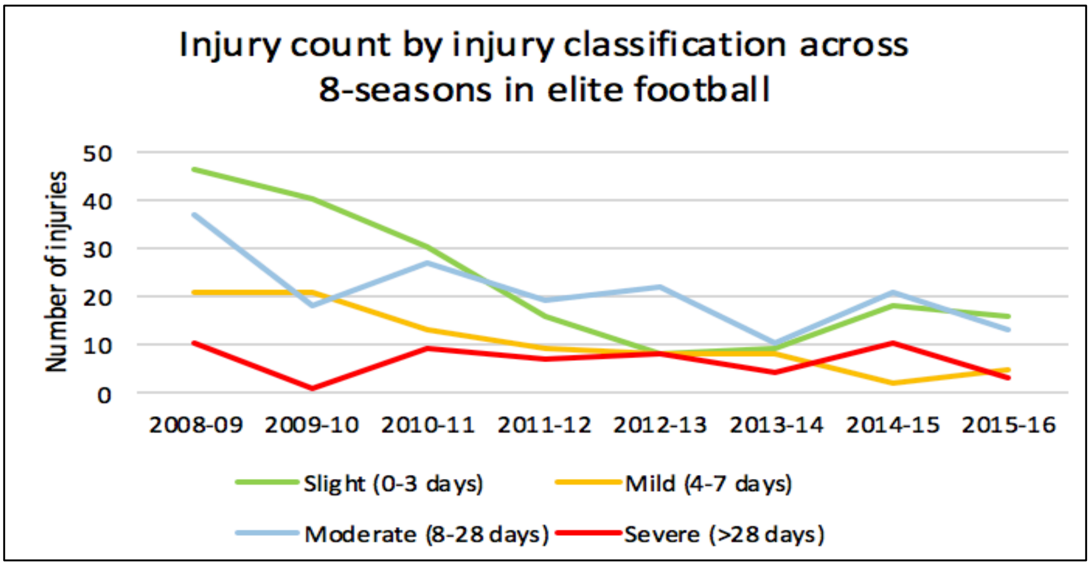


Figure 6.2 Classification of injury count across eight consecutive seasons in elite football.

When the total number of injuries were categorized, slight injuries (1-3 days, n=183) constituted 60%, mild (4-7 days n=87) 22%, moderate (7-28 days, n=167) 4% and severe (>28 days, n=52) 14% of the total 8-season injury count. However, injury count across the study did not maintain a uniform pattern as can be seen in Figure 6.2. In fact, between 2008-09 and the 2015-16 season incidence in all classifications showed reductions, slight injuries by 65%, mild by 76%, moderate by 64% and severe injury by 70%. When the number of days lost (severity) and injury type were collated over the 8-year study, joint injuries were the highest proportionally (39%), followed by ligaments (28%), muscle (24%), tendon (4%), soft tissue (4%), nerve (1%) and concussion (<1%). The severity of days lost to each injury type is illustrated clearly within figure 6.3 below.

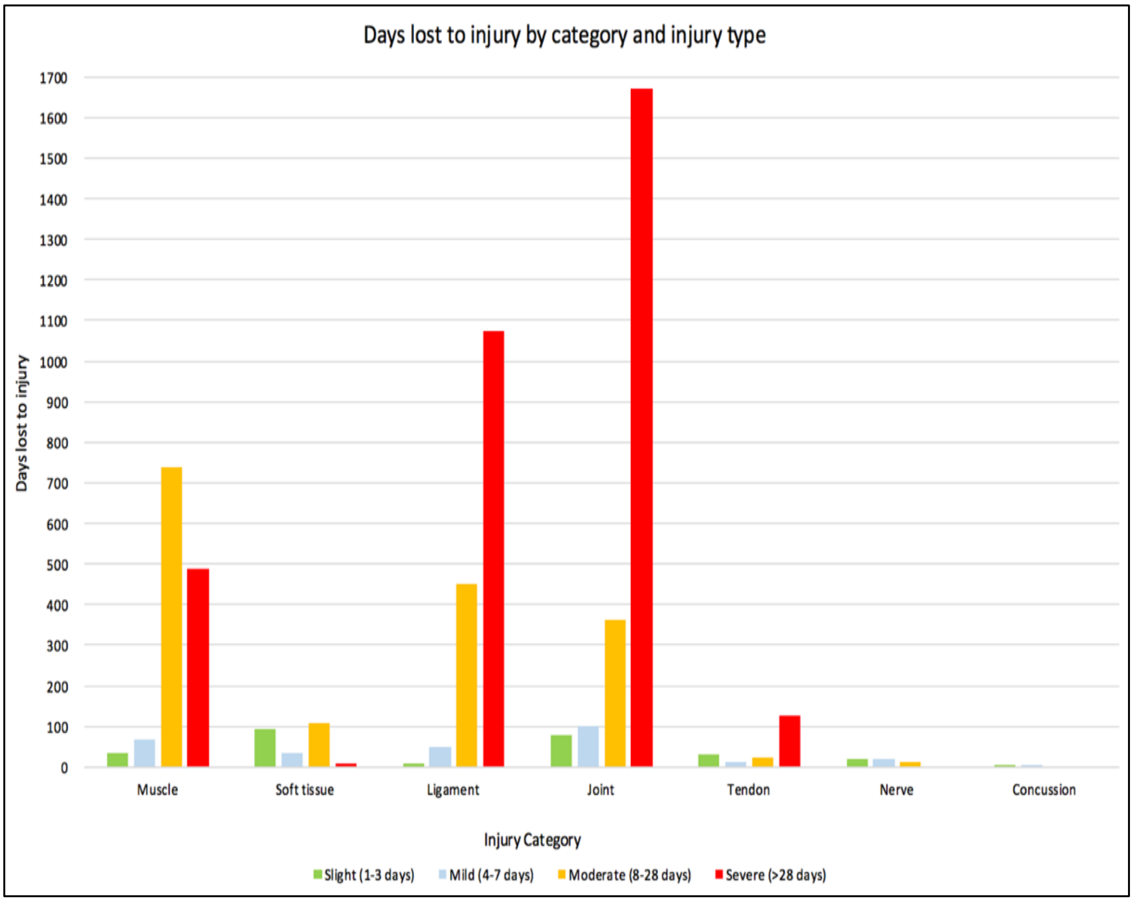


Figure 6.3 Graphical representation of days missed injury category for specific tissue type.

6.3.3 Pitch hardness and injury categorisation.

When injuries are classified by the relative hardness of the pitch upon which they occurred (aligned with the zones for relative pitch hardness proposed by UEFA 2018), the natural turf pitch hardness appears to affects injury rate, injury burden and specific tissues differently.

Table 6.4 Illustrates injury rate/burden by tissue injured on differing natural turf pitch hardness.

	Total	Muscle	Ligament	Joint	Tendon	Nerve	Soft tissue	Concussion
Soft Pitch <70G (N=94) Mean 64.89G SD 6.0 3,525 Exposure Hours	68	24	10	12	3	3	16	0
	680 days missed	179 days missed	398 days missed	72 days missed	6 days missed	5 days missed	20 days missed	0 days missed
	Injury Rate 19.29	**Injury Rate 6.18**	**Injury Rate 2.84**	**Injury Rate 3.4**	**Injury Rate 0.85**	**Injury Rate 0.85**	**Injury Rate 4.54**	**Injury Rate n/a**
	Injury Burden 192.91	**Injury Burden 50.78**	**Injury Burden 112.91**	**Injury Burden 20.43**	**Injury Burden 1.7**	**Injury Burden 1.42**	**Injury Burden 5.67**	**Injury Burden n/a**
Recommended 70-90G (N=1148) Mean 82.48G SD 5.43 43,050 Exposure Hours	309	77	42	84	23	12	69	2
	4194 days missed	1029 days missed	1106 days missed	1670 days missed	182 days missed	40 days missed	163 days missed	4 days missed
	Injury Rate 7.18	**Injury Rate 1.79**	**Injury Rate 0.98**	**Injury Rate 1.95**	**Injury Rate 0.53**	**Injury Rate 0.28**	**Injury Rate 1.60**	**Injury Rate 0.05**
	Injury Burden 97.42	**Injury Burden 23.9**	**Injury Burden 25.69**	**Injury Burden 38.79**	**Injury Burden 4.23**	**Injury Burden 0.93**	**Injury Burden 3.79**	**Injury Burden 0.09**
Hard pitch >90G (N=256) 95.58G SD 6.82 9,600 Exposure Hours	114	15	8	36	13	4	37	1
	778 days missed	119 days missed	77 days missed	470 days missed	37 days missed	6 days missed	65 days missed	4 days missed
	Injury Rate 11.88	**Injury Rate 1.56**	**Injury Rate 0.83**	**Injury Rate 3.75**	**Injury Rate 1.35**	**Injury Rate 0.42**	**Injury Rate 3.85**	**Injury Rate 0.10**
	Injury Burden 81.04	**Injury Burden 12.39**	**Injury Burden 8.02**	**Injury Burden 48.96**	**Injury Burden 3.85**	**Injury Burden 0.63**	**Injury Burden 6.77**	**Injury Burden 0.42**

The results for specific injury type, injury rate and injury burden determined by three differing zones of pitch hardness are shown in Figures 6.4 and 6.5 below. The frequency of both muscle (6.18/1000h) and ligament (2.84/1000h) injuries were greatest on the soft pitch when compared to either the recommended or hard surface. This contrast the injury rates of joints (3.75/1000h) and tendons (1.85/1000h) who experienced higher rates on the harder pitches (Figure 6.4). The recommended zone for natural turf pitch hardness appeared favorable, that is having the lowest rate of injury for joint, tendon, nerve and soft tissue. Regarding the injury burden on differing levels of pitch hardness (Figure 6.5), ligamentous injury was extremely debilitating on soft pitches (112.91/1000h), as was time lost accountable to muscle injury (50.78/1000h). The harder pitches affected days lost to injury differently with the most prevalent injuries being to joints (48.96/1000h). Whilst the incidence of soft tissue injuries is high, they appear equally effected by extremes of either hard or soft pitches. However, whilst incidence is high the burden for this injury type is relatively low in comparison to others (Figure 6.5).

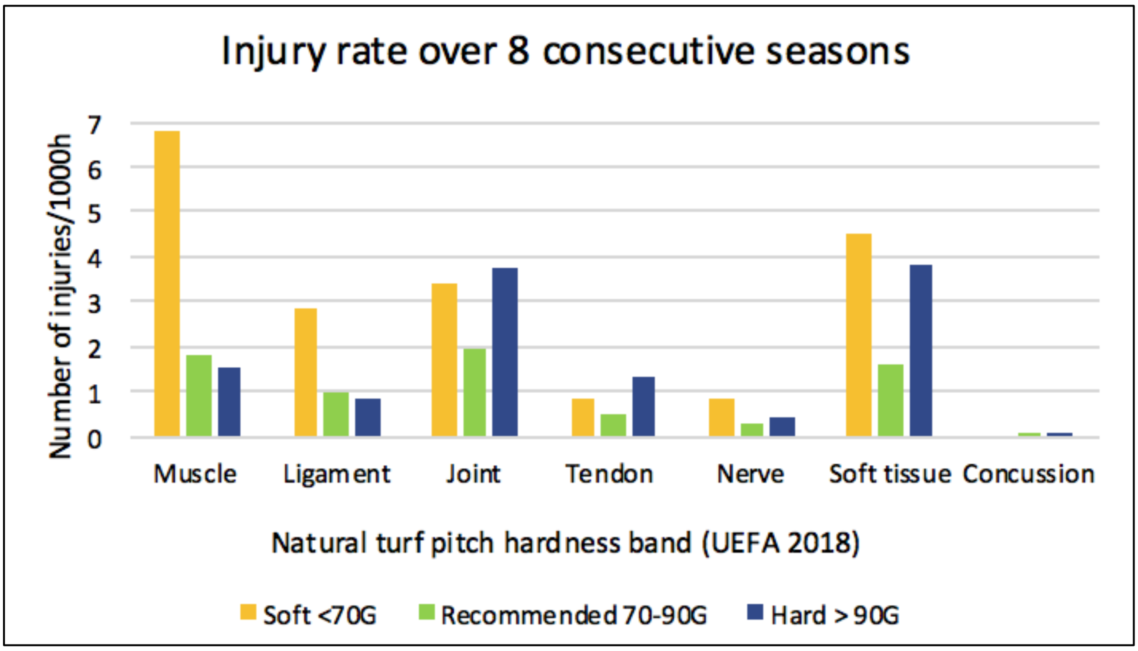


Figure 6.4 Injury incidence per 1000hours exposure in relation to natural turf pitch hardness.

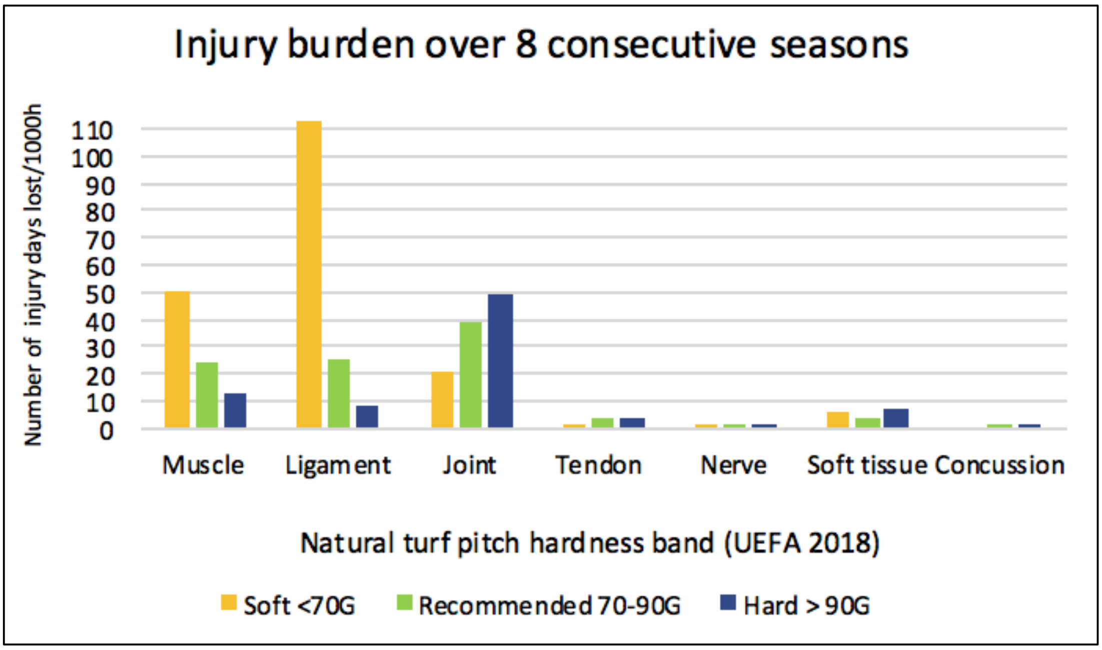


Figure 6.5 Injury burden per 1000hours exposure in relation to natural turf pitch hardness.

6.3.4 Pitch construction and injury.

Over the course of the study players were exposed to four different natural turf pitches namely Native soil (n=424, 15,900 exposure hours), Fibre sand (n=579, 21,712.5 exposure hours), Desso (n=487, 18,262.5 exposure hours) and Fibrelastic (n=7, 10.5 exposure hours). Due to the small exposure to Fibrelastic this data was deemed not amenable to further interpretation. On average, the Desso pitches were the hardest surface players were exposed to (85.85G, SD 5.12) followed by the Fibre sand (83.55G, SD 9.52), whilst the softest were the native soil pitches (81.09G, SD 9.18).

Injury rates were similar for native soil pitches (9.62/1000h) and Fibre sand (9.12/1000h) but were notably lower for the Desso pitch construction (7.61/1000h). Injury burden was the lowest on native soil (80.5/1000h), followed by Desso (102.01/1000h) and highest time was lost to injury was on exposure to the Fibre sand pitches (114.4/1000h). The ratio of injuries to exposure were 1 to 4.51 on Desso, 1 to 3.89 exposures on Fibre sand and 1 to 3.75 exposures on Native soil pitches.

When injury incidence was categorized the largest percentages of slight injuries (1-3 days) were noted on Native soil (44.4%), mild (4-7 days) on Fibre sand (20.7%), moderate (4-28 days) on Desso (36.7%) and the most severe (>28 days) also on Desso reinforced natural turf 14.39% (Table 6.5).

Table 6.5 Categorization of injury count across 8-seasons as a factor of pitch construction.

8 seasons	Native Soil (N=424)		Fibre sand (N=579)		Desso (N=487)		Fibrelastic (N=7)	
	Injury count	Days missed	Injury count	Days missed	Injury count	Days missed	Injury count	Days missed
Slight (1-3 days)	68 44.44%	96 7.5%	63 31.82%	103 4.15%	52 37.51%	72 3.86%	0	0
Mild (4-7 days)	30 19.61%	95 7.42%	41 20.71%	163 6.56%	16 11.51%	61 3.27%	0	0
Moderate (8-28 days)	43 28.1%	415 35.42%	72 36.36%	738 29.71%	51 36.69%	518 27.8%	0	0
Severe (>28 days)	11 7.19%	674 52.66%	21 10.61%	1480 59.58%	20 14.39%	1212 65.06%	1	25

Pitch type, also appeared to affect tissues in differing ways (Table 6.6). Whilst the number of muscle injuries was highest on Native soil (2.58/1000h) and lowest on the Desso pitches (1.86/1000h), the cost or burden of such muscular injuries were doubled on the Desso pitch by comparison (Desso 34.22 vs Native soil 17.32/1000h). Ligamentous (38.32/1000h) and joint (48.41/1000h) related injuries were most severe on the Fibre sand pitches. Whilst time loss attributable to tendon injury (10.88/1000h) was most prevalent on Native soil.

Table 6.6 The effect of natural turf pitch construction upon injury incidence and burden.

	Total	Muscle	Ligament	Joint	Tendon	Nerve	Soft tissue	Concussion
Native Sand soil (N=424) Mean 81.09G SD 9.18 15,900 Exposure Hours	153	41	20	28	22	4	38	0
	1280 days missed	274 days missed (7.61, SD 8.71)	273 (13.65, SD8.05)	489 (20.38,SD85.22)	173 (8.24, SD26.79)	4 days missed (1.0, SD 0.57)	67 days missed (1.81, SD 1.86)	0 days missed
	Injury Rate 9.62	**Injury Rate 2.58**	**Injury Rate 1.26**	**Injury Rate 1.76**	**Injury Rate 1.38**	**Injury Rate 0.25**	**Injury Rate 2.39**	**Injury Rate n/a**
	Injury Burden 80.50	**Injury Burden 17.23**	**Injury Burden 17.17**	**Injury Burden 30.75**	**Injury Burden 10.88**	**Injury Burden 0.25**	**Injury Burden 4.21**	**Injury Burden n/a**
Fibre sand (N=579) Mean 83.55G SD 9.52 21,712.5 Exposure Hours	198	41	25	57	15	9	49	2
	2484 days missed	428 days missed (11.26, SD 9.59)	832 (33.28,SD52.05)	1051 (20.61, SD33.88)	50 (3.33, SD2.02)	21 days missed (2.33, SD 1.12)	98 days missed (2.18, SD 1.97)	4 days missed (2.0, SD 2.0)
	Injury Rate 9.12	**Injury Rate 1.89**	**Injury Rate 1.15**	**Injury Rate 2.63**	**Injury Rate 0.69**	**Injury Rate 0.41**	**Injury Rate 2.26**	**Injury Rate 0.09**
	Injury Burden 114.4	**Injury Burden 19.71**	**Injury Burden 38.32**	**Injury Burden 48.41**	**Injury Burden 2.30**	**Injury Burden 0.97**	**Injury Burden 4.51**	**Injury Burden 0.18**
Desso (N=487) Mean 85.85 SD 5.12 18,262.5 Exposure Hours	139	34	15	46	2	6	35	1
	1863 days missed	625 days missed (18.94, SD 21.89)	476 (31.73,SD 56.74)	647 (23, SD 27.30)	2 days missed (1, SD 0)	26 days missed (4.33, SD3.01)	83 days missed (3.32, SD3.91)	4 days missed (4.0, SD 0)
	Injury Rate 7.61	**Injury Rate 1.86**	**Injury Rate 0.82**	**Injury Rate 2.52**	**Injury Rate 0.11**	**Injury Rate 0.33**	**Injury Rate 1.92**	**Injury Rate 0.05**
	Injury Burden 102.01	**Injury Burden 34.22**	**Injury Burden 26.06**	**Injury Burden 35.43**	**Injury Burden 0.11**	**Injury Burden 1.42**	**Injury Burden 4.54**	**Injury Burden 0.22**

6.4 Discussion

This study provides novel data highlighting how the hardness of natural turf football pitches may affect the injury rate and injury burden within elite football. Despite recommendations by the games governing body UEFA (2018), nearly one quarter of all exposures were on pitches harder or softer than those proposed in the guidelines, which had a notable effect upon the injuries seen. As such the resulting hardness of natural turf pitches affected injury risk in a non-uniform manner, consequently tissues appeared more or less susceptible to the 'band or level' of pitch hardness. Both the incidence and burden of ligamentous and muscular injuries were high on soft pitches, whereas joint and tendon pathology appeared more prevalent on harder natural turf. Finally, the hybrid construction of the natural turf pitch, affected both the incidence and burden of injury recorded in an idiosyncratic way. Thus, whilst the newer hybrid pitches appear to have supported a reduction in the incidence of injuries in comparison to Native soil, they have simultaneously demonstrated an increased burden or cost for such injury, regarding time loss. Collectively these findings demonstrate the natural turf pitch may be viewed as a risk factor for injury within elite football. Furthermore, the pitch construction and its relative hardness also contribute to the injuries recorded.

During the eight seasons 491 injuries were recorded with 286 (58%) in training, and 205 occurring in matches (42%). On average a player sustained 2.4 injuries per season, resulting in 61 injuries per season for a squad of 25 players. The total injury incidence was 8.74/1000h, with a training rate of 6.88/1000h in comparison to 32.02/1000h in match play. Whilst these figures are higher than those reported in the Champions

League audit 4.0/1000h training and 26.7/1000h match respectively, they are lower than some reported longitudinally within the Premier League which ranged from 31.2-59.2/1000h (Carling et al 2010). This type of variation appears typical within injury surveillance data, frequently being attributed to differing methodology (recording or definition of injury), population (playing level) and perhaps most likely the 'dynamic and recursive' origin of such injuries which hampers true comparison (Meeuwisse et al 2007). Whilst these may be applicable to the incidence data reported here, it may also be argued that as the team transitioned from League One, through the Championship to the Premier League that the playing style and intensity may account for some of this variation (Walden et al 2005). Nevertheless, the data would appear to be reflective of those at an elite level thereby enabling comparison.

However, injury incidence is not necessarily a true reflection of the impact such injuries may have upon the individual and the team. More recently focus has turned to the cost, or burden of such injuries, a factor shown to affect the success of elite teams in both league and cup competitions (Hagglund et al 2013, Bahr et 2018). Injury burden in both training and matches within this study was 100.68 days lost/1000h which reflects well in comparison to other reported rates in elite football which range from 105-209.6/1000h (Ekstrand et al 2019). Days lost to match injury was over five times of those sustained in training (397.69/1000h match, 74.93/1000h training). So whilst the incidence of injuries within training was higher than that of matches, the burden in relation to days lost was in fact far greater during competitive matches. This was particularly noticeable in the three tissues most susceptible to injury namely ligaments, joints and muscles.

Whilst the injury surveillance study provides efficacy in relation to previous studies, the novel findings of this study are apparent when such incidence and severity are examined relative to the surface hardness of the pitch upon which the injury originated. This is the first study within elite football to objectively analyse natural turf pitch hardness, compare this to accurate injury surveillance and exposure data to inform understanding as to whether pitch hardness can be viewed as a true extrinsic risk factor. Consequently, within this study it was remarkable to discover that the rate, burden and susceptibility of tissues to injury appear to be dependent upon the relative hardness of the pitch, upon which such injuries occurred. Whilst the majority of exposures to natural turf (76.7%) fell within the recommended levels of hardness proposed by UEFA (2018), some 17% of players' exposure to natural turf was harder than the that recommended with 6.3% being softer. Exposure of players to natural turf pitches outside of the recommended level of hardness (70-90G UEFA 2018) observed a surface dependent effect upon injury incidence and burden. As such the incidence of ligamentous (104.89 days lost/1000h exposure) and muscular injuries (50.78/1000hours) on soft pitches were extremely high when compared to other tissues, or indeed their own contrasting rates noted on harder pitches. Similarly, joint related pathology appeared more prevalent upon hard pitches (48.96/1000h) than either the recommended level (38.79/1000h) or those that were soft (20.43/1000h).

This mirrors participants within the perception study of chapter 3, who reported an increased risk of muscle (60% agreement) and ligament (42% agreement) on soft pitches and increased likely prevalence for joint (93% agreement) and tendon injury (54% agreement) on harder natural turf pitches. This reinforces the studies of Ronkainen et al (2012), Roberts et al (2104) and Mears et al (2018) who had reported on player perceptions regarding subjective hardness and injury comparing artificial with natural turf. Furthermore, it also supports the somewhat intuitive links between seasonally hard pitches and injury proposed by Hawkins et al (2001) and Woods et al (2002). However, most pertinently this study highlights the accuracy of key stakeholders' views within chapter 3 of this thesis, who perceived natural turf pitches should be seen as an extrinsic risk factor for injury, but one which affects a tissue's risk of injury in a very specific manner. The perceptions of the key stakeholders were unsupported within the literature until now, where this exploratory study provides both credence and further insight.

Tendon injury also displayed an increased injury burden, but was found to be most susceptible to the recommended level 4.23/1000h, followed by hard 3.85/1000h and soft 1.7/1000h. Attributing causality to such injuries is difficult because of their multi-factorial nature (van Mechelen et al 1992, Meeuwisse et al 2017). However, as the surface compliance of such natural turf is known to affect both energy expenditure (Ferris et al 1999, Geyer et al 2003, Katkat et al 2009, Sassi et al 2011) and musculo-skeletal load (Smith et al 2004, Stiles et al 2011), one may consider the impact natural turf hardness has upon injury related to such physiological demands. The relative hardness of such turf, being transient and affected by extraneous variables such as the weather, will change throughout the season, thereby altering the demands of any given pitch-player interaction (Rennie et al 2016). This variable external load, affects the internal load of players during exposure, which in turn will affect tissues are their likelihood of subsequent injury (Vanrenterghem et al 2017). Future studies need to examine natural turf pitch hardness, relating this to both the external and internal loads elite players in a controlled training environment. This approach would enable a better understanding of the mechanisms which underpin the injury incidence and burden findings described within this study.

Chapter 5 highlighted how pitch construction had developed in answer to the need for more robust natural turf pitches. The transition from Native sand soil (81.09G, SD 9.18), to Fibre sand (83.54G, SD 9.52) and then Desso (85.85G, SD 5.12) reinforced pitches accompanied an increased in their relative hardness. Given earlier findings that the relative hardness of the pitch may affect the incidence, burden and type of tissue at risk on such natural turf, it is perhaps not surprising that differences were evident between injury rate and burden recorded on the different natural turf pitches. It is apparent that as the natural turf pitch has developed over the 8-year study, to that of a more hybrid construction with reinforced root zones, the incidence rates particularly for slight to moderate injuries have reduced (Figure 6.2). Consequently, pitch construction explored in relation to injury rate has changed from native soil (9.62/1000h) to the more hybrid constructions Fibre sand (9.12/1000h), and Desso (7.61/1000h). As a result, the ratio of injury to exposures has also increased from native soil (1 injury to 3.75 exposures), Fibre sand (1 to 3.89 exposures) and to Desso where 1 injury occurs every 4.51

exposures. Why injury incidence on Fibre sand pitch construction is more akin to that of Native soil may be attributable to the variability within such surface, as demonstrated by the high standard deviation recorded.

Whilst the picture regarding injury incidence and hybrid pitch construction appears favorable particularly regarding the Desso pitches, this is not necessarily the case regarding the severity or burden of injuries. The cost of injuries relative to days lost on hybrid pitch constructions are higher than that of native sand soil (Fibre sand 114.4/1000h, Desso 102.01/1000h, Native soil 80.5/1000h). Thus whilst overall injuries on hybrid turf are reducing, the costs both to individual players and their club's actually appears to be increasing as result of exposure to such surfaces. This is perfectly demonstrated by injuries affecting muscle, where Desso pitches recorded the lowest incidence of muscle injuries with 1.86/1000h, compared to Fibre sand (1.89/1000h) and Native soil (2.58/1000h). However, the cost of muscle injuries on Desso was notably higher being 34.22 days lost/1000h exposure. In comparison that was nearly double the cost of Fibre sand (19.71/1000h) and Native soil (17.23/1000h). Such an increased burden is attributable to the changing composition of the muscle injuries seen on the differing natural turf pitches (Appendix 10.3). The frequency of muscle strains increased by 50%, with the incidence of Grade 1 muscle strains on native soil (n=10), increasing on both Fibre sand (n=15) and Desso (n=16). This was also true for the more severe Grade 2 strains (Native soil n=6, Fibre sand n=11, Desso n=10). Interestingly, the Desso pitches which showed the highest average hardness also demonstrated the greatest injury burden. This contrast the earlier findings that muscle injury had been linked to exposure on the softer surfaces. The reason for this is unclear but may reflect that harder surfaces promotes faster speed, which may in turn increased eccentric fatigue ultimately resulting in muscle injury (Hales and Johnson 2019). If this were the case, then it may provide some insight regarding the prevalence of hamstring injuries, which are reportedly increasing by 4% annually within elite football (Ekstrand et al 2016).

Fibre sand pitches reflected the highest injury burden for ligamentous injury (38.32 days lost/1000h), compared with Desso (26.06/1000h) and Native soil (17.17/1000h). Once more this contrasted the earlier finding which would have proposed higher injury cost for days lost on the softer Native soil pitch. Both reinforced natural turfs led to increased ligamentous ruptures. Whilst this study is focused upon hardness this result may indeed be a factor more akin to traction or torsional stability, where increased reinforced root zone on occasions provides too much traction leading to such rates of ligamentous rupture. Fibre sand pitches were also accountable for the greatest number and burden of joint injuries with the number of days lost to injury (48.41/1000h) in comparison to Desso (35.43/1000h) and Native soil (30.75/1000h). The main injury showing change was that of 'bone stress response' where there was no reported absence on native soil but five on Fibre sand and six recorded on Desso pitches. This type of injury represents the inability of the bone to withstand repetitive or excessive loading, resulting in structural fatigue, localized bone pain and tenderness (Warden et al 2014). They often progress to fatigue or full fracture if the loading pattern is not modified. This is of note as researchers have identified links between natural turf hardness and ground reaction force in both running and turning (Stiles et al 2011).

6.5 Methodological considerations

Research within the applied setting on elite footballers requires a pragmatic approach, which is accepting of many limitations that are intrinsically related to such a setting. This is demonstrated within this study where despite the use of agreed consensus statements and recognized exposure data, which enable benchmarking of injuries in relation to the external load of time, it does not inform regarding the intensity of training or matches. Neither does it account for the cumulative exposure to such pitches, or the acute or chronic training loads (Gabbett and Ullah 2012, Gabbett 2016, Rossi et al 2018). Another problem associated with injury surveillance in professional sports is that injury is often under reported as many players will continue to play in prodromal state (Weel et al 2014). Many will continue with the use of non-steroidal anti-inflammatory medication rather than miss training or games (Tscholl et al 2015). This may lead to both an under reporting of the true extent of injuries and/or an eventually increase the number or severity of injuries seen particularly those caused through overuse (Hammond et al 2009). Further, the study did not account for the mechanism of injury and as a result some of the injuries may have been affected by contact/external trauma rather than any interaction with the pitch. Finally, as Ekstrand et al (2018) have shown the relationships or effectiveness of communication between staff can significantly affect the injury burden recorded. Good pathways of communication and support can promote lower levels of injury burden (105/1000h) whereas poor communication and working relations increased likely injury burden (183.6/1000h). The often volatile working environment of elite professional football resulted in four different management teams over the course of the study. The medical and sports science staff remained relatively stable over the period, however such changes may have had some effect upon the injury rates observed.

6.6 Conclusion

Despite UEFAs recommendations for the hardness of natural turf, prior to this work no data was available to support the proposed banding of 70-90G. No objective reports linking such hardness on natural turf to individual performance, or that of the ball, nor information regarding relative injury risk has been provided within the literature. In essence, they are recommendations which are not enforced, nor scrutinized unlike those pertaining to artificial pitches. This study provides a novel approach, with the necessary methodological rigor regarding injury consensus, definitions, and exposure rates within both training and match play. Furthermore, the quantitative analysis of pitch hardness with the Clegg Hammer provided the necessary objectivity, missing within the literature to enable insights into how differing natural turf pitch hardness, may affect injury within elite football. As a result, the findings have shown injury incidence, injury burden and even the type of tissue at risk of injury may be related to the hardness of the natural turf pitch. Furthermore, the type of natural turf was also seen to affect the rate and burden of injury. Future studies need to examine natural turf pitch hardness, relating this to both the external and internal loads of elite players in a controlled training environment. It is hoped this would enable a better understanding of the mechanisms which underpin the results described within this study.

CHAPTER 7

How does the hardness of a natural turf pitch affect player loads in elite football?

7.1 Introduction

Association football is an exciting sport defined by bitter rivalries, periods of high intensity and high drama. Unfortunately, with over 250 million active participants, it is also a sport punctuated by relatively high risks of injury (Rahnama 2011). Despite its universal popularity, uncertainty remains concerning its multidimensional requirements (physiological, biomechanical and psychological) and therefore uncertainties when planning for optimal training and conditioning (Bradley et al., 2009; Drust, Atkinson, & Reilly, 2007; Mackenzie & Cushion, 2013; Rampinini et al., 2008, Aguiar et al 2012). Within any football match players randomly transition between brief maximal, or near-maximal, multidirectional efforts and longer periods of low-intensity activity or inactivity; all whilst performing a variety of technical and tactical skills (Bangsbo et al, 2006; Drust et al, 2007; Rampinini et al, 2009, Carling and Bloomfield, 2010). Temporary or permanent fatigue has been proposed to adversely affect such technical performance, highlighting the need for specificity within training (Drust et al., 2007; Rampinini et al., 2008; Russell and Kingsley, 2011). To address such complexities, coaches have adopted an ergonomic approach, whereby training sessions are compared to the competitive demands of match-play (Kelly and Drust 2007). Utilising small sided games (SSG) within training ensures that the variable properties of the game are preserved providing coaches with an environment to concomitantly train the tactical, physical and technical components in a similar fashion to match-play (Capranica et al., 2001; Gabbett, 2002; 2006; Jones and Drust, 2007; Rampinini et al., 2007; Frencken and Lemmink, 2008; Hill-Haas et al., 2009; Katis and Kellis, 2009, Hill-Haas et al 2010).

The quantification of training loads has enabled coaches and sports scientists to develop training drills and small sided games (SSG) to accommodate for the demands of the game. However, whilst the use of SSG has been accepted as a means of developing the specific football fitness (Impellizzeri et al 2006) no researchers have investigated how the relative hardness of the natural turf pitch affects the players' response to such conditioning stimuli. The conceptual model (Figure 2.5) presented within chapter 2 proposed that on exposure to any given natural turf pitch its hardness may affect the relative load the player experiences (Rennie et al 2016). This was reinforced by Vanrenterghem et al (2017) who proposed a novel framework to examine load monitoring with particular reference to distinct physiological and biomechanical pathways for load adaptation. They believed as players train they are exposed to external biomechanical load. Such external load leads to mechanical stresses being imparted on the tissues such as cartilage, bone, muscle and tendon. Such tissues are known to have a narrow window of optimal load specific to each tissue type. Either under or over-loading tissues when training or playing football can lead to tissue damage, whilst not providing enough time for adaptation may also lead to injury and/or poor performance.

The hardness of the surface seems an important consideration when it has been recognised to affect both energy expenditure (Pinnington et al 2001, Katkat et al 2009, Sassi et al 2011) and biomechanical load (Geyer et al 2003, Smith et al 2004, Kaila 2007, Stiles et al 2011). Hard or soft natural turf pitches have been demonstrated to affect the bounce and roll of the ball and as such performance of players and their team through the adaptation of passing and running performance strategies (Chapter 3, Ronkainen et al 2012, Roberts et al 2014, Mears 2018). Pitch hardness has also been perceived to affect loading to tissues and with that the risk of injury (Weel et al 2014). Furthermore, relative fatigue and the tempo of the games have also been perceived to be affected by the surface hardness (Chapter 3). Linking this knowledge with the temporal and spatial variability of natural turf pitch hardness demonstrated in Chapter 5, it raises questions regarding the optimisation of training on such surfaces and how their relative hardness will affect both the external and internal loads to which players are exposed.

Whilst researchers have begun to address training and match loads they have not accounted for the relative hardness of the pitch and how this may affect the individual player. Players may be able to achieve the task in hand on a variety of pitch hardness's (training or match) but the cost of such exposure is yet to be established. This chapter will attempt to address this by prospectively manipulating the surface hardness of an elite level natural turf football pitch. It will then explore how the relative pitch hardness affects the player load, in relation to external load (GPS and technical performance), and the effects on internal load (differential RPE, and heart rate).

7.2 Methodology

7.2.1 Participants

Sixteen full-time professional male football players from a Premier League club were recruited to participate in the study (mean age 25.06 years, SD 6.33). All participants gave written consent to participate in accordance with the university ethical procedures. The project also received formal approval from the coaching team. In advance of the training session players were separated by the coaching staff into four teams of equal ability and experience. Team A (mean age 25, SD 6.38), team B (mean age 26, SD 7.02), team C (mean age 25.25, SD 7.09) and team D (Mean age 24, SD 4.83). Four full-time professional goalkeepers from the same team as the outfield players, were also used during the testing session however their data was excluded from analysis.

7.2.2. Procedure

The testing session was a blinded randomized controlled trial performed over the course of one training session (March 2018). Neither the players, nor the coaching/support staff were made aware of the difference between the two relative pitch hardnesses. The average ambient air temperature was 8^{o}C, wind 17 km/hr, pressure 1030mb, with no precipitation over the testing session.

Ahead of the training session the pitch was prepared by ground staff into two separate levels of hardness (divided equally by the half way line). Aesthetically both halves of the pitch were identical, having full grass coverage, mowed to a height of 25mm, pattern-swept in accordance with premier league/UEFA requirements and lightly dusted with water in keeping with the normal practice ahead of any training session (UEFA, 2018). However, the groundstaff had manipulated the surface hardness of each half-pitch in the two days prior to testing. The soft half-pitch was achieved through an aeration process using a Toro Procore with 19mm tines (Figure 7.1), whilst the hard half-pitch was left unwatered in the two days prior and compacted with heavy rollers.

Figure 7.1 Toro Procore with 19mm tines

The relative hardness of the two pitches were measured with a 2.25 kg Clegg Hammer at 15 different sites across both pitch surfaces. The first drop of the clegg was recorded (ASTM, 2000) whilst the drop pattern utilised was the 15-drop protocol validated within Chapter 4. The relative average hardness was found to be 75G (SD 5.21 CV% 6.9) (soft) and 110G (SD 5.61 CV%5.1) (hard). Twenty balls of the same colour were available to use on each pitch, being inflated to the recommended standard pressure of 13 PSI ahead, and placed at the side of the goals, with yellow balls being used on the soft pitch, conversely white balls on the hard.

Pitches were called either the yellow ball or white ball pitch derived from the colour of ball used on that pitch (same ball i.e. Nike Premier League Fig 7.2) and were not referenced by their level of surface hardness.

Figure 7.2 Nike Premier League Ball 2018

On both the yellow ball (soft) and white ball (hard) pitch two training pitches were measured and marked out with cones in advance of the training session (Figure 7.3). Pitch dimensions were decided and organized by coaching staff as reflective areas for the purpose of playing two small sided games either 4V4 (4 outfield players and one goalkeeper per team) or 8V8 (8 outfield players and one goalkeeper per team). The dimensions were 4v4 (33.0m by 27.5m = 907.5m^2 or 113.43m per outfield player) or 8V8 (44.2m by 66.5m = 2939.3m^2 or 183.7m^2 per outfield player).

Players were separated into four teams of equal ability and experience by the coaching staff after which the training session was explained to the players as a group. Four games of 4V4 would be played against the same team, so that team A would compete against team B twice on the yellow ball pitch and twice on the white ball pitch. Simultaneously teams' C and D were playing on the opposing pitch. The timings of games were controlled by an external time keeper, totaling 4 x 4-minute games with 2 minutes rest between.

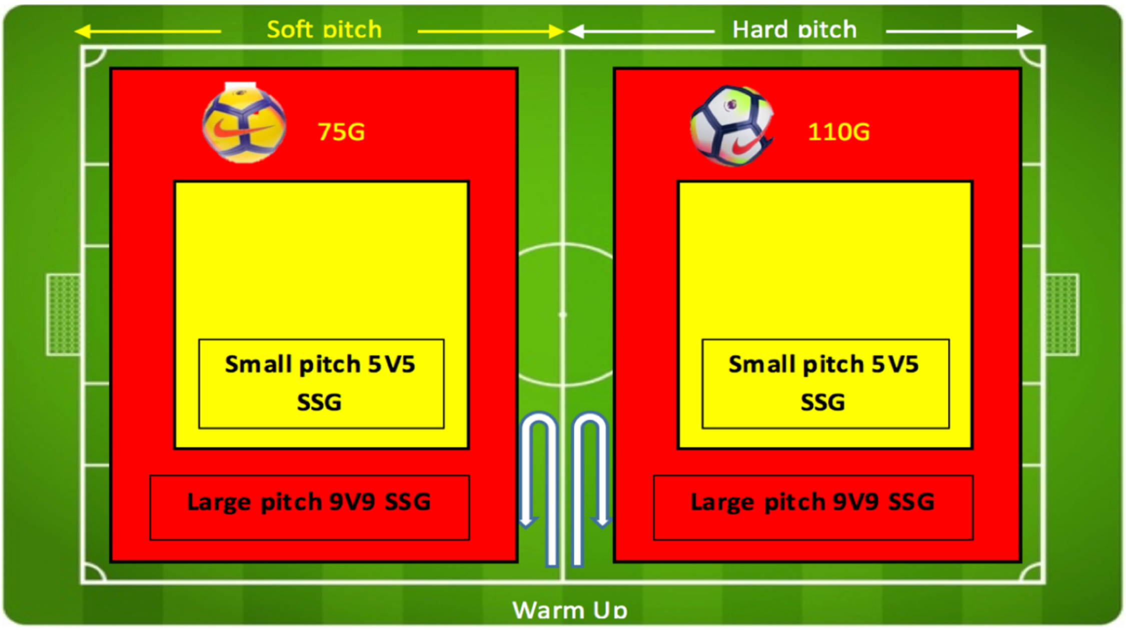


Figure 7.3 Schematic representation of the testing pitch

The Head Coach decided the pitch order sequence within the confines that four games needed to be played, with each pitch being played on twice (adopting ABBA approach to pitch rotation). To control for team variation team A played team B with the same referee, and the same goal keepers. Team C played team D with the same referee, and the same goal keepers. In order to maintain speed of play, ball servers were utilised and were positioned at the side of the goals enabling the game to re-start from the goal keeper quickly. These servers also remained with their allotted team throughout all games. The 8V8 games commenced immediately after the 2 minutes' rest following the fourth 4V4 game. Here Team A joined with Team B to play against the collective players of Teams C and D with games lasting 4 x 6 minutes with 2 minutes' rest.

All players wore tightly fitted Global Position System (GPS) vest tops with Heart Rate (HR) belts throughout the session in accordance with a normal training session. The session was recorded digitally with a fixed 4-camera system (Bosch video management). A standardised, warm up, providing identical exposure in terms of drill content and time on both the yellow and white ball pitches was performed by the clubs first team sports scientist.

7.2.3 Objective Outcome Measures

External Load

The use of a GPS enabled accurate monitoring of external load throughout the testing session. The activities were sampled at 10Hz with the Catapult Optimeye GPS system and a 100Hz triaxial accelerometer (Optimeye S5, Catapult Sports, Melbourne, Australia). These sampling rates have proven validity and reliability for high intensive movement demands (Kelly et al 2014). The micro sensor units were harnessed in a tight fitting lycra vest top, which were worn by all players throughout the testing session. The positioning of units within the vest secured the units between the scapulae of the players. All units were activated 15 minutes prior to the commencement of the testing session in accordance with the manufacturers recommendations. Data was downloaded post session to a PC and analysed using a custom software package (Logan Plus v.4.4, 208 Catapult Innovations^{TM}).

The session was clipped into the specific activity time frames such as 4V4 games and 8V8 games allowing a comparison of the GPS variables recorded between the hard (white ball) or soft (yellow ball) pitch. The variables of interest were meters per minute (m.min), high speed running distance (m), very high speed running (m) and sprinting distances (m), and combined high speed distance (m). In addition, the number of accelerations and decelerations were also examined in relation to the hard or soft pitch. Finally, "player load" was computed from the tri-axial accelerometer (100hz) and represented as the summation of changes in acceleration across all planes of movement (antero-posterior, mediolateral and vertical planes). The reliability and validity of these micro sensor units have been reported elsewhere (Kelly et al 2014).

The Catapult system was also utilised to record the sprint speed of the players (max velocity m/sec). This was recorded as the maximum velocity achieved over a 30m effort and was repeated on both the hard and soft pitch, immediately before and after the testing session.

In order to examine the players' technical performance, all SSGs were filmed using four fixed digital cameras, elevated six meters above the playing surface and positioned around the SSG area (Bosch video management system, 25Hz, Resolution 1920 x 1080 HD). A hand notational system combined with the video recordings, which were played back several times, was used to evaluate the technical performance. A count for each player was made for all of the defined technical actions in relation to SSG type either 4v4 or 8v8, and also in relation to pitch hardness (white ball hard, yellow ball soft). This process was performed by the club's performance analyst, the process by which he was familiar. The technical actions followed similar definitions to others researchers such as Sarmento, et al (2018) and are shown in table 7.1.

Table 7.1 Technical definitions used for analysis of players during Small Sided Games

Skill	Definition
Ground Pass	Any intentional played ball from one player to another. Passes include open play passes, goal kicks, corners and free kicks played as pass – but exclude crosses, keeper throws and throw-ins. Passes included are only those played below hip height
Aerial Pass	Any lofted ball where there is a clear intended recipient, must be over shoulder height and using the passes height to avoid opposition players.
Carry	Player in possession runs (dribbles) with the ball.
Take On	Player in possession attempts to beat an opponent with the ball at his feet.
Shot	Any goal attempt by a player.
Turnover	A possession ended by the opposition gaining control of the ball.
Time in possession	Possessions are defined as one or more sequences in a row belonging to the same team. A possession is ended by the opposition gaining control of the ball.
Seconds per pass	Time taken between each pass.

Reference- https://www.optasports.com/news/optas-event-definitions/

This method used by the club analysts has been recognized as a reliable evaluation of movement in soccer (Butterworth et al 2013, Mackenzie and Cushion 2013), however in-line reliability of coding was checked and re-checked. The level of agreement for recording of technical actions was determined using the number of exact agreements observed between the two analyses. An observation by observation breakdown of the results was obtained for test and re-test of the data sets enabled statistical calculation. Supplementation with kappa (the number of agreements that could be expected by chance). The reliability was an ‘almost perfect’ strength of agreement, 84% (κ = 0.84).

Internal load

Differential rating of perceived exertion (DRPE)

All DRPE scores were recorded via a numerically blinded CR100 scale (Borg et al 2010) labelled with idiomatic English verbal anchors by independent persons at the end of the 4V4 games during the rest period, and once more at the end of the 8V8 games (Appendix 10.4). The CR100 scale was chosen over the more common CR10 RPE scale as its finer grading has been demonstrated as more sensitive within soccer (Fanchini et al 2016, Barrett et al 2018), furthermore each player had been familiarised with the scale. DRPE was recorded for the 4V4 and 8V8 games corresponding to either the yellow or white ball pitch. Recorded perceptions focussed on session exertion (DRPE-S), leg muscle exertion (DRPE-L), breathing control (DRPE-B) and technical difficulty (DRPE-T). Additionally, following termination of the session (within 15-30 minutes) general perception data was obtained regarding both the yellow and white ball pitches. This explored general perceptions of both pitches such as which was perceived as harder, the player's preference of pitch, which was best to sprint upon, best to turn upon and whether either pitch caused any concerns for injury.

Heart Rate

Heart rate responses were recorded continuously at 1 second intervals throughout the entire training session using heart rate monitors, attached to each player with a chest strap (Polar Team[2], Polar-Electro OY, Kempele, Finland). These devices were the same ones which the players wear in training. Individual mean heart rate during different sections either 4V4 SSG or 8V8 SSG and separated in relation to the work performed on either the yellow ball (soft) or white ball (hard) to provide an indication of overall intensity in relation to surface hardness. Heart rate was also expressed in relation to recognised working bands of each player's maximum namely, 75-85%, or 86-100%. Players maximum heart rates were established from an intermittent maximal effort running test. The session was clipped into the specific activity time frames such as warm-up, 4 x 4V4 games and 4 x 8V8 games allowing a comparison of heart rate response between the hard or soft pitch.

7.3 Statistical Analysis

External load data

As the external load data did not achieve the desired level for normal distributions on testing with Shapiro Wilk, further analysis utilised Wilcoxon tests for repeated measures to establish statistical significance between the hard or soft pitch and the GPS variables recorded in both the 4V4 and 8V8 SSG format. GPS data will be described in relation to their mean, standard deviation and averaged per minute to allow comparison between 4V4 and 8V8 SSG formats. Technical data was analysed in relation to the SSG size and the surface hardness of the pitch. Descriptive statistics for count total, mean and events per minute were calculated. Wilcoxon tests for repeated measures were used to quantify any significant differences between the hard or soft pitch and the technical performance recorded in both the 4V4 and 8V8 SSG format.

Internal load data

Differential RPE was presented as mean and standard deviation with differences between the surface hardness being evaluated via Wilcoxon tests. Heart rate data was described through means, standard deviation and averaged per minute to allow comparison between 4V4 and 8V8 SSG formats. Shapiro-Wilk test showed that HR data was normally distributed. Consequently, repeated measures t tests were used to evaluate differences between the hard and soft pitch.

7.4 Results

7.4.1 External Load

Table 7. 2 A summary of the effects of pitch hardness and game size on external load.

External Load Measure	Number of participants	4V4 Hard pitch	4V4 Soft Pitch	8V8 Hard Pitch	8V8 Soft pitch
Total Distance (m)	N=16	Mean 960.71(1107-771) SD 98.46	Mean 955.70 (1080-762) SD 98.12	Mean 1402 (1579-1110) SD 158.84	Mean 1420 (1592-1191) SD 158.69
Meters per minute (m/min)	N=16	Mean 118.27 (136-95) SD12.08	Mean 117.63 (133-93) SD 12.08	Mean 116.55 (131-92) SD 13.20	Mean 115.78(129-97) SD 12.94
Accelerations	N=16	∑31.5 (3.94 p/min) SD1.31	∑38.5 (4.81 p/min) SD 1.32	∑44 (3.67 p/min) SD 1.52	∑41(3.41 p/min) SD 1.79
Decelerations	N=16	∑24.5 (3.13 p/min) SD 0.74	∑28 (3.50 p/min) SD 0.71	∑46.5 (3.88 p/min) SD 0.88	∑35.5 (2.95 p/min) SD 1.28
Player load	N=16	∑934 (117.25 p/min) SD 10.64	∑ 907(113.38 p/min) SD 10.66	∑1196 (99.67 p/min) SD 13.93	∑1220(101.67 p/min) SD 12.59

No significant difference between pitch hardnesses was established between the external loading variables of total distance (4V4 z=.362, p=0.717; 8V8 z=.207, p=0.836), meters per minute (4v4 z=.362, p=0.717; 8V8 z=.207, p=0.836), accelerations (4v4 z=-1.201, p=0.307; 8V8 z=.-.674, p=0.500) nor decelerations (4V4 z=.834, p=.404; 8V8 z=.-1.734, p=.083). However, player load was significantly different with the harder pitch resulting in higher level within 4V4 SSG (z=.2.741, p=0.006). On average players recorded an increased load of 3.87 arbitrary units per minute on the harder pitch. This finding was not replicated within the 8V8 SSG (z=1.293, p=0.196).

Table 7.3 Illustrates the descriptive data regarding the speed at which players performed during the SSG. On inspection the table suggests that harder pitches enable players to run greater distances at higher speeds than their softer counterparts. When all high intensity speed zones are examined collectively there is an approximate 10% increase in high intensity running within the 4V4 format in favor of hard pitch over soft. Furthermore, as the pitch size and playing numbers are increased to the 8V8 situation, a resultant 15% increase in combined high speed distance is noted. Combined speed differed significantly between 4v4 games in relation to surface hardness (z=-1.992, p=0.046), this was also evident within the 8V8 SSG (z=.-1.988, p=.046) demonstrating players ran further in high speed zones on the harder pitch.

Table 7.3 A summary of the effects of pitch hardness and game size on players speed.

External Load Measure	Number of participants	4V4 Hard pitch	4V4 Soft Pitch	8V8 Hard Pitch	8V8 Soft pitch
Combined Speed zones (5.0->7m.sec)	N=16	∑711m, (88.88 m/min) Mean 14.82,SD 15.58	∑644m, (80.50 m/min) Mean 13.42, SD 18.01	∑1599m, (133.25 m/min) Mean 33.31, SD 28.88	∑1364m, (113.66m/min) Mean 28.42, SD 26.75
Sprint zone (>7m.sec)	N=16	Mean 0.06 (1-0) SD .251	Mean 0.11 (2-0) SD.439	Mean 3.25 (9-0) SD 3.54	Mean 2.07(8-0) SD 2.63
Very High Speed (5.5-7m.sec)	N=16	Mean 11.58 (25-0) SD 8.43	Mean 7.63 (17-0) SD 5.55	Mean 35.0 (70-5) SD 19.60	Mean 27.23(53-13) SD 12.50
High Speed (5.0.-5.5m.sec)	N=16	Mean 32.82 (47-16) SD 10.01	Mean 19.23 (77-6) SD 19.23	Mean 61.67 (86-25) SD 19.79	Mean 55.94 (99-27) SD 22.98

Sprint performance (maximum velocity) was examined in isolation before and after the session using a 30m sprint runway task on both the hard and soft pitches. Wilcoxon tests revealed no significant difference between the hard or soft pitches prior to the session (z=.-.000, p=1.000). However, post-session testing showed a significant difference between maximum velocity and the relative pitch hardness (hard V soft post z=.-2.017, p=0.044). When comparison is drawn between the maximum velocity of each surface compliance pre and post testing the hard pitch observed no statistically significant difference (z=.310, p=0.756). The softer pitch observed a reduction in maximum velocity from pre to post testing (z=.-2.068, p=0.039).

Table 7.4 Average squad maximum velocity achieved during 30m sprint runway task on either surface.

Runway test	Mean	Standard Deviation
Pre-testing on Hard Pitch	8.23 m/sec	0.39
Pre-testing on Soft Pitch	8.23 m/sec	0.40
Post testing on Hard Pitch	8.18 m/sec	0.37
Post testing on Soft Pitch	8.04 m/sec	0.40

Technical data

Table 7.5 Demonstrates the variability within technical performance numbers across the SSG in relation to natural turf pitch hardness. Within the 4V4 format the hard pitch appears to promote more ground passes, carries, take on's and shots whereas the soft pitch sees more turnovers and aerial passes. Both time in possession and seconds per pass were also longer on average on the soft pitch compared to the hard one. However, the technical performance appears to adopt a different profile on the larger 8V8 format where the soft pitch demonstrated more ground and aerials passes and marginally more carries than its harder counterpart which demonstrates more take on's and marginally more shots and an increased time between each pass. The soft pitch in both the 4V4 and 8V8 format promotes more turnovers and increased duration of possession.

Table 7.5 A summary of the effects of pitch hardness and game size on technical performance.

	4v4 Hard	4v4 Soft	8v8 Hard	8v8 Soft
Ground Pass	∑ 164 (SD 1.66) 20.4 per minute	∑ 159 (SD 1.57) 19.88 per minute	∑ 110 (SD 2.10) 9.17 per minute	∑ 118 (SD 2.11) 9.83 per minute
Aerial Pass	∑ 13(SD.351) 1.63 per minute	∑ 14(SD.347) 1.75 per minute	∑ 29 (SD.707) 2.42 per minute	∑ 34 (SD.702) 2.83 per minute
Carry	∑ 32 (SD .531) 4.0 per minute	∑ 31 (SD.492) 3.88 per minute	∑ 31 (SD .754) 2.58 per minute	∑ 32 (SD.705) 2.67 per minute
Take on	∑ 40 (SD .570) 5.0 per minute	∑ 28 (SD .492) 3.5 per minute	∑ 23 (SD .620) 1.92 per minute	∑ 18 (SD .537) 1.5 per minute
Shot	∑ 65 (SD .579) 8.13 per minute	∑ 64 (SD .628) 8.0 per minute	∑ 15 (SD .480) 1.25 per minute	∑ 14 (SD .471) 1.17 per minute
Turnover	∑ 55 (SD .502) 6.88 per minute	∑ 57 (SD .498) 7.13 per minute	∑ 44 (SD .432) 3.67 per minute	∑ 49 (SD .365) 4.08 per minute
Time in possession	∑ 958 secs (SD8.71) Mean 8.71 seconds	∑ 913 secs (SD5.65) Mean 9.04 seconds	∑ 690 secs (SD 8.89) Mean 11.90 seconds	∑ 697 secs (SD 8.11) Mean 12.02 seconds
Seconds per pass	Mean 2.82 seconds	Mean 3.91 seconds	Mean 5.38 seconds	Mean 4.88 seconds

Wilcoxon repeated measures tests for the 4V4 SSG revealed that no statistically significant differences were evident between technical performance as a factor of surface hardness (Ground pass z=-.411, p=.681, Aerial pass z=-.186, p=0.853, Carry z=.-.168, p=.866, Take on z=-1.292, p=0.196 Shot z=-.632, p=0.528, Turnover z=-.700, p=0.484, time in possession z=-.375, p=.708). The 4v4 SSG on hard pitches were however shown to have significantly quicker tempo of passing, being than on their softer counterpart (z=-2.346, p=<0.019). Further testing for the 8V8 SSG showed no statistical significance between technical indices in relation to surface hardness (Ground pass z=-.040, p=0.968, Aerial pass z=-.582p=0.561, Carry z=-.235, p=0.814, Take on z=-.872, p=0.383, Shot z=-.191, p=0.849 Turnover z=-1.091, p=0.275, time in possession z=-.099, p=0.921, seconds per pass z=-.452,p=0.651).

7.4.2 Internal load

Differential RPE

Descriptive measures showed the means and standard deviations for players' perceptions of RPE to be similar across the hard and soft pitches with minimal differences.

Table 7.6 A summary of the effects of pitch hardness and game size on Differential RPE.

	4V4 Hard Pitch		4V4 Soft Pitch		8V8 Hard Pitch		8V8 Soft Pitch	
	mean	SD	mean	SD	mean	SD	mean	SD
DRPE-S	71.3	13.40	73.0	12.25	53.7	15.64	54.37	17.15
DRPE-L	68.4	13.76	67.1	14.85	54.6	15.86	54.1	16.16
DRPE-B	69.8	17.20	69.5	17.77	45.4	21.54	47.1	22.43
DRPE-T	53.7	21.91	52.5	22.99	42.3	19.84	42.6	18.22

The Wilcoxon paired samples test for each measure of the DRPE showed no statistical differences between the measures at p<.05 (RPE-S Soft 4V4 RPE-S hard p= 0.84, RPE-L soft 4V4 RPE-L hard p=0.461, RPE-B soft 4V4 RPE-B hard p= 0.465, RPE-T soft 4V4 RPE-T hard p= 0.311). This was also evident within the differential RPE scores reported for the 8V8 games with no statistical significance demonstrated by the Wilcoxon Paired Samples Test (RPE- S soft 8V8 RPE-S hard p=0.150, RPE-L soft 8V8 RPE-L hard p= 1.000, RPE-B soft 8V8 RPE-B hard p= 0.674, RPE-T soft 8V8 RPE-T hard p= 0.972.)

Difference between 4V4 and 8V8 on hard or soft natural turf pitches

When hardness of the pitch remained the same but the demands of the game changes from 4V4 to 8V8 there were notable differences in the average RPE score. Further testing using Wilcoxon Pairs T test showed statistical significance between the 4 v 4 and 8 v 8 RPE scores for soft pitches (RPE-S soft 4V4:8V8 RPE S soft p= 0.001, RPE-L soft 4V4:8V8 RPE-L soft p=0.011, RPE-B soft 4V4:8V8 RPE-B soft p= 0.001, RPE-T soft 4V4:8V8 RPE-T soft p=0.026) and also for hard pitches (RPE-S hard 4V4:8V8 RPE-S hard p=0.001, RPE-L hard 4V4:8V8 RPE-L hard p=0.008, RPE-B hard 4V4:8V8 RPE-B hard p= 0.002, RPE-T hard 4V4:8V8 RPE-T hard p=0.023). GPS and Heart rate data also follow this trend.

Heart Rate

Unfortunately, for six players heart rate data files were corrupted with too many artefacts to include within a meaningful analysis. Subsequently these were omitted from the analysis resulting in a ten player data set. The average heart rates of the ten players on the hard versus soft pitch across the two differing small sided games (4V4 or 8V8) are illustrated figures 7.4 and 7.5. Visual inspection demonstrates that whilst heart rates are lower on average in the 8V8 SSG than they are in the 4V4 SSG there appears to be no meaningful difference in HR for each player as a factor of surface hardness.

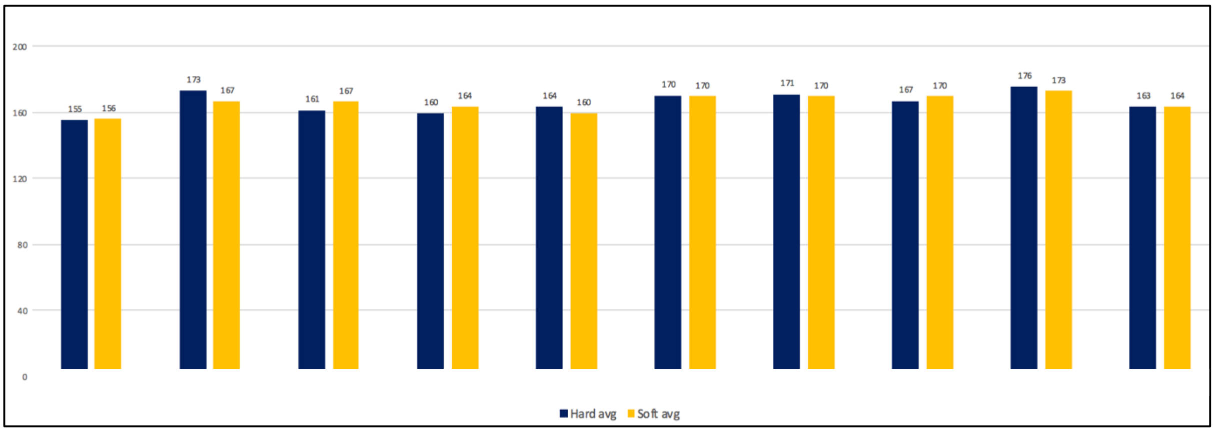


Figure 7.4 Average heart rate data for each player during 4V4 SSG on either hard or soft natural turf pitch.

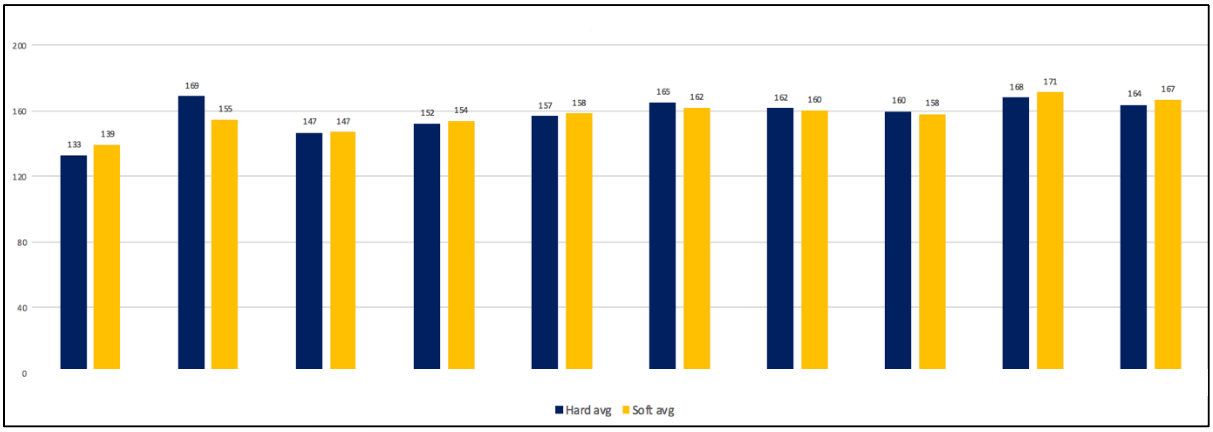


Figure 7.5 Average heart rate data for each player during 8V8 SSG on either hard or soft natural turf pitch

Heart rate data was further analysed in relation to the working bands of each player's maximum heart rate (75-85%, or 85-100%). The time recorded in each recognized zone shows greater differences for time spent in the 85-100% and 75-85% on both the hard and soft pitch for the 4v4 SSG but this less apparent in the 8 v 8 game (Table 7.7).

Table 7.7 A summary of the effects of pitch hardness and game size on heart rate.

	4V4 Hard	4V4 Soft	8V8 Hard	8v8 Soft
85-100% of Max HR (seconds)	Mean 179.1 SD 32.16	Mean 166.25 SD 47.53	Mean 160.9 SD 92.61	Mean 157.70 SD 103.85
75-85% of Max HR (seconds)	Mean 40.45 SD 24.40	Mean 56.05 SD 40.66	Mean 131.00 SD 47.48	Mean 138.70 SD 54.93

Whilst mean heart rates were higher within the 4V4 and to a lesser extent 8V8 situation on the hard pitch than the soft the large degree of sample variance make interpretation difficult. Repeated measures t tests only found a significant difference between the number of seconds spent in 75-85% zones during 4V4 SSG's between the SSG on the hard and soft pitch (p=0.038, <0.05 sig). A trend of increased time in heart rate zone 85-100% on a hard pitch for the 4V4 SSG's was found (p=0.07). No difference was observed within the 8V8 SSG's.

7.5 Discussion

The present study provides novel data quantifying how the surface hardness of a natural turf pitch affects the external and internal load experienced by elite footballers during a training session. The findings demonstrate that whilst pitch hardness does not significantly affect external load parameters such as total distance, acceleration or deceleration, it does affect the speed of both the individual and the game itself. Internal measures of load such as differential RPE and heart rate were also affected by the relative hardness of the pitch. Finally, players demonstrated the ability to accurately differentiate between surface hardness, whilst reporting differences in playability of the manipulated surfaces and their relative perceived injury risk.

External Load

It is well reported within the literature that reduction in both numbers of players and pitch size from 8V8 to 4V4 promotes a better training response or stimulus since the number of technical actions increases (Jones and Drust 2007, Owen et al 2011). Fewer players and a smaller pitch increases the opportunity for ball contacts and thereby the intensity of the game, as such frequency of shots, heart rate and RPE are all increased in comparison to larger games (Aguiar et al 2012). Larger pitch sizes with increased numbers of players promote a better organisation or structure to the game promoting a less intense, more possession based style football (Hill-Haas et al 2011, Owen et al 2011). Whilst this was evident within the findings of this study, thereby reinforcing the study design, what was also apparent was that the relative pitch hardness also affected technical outcome.

The hard pitch within the 4V4 SSG was shown to statistically differ compared to the soft regarding the tempo of passing, being significantly quicker than on their softer counterpart. Whilst not achieving significance the hard pitch also appeared to promote less time in possession, more ground passes, carries, take on's and shots. In contrast the soft pitch recorded more turnovers and aerial passes. However, within the 8V8 format the technical performance appears to adopt a different profile where the soft pitch demonstrated more ground and aerial passes and marginally more carries than its harder counterpart which displays more take on's, marginally more shots and an increased time between each pass. The soft pitch in both the 4V4 and 8V8 format promotes more turnovers and increased duration of possession. These findings support those reported in Chapter 3 where key stakeholders perceived the pitch hardness to significantly affect both the ball, their passing strategies and tempo of the game. Such changes in technical performance in relation to pitch hardness show the adaptability of players regarding their tactical and skill acquisition perspective.

One may argue that the adaptation of technical performance may be more of a secondary or reactionary process perhaps driven by the ball's interaction with the surface. However, from a more physical perspective the players were also shown to be affected by relative pitch hardness particularly with regards their speed and velocity. The combined high speed running distances recorded on the hard pitch were 10% (4V4 SSG) and 15% (8V8 SSG) greater on the hard pitch in comparison to the soft. Taken in context, the importance of such a disparity in high speed distance is significant as the exposure time was so small (8 minutes:4V4 and 12 minutes:8V8). If such trends were to continue over the duration of either a full training session or indeed a match situation clear differences would be expected in this measure of external load.

Sprinting performance was also found to be affected by pitch hardness. When maximum velocity was examined in the 30m sprint runaway task identical speed was found on both surface types (8.23m/sec) immediately prior to training. However, tests on session termination demonstrated a 2.31% reduction in maximum velocity on the soft pitch (8.04 m/sec) in comparison to no decrease on the hard pitch (8.18m/sec). When compared with the earlier findings, harder pitches enable players to achieve both greater distance at high speed and higher velocities even when fatigued in comparison to soft pitches.

'Player load' reported as a "summation of forces in all three planes of movement" and recorded using the tri-axial accelerometer housed within the GPS unit worn by the players, has been proposed as a more reflective measure of the movement demands on the player (Cummins et al 2013). Interestingly, a novel finding within this study was that player load was surface dependent, being significantly higher during the 4V4 games played on the hard natural turf pitch. The surface hardness may have contributed to such elevated player load, by promoting quicker games, higher max speed and demonstrating greater high speed durations, in comparison to the softer pitch.

Internal load

The findings reinforce those of others that differential RPE was affected by the size and number of players within the session (Owen et al 2011, Hill-Haas et al, 2009,). The 4V4 SSG promoted significantly higher DRPE scores for all variables when compared to the 8V8 format (30% difference). When averaged the data suggest the hard pitch is perceived to increasingly affect the perceived load on the players' legs and the technical demands of playing on such a surface. This may be possibly due to the associated increase in ground reaction force and the speed increases witnessed on the harder pitch (Stiles et al 2011). Whereas, the softer pitch was perceived to have affected their breathing more so than on the harder one, which may in part be due to the energy expenditure being higher on such more compliant surfaces (Sassi et al 2011). However, there were no significant effects for differential RPE as a result of surface hardness independently in either the 4V4 or 8V8 format. In part this may be due to players adapting their relative leg stiffness, in order to maximise their performance on the two differing pitches (Ferris et al 1999, Stafilidis and Arampatzis 2007).

Within elite football, heart rate as a measure of internal load has been known to be difficult to quantify due to the sporadic, intermittent nature of the game (Kelly and Drust 2009). Undoubtedly, the reduced sample size and large sample variance negatively affected a meaningful analysis. However, despite this limitation, the 4V4 SSG, provided the only significance regarding heart and surface type with time spent in the 75-85% zones being higher on the softer pitch. Whilst not statistically significant the surface effect for the 4V4 SSG's on the hard pitch (heart rate zone 85-100%) did appear to be moving towards significance. The results are difficult to interpret due to the small numbers and large variance but heart rate appears to be resistant to surface compliance. Perhaps the small time exposure limits the significance between heart rate and surface hardness or the fact that the energy expenditure in relation to surface hardness proposed by other researchers was not sufficient to drive a heart rate response. The sporadic movement patterns make such interpretation very difficult in a one off exposure.

Players' perceptions

Primarily, the study showed players were clearly able to differentiate between the two differing surface hardness's. Despite being blinded to the manipulation of the two pitches relative hardness 14 of the 16 outfield players within this study were able to correctly differentiate the two pitches in relation to their relative hardness. One player reported being unaware of any difference and one incorrectly identified the pitch hardness. Additionally, players demonstrated a preference for which surface they would rather play on with over 57% (n=9) preferring soft in contrast to the harder pitch (32%, n=5). Two players expressed no preference regarding their surface of choice. These preferences appear driven by comfort with negative perceptions of the hard pitch raising comments like "*the ground was too hard, it hurt my feet*". Whilst comments that the softer pitch it "*was better for control*" were countered by more negative perceptions that "*it cut up more*".

The players' preferences regarding sprinting and turning resulted in 50% (n=8) favouring the harder pitch, 31.25% the soft (n=5) and three players expressing no difference. Players reported being "able to push off and grip better" on the harder pitch and furthermore they "felt it less tough on their legs". Interestingly, five players (31.25%) reported concerns of muscle fatigue on the soft pitch, whereas six players (37.5%) specifically expressed concerns over their hamstrings on the hard pitch. Furthermore, three players reported joint soreness/pain on the hard pitch. Consequently, even with short exposure some players reported concerns regarding specific tissues and their likelihood of injury. This highlights the need for those responsible for rehabilitation and/or improving fitness of players to be more aware of pitch hardness as such negative perceptions may drive anxiety and increase injury risk in some players (Bruckner et al 2014, Gouttebarge et al, 2018).

7.6 Methodological considerations

Undoubtedly one of the major limitations of this study was the restricted number of players, this was of particular concern regarding the heart rate data where 6 of the 16 players' data was found not viable. A further issue was the limitation surrounding the total time exposure of players within the session to either the hard or soft pitch. In total players were exposed to 8 minutes of activity on each pitch during the 4V4 SSG and 12 minutes within the 8V8 SSG. This limited exposure probably only produced a 'snap-shot' of the effect that pitch hardness may have had upon the variables measured. Furthermore, the use of SSG whilst a useful means of promoting training adaptation and preparation of players may not be truly reflective of the larger 11v11 game. Whilst, the use of DRPE has been increasingly used within the applied setting, it is still unclear how sensitive a measure it really is (Barrett et al 2018). The design of this study with very limited exposure may have made the use of such a tool very difficult for the players to interpret and record their perceptions. Finally, regarding the mechanical testing of surface hardness, the Clegg Hammer has previously been questioned as its weight does not necessarily simulate the loads to which the player is exposed. Saunders et al (2011) compared the Clegg Hammer with ground reaction forces obtained from a force plate and showed a low correlation (r=0.2), concluding that valid discrimination of the surface hardness is not reflective of loads experienced by humans. However, the findings that some variables are sensitive to change in surface hardness supports the design of this study. Its findings reinforce the view of Young and Fleming (2007) that the Clegg Hammer is indeed a useful way of objectively rating surfaces. Future research needs to examine the full size pitch and the 11v11 format in a similar manner to better understand the effects of pitch hardness on real match loads. Additionally, longitudinal studies should be instigated to explore how acute and chronic exposure to varying pitch hardness influences external load, internal load, and their dose response.

7.7 Conclusion

This study reinforces perceptions that pitches affect tissues in a specific manner, whilst simultaneously providing greater insight as to how the pitch hardness influences internal and external load. Hard pitches increased external loads such as speed and maximal velocity, as well as player load values in comparison to soft pitches. Furthermore, hard pitches enabled players to maintain maximum velocity even when fatigued, a factor which may be implicit in the number of hamstring injuries which plague the professional game. Technically, harder pitches appeared to promote faster games, with reduced periods of possession and less time between each pass. Whilst the significance of pitch hardness on internal loads was less, with only heart rate showing signs of significance within the 4V4 SSG. These findings are of importance to all key stake holders as they will enhance training prescription and periodisation, whilst optimising adaptation and minimising injury risk.

CHAPTER 8

SYNOPSIS:

Can the natural turf pitch
affect injury risk or performance
within elite football?

8.0 Chapter Prelude

The aim of this chapter is to synthesise the findings and outline the practical application obtained within this thesis. To achieve this a holistic approach is adopted, with discussion extending across broad but important themes for the applied setting. Finally, recommendations for future research regarding the hardness of natural turf pitches within elite football are presented.

8.1 Achievement of the objectives

The aim of this thesis was to explore the relationship between hardness of natural turf pitches, injury and performance in elite football. This was driven by the concerns of those working in the applied setting. The available literature was limited and fraught with methodological issues which offered no objective assessment of pitches, consequently little empirical evidence could be found to validate these concerns. This thesis has aimed to address these short comings, showing that there is indeed a question to answer (chapter 3), that methodological concerns can be overcome (chapter 4 and chapter 6) and that in doing so rich information can be explored regarding the natural turf's relative hardness (chapter 5) and its effect on injuries (chapter 6) and performance (chapter 7) within elite football. Whilst these findings provide a platform for future research, they provide those working within elite football insight into the importance such natural turf pitch hardness can have upon injury and performance. This new knowledge should empower those within the applied setting to harness the relative hardness of natural turf thereby maximising the performance of their players whilst minimising their risk of injury.

Objectives:

1. **To explore perceptions of key stakeholders within professional football that the hardness of the natural turf pitch, could be considered a potential injury risk, which affect both the performance of the player and the ball.**

   Chapter 3, outlined not only do key stakeholders perceive the natural turf pitch hardness to be a significant risk factor for injury, but also that its effect on specific tissues can be surface dependent. Concerns extended beyond injury, detailing how the relative hardness also affected the bounce and roll of the ball and their need for behavioural adaption to accommodate to the surface hardness. Finally, it highlighted how collaborative working relationships between groundstaff and other stakeholders may be key to improving such perceptions.

2. **To develop a practical methodological approach to objectively testing pitch hardness.**

   Overall the results have methodological rigor, utilise recognised consensus and injury surveillance, whilst being obtained longitudinally from one elite football club. Chapter 4, questioned past protocols evaluating and testing such natural turf pitch hardness with a Clegg Hammer (2.25kg). It proposed and validated a football specific testing process, reflective of the demands of the game but not so time consuming or damaging to the pitch that it precluded its use close to player exposure. The quantification of pitch hardness has allowed, for the first time, prospective injury data to be explored in relation to pitch hardness.

3. **To prospectively examine the relative hardness of new hybrid natural turf pitches.**

   The development of new reinforced hybrid natural turf pitches, whilst needed to ensure their status as the surface of choice within the elite game had not been investigated thoroughly. This thesis has shown nearly one quarter of all exposures fell outside the recommended range of relative hardness proposed by UEFA. The development of hybrid natural turf pitches has shown them to be more stable structures, showing significantly less variability than the Native soil pitches. However, the cost of improved stability is demonstrated by an increase in their relative hardness (Chapter 5).

4. **To examine relationships between prospectively collected injury and objective pitch hardness.**

Adopting a logical, pragmatic approach within this thesis to methodological rigor has helped us develop a greater understanding, of the links between pitch hardness and epidemiology of injury in elite football. The findings of which reinforce those of chapter 3 where the risk of injury to specific tissues was surface dependent. Hard pitches were seen to affect the injury incidence and burden of joints and tendons in contrast to soft pitches which adversely affected injury risk to ligaments and muscles. Interestingly, the new hybrid pitches affected the injury burden seen, this was particularly noticeable for muscle injures.

5. To evaluate the acute influence of pitch hardness on player load.

The pitch manipulation study within chapter 7, demonstrated that both the external and internal load of players could be affected by relative hardness. Additionally, the bounce and roll of the ball impacted on passing and running performance in a surface dependent manner, affecting the tempo of the game. Perhaps the most pertinent finding was regarding maximum velocity where the hard pitch promoted higher speeds than the soft pitch, even when players were fatigued. This may have an effect particularly on 'speed related' injuries such as hamstring strains, which remain a major concern within elite football.

8.2 A conceptual framework for the natural turf pitch and how it may influence a footballer's risk of injury.

Chapters 1 and 2 introduced the idea that the relative hardness of the natural turf pitch could be considered a risk factor for injury within elite football. Whilst the available literature was unable to confirm this relationship within elite football, a broader conceptual framework of how pitch hardness may influence a footballer's risk of injury was proposed (Figure 8.1).

Research thus far has attempted to evaluate the impact of relative hardness of playing surface through subjective comparisons of artificial and natural turf pitches, or inferences regarding climatic variation. This paucity in literature raised the question as to whether pitch hardness is perceived to have an impact on injury and performance, if so in what way and could this impact be evaluated objectively. Chapter 3 explored perceptions of key stakeholders and found despite disparity in reporting between occupations, stakeholders perceived there to be a significant risk of injury in relation to increasing pitch hardness. This is of concern as they also felt pitches were getting significantly harder over time. Interestingly, the finding that the groundstaff perceived soft pitches to carry a higher injury risk than hard pitches, may explain why such pitches are getting harder, perhaps in their attempts to mitigate this perceived risk. Moreover, stakeholders perceived risk to differing tissues was dependent upon the relative hardness of that surface, a factor that was also evident in chapter 7. Hard pitches were thought to increase risk of joint and tendon injury whilst, softer pitches adversely

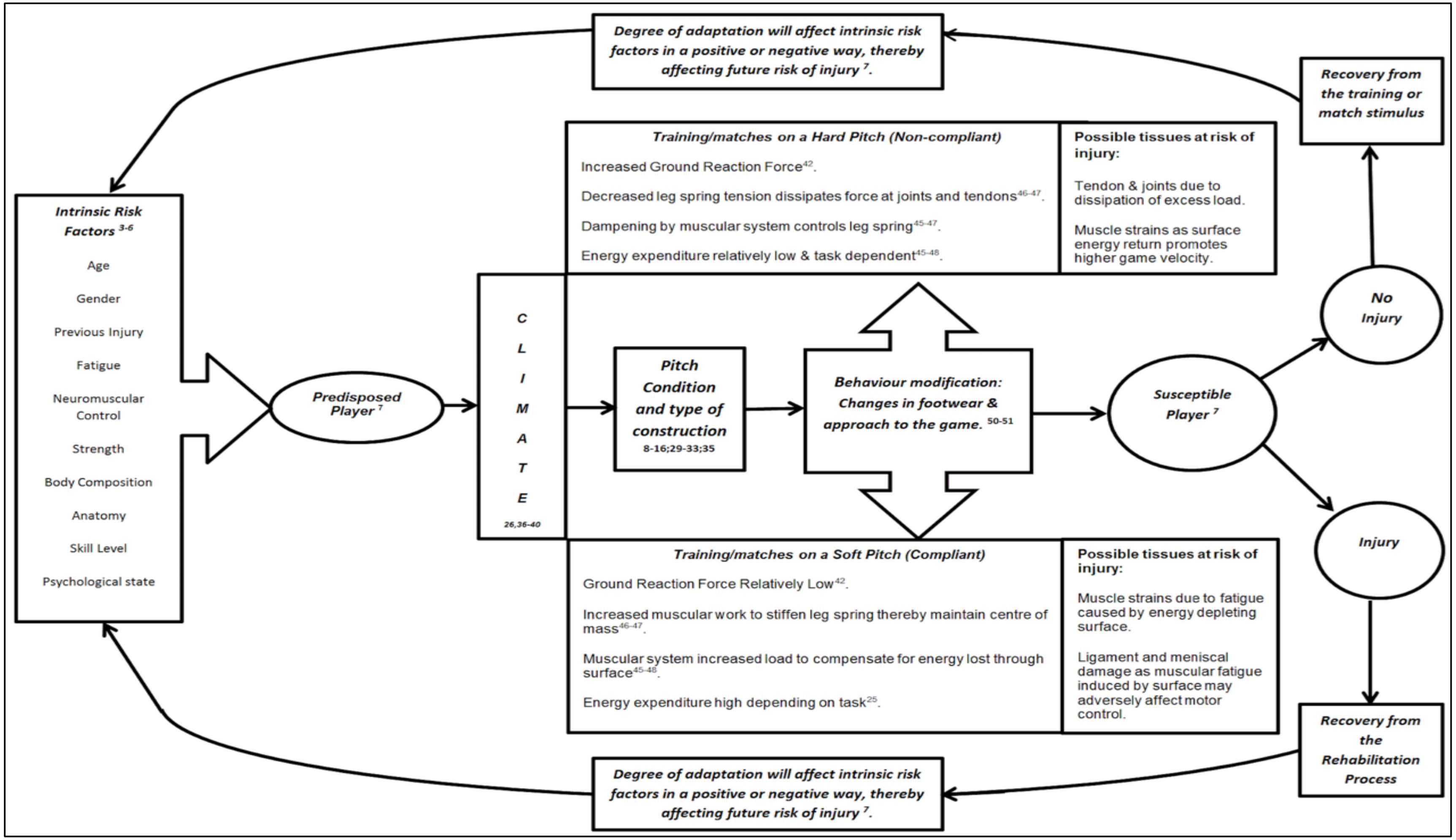


Figure 8.1 A conceptual framework for the natural turf pitch and how it may influence a footballer’s risk of injury (Rennie et al 2016).

affected muscles and ligaments. These findings suggest there is a question to be answered regarding the role of pitch hardness injury and performance.

Although the findings within this thesis can be seen to reinforce this model, they have generated further questions which will be explored in subsequent sections of this synopsis. Overall the results have methodological rigor, utilise recognised consensus and injury surveillance, whilst being obtained longitudinally from one elite football club. The quantification of pitch hardness has allowed, for the first time, prospective injury data to be explored in relation to pitch hardness. The original framework of load and adaptation in relation to pitch hardness was supported by perceptions of key stakeholders within chapter 3, and by the injury surveillance data of chapter 6. As was the role of new hybrid natural turf pitches and their role in performance and injury discussed in chapters 5 and 6. However, this thesis has generated new knowledge founded on objective measurements of natural turf pitch hardness. The collation of prospective injury surveillance and detailed information on player load and technical performance have advanced understanding. These findings are summarised within an adapted model (Figure 8.2), highlighting the hardness of natural turf pitch and its affect upon risk of injury and performance within elite football.

Clearly, whilst intrinsic risks remain, the extrinsic risk factor of the natural turf pitch has advanced to a hybrid construction, which is more robust to the effects of climate and footfall. However, such advancements affect both players' performance and susceptibility to injury (chapters 5-7). Figure 8.2 illustrates how the players' perceptions, behaviours', external and internal loads depend idiosyncratically upon the natural turf

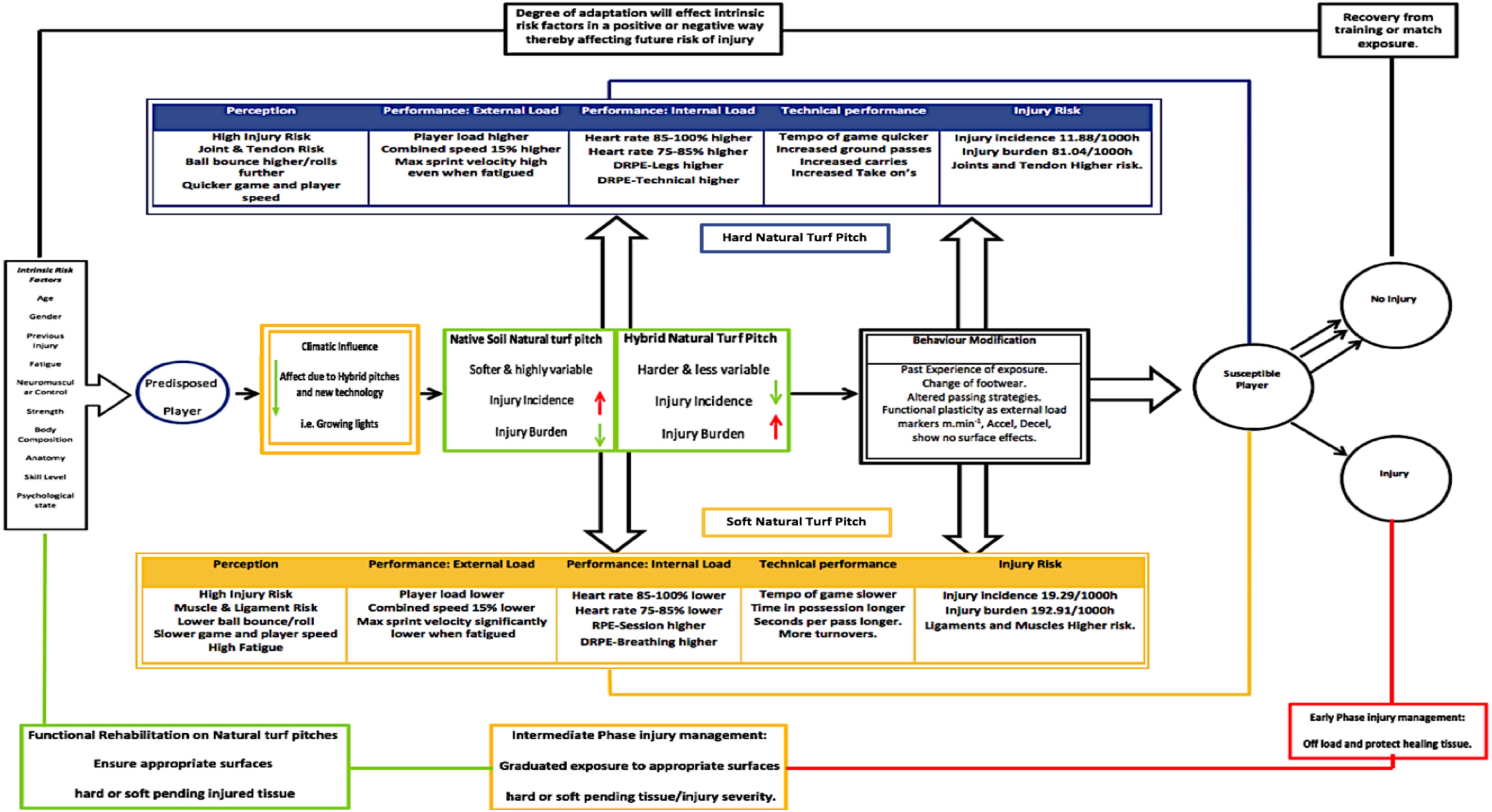


Figure 8.2 A model demonstrating natural turf pitch hardness and its effect on injury and performance within elite football.

pitch construction and its relative hardness. This affects the adaptation period required ahead of the next exposure to the natural turf pitch, impacting on the susceptibility of each player to future injury or adverse performance (Meeuwisse et al 2007, Rennie et al 2016). Knowledge of this can empower the coach, sports scientist, physiotherapist and player to optimise the training overload principle, maximising adaptation and thereby improving performance. This adaptation period should be considered with each player independently. Their readiness to perform again, will be determined the exposure to either the soft or hard pitch, and how this affected their perception, behaviour, external and internal load relative to their intrinsic risk. These interactions determine the susceptibility of each player moving forward. Equally, if exposure to the pitch results in injury the rehabilitation process must account for the effect of surface hardness on the healing tissue. Failure to address this may lead to overload of the tissue, prolonged rehabilitation, re-injury or a return to play which comes at the expense of increased intrinsic risk. The model (Figure 8.2) provides an 'educative framework' for users to help them better understand the effect of surface hardness on players within elite football.

8.3 Pitch quality standards

Whilst the demands of the game remain relatively unchanged, the platform upon which players are exposed alters in relation to climatic conditions and footfall (Chapter 5). Despite such temporal and spatial variation, natural turf remains the preferred surface of choice within elite football. Developments within soil technology, the transition to sand based pitches with reinforced root zones known as hybrid natural turf pitches has undoubtedly improved the pitch quality standards within the elite game. The role of differing natural turf constructions was not reported within the previous conceptual model, and this omission has been shown within this thesis noteworthy of inclusion. Such development within natural turf has not been to universal acclaim, with both the players and media on occasions being openly critical of such pitches. Governing bodies such as UEFA have responded with recommendations, which are neither policed, nor enforced. Chapter 5 illustrated this, as nearly one quarter of exposure fell outside these recommendations and it is these exposures, which generally speaking, are most affected by injury. Although, the general perceptions of artificial pitches remain somewhat negative regarding both performance and injury, they are stringently monitored and regulated (FIFA, 2015, Fleming, 2011, Charalambous et al, 2016). Simply because natural turf is the surface of choice does not mean it is without risk (Chapters 3, 6, 7).

This thesis has clearly shown the hybrid natural turf surfaces are significantly harder than the previous native sand soil pitches they have replaced (chapter 5). This factor was of concern to key stakeholders (chapter 3), and seen to affect injury rate and burden (chapter 6). Perhaps most relevant was the change in the degree of temporal variation longitudinally. Player exposure to pitch hardness on native soil could fluctuate from extremely soft to extremely hard almost overnight. Players reported that the softer pitches often left them ‘feeling leggy’ and led to higher levels of fatigue whereas hard pitches led to joint soreness and tendon pain. These may be due to energy depleting nature of such surfaces or the need to dissipate excessive ground reaction forces. Temporal variation was shown to have reduced significantly with the advent of hybrid natural turf (Chapter 5) which was also true for spatial variation. As a consequence, players now are exposed to less extreme levels of hardness/softness on exposure to natural turf pitches. Interestingly, the incidence of injuries reported has also reduced over the thesis timeline (Chapter 6). Whilst these reductions may be attributable to improvements in load monitoring with GPS, and thereby an understanding of the relationships between acute and chronic load, the improved quality/consistency of natural turf pitches may also have contributed. However, the burden of injury (number of days lost) on such hybrid turf has notably increased. Interestingly, the Desso pitches which showed the highest average hardness also demonstrated the greatest injury burden. This contrasts the earlier findings that muscle injury had been linked to exposure on the softer surfaces. The reason for this is unclear but may reflect that harder surface of the Desso pitch promotes faster speeds and increased eccentric fatigue, ultimately resulting in muscle injury (Hales and Johnson 2019). Alternatively, the reduced variability in the relative hardness of hybrid pitches may limit the ‘band width’ or exposure to such extremes. Thereby reducing player’s robustness and/or experience of pitches which fall outside of their normal profile. This narrower window of hardness exposure promotes an environment in which they can perform at high intensity, ultimately leading to over-reaching. This may account for the increased injury burden. This highlights the complexity of injuries within elite sport as not only the hardness but also the construction, which is seen to affect burden. More factors at play necessitates more detailed investigations on moisture content, shear strength, traction and energy restitution on such differing construction.

8.4 Injury and natural turf pitch hardness

Adopting a logical, pragmatic approach within this thesis to methodological rigor has helped us develop a greater understanding of the links between pitch hardness and epidemiology of injury in elite football. The use of recognised consensus definitions, injury surveillance, together with reliable testing equipment/protocols provide data capable of informing practice regarding the preparation and recovery of players (Chapters 4-7). Furthermore, this knowledge can also help inform ground staff about the pitches they are creating/maintaining, and their likely effect upon injury.

Perhaps the dominant theme of the thesis was the ability of users to differentiate pitch hardness and relate it to relative injury risk (Chapters 3,6,7). Tissues are known to have a narrow window for optimal load dependent on their type. Under or over-loading tissues when training or playing football can lead to damage, whilst not providing enough time for adaptation may also lead to injury. For any given task an appropriate degree of muscle contraction is required to achieve the desired displacements and velocities of the body on the pitch (Ferris et al 1998). Additionally, the player's muscles must (1) generate additional force to compensate for the inevitable energy dissipated through surface compliance, (2) modify the required force according to the level of strain development in the tendons, and (3) minimise the peak impact forces experienced by their joints during loading of the stance leg (Geyer et al 2003, Ferris et al 1999, Hardin et al 2004). Consequently, a player running on a compliant (soft) pitch expends more energy for any given running velocity when compared to running on a less compliant (hard) pitch in order to compensate for energy dissipated through the surface. Soft pitches negatively affect the ability of the muscles to utilise the elastic properties of their tendons leading to an over-dependence on the muscles to maintain performance leading to fatigue. This has been confirmed through demonstration of a negative relationship between surface compliance and oxygen consumption (Katkat et al 2009). As a result, muscles need to work harder due to the energy depleting nature of the surface. Therefore, considered in isolation, playing on more compliant surfaces may induce localised muscle fatigue. Over a more cumulative time frame the additional muscular effort may cause an increased risk of muscle strains (Chapters 3, 6).

Conversely, the player running on a hard pitch will experience increased loading through joints and tendons due to increases in impact forces (Chapters 3 and 6). The musculoskeletal system ‘dampens’ this by reducing leg stiffness, effectively cushioning each step. In the short term, these excessive ground reaction forces may be dissipated through the aforementioned spring system, which may have accounted for the stable measures of external load, such as meters per minute, being independent of surface hardness within chapter 7 (Geyer et al 2003, Ferris et al 1999, Hardin et al 2004). Consequently, the pitch can affect the musculoskeletal system of players in both an acute and chronic manner. Previous injury, repetitive impacts or insufficient adaptation/recovery between exposures would reduce the load required to initiate tissue breakdown and resulting injury. Thus, the relative hardness or softness of a pitch may influence the loads and fatigue experienced by the musculo-skeletal system (Smith et al 2004, Kaila et al 2007, Katkat 2009). Failure to provide players with sufficient time for musculoskeletal adaption following pitch exposure could increase their risk of injury. This could be acute, causing immediate injury or through repeated exposure result in more chronic overuse injury (Meeuwisse et al 2007).

The risks to injury and performance of such perceptions and their potential impact are mitigated through behaviour adaptation. Chapter 7 found that pitch hardness affected the bounce and roll of the ball impacting on differing passing strategies and running performance. In turn these affected perceived levels of fatigue and even the tempo of the game (Chapter 3 and 7). Interestingly, the fact that key stakeholders reportedly adapted their running and passing strategies in relation to relative hardness is important because this behavioural adaptation creates an almost functional plasticity (Liu-Ambrose et al 2012). Their motor learning through subsequent successes and failures on differing pitch hardness's informs their future decisions and performance, leading to a more adaptable and robust system (Milton et al 2007). In essence players are continually adjusting and fine tuning their musculo-skeletal system, from their feet upwards i.e. the point of contact with the surface. This is an attempt to successfully achieve the task at hand, whilst using their past experiences to avoid exposing their tissue to risk of injury. Injury or poor performance, physical or technical, could therefore be viewed as outcomes which have precursors, one of which is the interaction with the pitch surface. Consequently, the findings within this thesis suggest that perceptions, incidence and burden of injury and the role of natural turf pitch hardness have significant implications for the applied setting (Chapters3,5-7).

A practical program which provides stakeholders such as physiotherapists and sports scientist with objective measures for the hardness of the natural turf they were about to expose their player to, would be of major benefit. Within rehabilitation careful consideration is needed where players are exposed to such surfaces. As demonstrated within chapters 3, 6 and 7 of this thesis, the relative pitch hardness has a significant effect on the player's injury risk, external/internal load and their overall performance. Incorrect or over exposure to specific pitch hardness may lead to an exacerbation of the player's symptoms and on occasion even to a recurrence of the initial injury. Physiotherapists need to consider what level of hardness will best aid the player's recovery, and or, service the demands of the task. For example, a player recovering from Achilles tendonopathy may best be exposed early in the rehabilitation to more compliant surfaces to reduce loading, and minimise pain. Whereas, towards end-stage functional rehabilitation when plyometric drills are being prioritised, less compliant harder surfaces would be best suited. Such considerations are also important to the sports science team particularly regarding fitness testing. Repeat shuttle drills or test for high speed are unlikely to reflect the true ability of players if they are performed upon compliant natural turf. The bias such results would produce, negates their benefit and may expose players to unnecessary risk.

Within elite football the costs of injuries are high, but extend far beyond incidence rates and days lost, or their effects on relative success of the club (Hagglund et al 2013).

Financially, the cost to clubs on lost wages can be large and the prospects of future earnings of player contracts may also arguably be affected by injury (Ekstrand et al 2013). On a more humanistic level, whilst injuries are known to restrict playing time, they more importantly increase the intrinsic risk of the player, thereby making them more susceptible in the future (Meeuwisse et al 2007). As such past injury is often identified as a predictor of future risk, and on occasions can almost define the identity of a player (Hagglund et al, 2006). However, the psychological effects that injuries have on the mental health and well-being of players is perhaps of most concern. Distress, anxiety and sleep disturbances are all prevalent following injury within elite football. Players who have one or more severe injuries (>28 days) over their career were 2-4 times more likely to report symptoms of common mental health difficulties than those who had not (Gouttebarge et al 2018). Within this thesis over 50 severe injuries were reported, accounting for 3,391 days lost highlighting the gravity of risk that players can face. It is therefore imperative that all key stakeholders take the necessary precautions to ensure exposure to natural turf pitches does not increase any player's likelihood of injury.

8.5 Performance and natural turf pitch hardness.

Within modern professional football, the high intensity efforts, have changed the game as both a spectacle and an injury risk to those participating, making the findings regarding pitch hardness and speed highly pertinent (Chapter 7, Gabbett and Ullah 2012). Barnes et al (2014) in a longitudinal study of the English Premier League reported a 30-80% increase in such high intensity efforts and sprinting. Perhaps the increase in pitch hardness reported perceptually by key stakeholders in chapter 3, later reinforced by the objective changes shown in pitch hardness within chapter 5, and shown statistically to affect maximum velocity even when fatigued, in chapter 7, may have contributed to such changes within the game. The mechanisms by which the hard pitches may promote such performance are unclear. One may argue that hard pitches return more energy to the player (Pinnington and Dawson 2001, Sassi et al 2011), even as this study shows when they are fatigued, to enable them to perform near to their maximum speed. Within athletics it is generally believed that hard tracks improve sprint performance, assuming an increase in the rate of ground reaction force generation in comparison to a softer track (Weyand et al 2000). In their report entitled ‘the science of speed”, Majumbar and Robergs (2011) cite the early works of McMahon and Green (1979) who concluded that very compliant, soft running surfaces contribute to an increase in ground contact time and decreased step length, leading to slower running speeds. However, these arguments are countered by other researchers of track compliance who propose that as humans are able to adjust their behaviour depending on the surface characteristics, they are therefore not affected by surface compliance levels (Stafilidis and Arampatzis 2007). Some support for this could be found within chapter 7 where, measures of external load were relatively stable between different levels of surface hardness, suggesting players may modify lower limb stiffness, to maximise performance return independent of the surface.

The findings around maximum velocity and the surface dependent nature of combined high speed running demonstrated within chapter 7, may provide insight regarding the prevalence of hamstring injuries within elite football. Such injuries, whose incidence, known to be increasing 4% annually, are a major burden within elite football (Ekstrand et al 2013). They are often associated with high speed running and sprinting a factor which this thesis has shown to be surface dependent (Chapter 7). Interestingly, developments within natural turf pitch construction have led to increasing exposure in training to pitches of a more hybrid nature, which are also known to be harder (Chapter 5). Such transition is motivated by the need for consistency of surface. This enables transfer of both technical and physical skill sets between training and matches. However, as this thesis illustrates this may affect the speed profiles of players, enabling them to achieve higher speeds during the training week, irrespective of fatigue. Whilst this may not lead to injury or performance reduction acutely, the cumulative effects may make players susceptible to such speed related injuries as hamstring strains when exposed to their greatest load, that of match day. This knowledge is pertinent to coaches, sports scientists and physiotherapists as burden of injuries has been shown to affect the relative success of teams (Hagglund et al 2013). An understanding that the relative hardness of the pitch that their players are exposed on any specific day, and those they have been exposed to recently, will affect the technical and physical ability to meet their demands is essential. Education of key stakeholders regarding pitch hardness is therefore of paramount importance. Knowledge of this extrinsic risk enables stakeholders to control variables such as speed and acute/chronic fatigue by manipulating pitch size, playing numbers, work to rest ratios and player management of specific positions. In doing so, this may help mitigate such risks through appropriate management of pitch exposure and the adaptation process.

8.6 Collaborative working

Both chapters 3 and 7 have illustrated the importance that the groundstaff can play in performance. Their ability to manipulate the surface hardness may be seen to enhance or inhibit performance. Perhaps like in cricket, the hardness of the natural turf pitch needs to be linked to what the team are hoping to achieve in their style, enabling them to maximise their playing performance. However, perhaps unlike cricket, this thesis portrayed elite football to have a somewhat fractured working environment, with little collaborative working between key stakeholders and groundstaff (Chapter 3). The relationship between staff regarding preparation, maintenance and expectation of natural turf pitches demonstrated a disparity of all those involved. Poor communication and a lack of accountability prevailed, and as such players and coaches despite having not expressed their wishes, readily complained, or perhaps worse still did not convey their concerns regarding the hardness of the surfaces on which they train or play. Furthermore, the sports science and physiotherapy staff who despite perceiving risk to both performance and likely injury, did not address such perceived problems and reported to have done little to affect change. Finally, governing bodies such as the FA and UEFA, whose recommendations regarding the natural turf hardness are not enforced, policed, or governed have a role to play in reducing incidence and burden of the injuries highlighted by this thesis. Ekstrand (2019) has shown better working/communication between managers and medical, and or between sports science and medical leads to significant reduction in the injury rates/burden of teams. The relationship with groundstaff also needs to change as they provide the platform upon which to train/play. As seen within chapter 7, where the groundstaff manipulated the pitch hardness, this collaborative working is achievable within the elite setting. Adopting this approach, with recognisable governance, may help reduce the likelihood of injury in relation to pitch hardness. Such collaboration would help promote natural turf pitches reflective of how team would like to play, and ones which the coaches, players and groundstaff understand how they affect load, adaptation, performance and injury.

8.7 Limitations

Research within the applied setting requires a level of pragmatism. Access to clubs and exposure to players is often difficult as the apparent need for secrecy and protection of the club's assets namely the players is viewed with the upmost importance. Unfortunately, this limits the generalisability of the research and may be viewed as a confounding variable within this study where only one club was examined. In order to understand fully how pitch hardness affects the performance or injury risk of players, researchers need tools which are reflective of the loads to which players are exposed. Whilst the Clegg Hammer is both reliable, valid and provides a rating for any given surface it is not necessarily reflective of player loads (Young and Flemming 2007, Saunders et al 2011). Whilst monitoring of external and subsequent internal load with GPS and accelerometry has been validated, researchers looking to investigate player-surface interaction require such devices to be incorporated closer to the interface between the surface and the player, namely the boot instead of between the scapulae. Finally, the past medical history of the players was not accounted for within the thesis.

This may have affected some of the injury prevalence seen within the study and its susceptibility to pitch hardness warrants further investigation.

8.8 Future Research

Multi-centre trials are needed, preferably overseen and enforced by the governing bodies, utilising recognised injury surveillance techniques and objective measures of natural turf pitches. A test battery investigating the pitch across many dimensions should be included similar to that used to certify artificial turf, which includes measures of moisture content, energy return and traction. This equipment needs to be portable, and not adversely affect the playing surface in order that it can be used close to player exposure. This would provide the necessary sample size, for appropriate modelling or machine based learning, driving a better understanding of hardness of natural turf and its effects on injury and performance. The use of diagnostic imagery as a means of quantifying the effects of exposure of tissues to differing hardnesses, could also be employed by researchers. Pre and post ultrasound scans for tendons, dynamic MRI scans for muscle and investigations of bone metabolism may highlight underlying pathological processes driven by surface exposure. Furthermore, the use of heart rate variability or sleep monitoring post exposure may provide insight to the adaptation required after exposure to such natural turf pitches.

8.9 General conclusions

In summary, this thesis has taken the first step towards exploring how the hardness of natural turf pitches could be viewed as a risk factor for injury within elite football. It both recognises and reports stakeholders' concerns regarding pitch hardness documenting how it is specifically thought to affect injury risk and performance. The novel design and methodology enabled detailed investigation of how natural turf pitches are changing and affecting both injury and performance. Profiles of injury, technical and physical performance measures were found to be dependent upon relative surface hardness. The final pitch hardness manipulation study, the first of its kind, provided insight of how such surface hardness affects external and internal loads experienced by players.

Further multi-centre studies are now required to explore the effects of surface hardness injury and performance. Whilst these findings provide a platform for future research, they provide those working within elite football insight of the importance natural turf pitch hardness can have upon injury and performance. This new knowledge should empower those within the applied setting to harness the relative hardness of natural turf thereby maximising the performance of their players whilst minimising their risk of injury.

8.10 The novel findings of the thesis

Pitch construction

- Variability in pitch hardness due to climatic variability has been reduced following the development of Hybrid natural turf and new technology such as growing lights.
- Native soil natural turf pitches are generally softer, and more variable, than Hybrid counterparts.
- Hybrid natural turf pitches carried a low injury incidence but a high injury burden, compared with native soil pitches which showed high rates of injury incidence but low burdens.
- Natural turf pitches are becoming increasingly hard, a factor perceived to be a significant risk for injury.
- Key stakeholders perceived pitch hardness could significantly affect their performance and likelihood of injury, but did not perceive the need for developing good working relationships with their groundstaff.

Hard pitches

- Were perceived to affect joint soreness/pain and risk of tendon injury. They also affected the ball bounce and roll, whilst promoting quicker passing game.
- Harder pitches enabled 15% higher player speeds than soft.
- Players can achieve their maximum velocity, even when fatigued on hard, but not soft natural turf.

Soft pitches

- Affect both the perceived and recorded risk of muscle/ligamentous injuries in particular.
- They produced a lower ball bounce/roll, slower game and player speeds.
- They were very fatiguing surfaces to play upon.
- The injury burden on soft natural turf (number of days missed) was nearly double that of hard pitches.

CHAPTER 9

REFERENCES AND BIBLIOGRAPHY

REFERENCES

Adams, W.A. & Gibbs, R.J. (1994) *Natural turf for sport and amenity: science and practice*. Wallingford, Oxon, UK: CAB International.

Adkison, J.W., Requa, R.K., Garrick, J.G. (1974) Injury rates in high school football: a comparison of synthetic surfaces and grass fields. *Clinical and Orthopaedics Related Research*, 99,131-136.

Aguiar, M., Botelho, G, Lago, C., Macas, V. (2012), A review of the effects of soccer small sided games. *Journal of Human Kinetics*, 33, 103-113.

Akenhead, R. and Nassis, GP., (2016) training load and player monitoring in high level football: current practice and perceptions. *International Journal of Sports Physiology and performance*, 11, 587-593.

Alles, W.F., Powell, J.W., Buckley, W. and Hunt, E.E. (1979) The national athletic injury/illness reporting system 3-year findings of high school and college football injuries. *Journal of Orthopaedic and Sports' Physical Therapy* 1 (2), 103-108.

Almutawa, M., Scott, M., George, K.P., and Drust, B. (2014) The incidence and nature of injuries sustained on grass and 3rd generation artificial turf: A pilot study in elite Saudi National team footballers. *Physical Therapy in Sport* 15 (1), 47-52.

Altman, D.G.; Matthews, J.N. (1996) Statistics notes. Interaction 1: Heterogeneity of effects. *British Medical Journal*, 313, 486

American Society for Testing and Materials (2000a), Annual book of ASTM standards. Vol. 15.07. *End use products. Standard test for shock attenuation characteristics of natural playing surface systems using lightweight portable apparatus.* F1702-96. ASTM, West Conshocken, PA.

American Society for Testing and Materials (2000b), Annual book of ASTM standards. Vol. 15.07. End use products. Standard test method for shock-absorbing properties of playing surface systems and materials. F355-95 Procedure A. ASTM, West Conshocken, PA.

Andersson, H., Ekblom, B., and Krustrup, P. (2008) Elite football on artificial turf versus natural grass: Movement patterns, technical standards, and player impressions. *Journal of Sports Sciences* 26, 113–122.

Anderson, F.D., Fleming, P.R., Sherratt, P.J. and Severn, K., (2018). Novel field equipment for assessing the stability of natural and hybrid turfs. *Sports Engineering*, .1-11

Atkinson, G. and Nevill, A.M. (1998) Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 26: 217.

Bahr, R., and Holme, I. (2003) Risk factors for sports injuries-a methodological approach. *British Journal of Sports Medicine* 37:384–392

Bahr R. and Krosshaug, T. (2005) Understanding injury mechanisms: a key component to understanding injury in sport. *British Journal of Sports Medicine,* 39, 324–329

Bahr, R., Clarsen, B., Ekstrand J., (2018) Why we should focus on the burden of injuries and illness, not just their incidence. *British Journal of Sports Medicine* 52, 16, 1018-1021.

Baker, S.W. and Isaac, S.P. (1987b) The effect of rootzone composition on the performance of winter games pitches. II. Playing quality. *Journal of the Sports Turf Research Institute*, 63, 67-81.

Baker, S. (1989) Soil physical conditions of the rootzone layer and the performance of winter games' pitches. *Soil Use and Management*, 5 (3), 116-122.

Baker, S., Gibbs, R.J., and Adams, W.A. (1991) Making the most of natural turf pitches. Final results of a case studies approach: II. *Playing quality. Natural Turf Pitch Prototypes Advisory Panel Report* No. 7, Sports Council.

Baker, S., Gibbs, R.J., and Adams, W.A. (1992) Case studies of the performance of different designs of winter games pitches. I. Playing quality and usage. *Journal of the Sports Turf Research Institute*, 68, 20-32.

Baker SW. (1997). The reinforcement of turfgrass areas using plastic and other synthetic materials: a review. *International Turf Society Research Journal* 1997; 8: 3-13.

Baker, S.W. and Canaway, P.M. (1993) Concepts of playing Quality: Criteria and measurement. *International Turfgrass Society Research Journal* 7, 172-181.

Baker S.W., Wheater J.A. and Spring C.A. (2007) Performance requirements for surface hardness of winter games pitches. *Journal of Turfgrass and Sports Surface Science* 83, 83-89.

Bangsbo, J., Mohr, M., Krustrup, P. (2006). Bangsbo J, Mohr M, Krustrup P. Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Science*. 24(7):665-74. *Journal of Sports Sciences*. 24. 665-74.

Barnes C, Archer DT, Hogg B, Bush M, Bradley PS. (2014) The evolution of physical and technical performance parameters in the English Premier League. *International Journal Sports Medicine,* 35, 1095-100.

Barrett, S., McLaren, S., Spears, I., Ward, P., and Weston, M. (2018) The influence on playing position and contextual factors on soccer players' match differential ratings of perceived exertion: A preliminary investigation. *Sports,* 6, 13, 1-8.

Bartlett, M.D., James, I. T., Ford, M. and Jennings-Temple, M. A. 2009. Testing natural turf sports surfaces: The value of performance quality standards. *Proceeding of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 223, 21–29.

Bell, M.J., Baker, S.W., and Canaway, P.M., (1985) Playing quality of sports surfaces: a review *Journal of the Sports Turf Research Institute* 61, 26-45.

Bell, M.J. and Holmes, G. (1988). The playing quality of Association Football pitches. *Journal of Sports Turf Research Institute* 64, 19-47.

Bengtsson, H., Ekstrand, J., Hägglund, M. (2013) Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study, *British Journal of Sports Medicine* (47), 12, 743-747.

Bianchi, FP, Veneziani, V., Cantalice, MA., Notarnicola, A. Tafuri, S. (2018) Epidemiology of injuries among Italian footballers: the role of the playing field. *British Journal of Sports Medicine* 0, 1-6.

Bloomfield, J., Polman, R. and O'Donoghue, P. (2007) Physical demands of different positions in FA premier league soccer. *Journal of Sports Science and Medicine* 6(1):63-70.

Borg, E.; Borg, G.; Larsson, K.; Letzter, M.; Sundblad, B.M. (2010) An index for breathlessness and leg fatigue. *Scandinavian. Journal Medicine and Science in Sport,* 2010, 20, 644–650.

Bowers Jr KD., Martin RB. Turf-toe: a shoe-surface related football injury, *Medicine and Science in Sports* 1976; 8 (2): 81-83.

Bradley PS, Sheldon W, Wooster B, (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Science* 27:159-68.

Braidwood K, (2017) *Are serious knee injuries in the Premier League really at 'epidemic' levels?* Available at https://www.bbc.co.uk/sport/football/40679002 (accessed August 2017).

Bruckner, P., Nealon, A., Morgan, C., Burgess, D. (2014) Recurrent hamstring muscle injury: applying the limited evidence in the professional football setting with a seven-point programme. *British Journal of Sports Medicine* 48, 929-938.

Butterworth, A., O'Donoghue, P., and Cropley, B. (2013), Performance profiling in sports coaching: a review*, International Journal of Performance Analysis in Sport*, 13, 572-593.

Canaway, P.M., Bell, M.J., Holmes, G, and Baker, S.W. (1990) Standards for the playing quality of natural turf for Association Football in. R.C. Schmidt, Homer, E.F., E.M. Milner E.M and Morehouse C.A (eds) (1990). *Natural and Artificial Playing Fields: Characteristic and Safety Features.* American Society for Testing and Materials, Philadelphia, pp. 29-47. Chivers, 1.H., Aldous, D.E. 1.

Canaway, P.M. (1994) A field trial on isotropic stabilisation of sand rootzones for football using Netlon mesh elements *Journal of the Sports Turf Research Institute* 70, 100-109

Caple, M. (2011) *Mechanical behaviour of natural turf sports surfaces*. PhD Thesis, Cranfield University.

Caple M, James I, Bartlett M. (2012) Mechanical behaviour of natural turf sports pitches across a season. *Sports Engineering* 15,129-141.

Capranica L. Tessitore A. Guidetti L. Figura F. (2001) Heart rate and match analysis in pre-pubescent soccer players. *Journal of Sports Sciences*. 19, 379-384.

Carling C., Bloomfield J. (2010) The effect of an early dismissal on ensuing player work-rate in a professional soccer match. *Journal of Sports Science and Medicine,* 2010*.* 13(2), 126-128.

Carron, A. V., Colman, M. M, Wheeler, J., & Stevens, D. (2002). Cohesion and performance in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, 24, 168-188.

Charalambous, L., Wilkau, HCL, Potthast, W., Irwin, G. (2016) The effects of artificial surface temperature on mechanical properties and player kinematics during landing and acceleration. *Journal of Sport and Health Science* 5, 355-360.

Chivers IH, Aldous DE, Orchard J. (2005) The Relationship of Australian Football grass surfaces to anterior cruciate ligament injury. *International Turfgrass Society* Research Journal, 10: 327-32.

Chomiak, J. Junge, A. Petersn, L. (2000) 'Severe Injuries in Football Players', *The American Journal of Sports Medicine*, 28(5), 58–68.

Clanton T.O., Butler, J.E., and Eggert, A. (1986) Injuries to the metatarsophalangeal joints in athletes. *Foot and Ankle* 7 (3), 162-176.

Clegg, B. (1976). An impact testing device for in situ base course evaluation. *Australian Road Research Bureau.* Proceedings 8, 1–6.

Cummins, C., Orr, R., O'Connor, H., West, C. (2013) Global positioning systems and microtechnology sensors in team sports: a systematic review *Sports Medicine*, October, 43, (10), 1025-1042.

Deloitte (2018) Annual Review of Football Finance available at https://www2.deloitte.com/uk/en/pages/sports-business-group/articles/annual-review-of-football-finance.html

Desso Sports System (2014) Desso GrassMaster hybrid grass, Desso. Available at: http://www.dessosports.com/hybrid-grass (Accessed: 4 January 2015).

Dixon S, Fleming P, James I, Carr. MJ. (2015) *The science and engineering of sport surfaces*. Routledge Research in Sports Technology and Engineering 2015.

Dragoo, J.L. and Braun, H. J. (2010) The effect of playing surface on injury rate a review of the current literature. *Sports Medicine* 40 (11): 981-90.

Drust, B., Atkinson, G., Reilly, T., Future perspectives in the evaluation of the physiological demands of soccer (2007) *Sports Medicine* 37 (9), 783-805.

Dupont G, Nedelec M, McCall A, McCormack D, Berthoin S, Wisløff U. (2010) Effect of 2 soccer matches in a week on physical performance and injury rate. *American Journal of Sports Medicine,* 38: 1752-1758.

Ekstrand, J and Gillquist, J. (1983) Soccer injuries and their mechanisms: A prospective study. *Medicine and Science in Sports and Exercise* 15, 267-70.

Ekstrand, J., Timpka, T. and Hagglund, M. (2006) Risk of injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study. *British Journal of Sports Medicine* 40, 975-80

Ekstrand, J., Hagglund, M., and Walden, M. (2011) Injury incidence and injury patterns in professional football: the UEFA injury study. *British Journal of Sports Medicine*, 45 (7), 553-558.

Ekstrand, J., Hagglund, M., Kristenson, K., Magnusson, H. and Walden, M. (2013) Fewer ligament injuries but no preventive effect on muscle injuries and severe injuries: 11 year follow up of the UEFA Champions League injury study. *British Journal of Sports Medicine* 47, 732-737.

Ekstrand, J., Walden, M., Hagglund, M. (2016) Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA elite club injury study. *British Journal of Sports Medicine*, 50 (12), 731-737.

Ekstrand, J., Lundqvist, D., Davison, M., D'Hooghe, M. (2019) Communication quality between the medical team and the head coach/manager is associated with injury burden and player availability in elite football clubs. *British Journal of Sports Medicine*, 53, 304-308.

Fanchini, M., Ferraresi, I., Modena, R., Schena, F., (2016) Use of the CR100 scale for session rating of perceived exertion in soccer and its interchangeability with the CR10. *International Journal of Sports Physiology and Performance*, April, 11(3), 388-392.

Fédération Internationale de Football Association (FIFA), FIFA Quality Concept for Football Turf - Handbook of Test Methods, 2015. https://football-technology.fifa.com/media/1016/football_turf_handbook_of_test_methods_2015.pdf

Ferris, D.P., Louie, M., Farley, C.T. (1998) Running in the real world: adjusting leg stiffness for different surfaces. **65** *Proceedings of the Royal Society of London. Series B: Biological Sciences available at* http://doi.org/10.1098/rspb.1998.0388.

Ferris, D.P., Liang, K. and Farley, C.T. (1999) Runners adjust leg stiffness for their first step on a new running surface. *Journal of Biomechanics.* 32, 787–794

Fleming, P., (2011) Artificial turf systems for sport surfaces: current knowledge and research needs, *Proc. Inst. Mech. Eng. Part P J. Sport. Eng. Technology*. 225, 43–64.

Football Association (2004) *Performance quality standard*. Available at: http://www.thefa.com/Grassroots/FacilityDevelopment/Guidance+Notes/Postings/2004/12/Pitches Performance Quality Standard. Accessed 8th October 2005.

Ford, PG., (2013) *An investigation into the agronomic factors affecting sustainability, surface hardness and rotational traction on community-level football grounds during drought conditions*. PhD Thesis, University of Ballarat, Australia.

Forrester, S. E. and Tsui, F. (2014) 'Spatial and temporal analysis of surface hardness across a third-generation artificial turf pitch over a year', *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 228(3), pp. 213–220. doi: 10.1177/1754337114523756

Fraser, D., (2017) JLT sports injury Index: English premier league 2016/17 review. www.jltspeciality.com.

Frencken, W.G.P. and Lemmink, K.A.P.M. 2008. "Team kinematics of small-sided soccer games: A systematic approach". *In Science and football VI,* Edited by: Reilly, T. and Korkusuz, F. 161–166. London: Routledge.

Fuller, C. W., Ekstrand, J, Junge A, Andersen, T.E, Bahr, R., Dvorak R.J., Hägglund, M., McCrory, P. and Meeuwisse, W. H. (2006) Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *British Journal of Sports Medicine*. 40,193–201.

Fuller, C.W., Dick, R.W., Corlette J, and Schmalz, R. (2007) Comparison of the incidence, nature and cause of injuries sustained on grass and new generation artificial turf by male and female football players. Part 1: match injuries. *British Journal of Sports Medicine* 41 (Suppl I);i20-i26.

Fuller CW, Dick RW, Corlette J, Scmalz, R. (2007) Comparison of the incidence, nature and cause of injuries sustained on grass and new generation artificial turf by male and female football players. Part 2: training injuries. *British Journal of Sports Medicine* 41 (Suppl I), i27-i32.

Fuller, C.W., June, A. and Dvorak, J. (2012) Risk management: FIFA's approach for protecting the health of football players. *British Journal of Sports Medicine* 46, 11–17.

Gabbett TJ. (2006) Performance changes following a field conditioning program in junior and senior rugby league players. *Journal of Strength and Conditioning Research*,20: 215–21.

Gabbett TJ, Ullah S. (2012) Relationship between running loads and soft-tissue injury in elite team sport athletes. *Journal of Strength and Conditioning Researc*h 26:953–60.

Gabbett, TJ., (2016) The training-injury prevention paradox: should athletes be training smarter and harder? *British Journal of Sports Medicine* 50:273-280.

Geyer, H., Seyfarth, A., and Blickhan R. (2003) Positive force feedback in bouncing gaits? **270** *Proceedings of the Royal Society of London. Series B: Biological Sciences* available at http://doi.org/10.1098/rspb.2003.2454

Gissane, C., White, J., Kerr K, and Jennings, D. (2001) An operational model to investigate contact sports injuries. *Medicine and Science in Sports and Exercise* 33, 1999–2003.

Glasgow, P., Bleakley, CM., Phillips, N. (2013) Being able to adapt to variable stimuli: the key driver in injury and illness prevention? *British Journal of Sports Medicine*, Jan 47(2), 64-65.

Gouttebarge, M. H. W. Frings-Dresen, J. K. Sluiter, (2015) Mental and psychosocial health among current and former professional footballers, *Occupational Medicine*, Volume 65, Issue 3, April, 190–196.

Gratton, C. and Jones, I. (2010) *Research Methods for Sports Studies*: Taylor & Francis.

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

Hägglund M, Waldén M, Bahr R, (2005). Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *British Journal of Sports Med*icine, 39:340–6.

Hägglund M, Waldén M, Ekstrand J, (2006). Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. *British Journal of Sports Med*icine, 40, 767-772.

Hägglund M, Walden M, Magnusson H, Kristenson K, Bengtsson H, Ekstrand J. (2013) Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League Injury Study. *British Journal of Sports Med*icine. 47(12):738–742.

Hales, ME., and Johnson, JD. (2019) The influence of sports-field properties on muscle recruitment patterns and metabolic response. *International Journal of Sports Physiology and Performance*. January, 14(1), 83-90.

Hammond LE, Lilley JM, Pope GD., (2009) Playing hurt and other issues: considerations for the interpretation of epidemiological evidence in sports medicine [abstract]. *British Journal of Sports Med*icine.43

Hardin, E.C., Van Den Bogert, A.J. and Hamill, J. (2004) Kinematic Adaptations during Running: Effects of Footwear, Surface, and Duration. *American College of Sports Medicine* 838-844 available at: http://people.umass.edu/~jhamill/PDF/Hardin%20et%20al_2004.pdf

Hawkins, R.C. and Fuller, C.W. (1999) A prospective epidemiological study of injuries in four English professional football clubs. *British Journal of Sports Medicine* 33, 196–203.

Hawkins, R. D., Hulse, M. A., Wilkinson, C., Hodson, A., & Gibson, M. (2001). The association football medical research programme: An audit of injuries in professional football. *British Journal of Sports Medicine*, 35, 43–47.

Hill-Haas SV, Coutts AJ, Rowsell GJ, et al (2009). Generic versus small- sided game training in soccer. *International Journal of Sports Medicine*. 30:636–42.

Hill-Haas, SV, Coutts, AJ, Dawson, BT, and Rowsell, GJ. (2010) Time-motion characteristics and physiological responses of small-sided games in elite youth players: The influence of player number and rule changes. *Journal of Strength and Conditioning Research* 24: 2149-2156.

HMSO (1974) Health and safety at work etc. Act 1974. London: HMSO.

Holmes, G. and Bell, M.J. (1986) A pilot study of the playing quality of football pitches. *Journal of the Sports Turf Research Institute*, 62, 74-90.

Iaia, F.M., Rampinini, E. and Bangsbo, J., (2009) High intensity training in football. *International Journal of Sports Physiology and Performance* 4, 291-306.

Impellizzeri FM, Marcors SM, Castagna C. (2006) Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine*. 27:483–92.

Institute of Groundsmanship, *Guidelines for performance quality standards Part one: sports surfaces natural and non-turf, 2001* (IOG, Milton Keynes, UK).

Institute of Groundsmanship (2004) *An Introduction to performance quality standards*. 2nd ed. Milton Keynes, UK.

Ispirlidis, L., Fatouros, L., Athanasios et al (2008) Time course changes in inflammatory and performance responses following a soccer game. *Clinical Journal of Sports Medicine* Sept,18, (5), 423-431.

James, IT., McLeod, AJ (2010). The effect of maintenance on the performance of sand-filled synthetic turf surfaces *Sports Technology*, Volume 3, 2010 - Issue 1.

James, I. T. (2011), Advancing natural turf to meet tomorrow's challenges, S*ports Engineering and Technology,* vol. 225.

Jaspers, A, Beeck T, Brink MS., Frencken, W., Staes F., Davis JJ., Helsen, WF. (2018) Relationships between external and internal training load in professional soccer: what can we learn from machine learning. *International Journal of Sports Physiology and Performance*, 13, 625-630.

Jennings-Temple, M. (2005) *Linking soil moisture status of winter sports pitches to measures of playing quality*, Engineering Doctoral thesis, Cranfield University.

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

Kaila, R. (2007) Influence of modern studded and bladed soccer boots and sidestep cutting on knee loading during match play conditions. *The American Journal of Sports Medicine* 35(9), 1528-1536.

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

Katkat, D., Bulut, Y., Demir, M. and Akar, S. (2009) Effects of different sports surfaces on muscle performance. *Biology of Sport* 26:285-296.

Keene, J. S., Narechania, R. G., Sachtjen, K. M., & Clancy, W. G. (1980). Tartan Turf® on trial: A comparison of intercollegiate football injuries occurring on natural grass and Tartan Turf®. *The American Journal of Sports Medicine*, *8*(1), 43–47. https://doi.org/10.1177/036354658000800108

Kelly DM, Drust B. (2009) The effect of pitch dimensions on heart rate responses and technical demands of small- sided soccer games in elite players. *Journal of Science and Medicine in Sport*, 12: 475-479.

Kelly, V., Macfarlane, S., Tannath, TJU., (2014). The validity and Reliability of Global Positioning Systems in Team Sport: A Brief Review. *The Journal of Australian Strength and Conditioning.* 22, (5), 186-190.

Kristenson, K., Bjorneboe, J., Walden, M., Andersen, T.E., Ekstrand, J. and Hägglund, M. (2013) The Nordic football injury audit: higher injury rates for professional football clubs with 3rd generation artificial turf at their home venue. *British Journal of Sports Medicine* 47, 775-781.

Liu-Ambrose T, Nagamatsu LS, Hsu CL, et al. (2012) Emerging concept: 'central benefit model' of exercise in falls prevention *British Journal of Sports Medicine* 47:115–7.

Longo, U.G., Loppini, M. and Cavagnino, R. (2012) Musculoskeletal problems in soccer players : current concepts. *Clinical Cases in Mineral and Bone Metabolism* 9(2), 107–111.

Mackenzie, R., & Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *Journal of Sports Sciences*, *31*(6), 639–676.

Majumdar, AS., Robergs, RA., (2011) The science of speed: Determinants of performance in the 100m sprint. *International Journal of Sports Science and Conditioning* 6 (3), 479-493.

McBain K, Shrier I, Shultz R*, et al* (2011) Prevention of sport injury II: a systematic review of clinical science research, *British Journal of Sports Medicine* 46,174-179.

McClements I, Baker SW. (1994) The playing quality of rugby pitches. *Journal of Sports Turf Research Institute*; 70:29–43.

McIntosh, A. (2005) Risk compensation, motivation, injuries and biomechanics in competitive sport. *British Journal of Sports Medicine* 39, 2–3.

McMahon, T. and Greene, P., (1979) The Influence of Track Compliance on Running, *Journal of Biomechanics*, 12, 893-904.

McNitt AS, Landschoot PJ. (2003) Effects of soil reinforcing materials on the surface hardness, soil bulk density and water content of a sand root zone. *Crop Science* 43, 957-66.

McNitt, A.S., Landschoot, P.J., & Petrukak, D.M. (2004) Evaluation of the playing surface hardness of an infilled synthetic turf system. In: Nektarios, P.A., Ed. *Proceedings of the first international conference on turfgrass management and science for sports fields*, Athens, Greece, Leuven, Belgium: ISHS, 559- 569.

Mears, A. Osei-Owusu, P, Harland, A.R. et al (2018) Perceived links between playing surfaces and injury: A worldwide study of elite association football players. *Sports Medicine* 4,40, 1-11.

Meeuwisse, W. (1994) Assessing causation in sport injury: A multifactorial model. *Clinical Journal of Sports Medicine* 4, 66–170

Meeuwisse, W.H., Tyreman, H., Hagel, B., and Emery, C. (2007) A dynamic model of etiology in sport injury: The Recursive Nature of Risk and Causation. *Clinical Journal of Sports Medicine*, 17(3), 215-219.

Milburn, P.D. and Barry, E.B. (1998). Shoe-surface interaction and the reduction of injury in rugby union. *Sports Medicine, 25*(5), 319-327.

Miller, G. L. (2004), Analysis of Soccer Field Hardness, Nektarios, P. A. (ed.), in: Nektarios, P. A. (ed.), *Proceedings of the first international conference on turfgrass science and management for sports fields*, ISHS, Leuven, pp. 287-294.

Milton J, Solodkin A, Hluštík P. (2007) Small SL The mind of expert motor performance is cool and focused. *Neuro Image*, 35:804–13.

Mohr, M., Krustrup, P., Bangsbo, J., (2005) Fatigue in soccer: A brief review. *Journal of Sports Sciences*, June 23(6) 593-599.

Morgan, BE., and Oberlander, MA., (2001) An examination of injuries in major league soccer. The inaugural season. *American Journal of Sports Medicine*. Jul-Aug, 29(4), 426-30.

Murphy, D.F., Connolly, D.A.J. and Beynnon, B.D. (2003) Risk factors for lower extremity injury. *British Journal of Sports Medicine* 37, 13–29.

Nigg, BM, and Yeadon, MR. (1987) Biomechanical aspects of playing surfaces. *Journal of Sports Science*, 5, 117-45.

Norton, K., Schwerdt, S. and Lange, K. (2001) Evidence for the aetiology of injuries in Australian football. *British Journal of Sports Medicine* 35, 418-423.

Noya Salces, J., Gomez-Carmona, PM., Gracia-Marco, L., Molinaer-Urdiales, D., Sillero-Quintana, M. (2014) Epidemiology of injuries in first division Spanish football. *Journal of Sports Sciences*, 32(13), 1263-70.

Orchard, J.W., Seward, H. and McGivern (1999) Rainfall, evaporation and the risk of non-contact anterior cruciate ligament injury in the Australian Football League. *The Medical Journal of Australia* 170, 304-306.

Orchard, J.W. (2001) The AFL Penetrometer study: work in progress. *Journal of Science and Medicine in Sport* 4, 220–32.

Orchard, J.W., (2002) Is There a Relationship Between Ground and Climatic Conditions and Injuries in Football? *Sports Medicine* 32 (7), 419-432.

Orchard, J., Rae, K., Brooks, J., Hagglund, M., Til, L., Wales, D., Wood, T., (2010) Revision, uptake and coding issues related to the open access Orchard Sports Injury Classification System (OSICS) versions 8, 9, and 10.1. *Journal of Sports Medicine* 1, 207-214.

Owen, A L., Wong, DP., McKenna, M., Dellal, A. (2011) Heart rate responses and technical comparison between small vs large sided games in elite professional soccer. *Journal of Strength and Conditioning Research*. August, 25(8), 2104-2110.

Petrass, L.A., Twomey, D.M., (2013) The relationship between ground conditions and injury: what level of evidence do we have? *Journal of Science and Medicine in Sport.* 16(2),105–12.

Pinnington, H. C., and Dawson, B. (2001) The energy cost of running on grass compared to soft dry beach sand. *Journal of Science and Medicine in Sport* 4, 416–430.

Plaza-Carmona, M., Vicente-Rodriguez, G., Martin-Garcia M, Burillo, P., Felipe, J., Mata, E., Casajús, J., Gallardo, L., and Ara, I. (2014) Influence of hard vs. soft ground surfaces on bone accretion in pre-pubertal footballers. *International Journal of Sports Medicine* 35, 55-61.

Poulos CC, Gallucci J, Gage WH, Baker J, Buitrago S, Macpherson AK. (2014), The perceptions of professional soccer players on the risk of injury from competition and training on natural grass and 3rd generation artificial turf. *BMC Sports Science and Medicine Rehabilitation* 6–11.

Rahnama, N. (2011) Prevention of football injuries. *International Journal of Preventative Medicine* 2(1), 38-40.

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

Rampinini E, Impellizzeri FM, Castagna C, Coutts, A., & Wisløff, U (2008). Effect of match- related fatigue on short-passing ability in young soccer players. *Medicine and Science in Sports Exercise*. 40:934–42.

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

Rennie D.J., Vanrenterghem, J., Littlewood, M., Drust B. (2016) Can the natural turf pitch be viewed as a risk factor for injury within Association Football? J*ournal of Science and Medicine in Sport* 19, 547-552.

Roberts J, Osei-Owusu P, Harland A, Owen A, Smith A (2014). Elite football players' perceptions of football turf and natural grass surface properties. *Procedia Engineering* 72, 907–12.

Rodeo, S.A., O'Brien, S. and Warren, R.F. (1990) Turf-toe: an analysis of metatarsophalangeal joint sprains in professional football players. *American Journal of Sports Medicine* 18 (3), 280-285.

Rogers, J.N., (1988). *Impact absorption and traction characteristics of turf and soil surfaces*. Ph.D. diss., Pennsylvania State Univ., University Park, PA

Rogers, J. & Waddington, D. (1990). *Portable Apparatus for Assessing Impact Characteristics of Athletic Field Surfaces. Natural and Artificial Playing Fields: Characteristics and Safety Features*. 96-110.

Ronkainen J, Osei-Owusu P, Webster J, Harland A, Roberts J (2012). Elite player assessment of playing surfaces for football. *Procedia Engineering*. 34, 837–42.

Rossi A, Pappalardo L, Cintia P, Iaia FM, Fernàndez J, Medina D (2018) Effective injury forecasting in soccer with GPS training data and machine learning. PLoS ONE 13(7): e0201264. https://doi.org/10.1371/journal.pone.0201264

Russell, M. and Kingsley, M. (2011) Influence of Exercise on Skill Proficiency in Soccer, *Sports Medicine*, 41, 523

Sarmento, H., Clemente, FP., Harper, LD., Costa, IT., Owen, AL, Figueiredo, AJ, (2018) Small sided games in soccer-a systematic review. *International Journal of Performance Analysis in Sport,* 18(5), 693-749

Sassi, A., Stefanescu, A., Mensaspa, P., Bosio, A., Riggio, M. and Rampinini, E. (2011) The cost of running on natural grass and artificial surfaces. *Journal of Strength and Conditioning Research* 25(3), 606–611.

Saunders N, Twomey D, and Otago L (2011) Clegg hammer measures and human external landing forces: is there a relationship? *International Journal of Sports Science and Engineering* 05(08), 231–236

Seward, H., Orchard, J., Hazard, H., Collinson, D. (1993) Football injuries in Australia at the elite level *Medical Journal of Australia*, Sept, 6;159(5), 298-301.

Smith, N., Dyson, R., and Janaway, L. (2004) Ground reaction force measures when running in soccer boots and soccer training shoes on a natural turf surface. *Sports Engineering* 7 (3), 159–6.

Snow, A., (2015) The FA national game. The state of the game 2015 report. http://www.thefa.com/-/media/files/pdf/fa-competitions-archive/fa-competitions-1415/9386-fa-state-of-the-game-final-apr15.ashx?la=en

Soligard, T., Bahr, R. and Andersen, T.E. (2010) Injury risk on artificial turf and grass in youth football tournaments. *Scandinavian Journal of Medicine and Science in Sports* 6,1-6.

Sport England (2017) Active Lives Adult Survey https://www.sportengland.org/media/12458/active-lives-adult-may-16-17-report.pdf

Spring, C. A. and Baker, S. W. (2006). Examination of a new form of fibre reinforcement including polypropylene and polyurethane fibres for winter games pitch rootzones. *Journal of Turfgrass and Sports Surface Science*, 82: 30–37.

Stafilidis, S. and Arampatzis, A. (2007), Track compliance does not affect sprinting performance, Journal of Sports Sciences, vol. 25, no. 13, pp. 1479-1490.

Stevenson, M. and Anderson, B. (1981) The effects of playing surfaces on injuries in college intramural touch football. *Recreational Sports Journal* 5(3), 59–64.

Stiles, V.H., James, I.T., Dixon, S.J., and Guisasola, I.N. (2009) Natural Turf surfaces: The case for continued research. *Sports Medicine* 39, 65-84

Stiles, V.H., Guisasola, I.N., James, I.T., and Dixon. J. (2011) Biomechanical responses to changes in natural turf in running and turning. *Journal of Applied Biomechanics*, 27(1), 54-63.

Stiles, V., Dixon, S. (2015) I.N. *The science and engineering of sport surfaces*. *Routledge Research in Sports Technology and Engineering*, Chapter 4, Routledge, London.

Straw, CM., Samson, CO., Henry, CN. Brown C., Brown, M. (2018) Does variability within natural turfgrass sports influence ground derived injuries? *European Journal of Sports Science*. 18:6, 893-902.

Thomson, A. and Rennie, D.J. (2016) Evolution of natural grass playing surfaces for elite football. *Aspetar Sports Medicine Journal* 2,322-327

Thornton, D.J. (1973) A field trial of sports field construction materials extremely high in sand. *Journal of the Sports Turf Research Institute*, 49, 29-44.

Tscholl P.M, Vaso, M., Weber A, and Dvorak, J. (2015) High prevalence of medication use in professional football tournaments including the World Cups between 2002 and 2014: a narrative review with a focus on NSAIDs *British Journal of Sports Medicine* 49, 580-582

Twomey, D. M., Otago, L. and Saunders, N. (2011) 'Challenges in the development of standards for synthetic turf for Australian football and cricket', *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 225(2), pp. 93–101. doi: 10.1177/1754338X10392310.

Twomey, D. M., Otago, L., Ullah, S., & Finch, C. F. (2011). Reliability of equipment for measuring the ground hardness and traction. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, *225*(3), 131–137. https://doi.org/10.1177/1754337111404848

Twomey, D. M., Finch, C. F., Lloyd, D. G., Elliott, B. C., & Doyle, T. L. (2012). Ground hardness and injury in community level Australian football. *Journal of Science and Medicine in Sport*,15(4), 305–310.

Twomey, D. M., White, P. E., & Finch, C. F. (2012). Injury risk associated with ground hardness in junior cricket. *Journal of Science and Medicine in Sport*, 15(2), 110–115.

Twomey DM, Petrass LA, Orchard JW, Finch CF (2014). Ground condition as a risk factor in sports injury aetiology studies: the level of concordance between objective and subjective measures. *Injury Epidemiology* 1–27.

UEFA (2018) *UEFA Pitch Quality Guidelines Natural turf pitch management* – 2018 editionavailableathttps://www.uefa.com/MultimediaFiles/Download/uefaorg/Stadium&Security/02/54/11/97/2541197_DOWNLOAD.pdf

Van Mechelen, W., Hlobil, H. and Kemper, H. (1992) Incidence, severity, etiology and prevention of sports injuries - a review of concepts. *Sports Medicine* 14, 82–99.

Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B. (2017) Training load monitoring in team sports: a novel framework separating physiological and biomechanical load-adaptation pathways. *Sports Medicine*, 47(11):2135–2142.

Van Wijk, A.L.M. (1980) *Playing conditions of grass sports fields*. Wageningen: Centre for Agricultural Publishing and Documentation.

Walden, M., Hagglund, M., Ekstrand, J. (2005) UEFA Champions League study: a prospective study of injuries during the 2001-2002 season. *British Journal of Sports Medicine* 39, 542–546.

Walden, M., Hagglund, M., Orchard, J., Kristenson, K. and Ekstrand, J. (2013) Regional differences in injury incidence in European professional football. *Scandinavian Journal of Medicine and Science in Sports* 23 (4), 424-430

Wallace LK, Slattery KM, Coutts AJ., (2014) A comparison of methods for quantifying training load: relationships between modelled and actual training responses. *European Journal of Applied Physiology*. 114(1):11–20

Warden, S.J., Davis, I.S., and Fredericson, M., (2014) Management and prevention of bone stress in long distance runners, *Journal of Orthopaedic and Sports Physical Therapy,* 44(10), 749-765.

Weel, H., Opdam, KTM., Kerkhoffs GMMJ., (2014) Stress fractures of the foot and ankle in athletes, an overview. *Clinical research on foot and ankle*, 2(4), 1-6.

Weston, M. (2018) Training load monitoring in elite English soccer: A comparison of practices and perceptions between coaches and practitioners. *Science and Medicine in Football,* Jan, 216-244.

Weyand, P.G., Sternlight, D.B., Bellizi, M.J., and Wright, S., (2000) Faster top running speeds are achieved with greater ground reaction forces not more rapid leg movements. *Journal of Applied Physiology,*89,(5), 1991-1999

Williams, S., Hume, P.A., Kara, S. (2011) A Review of Football Injuries on Third and Fourth Generation Artificial Turfs Compared with Natural Turf. *Sport Medicine*, 41 (11), 903-923.

Woods, C., Hawkins, R., Hulse, M. and Hodson, A. (2002) The Football Association Medical Research Programme: an audit of injuries in professional football—analysis of preseason injuries. *British Journal of Sports Medicine* 36, 436–41.

Wright, WD., Marsden, (2010) Survey research and social science: History, current practice, and future prospects, Handbook of survey research, 2nd edition, Chapter 1, Emerald Group Publishing Limited.

Young, C. and Fleming, P. R. (2007). A review of mechanical impact testing devices for sport surfaces. *In Proceedings of the First International Conference of the SportSURF Network: Science, Technology and Research into Sport Surfaces* (STARSS 2007), Loughborough University, UK, CD, ISBN 978-1-897911-30-3.

CHAPTER 10

APPENDICES

10.1 Appendix 1: Publication.

10.2 Appendix 2: Relating to Chapter 3.

10.3 Appendix 3: Relating to Chapter 6.

10.4 Appendix 4: Relating to Chapter 7.

Chapter 10.1 Appendix 1.

Journal of Science and Medicine in Sport 19 (2016) 547–552

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Review

Can the natural turf pitch be viewed as a risk factor for injury within Association Football?

David J Rennie[a,*], Jos Vanrenterghem[b], Martin Littlewood[c], Barry Drust[d]

[a] Leicester City Football Club, Department of Medicine and Sports Science, King Power Stadium, England
[b] Biomechanics, Liverpool John Moores University, England
[c] Sport Social Science, Liverpool John Moores University, England
[d] Applied Physiology, Liverpool John Moores University, England

ARTICLE INFO

Article history:
Received 11 February 2015
Received in revised form 4 May 2015
Accepted 2 July 2015
Available online 10 July 2015

Keywords:
Soccer/football
Injuries
Natural turf
Hardness
Sports surfaces

ABSTRACT

Objectives: A review of the current literature is used to propose a 'conceptual model for relative pitch hardness' and how this may affect incidence of injury within Association Football. Based upon the injury risk and causation model of Meeuwisse et al. (Clin J Sport Med 2007; 17(3):215), it may provide researchers a necessary framework to guide future research investigations.
Design: A literature review.
Methods: A comprehensive search of electronic databases available until October 2014, and supplemental hand searching was conducted to identify relevant studies. Studies were deemed relevant if they met the following criteria: published in English, presented or referenced in an epidemiological study or provided data directly and/or related to the surface of the football pitch, ball or boot to surface interaction and injury. Further information was sourced on surface hardness, players' movement patterns and physiological demands within football.
Results: Papers varied in methodological quality, with comparative studies examining injury rates on artificial versus natural turf pitches being most prevalent. No prospective studies were found that objectively measured the relationship between hardness of natural turf and injury risk within football.
Conclusions: The literature review into natural turf pitches and injury within football has largely been unable to confirm that pitch hardness can be viewed as a significant extrinsic risk factor. Methodological concerns, including objectivity in pitch assessment and uniformity in defining injuries undermine the efficacy of available work. Future studies are needed utilising objective assessment tools to draw more definitive conclusions regarding pitch hardness as an extrinsic factor for injury within football.

1. Introduction

For the elite football player, injury rates are high with reported values in training between 1.5 and 7.6 injuries in each 1000 h exposure. This value increases in matches to 12–35 injuries per 1000 h.[1,2] Researchers have attempted to attribute causality to injuries, proposing numerous risk factors that may influence injury occurrence. Consequently, relative injury risk is often broken down into intrinsic risks within the players, such as age, gender and previous injury, or extrinsic factors such as the pitch, opponents' actions, footwear or poor rehabilitation.[3–6] Intrinsic risk factors only become relevant once the player is exposed to the extrinsic environment of either training or matches. Thus, exposure to the external environment initiates a cyclical balance between susceptibility and adaptation, which if unstable may lead to injury. The complexity of such risk factors necessitates a multi-variant approach when examining the contribution of any factor(s) to injury.[7]

This article will consider one extrinsic factor to which all players are exposed, namely the pitch on which the game is played. Historically, grass pitches have been the playing surface in football for both training and matches. Quality standards have been published for the management of natural turf football pitches within England to enhance pitch safety and performance.[8–11] Despite recognition that the natural turf pitch can be a factor for injury[12–16] there has been little in the way of scientific evaluation of its risk value to the players.

This paper will (1) establish the current level of evidence, (2) discuss methodological concerns associated with research into pitch

* Corresponding author.
E-mail address: dave.rennie@lcfc.co.uk (D.J. Rennie).

http://dx.doi.org/10.1016/j.jsams.2015.07.009
1440-2440/

hardness, and (3) propose a 'conceptual model' of pitch hardness and injury risk within football which could provide a framework to guide future research.

2. Methodology: Approach to the development of the literature review

Literature was examined using Web of Knowledge, Scopus, MEDLINE, SportsDiscuss, ProQuest Direct Med, Cochrane library, CINAHL, Scirus and Google scholar. Databases were searched using the following terms: Soccer/football injuries, natural turf, grass and inj*, shoe interface and sports surfaces. Due to limited search findings with specific relevance to soccer, supporting evidence from other team sports was included to provide a better understanding of pitches and their effect on injury risk. References were deemed relevant if they met the following criteria: published in English, presented or referenced in an epidemiological study or provided data directly and/or related to the surface of the pitch, ball or boot to surface interaction and injury. In an attempt to add more global understanding to how the surface hardness may affect players' movement patterns and physiological demands (issues that may be related to injury occurrence), further information was sourced on the effects of surfaces on energy expenditure, leg stiffness and running gait.

3. Current evidence that natural turf pitches affect injury incidence within Association Football

An extensive review across all football codes, reports that links between ground conditions and injury were mostly intuitive. From the available research papers ($N = 79$) only five studies objectively measured pitches with none reporting strong associations between pitch hardness and an increased risk of injury.[17] The majority of studies have instead adopted subjective means of pitch assessment, were poorly standardised and lacking sufficient definition. This makes it difficult to draw firm conclusions regarding the relationship between pitch hardness and injury.[18]

The paucity of research specifically related to Association Football is apparent as three studies were reported within this sport.[17] All of the available data used subjective assessments of pitch conditions reporting associations of 24%[19,20] and 21%[21] between pitches and injury. It is unclear whether subjective measures provide a true reflection of pitch hardness and linking them to injury is difficult. Twomey et al.[18] showed only 50–60% concordance between subjective and objective assessment of pitch hardness. The failure to denote a more comprehensive relationship between these approaches makes it questionable if subjective assessment is sufficiently robust to establish links between injury and pitch hardness. This is therefore a major limitation in the available data sets.

Within football objective measures of pitch hardness derived from devices such as the Clegg hammer[8–11] have been reported but no studies have linked the values to the incidence of injuries. Other sports have used equipment such as the Clegg hammer,[18,22,23] or the Penetrometer[22,24–26] to gain objective measurements of hardness though a lack of consistency with respect to the equipment and protocols used impacts on transferability and applicability.[22] Consequently, the available research may not have (a) effectively determined a true representation of the pitch hardness or (b) evaluated how this variable may directly influence the risk of injury. On the whole then there seems to be little available research that effectively directly investigates the impact of pitch surface on injury. This would seem to be an important omission for both our theoretical understanding of injury mechanisms and practical approaches to injury prevention.

Indirect evidence that pitch hardness may adversely affect injury has been drawn from research that (a) compares injury incidence between artificial and natural turf pitches; (b) proposes a seasonal bias for injuries; or (c) critically interprets how the pitch may impact factors that can lead to injury such as biomechanical load, speed of the game and player movement.

Pitch hardness: Injury incidence on artificial versus natural turf: The majority of research in football relating pitches to injury focuses on comparative studies outlining the incidence of injury on artificial or natural grass surfaces.[12–16] First Generation artificial turf pitches in the 1970's with their short nylon fibres were reported as being hard.[27] This made the playing characteristics different from natural grass pitches with many studies reporting a significant increase in the incidence of injuries, particularly abrasions and sprains.[12–15] The artificial pitches of today are more representative of their grass counterparts with longer fibres and rubber granular infill promoting more acceptable levels of hardness.[16] Such are the improvements in artificial surfaces that many studies report no significant differences in injury incidence between them and the natural turf pitch.[16,27,28] Nevertheless, evidence remains indicating persistent differences between injuries sustained on the two different surfaces.[29–33]

None of these studies reported what characteristics of the playing surface were directly attributable for the injury rates witnessed, nor did they objectively scrutinise the pitches. This suggests an inherent assumption amongst some researchers that pitches remain constant over time. This however is not the case as even artificial pitches demonstrate large degrees of temporal and spatial variation.[34] Natural turf pitches are living things and will exhibit greater temporal and spatial variation than their artificial counterparts. Research using 'natural turf' as an undefined variable in injury studies may mask the variation within and among such surfaces. This observation could be highly significant in investigations of this nature.[35]

Seasonal bias, pitch hardness and injuries: In England, one of the largest epidemiological studies in football reported evidence for an early season bias for injury. The study reported peaks in training injuries in July while match injuries seemed to be at their highest in August.[36] Surface dryness (hardness) over the pre-season period was associated with 70% of injuries a value which fell to 51% during the season. Wet or muddy pitches were recorded in 40% of all in season injuries whereas they were only noted in 8% of those injuries sustained in pre-season. These findings were supported by the results from the UEFA Champions League study which prospectively tracked injury data from 27 top clubs, across ten European countries between 2001 and 2012.[37] This longitudinal approach corroborating the findings of Hawkins[36] highlights the apparent robustness of an increase in injury during the early season period when pitches are frequently reported as being harder.[38,39]

Such relationships are also noted in the Australian Football League (AFL) where the prevailing climatic conditions in the northern territories of Australia lead to drier, harder, pitches. These conditions were associated with a 2.8 fold increase in rates of Anterior Cruciate Ligament (ACL) injuries than the softer wetter pitches of the southern regions.[26] Variable climatic conditions were also highlighted in the Champions League study[40] where geographically regionalised injury differences were reported. This may suggest that the prevailing climatic conditions of varied countries and therefore their pitch conditions (hard or soft) may influence the injury rates recorded. However, unlike the AFL study,[26] the Champions League study[40] did not evaluate the pitch conditions at time of injury.

Some caution must be exercised when attempting to make causal attributions regarding seasonal bias for injury and pitch hardness. Reduced early seasonal fitness levels, changes in footwear and the high exposure to training loads over the pre-season period may also contribute to the increased risk of injury.[41] Consequently, reduction in injury rates over the season may be more attributable to the physiological adaptations associated with match/training exposure than any change in pitch hardness accountable to seasonal change.

Thus far researchers have attempted to establish direct links between injury risk, and pitch hardness, through subjective reporting of pitch conditions. The failure to match objective pitch hardness measurements with the precise injury location on the pitch makes conclusions somewhat erroneous.[17] Adopting a more integrated approach, incorporating an engineering and biomechanical analysis of natural turf and its effect on human movement, may promote better understanding of the processes by which the pitch may underpin injury within football.[35]

Pitch hardness and biomechanics: As objective information on pitch hardness within the literature is sparse, it may be prudent to examine laboratory based studies that have collected biomechanical data investigating the effect that the surface has on the individual. This data may support the inference linking pitch hardness and injury. Any surface on which a player runs will affect them kinetically, through the forces to which they are exposed and kinematically, in the way they adapt their movement to accommodate such forces. Consequently, an understanding of how the body adapts to such loading may provide the cornerstone of any rationale as to how the pitch may influence injury within football.

Few biomechanical studies have been performed using a natural grass surface. The tools required for such objective testing are considered difficult to apply within a field setting as complicating extraneous variables negatively impact the objective data recorded. Some researchers have, however, attempted to analyse the effect of different natural turf constructions and hardness, on kinetic data within the laboratory setting.[42–45] These researchers cultivated grass within 45 trays which were used to form a runway overlaying a force platform permitting ground reaction force data to be obtained. Such research suggests that significant differences are evident in rates of loading between different experimental turf hardness conditions. Ground reaction forces in both running and turning movements were noted as being surface dependent. More specifically, harder surfaces resulted in increased loading values when compared to softer counterparts.[42] This data is however limited in its ability to generalize insights into injury mechanisms and/or injury risk in elite players due to small subject numbers ($n = 8$), the population used (university students) and the speed at which the trials were executed (3.83 m/s). These speeds are substantially slower than those observed in games (5.5–6.9 m/s = high speed run and over 7 m/s = sprint).

Despite its limitations, such research suggests that the surface hardness of natural turf may affect the loads and movement adopted by the players. An examination of the literature surrounding 'running gait' corroborates this, highlighting that runners adjust the stiffness of their leg to accommodate the surface stiffness beneath their foot.[45] Additionally, whilst running, the individual will co-ordinate the actions of many muscles, tendons and ligaments so that the leg behaves like a single mechanical spring during the ground contact.[46,47] Ferris[46] concluded that such adaptation to the relative surface compliance is regulated within the first step on the surface. Runners show a decreased leg stiffness of 29% between the last step on a soft surface and the first step on the hard surface. The ability to change leg stiffness quickly allows the individual to maintain dynamic stability when running on varied and unpredictable terrain. This is pertinent within football as pitch construction varies resulting in non-uniform surface hardness with respect to the prevailing climatic conditions. Consequently, there is marked variability between pitches and within the same pitch. The ability of players to adapt quickly to changes in hardness is therefore an asset, but may incur a cost, namely increased energy expenditure, which in turn may predispose players to fatigue.[45–47] Within amateur football, players' running speeds and the metabolic energy costs were studied on natural grass, artificial surface or asphalted track.[48] No differences were found in running speed for the players', however a significant main effect for surface was noted, with the natural and artificial turf being of similar compliance resulting in similar levels of energy expenditure. Increases in surface dependent energy expenditure singularly may not appear significant however, utilising Meeuwisse's[7] model of injury risk and once considered collectively over a football-season, the cumulative effects may predispose the player to fatigue/overload induced injuries. The relative hardness or softness of the pitch therefore determines how hard the players have to work during any given match or training session. The players still achieve the requirements of the task, namely to complete the match or training session, but the energy required to do so may be enough to make them susceptible to injury in the near future.[45–47]

Pitch hardness affects game speed and injury: As research and development into artificial pitches has progressed, so too have developments and innovation associated with grass surfaces. Such developments may have been an attempt to answer user requirements for faster, harder, higher traction pitches. They may also be attributable to media/spectator expectations for a more consistent playing surface. Such surfaces provide the platform upon which the modern player can exploit their strength, power, and speed.[35] Research by Norton[25] offers a link between pitch hardness and its effect on the game and the individual. They examined the effect of pitch hardness on the speed of the game, concluding that pitch hardness was significantly correlated with game speed within the AFL. They noted hard pitches witnessed faster play, more scoring shots and significantly longer stoppages in play than games played on softer pitches. Collision rates were also increased which coupled with the increased mean player speed led to a higher incidence of injuries on the harder surfaces. If indeed harder pitches promote quicker speeds, players may spend a greater proportion of any game within high intensity or sprint zones, which may have a twofold effect on the player. Firstly, they may experience higher levels of fatigue and thereby increase their likelihood of becoming injured in the later stages of games. Secondly, exposing the players to excessive or prolonged loading at such speeds may overload the musculoskeletal system, increasing their susceptibility to potential injury.[25] Unfortunately, as there have been no studies in football regarding the hardness of pitches and their effect on match speed or fatigue, any assumptions are purely hypothetical but warrant research in the future.

Pitch Hardness: Methodological concerns: Undoubtedly, methodological issues are important factors that impact the quality of the evidence available. Knowledge of the mechanisms by which the pitch may affect injury rates is limited by our current understanding of the pitch, exposure rates of players, the loading experienced by players and by the means for reporting and recording mechanism for injuries. Evidence supporting the pitch's involvement in injury within football thus far, lies within epidemiological studies from which, one can draw no direct link to the proposed models of injury risk.

Currently, the evidence that natural turf pitches can be viewed as a risk factor for injury in Association Football is constrained by the subjective methodology adopted. A major limitation is that pitch conditions are open to interpretation and are likely to be an amalgam of a number of variables such as hardness, traction, grass cover and moisture.[49] The subjective nature of classifications such as wet/soft or dry/hard lack detailed descriptions of whether this truly reflects the entire surface or the area in which the injury occurred. Furthermore, the use of retrospective recall and the absence of reported reliability for both the subjective tests used and of the assessors performing them, makes their reported findings

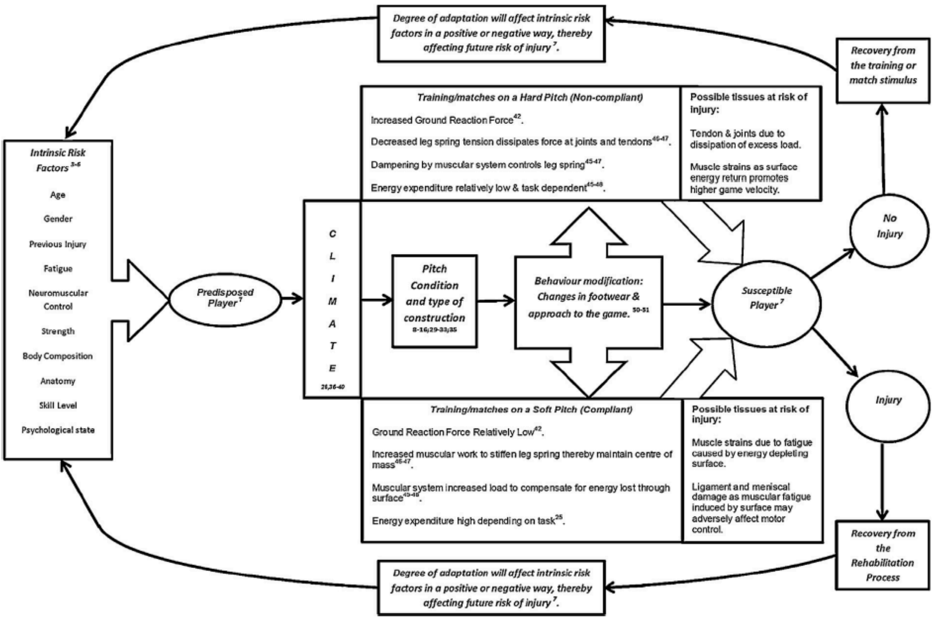


Fig. 1. A conceptual framework for the natural turf pitch and how it may influence a footballers risk of injury.

questionable and generalisation difficult. Unquestionably, technical difficulties are evident when it comes to testing pitch hardness. Equipment costs, portability, reliability, validity and availability are all potential obstacles. Nevertheless, to evaluate such surfaces and investigate their role within football injuries, researchers will need to adopt, develop and improve objective measures to evaluate the surface. These, must then be incorporated into longitudinal studies and compared prospectively with incidence of injury data collated in line with universally agreed definitions of injury and corroborated with time exposure data.[57]

A further confounding methodological reason why the literature does not support an associated rise in injury with increased pitch hardness may be found in the theory of 'modifiable risk', which sees individual players modify their behaviour in accordance with the demands of the situation or their past experiences.[50] Such behaviour modification was reported in a comparative study of Swedish elite footballers during competitive games on artificial turf and grass.[51] No differences were observed between players on artificial turf and natural grass in terms of total distance covered, high intensity running, number of sprints, standing tackles or headers per game. However, there were statistically significant fewer sliding tackles on artificial turf than grass. This may be indicative of modifiable risk on the part of the players. Additional, behaviour modification was noted in the passing strategies adopted, with more short and midfield-to-midfield passes on the artificial turf than grass. The players' perception was also affected by the surface with the male players reporting a negative overall impression, poorer ball control, and greater physical effort on the artificial turf. This behaviour modification may in part account for the stability in injury incidence within professional soccer when surfaces are compared. It is possible the player self regulates their activity or behaviour on any given pitch so as to minimise their risk of injury. Such behaviour modification may therefore make any interpretation of pitch hardness or injury incidence data and research difficult.

Perhaps researchers in the applied setting need to take a more pragmatic approach which provides reliable, objective data about the pitch without adversely affecting the playing surface. This will allow testing to be performed close enough to the match or training session to allow inference to be drawn at the appropriate time to both exposure and injury surveillance data. This would enable a more accurate real time reflection of the interaction of pitches and their effect on the player and their risk of injury.

4. A conceptual framework for the natural turf pitch and its influence on risk of injury

To conceptualise a model for the football pitch and how it may influence injury necessitates recognition of methodological limitations within available research and an awareness of factors affecting human locomotion. Thus far research has focused on the pitch as a primary risk factor where exposure results in injury. Clearly this is limited as not all players who encountered the surface on that day were injured. Perhaps researchers need to consider the dynamic, recursive nature of player-pitch interaction investigating how single and cumulative exposures to varied hardness's's of pitches affect injury risk. Such an approach supports a conceptual model founded upon the work of Meeuwisse.[7]

Analysis of player movement patterns has enabled researchers to determine the physiological demands of such movement.[52–54] Consequently, football can be viewed as an intermittent sport punctuated by bouts of repeated high intensity exercise.[54] Players continually change direction and speed, adopting unorthodox movement patterns enabling them to execute the technical skills required to outperform their opponents.[52,54] Such movement profiles may affect the energy expenditure, musculo-skeletal load, fatigue and injuries seen in professional football. Additionally, as surface compliance is known to affect both energy expenditure[45–48,57] and musculo-skeletal load,e[42,58] one may consider the impact of the natural turf pitch conditions on such physiological demands. The relative hardness of any natural turf pitch being transient and affected by extraneous variables such as the weather, will change throughout the season, thereby altering the demands of any given pitch-player interaction.

The conceptual model in Fig. 1, addresses the extrinsic risk that pitch hardness may play within football injuries. It highlights how interactions between the player and the pitch can alter the 'intrinsic' make-up of the player, subsequently affecting how susceptible the player is to future injury. To aid understanding of the proposed model, a number of examples of how the natural turf pitch could affect physiological demands, and thereby the potential for injury are highlighted below.

For any given task an appropriate degree of muscle contraction is required to achieve the desired displacements and velocities of the body on the pitch.[55] Additionally, the player's muscles must (1) generate additional force to compensate for the inevitable energy dissipated through surface compliance, (2) modify the required force according to the level of strain development in the tendons, and (3) minimise the peak impact forces experienced by their joints during loading of the stance leg.[45–47,55] Consequently, a player running on a compliant (soft) pitch expends more energy for any given running velocity when compared to running on a less compliant (hard) pitch in order to compensate for energy dissipated through the surface. Soft pitches negatively affect the ability of the muscles to utilise the elastic properties of their tendons leading to an over dependence on the muscles to maintain performance leading to fatigue. This has been confirmed through demonstration of a negative relationship between surface compliance and oxygen consumption.[56] As a result, muscles need to work harder due to the energy depleting nature of the surface. Therefore, considered in isolation, playing on more compliant surfaces may induce localised muscle fatigue. Over a more cumulative time frame the additional muscular effort may cause an increased risk of muscle strains. Conversely, the player running on a hard pitch will experience increased loading through joints and tendons due to increases in impact forces.[42–45] The musculoskeletal system 'dampens' this by reducing leg stiffness, effectively cushioning each step. In the short term, these excessive ground reaction forces may be dissipated through the aforementioned spring system,[45–47,55] though the efficacy of this would decrease the more fatigued the players became. Consequently, the pitch can affect the musculoskeletal system of players in both an acute and chronic manner. Previous injury, repetitive impacts or insufficient adaptation/recovery between exposures would reduce the load required to initiate tissue breakdown and resulting injury.

This proposed model suggests the pitch can play a significant factor in the physiological and biomechanical demands of any given task. Thus, the relative hardness or softness of a pitch may influence the loads and fatigue experienced by the musculo-skeletal system.[43,44,56] Failure to provide players with sufficient time for musculoskeletal adaption following pitch exposure could increase their risk of injury. This could be acute, causing immediate injury or through repeated exposure result in more chronic overuse injury[7] (Fig. 1).

5. Summary

The literature regarding natural grass pitches and injury within football has largely been unable to confirm the contention that the pitch hardness can be considered a significant extrinsic risk factor in injury. The adoption of comparative studies, where the temporal grass pitch, is compared with its artificial counterpart, has limited research into the effects of the grass surface and its influence on injury. Such research masks the variation within and among such natural turf surfaces. Anecdotal evidence for the effects that grass football pitches have on injury has been reported but no studies have included objective measurement. Although biomechanical analysis of natural turf is difficult there are trends suggesting researchers are realising the importance of such work and commencing studies to address the need for such data. Perhaps most pertinently, the literature outlines a negative relationship between surface compliance and energy expenditure suggesting that the pitch affects the physiological demands of any given training session or match. This may be one link in the chain between pitch hardness and the relative injury risk of each player. It is hoped with increased use of objective pitch testing, a better understanding of how the player and pitch interact will help us to understand how relative pitch hardness contributes to injury.

References

1. Rahnama N. Prevention of football injuries. *Int J Prev Med* 2011; 2(1):38–40.
2. Longo UG, Loppini M, Cavagnino R et al. Musculoskeletal problems in soccer players: current concepts. *Clin Cases Miner Bone Metab* 2012; 9(2):107–111.
3. Bahr R, Krosshaug T. Understanding injury mechanisms: a key component to understanding injury in sport. *Br J Sports Med* 2005; 39:324–329.
4. Murphy DF, Connolly DAJ, Beynnon BD. Risk factors for lower extremity injury. *Br J Sports Med* 2003; 37:13–29.
5. Meeuwisse W. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med* 1994; 4:66–170.
6. Bahr R, Holme I. Risk factors for sports injuries—a methodological approach. *Br J Sports Med* 2003; 37:384–392.
7. Meeuwisse WH, Tyreman H, Hagel B et al. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clin J Sport Med* 2007; 17(3):215–219.
8. Bell MI, Holmes G. The playing quality of association football pitches. *J Sports Turf Res Inst* 1988; 64:19–47.
9. Baker SW, Canaway PM. Concepts of playing quality: criteria and measurement. *J Sports Turf Res Inst Chem* 1993; 20:172–181.
10. Baker SW, Wheater JA, Spring CA. Performance requirements for surface hardness of winter games pitches. *J Turf Sports Surf Sci* 2007; 83:83–89.
11. Canaway PM, Bell MJ, Holmes G et al. Standards for the playing quality of natural turf for Association Football, in *Natural and artificial playing fields: characteristic and safety features. ASTM STP 1073*, Schmidt RC, Homer EF, Milner EM, Morehouse CA, editors, Philadelphia, American Society for Testing and Materials, 1990, p. 29–47 (Chivers,.H., Aldous, D.E.).
12. Adkison JW, Requa RK, Garrick JG. Injury rates in high school football: a comparison of synthetic surfaces and grass fields. *Clin Orthop Relat Res* 1974; 99:131–136.
13. Alles WF, Powell JW, Buckley W et al. The national athletic injury/illness reporting system 3-year findings of high school and college football injuries. *J Orthop Sports Phys Ther* 1979; 1(2):103–108.
14. Keene JS, Narechania RG, Saehtjen KM et al. Tartan Turf on trial: a comparison of intercollegiate football injuries occurring on natural grass and tartan turf. *Am J Sports Med* 1980; 8(1):43–47.
15. Stevenson M, Anderson B. The effects of playing surfaces on injuries in college intramural touch football. *J Nat Intramural-Recreational Sports Assoc* 1981; 5:59–64.
16. Williams S, Hume PA, Kara S. A review of football injuries on third and fourth generation artificial turfs compared with natural turf. *Sports Med* 2011; 41(11):903–923.
17. Petrass LA, Twomey DM. The relationship between ground conditions and injury: what level of evidence do we have? *J Sci Med Sport* 2013; 16(2):105–112.
18. Twomey DM, Petrass LA, Orchard JW et al. Ground condition as a risk factor in sports aetiology studies: the level of concordance between objective and subjective measures. *Inj Epidemiol* 2014; 1:27.
19. Sullivan JA, Gross RH, Granna WA et al. Evaluation of injuries in youth soccer. *Am J Sports Med* 1980; 8(5):325–327.
20. Ekstrand J, Gillquist J. The avoidability of soccer injuries. *Int J Sports Med* 1983; 4(2):124–128.
21. Chomiak J, Junge A, Peterson L. Severe injuries in football players. Influencing factors. *Am J Sports Med* 2000; 28(5):s58–s68.
22. Twomey DM, Otago L, Ullah S. Reliability of equipment for measuring the ground hardness and traction. *Proc Inst Mech Eng J Sports Eng Technol* 2011; 225:131–137.
23. Twomey DM, White PE, Finch C. Injury risk associated with ground hardness and injury in Junior cricket. *J Sci Med Sport* 2012; 15:110–115.
24. (a) Orchard JW. The AFL Penetrometer study: work in progress. *J Sci Med Sport* 2001; 4:220–232;
(b) Iaia FM, Rampinini E, Bangsbo J. High intensity training in football. *Int J Sports Physiol Perform* 2009; 4:291–306.
25. (a) Norton K, Schwerdt S, Lange K. Evidence for the aetiology of injuries in Australian football. *Br J Sports Med* 2001; 35:418–423;
(b) Gregson W, Drust B, Atkinson G et al. Match to match variability of high-speed activities in Premier league soccer. *Int J Sports Med* 2010; 31(4):237–242.

26. Orchard JW, Seward H, McGivern J et al. Rainfall, evaporation and the risk of non-contact anterior cruciate ligament injury in the Australian Football League. *Med J Aust* 1999; 170:304–306.
27. (a) Dragoo JL, Braun HJ. The effect of playing surface on injury rate a review of the current literature. *Sport Med* 2010; 40(11):981–990;
(b) Geyer H, Seyfarth A, Blickhan R. Positive force feedback in bouncing gaits? *Proc R Soc Lond B* 2003; 270:2173–2183.
28. Soligard T, Bahr R, Andersen TE. Injury risk on artificial turf and grass in youth football tournaments. *Scand J Med Sci Sports* 2010; 6:1–6.
29. Ekstrand J, Timpka T, Hagglund M. Risk of injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study. *Br J Sports Med* 2006; 40:975–980.
30. Fuller CW, Dick RW, Corlette J et al. Comparison of the incidence, nature and cause of injuries sustained on grass and new generation artificial turf by male and female football players. Part 1: match injuries. *Br J Sports Med* 2007; 41(Suppl I):i20–i26.
31. Fuller CW, Dick RW, Corlette J et al. Comparison of the incidence, nature and cause of injuries sustained on grass and new generation artificial turf by male and female football players. Part 2: training injuries. *Br J Sports Med* 2007; 41(Suppl I):i27–i32.
32. Kristenson K, Bjorneboe J, Walden M et al. The Nordic football injury audit: higher injury rates for professional football clubs with 3rd generation artificial turf at their home venue. *Br J Sports Med* 2013; 47:775–781.
33. Almutawa M, Scott M, George KP et al. The incidence and nature of injuries sustained on grass and 3rd generation artificial turf: a pilot study in elite Saudi National team footballers. *Phys Ther sport* 2014; 15:47–51.
34. Forrester SE, Tsui F. Spatial and temporal analysis of surface hardness across a third generation artificial turf pitch over a year. *Proc Inst Mech Eng, P: J Sports Eng Techno* 2014; 228(3):213–220.
35. Stiles VH, James IT, Dixon SJ et al. Natural turf surfaces: the case for continued research. *Sports Med* 2009; 39:65–84.
36. Hawkins RC, Fuller CW. A prospective epidemiological study of injuries in four English professional football clubs. *Br J Sports Med* 1999; 33:196–203.
37. Ekstrand J, Hagglund M, Kristenson K et al. Fewer ligament injuries but no preventive effect on muscle injuries and severe injuries: 11 year follow up of the UEFA Champions League injury study. *Br J Sports Med* 2013; 0:1–7.
38. Walden M, Hagglund M, Ekstrand J. UEFA Champions League study: a prospective study of injuries during the 2001–2002 season. *Br J Sports Med* 2005; 39:542–546.
39. Ekstrand J, Hagglund M, Walden M. Injury incidence and injury patterns in professional football: the UEFA injury study. *BR J Sports Med* 2011; 45(7):553–558.
40. Walden M, Hagglund M, Orchard J et al. Regional differences in injury incidence in European professional football. *Scan J Med Sci Sports* 2013; 23(4):424–430.
41. Woods C, Hawkins R, Hulse M et al. The Football Association Medical Research Programme: an audit of injuries in professional football—analysis of preseason injuries. *Br J Sports Med* 2002; 36:436–441.
42. Stiles VH, Guisasola IN, James IT et al. Biomechanical responses to changes in natural turf in running and turning. *J Appl Biomech* 2011; 27(1):54–63.
43. Smith N, Dyson R, Janaway L. Ground reaction force measures when running in soccer boots and soccer training shoes on a natural turf surface. *Sport Eng* 2004; 7:159–167.
44. Kaila R. Influence of modern studded and bladed soccer boots and sidestep cutting on knee loading during match play conditions. *Am J Sports Med* 2007; 35(9):1528–1536.
45. Geyer H, Seyfarth A, Blickhan R. Positive force feedback in bouncing gaits? *Proc R Soc Lond B* 2003; 270:2173–2183.
46. Ferris DP, Liang K, Farley CT. Runners adjust leg stiffness for their first step on a new running surface. *J Biomech* 1999; 32:787–794.
47. Hardin EC, Van Dev Bogert AJ, Hamill J. Kinematic adaptations during running: effects of footwear, surface, and duration. *Med Sci Sports Exerc* 2004; 36(4):838–844.
48. Sassi A, Stefanescu A, Mensaspa P et al. The cost of running on natural grass and artificial surfaces. *J Strength Cond Res* 2011; 25(3):606–611.
49. Twomey DM, Finch C, Lloyd D et al. Ground hardness and injury in community level Australian Football. *J Sci Med Sport* 2012; 15(4):305–310.
50. McIntosh A. Risk compensation, motivation, injuries and biomechanics in competitive sport. *Br J Sports Med* 2005; 39:2–3.
51. Andersson H, Ekblom B, Krustrup P. Elite football on artificial turf versus natural grass: movement patterns, technical standards, and player impressions. *J Sports Sci* 2008; 26:113–122.
52. Bloomfield J, Polman R, O'Donoghue P. Physical demands of different positions in FA premier league soccer. *J Sports Sci Med* 2007; 6(1):63–70.
53. Iaia FM, Rampinini E, Bangsbo J. High intensity training in football. *Int J Sports Physiol Performance* 2009; 4:291–306.
54. Gregson W, Drust B, Atkinson G et al. Match to match variability of high-speed activities in Premier league soccer. *Int J Sports Med* 2010; 31(4):237–242.
55. Ferris DP, Louie M, Farley CT. Running in the real world: adjusting leg stiffness for different surfaces. *Proc Biol Sci* 1998; 265(1400):989–994.
56. Katkat D, Bulut Y, Demir M et al. Effects of different sports surfaces on muscle performance. *Biol Sport* 2009; 26:285–296.
57. Pinnington HC, Dawson B. The energy cost of running on grass compared to soft dry beach sand. *J Sci Med Sport* 2001; 4:416–430.
58. Plaza-Carmona M, Vicente-Rodriguez G, Martin-Garcia M et al. Influence of hard vs. soft ground surfaces on bone accretion in prepubertal footballers. *Int J Sports Med* 2014; 35:55–61.

Chapter 10.2 Appendix 2.

Pertaining to Chapter 3:

10.1.2 Sample Questionnaire

Introduction

The following questionnaire explores your perceptions whether the relative hardness or softness of pitches on which professional players' train and play matches may be considered a risk factor in them becoming injured. Furthermore, it will also examine the effects that the pitch has on the ball, on player movement, and on tactics.

The questionnaire is aimed at **all individuals currently working in professional football**, namely players, managers, physiotherapists, sports scientists, and grounds staff. Your responses to this questionnaire will help to inform grounds men, managers, coaches, sports scientists and physiotherapists in an attempt to promote quality surfaces whilst reducing any injury risk.

The information provided will be treated in the strictest confidence. By completing and returning the questionnaire I understand that I have given my consent to utilise it within the study. I do however understand that I can withdraw from the study at any time.

The questionnaire should take no longer than 15 minutes to complete.

The questionnaire is divided into 4 sections. Please respond to all sections of the questionnaire that are applicable to you. Respondents are identified at the beginning of each section (i.e., 'players', 'managers', physiotherapists, sports scientists, grounds men, referees or 'all respondents').

PART I: Personal information To be completed by **All respondents.**

This section concerns general information about you, the respondent. (Please tick the appropriate response)

If completing on line please copy this symbol and then paste into the relevant

responses. ✓

1.

	Male	Female
Gender:		

2.

	16-25	26-35	36-45	46-55	56-65	66-75	75+
Age:							

3. Which of the following best describes your ethnicity?

	White	Mixed white	Black African	Black Caribbean	Asian	Other please state
Ethnicity:						

4. Please state the category that best describes your current and/or most recent (i.e., within the last 12 months) occupation? (Please tick one response only)

	Player	Manager	Physiotherapist	Sports Scientist	Groundsman	Other please state
Occupation						

5. How many years have you been involved in professional football?

	0-5	6-10	11-15	16-20	21-25	26+

6. Approximately how many seasons have/did you perform your role/roles in each league?

Post Held	International	Premier League	Championship	League 1	League 2	Other
Player:						
Manager:						
Physiotherapist:						
Sports Scientist:						
Groundsmen:						

7. **Players only.** If not applicable go to question 8.

Date of Birth	Height	Weight	Position i.e. Striker, Midfield, Centre back, Full back, Goalkeeper	Current Club

PART II: Perceptions that a pitch may be a risk factor for injury (All Respondents)

8. Please respond to each of the following statements. The responses range from 1 (i.e., strongly agree) to 5 (i.e., strongly disagree) (N = Neutral) (NA = Not Applicable). Please *circle* your response to each statement.

	SA	A	N	D	SD	NA
i. I believe that the pitch surface can cause injury	1	2	3	4	5	NA
ii. I have experienced an injury which I believed was due to the pitch.	1	2	3	4	5	NA
iii. I have seen others get injuries that I put down to the pitch	1	2	3	4	5	NA
iv. I believe that hard pitches result in more injuries	1	2	3	4	5	NA
v. I believe that soft pitches result in more injuries	1	2	3	4	5	NA
vi. I believe variability of hardness/softness across a pitch is a problem and may cause injuries	1	2	3	4	5	NA

9. Please respond to each of the following statements. The responses range from 1 (i.e., strongly agree) to 5 (i.e., strongly disagree) (N = Neutral) (NA = Not Applicable). Please *circle* your response to each statement

Hard pitches often cause	SA	A	N	D	SD	NA
i. Joint soreness or pain	1	2	3	4	5	NA
ii. Ligament damage	1	2	3	4	5	NA
iii. Tendon damage	1	2	3	4	5	NA
iv. Muscle strains	1	2	3	4	5	NA
v. Bone fracture	1	2	3	4	5	NA
vi. Concussion	1	2	3	4	5	NA
vii. Bruising/dead leg	1	2	3	4	5	NA
viii. Cuts/abrasions	1	2	3	4	5	NA

10. Please respond to each of the following statements. The responses range from 1 (i.e., strongly agree) to 5 (i.e., strongly disagree) (N = Neutral) (NA = Not Applicable). Please *circle* your response to each statement

Soft pitches often cause	SA	A	N	D	SD	NA
i. Joint soreness or pain	1	2	3	4	5	NA
ii. Ligament damage	1	2	3	4	5	NA
iii. Tendon damage	1	2	3	4	5	NA
iv. Muscle strains	1	2	3	4	5	NA
v. Bone fracture	1	2	3	4	5	NA
vii. Concussion	1	2	3	4	5	NA
vii. Bruising/dead leg	1	2	3	4	5	NA
viii. Cuts/abrasions	1	2	3	4	5	NA

11. Have you noticed a change in pitches over your time in the game? If not go to question 12.	Yes	No
i. The pitches are getting harder or softer?	Harde r	Softer

12. Have you noticed a change in the frequency of specific injuries over the years? If not go to question 13.	Yes	No

12a. Please give reasons/examples for your response to question 11:

More frequent   Less frequent:

13. Do you believe that injuries follow a seasonal trend where players pick up certain injuries due to the pitch hardness/softness at that time of year? If not go to question 14.	Yes	No

13a please respond to each of the following statements. The responses range from 1 (i.e., strongly agree) to 5 (i.e., strongly disagree) (N = Neutral) (NA = Not Applicable). Please *circle* your response to each statement

There is often a high number of injuries between these months due to pitch hardness/softness	SA	A	N	D	SD	NA
August to September	1	2	3	4	5	NA
October to November	1	2	3	4	5	NA
December to January	1	2	3	4	5	NA
February to March	1	2	3	4	5	NA
April to May	1	2	3	4	5	NA

If you have any ***other*** comments regarding seasonal bias of injuries, please state them below:

PART III: Pitch hardness and its effect on YOU or YOUR TEAM and their performance (All respondents)

14. Regarding Pitch hardness/softness please respond to each of the following statements. The responses range from 1 (i.e., VS=Very Soft) to 5 (i.e., VH= Very Hard) (M = Medium) (NA = Not Applicable). Please *circle* your response to each statement

	VS	S	M	H	VH	NA
i. I/ my players are often tired or leggy after playing on this type of pitch	1	2	3	4	5	NA
ii. I/my players high intensity running and sprinting is better on is type of pitch	1	2	3	4	5	NA
iii. My/players acceleration, deceleration and ability to stop is best on this type of pitch	1	2	3	4	5	NA
iv. My/players ability to cut and change direction is best on this type of pitch	1	2	3	4	5	NA
v. Players tend to adopt a shorter passing strategy on this type of pitch	1	2	3	4	5	NA
vi. Players tend to adopt a longer passing strategy on this type of pitch	1	2	3	4	5	NA
vii. The tempo of the training/matches are better on this type of pitch	1	2	3	4	5	NA
viii. This type of pitch would be my preference to train.	1	2	3	4	5	NA
ix. I would prefer matches to be played in on this type of pitch	1	2	3	4	5	NA

15. Regarding footwear and pitch surface

i. Do you ever change your footwear to accommodate pitch hardness/softness?	Yes	No
ii. Have you ever suggested to others they should change their footwear to accommodate pitch hardness/softness?	Yes	No

If the answer to question 15 is No on both occasions go to question 16.

15a. Please give a reason for your response to question 15:

16. Have you ever prevented a player training or playing a match because of the hardness/softness of the pitch surface? If not go to question 17	Yes	No

16a. Please give a reason for your response to question 16:

17. Regarding Pitch hardness/softness and how it influences the ball please respond to each of the following statements. The responses range from 1 (i.e., VS=Very Soft) to 5 (i.e., VH= Very Hard) (M = Medium)
(DK=Don't Know). Please *circle* your response to each statement

	VS	S	M	H	VH	DK
i. Ball bounce is higher on this type of pitch	1	2	3	4	5	DK
ii. Ball bounce is more consistent on this type of pitch	1	2	3	4	5	DK
iii. The ball rolls further on this type of pitch	1	2	3	4	5	DK
iv. It is easier to dribble with the ball on this type of pitch	1	2	3	4	5	DK
v. It is easier to strike to ball harder on this type of pitch	1	2	3	4	5	DK
vi. The ball is in play more on this type of pitch	1	2	3	4	5	DK

PART IV: This section explores the relationships between you and the ground staff regarding pitch use and preparation.
All respondents.

18. Please respond to each of the following statements. The responses range from 1 (i.e., strongly agree) to 5 (i.e., strongly disagree) (N = Neutral) (NA = Not Applicable). Please *circle* your response to each statement.

	SA	A	N	D	SD	NA
Before each season I give the Grounds man specific instructions as to how I want our match pitch prepared.	1	2	3	4	5	NA
I determine which area my team trains each day.	1	2	3	4	5	NA
I meet with the Grounds man daily and discuss how I want the training pitch prepared.	1	2	3	4	5	NA
I meet with the Grounds man to discuss how I want the match pitch prepared for each game.	1	2	3	4	5	NA
I tell the Grounds man the cut height of the grass I require.	1	2	3	4	5	NA
I ask for a specific watering schedule before games.	1	2	3	4	5	NA
I have a close working relationship with our Grounds man	1	2	3	4	5	NA
I am satisfied with the pitches at our training ground.	1	2	3	4	5	NA
I am satisfied with the pitches at our Stadium.	1	2	3	4	5	NA
I believe the pitch can significantly influence the performance of my team.	1	2	3	4	5	NA

PART V. This section allows for further response and comments

20. If you would like to add any further comments regarding pitches and how they affect injury or performance please state them below:

I would like to thank you for taking the time to complete this questionnaire.

Please return to:
David Rennie, Head Physiotherapist, Leicester City Football Club Training Ground, Middlesex Road, Leicester, LE2 8PB

Or via email:
dave.rennie@lcfc.co.uk

10.2 Results Tables

Table Categorisation of subjects by occupation.

Occupation	Frequency	Percent	Cumulative Percent
Player	253	60.4	60.4
Manager or Coach	29	6.9	67.3
Physiotherapist	81	19.3	86.6
Sports Scientist	34	8.1	94.7
Groundstaff	22	5.3	100
Total	419	100	100

Table Kruskal-Wallis test results for general perceptions that pitches can cause injury and occupation.

	I believe the pitch surface can cause injury	I have experienced an injury caused by the pitch	I have seen others get injuries I put down to the pitch	I believe that hard pitches result in more injuries	I believe that soft pitches result in more injuries	I believe variability of hardness/softness of a pitch, is a problem and may cause injury
Chi-Square	26.382	12.417	13.433	21.271	16.686	35.480
df	4	4	4	4	4	4
Asymp. Sig	.000**	.015**	.009**	.000**	.002**	.000**

d. Kruskal-Wallis Test
e. Grouping Variable Occupation
f. Significance level *p<0.05, **p<0.01

Median reported scores for general perceptions of pitches by occupation.

Occupation	I believe the pitch surface can cause injury	I have experienced an injury caused by the pitch	I have seen others get injuries I put down to the pitch	I believe that hard pitches result in more injuries	I believe that soft pitches result in more injuries	I believe variability of hardness/softness of a pitch is a problem and may cause injury
Player	2.000	2.000	2.000	2.000	3.000	2.000
Manager/Coach	2.000	2.000	2.000	2.000	3.000	2.000
Physiotherapist	1.000	2.000	2.000	2.000	3.000	2.000
Sports Scientist	2.000	2.000	2.000	3.000	2.500	2.000
Groundstaff	2.000	3.500	2.000	2.500	2.000	2.000
Total	2.000	2.000	2.000	2.000	3.000	2.000

Where scores of 1.0 strongly agree, 3.0 shows neutral views, and 5.0 strongly disagrees.
Scores of 6.0 indicate the stakeholder felt it was not applicable to answer.

Nb. Regarding the question: ‘I believe variability of hardness/softness of a pitch is a problem and may cause injury’. The resulting Kruskal-Wallis test was highly significant whereas the data above show the median scores for occupational difference to be the same. The median score does not demonstrate the difference clearly and perhaps a better representation of significant occupational variation in the data is seen in the figure below.

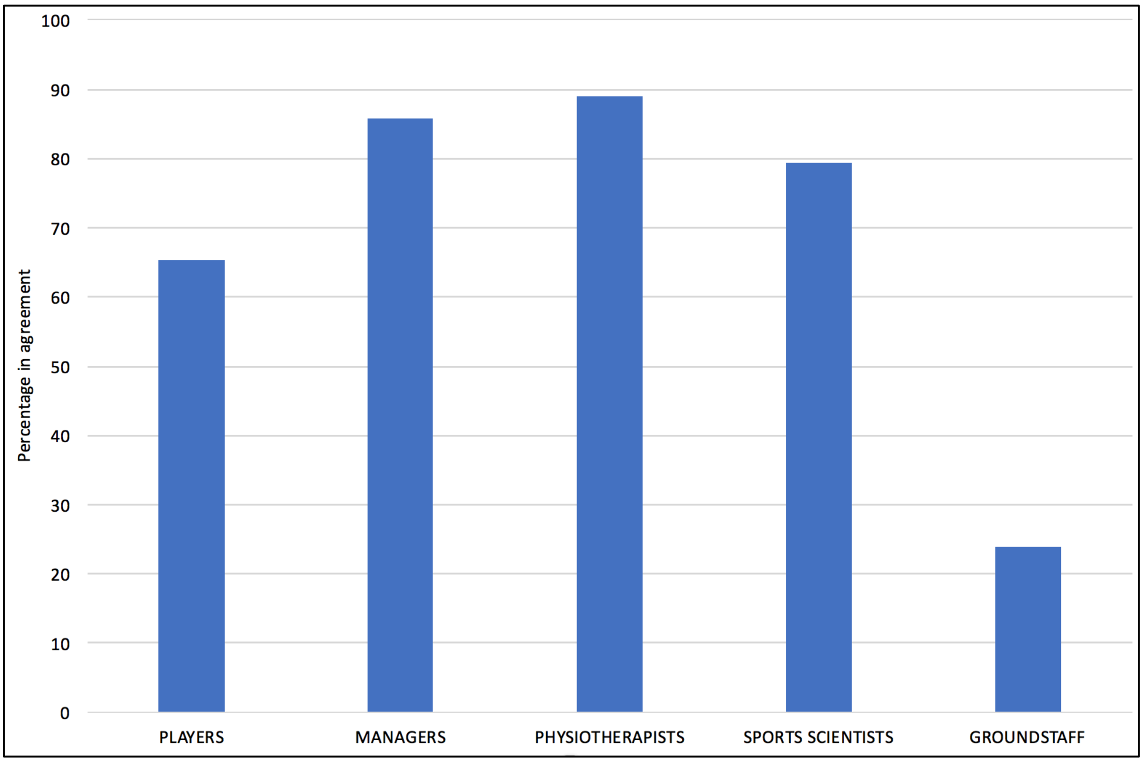


Figure Illustrating the percentage agreement by occupation that the variability of hardness/softness of a natural turf pitch is a problem and may cause injury.

Table Kruskal-Wallis test results for hard pitches and perceived injury risk determined by occupation.

Hard pitches cause?	Joint soreness/pain	Ligament Damage	Tendon Damage	Muscle Strains	Bone fracture	Concussion	Bruising	Cuts/Abrasions
Chi-Square	14.328	22.921	12.267	9.941	5.713	7.891	6.774	21.408
df	4	4	4	4	4	4	4	4
Asymp. Sig	.006**	.000**	.015**	.041**	.222	.096	.148	.000**

a. Kruskal-Wallis Test b. Grouping Variable Occupation c. Significance level *p<0.05, **p<0.01

Table: Median reported scores for hard pitches and perceived injury risk determined by general occupation.

Occupation	Joint soreness/pain	Ligament Damage	Tendon Damage	Muscle Strains	Bone fracture	Concussion	Bruising	Cuts/Abrasions

Player	1.000	3.000	2.000	3.000	3.000	3.000	3.000	2.000
Manager/Coach	1.000	3.000	2.000	3.000	3.000	3.000	3.000	2.000
Physiotherapist	2.000	3.000	2.000	3.000	3.000	3.000	3.000	2.000
Sports Scientist	2.000	3.000	2.500	3.000	3.000	3.000	3.000	2.000
Groundstaff	2.000	2.000	3.000	3.000	3.000	2.000	3.000	3.000
Total	2.000	3.000	2.000	3.000	3.000	3.000	3.000	2.000

Where scores of 1.0 strongly agree, 3.0 shows neutral views, and 5.0 strongly disagrees.
Scores of 6.0 indicate the stakeholder felt it was not applicable to answer.

Table: Kruskal-Wallis test results for soft pitches and perceived injury risk determined by occupation.

Soft pitches cause?	Joint soreness/pain	Ligament Damage	Tendon Damage	Muscle Strains	Bone fracture	Concussion	Bruising	Cuts/Abrasions
Chi-Square	10.650	9.863	12.466	4.746	16.972	9.154	2.508	2.923
df	4	4	4	4	4	4	4	4
Asymp. Sig	.031**	.043**	.014**	.314	.002**	.057	.643	.571

a. Kruskal-Wallis Test
b. Grouping Variable Occupation
c. Significance level *p<0.05, **p<0.01

Table: Median reported scores for soft pitches and perceived injury risk determined by general occupation.

Occupation	Joint soreness/pain	Ligament Damage	Tendon Damage	Muscle Strains	Bone fracture	Concussion	Bruising	Cuts/Abrasions
Player	4.000	3.000	3.000	2.000	4.000	4.000	4.000	4.000
Manager/Coach	4.000	3.000	3.000	2.000	3.000	4.000	4.000	4.000
Physiotherapist	3.000	3.000	3.000	2.000	3.000	4.000	4.000	4.000
Sports Scientist	3.000	3.000	3.500	2.000	3.000	4.000	4.000	4.000
Groundstaff	3.000	4.000	3.000	2.500	2.500	3.000	4.000	3.500
Total	3.000	3.000	3.000	3.000	3.000	3.000	4.000	4.000

Where scores of 1.0 strongly agree, 3.0 shows neutral views, and 5.0 strongly disagrees. Scores of 6.0 indicate the stakeholder felt it was not applicable to answer.

Table : Kruskal-Wallis test results for pitch hardness and how it affects the individual and the team as determined by occupation.

Question ?	I/or my players are often leggy after playing on this type of pitch	I/my players high intensity running and sprinting is often better on this type of pitch	I/My players acceleration, deceleration and ability to stop is best on this type of pitch	I/My players ability to cut and change direction is best on this type of pitch	Players tend to adopt a shorter passing strategy on this type of pitch	Players tend to adopt a longer passing strategy on this type of pitch	The tempo of training /matches are better on this type of pitch	I would prefer to train on this type of pitch	I would prefer to play matches on this type of pitch
Chi-Square	50.202	5.472	0.663	12.950	1.349	22.184	2.172	5.001	60.112
df	4	4	4	4	4	4	4	4	4
Asymp. Sig	.000**	.242	.956	.012**	.853	.000**	.704	.287	.000**

a. Kruskal-Wallis Test b. Grouping Variable Occupation c. Significance level *p<0.05, **p<0.001

Table. Median reported scores for pitch hardness and how it affects the individual and the team as determined by general occupation.

Occupation	I/or my players are often leggy after playing on this type of pitch	I/my players high intensity running and sprinting is often better on this type of pitch	I/My players acceleration, deceleration and ability to stop is best on this type of pitch	I/My players ability to cut and change direction is best on this type of pitch	Players tend to adopt a shorter passing strategy on this type of pitch	Players tend to adopt a longer passing strategy on this type of pitch	The tempo of training/matches are better on this type of pitch	I would prefer to train on this type of pitch	I would prefer to play matches on this type of pitch
Player	1.000	3.000	3.000	3.000	4.000	2.000	3.000	3.000	3.000
Manager/Coach	1.000	4.000	3.000	3.000	4.000	2.000	3.000	3.000	3.000
Physiotherapist	1.000	4.000	3.000	3.000	4.000	2.000	3.000	3.000	3.000
Sports Scientist	1.000	3.000	3.000	3.000	4.000	2.000	3.500	3.000	3.000
Groundstaff	3.000	4.000	3.000	2.500	4.000	3.200	3.000	3.000	2.000
Total	1.000	3.000	3.000	3.000	4.000	2.000	3.000	3.000	3.000

Where scores of 1.0 very hard, 2.0 hard 3.0 medium, 4.0 soft and 5.0 very soft. Scores of 6.0 indicate the stakeholder felt it was not applicable to answer.

Table Kruskal-Wallis test results for perceptions of relationships between key stakeholders and groundstaff as determined by occupation.

Question?	Before each season I give the groundsman specific instructions as to how I want the pitch prepared	I determine which area my trains each day	I meet with the groundsman daily to discuss how I want the training pitch prepared.	I meet with the groundsman to discuss how I want the match pitch prepared.	I tell the groundsman the cut height of the grass I require.	I ask for a specific watering schedule before games.	I have a close working relationship with our groundsman.	I am satisfied with the pitches at our training ground	I am satisfied with the pitch at our Stadium	I believe the pitch can significantly influence the performance of my team.
Chi-Square	16.701	40.391	26.120	19.168	19.332	23.593	61.715	2.029	2.356	5.122
df	3	3	3	3	3	3	3	3	3	3
Asymp. Sig	.001**	.000**	.956	.012*	.853	.000**	.704	.566	.502	.163

a. Kruskal-Wallis Test
b. Grouping Variable Occupation
Significance level *p<0.05, **p<0.01

Table. Median reported scores of perceived relationships between key stakeholders and groundstaff as determined by occupation.

Occupation	Before each season I give the groundsman specific instructions as to how I want the pitch prepared	I determine which area my trains each day	I meet with the groundsman daily to discuss how I want the training pitch prepared.	I meet with the groundsman to discuss how I want the match pitch prepared.	I tell the groundsman the cut height of the grass I require.	I ask for a specific watering schedule before games.	I have a close working relationship with our groundsman.	I am satisfied with the pitches at our training ground	I am satisfied with the pitch at our Stadium	I believe the pitch can significantly influence the performance of my team.
Player	6.000	6.000	6.000	6.000	6.000	6.000	6.000	3.000	2.000	2.000
Manager/Coach	5.000	3.000	4.000	5.000	5.000	5.000	3.000	4.000	2.000	2.000
Physiotherapist	6.000	6.000	6.000	6.000	6.000	6.000	5.000	3.000	2.000	2.000
Sports Scientist	6.000	6.000	6.000	6.000	6.000	6.000	4.000	2.500	2.500	2.000
Total	6.000	6.000	6.000	6.000	6.000	6.000	4.500	2.000	2.000	2.000

Where scores of 1.0 strongly agree, 2.0 agree 3.0 neutral, 4.0 disagree and 5.0 strongly disagree. Scores of 6.0 indicate the stakeholder felt it was not applicable to answer.

Anecdotal evidence of media reported perceptions that pitches may be a risk factor for injury.

Perhaps, this lack of clarity, makes interpretation of such risk difficult, and as a result, it is often commonplace to read, or hear of television pundits and even players commenting on the link between pitches and injury without any firm foundation.

The following quotes demonstrate such concerns regarding the link between pitches and injury. Players such as Bournemouth striker Glenn Murray reportedly blamed pitches for the spate of top flight knee injuries. "I can't believe how common ACL's (anterior cruciate ligament ruptures) are becoming; new style pitches are to blame. If they don't give our bodies do! Killing us!"[5]. The Evening Standard reported television pundit Harry Redknapp's views on Arsenal Football Club's injury list stating "Maybe Arsenal's injuries are down to the pitches. The Emirates pitch is absolutely immaculate, maybe it's too good. It could make them more susceptible to injury when they don't play on it"[6]. The recent England manager, Roy Hodgson believes modern pitches may be to blame for the recent spate of injuries blighting the England squad. "I honestly believe the pitches, strangely enough, in getting so much better have provoked more injuries. At Blackburn, we had lots of 'Gilmore groins' (sportsman's hernias) maybe it was too good, leading them to stretch and slide more?

In a recent report, on the BBC sport-football entitled "Are serious knee injuries in the Premier League really at 'epidemic levels,' former professional footballer, chief executive and current BBC sport pundit, Pat Nevin examined potential causes, one of which was the pitch itself. Nevin was quoted stating, "We need further statistical work, but I have heard many complaints from Premier league managers that the ultra-hard pitches seem to be exacerbating the problem. On top of this, remember the players are training on precisely the same style of pitches everyday as well. I know for a fact, that some managers are concerned about this, and have to accept it limits the time some players are able to train. Yes, the game continues to get faster, but the lack of give in 'modern' pitches certainly has an effect. In the simplest terms, modern pitches look fantastic; they are beautifully flat and can cope with huge wear and tear. The groundsmen make them look beautiful for the TV, but when the changeover was happening did anyone ask the players, the managers or the medics what was needed?[8]"

10.3 Appendix 3

Pertaining to chapter 6

Table Globalized injury grouping classification.

Injury type	Recorded injury classifications
Muscle	Muscle strain Graded (grade 0-3), delayed onset muscle soreness (DOMS) and trigger points.
Ligament	Ligamentous sprain Graded (grade 1 and 2), Rupture.
Joint	Fracture, chondropathy, meniscus, joint effusion, stress response, dysfunction, dislocation, subluxation, fat pad dysfunction, synovitis, impingement, disc prolapse and joint infection.
Tendon	Tendonopathy, Para-tendonopathy, Rupture.
Nerve	Adverse Neural Tension, Compression.
Soft tissue	Hernia, Bursitis, Haematoma, Contusion, Laceration, Blister.
Concussion	Concussion (any head trauma leading to time loss).

Table

	Muscle	Ligament	Joint	Tendon	Nerve
Training (N=1109)	70	36	87	28	13
	727 days missed	674 days missed	1486 days missed	72 days missed	41 days missed
	Grade 1: 25	Grade 1: 22	Fracture: 4	Para-tendonopathy: 5	Adverse tension: 13
	Grade 2: 13	Grade 2: 11	Stress response: 7	Tendonopathy:23	Compression: 0
	Grade 3: 0	Grade 3: 3	Effusion: 13	Rupture: 0	
Match (N=388)	46	24	45	11	6
	600 days missed	917 days missed	726 days missed	153 days missed	10 days missed
	Grade 1: 16	Grade 1: 13	Fracture: 3	Para-tendonopathy: 2	Adverse tension: 5
	Grade 2: 14	Grade 2: 7	Stress response: 5	Tendonopathy: 8	Compression: 1
	Grade 3: 0	Grade 3: 4	Effusion: 4	Rupture: 1	

When the recommended zones for relative pitch hardness proposed by UEFA (2018) are examined in relation to injury clear pitch hardness affects injury frequency in differing ways in relation to specific tissue type.

	Muscle	Ligament	Joint	Tendon	Nerve
Soft	24	10	12	3	3
<70G	179 days missed	398 days missed	72 days missed	6 days missed	5 days missed
(N=94)	Grade 1: 6	Grade 1: 7	Fracture: 0	Para-tendonopathy: 0	Adverse tension: 3
	Grade 2: 4	Grade 2: 1	Stress response: 1	Tendonopathy: 3	Compression: 0
	Grade 3: 0	Grade 3: 2	Effusion: 0	Rupture: 0	
Recommended	77	42	84	23	12
70-90G	1029 days missed	1106 days missed	1670 days missed	182 days missed	40 days missed
(N=1148)	Grade 1: 30	Grade 1: 22	Fracture: 5	Para-tendonopathy: 2	Adverse tension: 12
	Grade 2: 20	Grade 2: 15	Stress response: 7	Tendonopathy: 20	Compression: 0
	Grade 3: 0	Grade 3: 5	Effusion: 12	Rupture: 1	
Hard	15	8	36	13	4
>90G	119 days missed	77 days missed	470 days missed	37 days missed	6 days missed
(N=256)	Grade 1: 5	Grade 1: 6	Fracture: 2	Para-tendonopathy: 5	Adverse tension: 3
	Grade 2: 3	Grade 2: 2	Stress response: 4	Tendonopathy:8	Compression: 1
	Grade 3: 0	Grade 3: 0	Effusion: 5	Rupture: 0	

Table Pitch construction and injury.

8 seasons	Native Soil (N=424)		Fibre sand (N=579)		Desso (N=487)		Fibrelastic (N=7)	
Category of injury	Injury count	Days missed	Injury count	Days missed	Injury count	Days missed	Injury count	Days missed
Total	153	1280	198	2484	139	1863	1	25
Total exposures resulting in injury	113 exposures		149 exposures		108 exposures		1 exposure	
Injury count and severity in relation to pitch type and injury categorization								
Slight (1-3 days)	68 44.44%	96 7.5%	63 31.82%	103 4.15%	52 37.51%	72 3.86%	0	0
Mild (4-7 days)	30 19.61%	95 7.42%	41 20.71%	163 6.56%	16 11.51%	61 3.27%	0	0
Moderate (8-28 days)	43 28.1%	415 35.42%	72 36.36%	738 29.71%	51 36.69%	518 27.8%	0	0
Severe (>28 days)	11 7.19%	674 52.66%	21 10.61%	1480 59.58%	20 14.39%	1212 65.06%	1	25

Table Muscle injures by pitch type

	Native soil	Fibre sand	Desso	Fibrelastic
Muscle injury count	41	41	34	0
Days missed to muscle injury	274 (7.61, SD8.71)	428 (11.26,SD9.59)	625 (18.94,SD21.89)	0
Grade 1 Strain	10	15	16	0
Grade 2 Strain	6	11	10	0
Grade 3 Strain	0	0	0	0
Trigger points	24	14	4	0
DOMS	2	1	4	0

Table Joint injures by pitch type

	Native soil	Fibre sand	Desso	Fibrelastic
joint injury count	28	57	46	1
Days missed to joint injury	489 (20.38,SD85.22)	1051 (20.61, SD33.88)	647 (23, SD27.30)	25
Dysfunction	17	24	23	0
Meniscus	1	3	1	0
Stress response	0	5	6	1
Effusion	5	6	6	0
Chondropathy	1	3	1	0

Table Tendon injures by pitch type

	Native soil	Fibre sand	Desso	Fibrelastic
Tendon injury count	22	15	2	0
Days missed to tendon injury	173 (8.24, SD26.79)	50 (3.33, SD2.02)	2	0
Para-tendonopathy	6	1	0	0
Tendonopathy	15	14	1	0
Rupture	1	0	0	0

Table Ligament injures by pitch type

	Native soil	Fibre sand	Desso	Fibrelastic
Ligament injury count	20	25	15	0
Days missed to ligament injury	273 (13.65, SD8.05)	832 (33.28,SD52.05)	476 (31.73,SD 56.74)	0
Grade 1 Strain	15	14	6	0
Grade 2 Strain	5	7	6	0
Grade 3 Strain	0	4	3	0

Appendix 10.4

Pertaining to chapter 7

7.8.1 Appendix: Differential RPE questionnaire

Q1

Using the verbal expressions on the scales below, please rate your perception of yellow ball 4 V 4 games.

Session Exertion	Leg Muscle Exertion	Breathing Control	Technical Difficulty
Maximal	Maximal	Maximal	Maximal
Extremely hard	Extremely hard	Extremely hard	Extremely hard
Very hard	Very hard	Very hard	Very hard
Hard	Hard	Hard	Hard
Somewhat hard	Somewhat hard	Somewhat hard	Somewhat hard
Moderate	Moderate	Moderate	Moderate
Easy	Easy	Easy	Easy
Very easy	Very easy	Very easy	Very easy
Nothing at all	Nothing at all	Nothing at all	Nothing at all
CR100® Scale	CR100® Scale	CR100® Scale	CR100® Scale

Q2

Using the verbal expressions on the scales below, please rate your perception of white ball 4 V 4 games.

Session Exertion	Leg Muscle Exertion	Breathing Control	Technical Difficulty
Maximal	Maximal	Maximal	Maximal
Extremely hard	Extremely hard	Extremely hard	Extremely hard
Very hard	Very hard	Very hard	Very hard
Hard	Hard	Hard	Hard
Somewhat hard	Somewhat hard	Somewhat hard	Somewhat hard
Moderate	Moderate	Moderate	Moderate
Easy	Easy	Easy	Easy
Very easy	Very easy	Very easy	Very easy
Nothing at all	Nothing at all	Nothing at all	Nothing at all
CR100® Scale	CR100® Scale	CR100® Scale	CR100® Scale

Q3

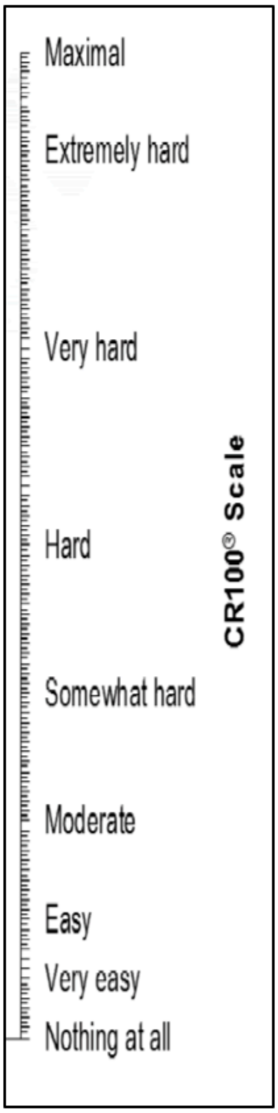
Using the verbal expressions on the scales below, please rate your perception of yellow ball 8 V 8 games.

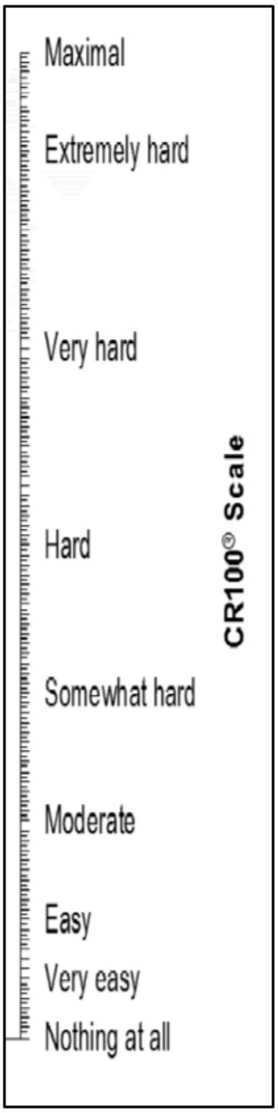
Session Exertion	Leg Muscle Exertion	Breathing Control	Technical Difficulty
CR100® Scale	CR100® Scale	CR100® Scale	CR100® Scale
Maximal	Maximal	Maximal	Maximal
Extremely hard	Extremely hard	Extremely hard	Extremely hard
Very hard	Very hard	Very hard	Very hard
Hard	Hard	Hard	Hard
Somewhat hard	Somewhat hard	Somewhat hard	Somewhat hard
Moderate	Moderate	Moderate	Moderate
Easy	Easy	Easy	Easy
Very easy	Very easy	Very easy	Very easy
Nothing at all	Nothing at all	Nothing at all	Nothing at all

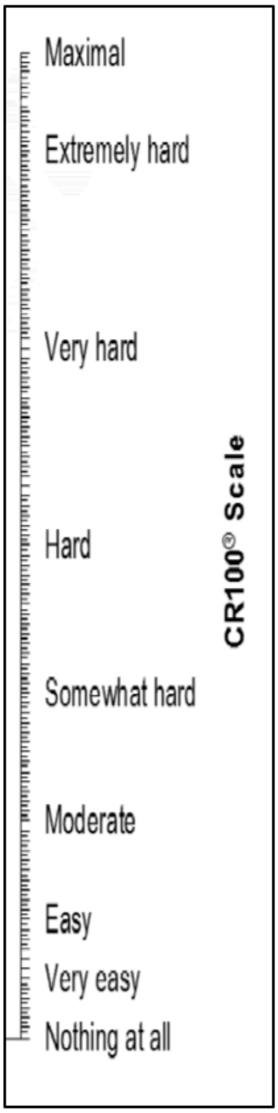
Q4

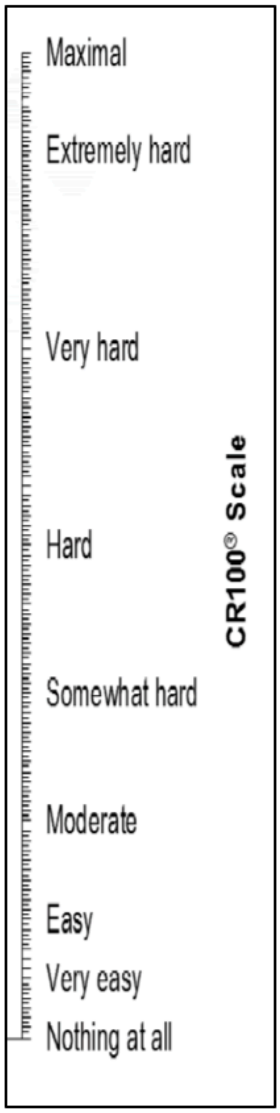
Using the verbal expressions on the scales below, please rate your perception of white ball 8 V 8 games.

Session Exertion	Leg Muscle Exertion	Breathing Control	Technical Difficulty









Q 5 Which pitch surface did you perceive to be harder?

Both Same

☐

☐

☐

Q 6 Which pitch surface did you prefer playing on?

Both Same

☐

☐

☐

Neither

☐

Why?

Q 7 On which pitch surface did you find it best to Jump on?

Both Same   Neither

☐ ☐ ☐ ☐

Why?

Q 8 On which pitch surface did you find it best to push off on?

Both Same   Neither

☐ ☐ ☐ ☐

Why?

Q 9 On which pitch surface did you find it best to land on?

Both Same			Neither
☐	☐	☐	☐

Why?

Q 10 Did you feel uncomfortable or have any injury concerns on either pitch?

	Joint soreness or pain
	Tendon pain
	Muscle fatigue
	Ligament Damage
	Abrasions

	Joint soreness or pain
	Tendon pain
	Muscle fatigue
	Ligament Damage
	Abrasions

Any other comments?