PLAYER PROTOCOLS FOR FOOTBALL BOOT TESTING

by

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ABSTRACT

Football is the most popular sport and played by more players worldwide than any other sport. The football boot industry is therefore big, competitive and still growing. Today, football boot designs are subcategorised into four categories, of which three are linked to specific skill performance enhancing claims: The power boot for enhanced shooting performance, the touch/control boot for enhanced ball control and the speed boot for enhanced speed generation. In comparison to the strong marketing claims, little research has been published on the impact of football boot design on performance, injury and comfort. Therefore, little is known about the importance and impact of changing boot design.

The outcome of this thesis offers researcher and the football boot industry validated human test protocols for power boot, touch/control and speed boot designs. The outcome of the thesis also advances the knowledge of how the football boot impacts performance, comfort and highlights the potential links between plantar comfort and injury risk.

Rule based system assessment was performed to validate a boot performance conceptual framework linking the player and their desired movements during a football match with the football boot and its different components.

The three protocols for assessment of key performance aspects for power boots, touch/control boots and speed boots were validated using test-retest reliability assessment through relative and absolute reliability measures. The power boot protocols involved shooting assessment measuring ball velocity, offset from target, success and player perception of ball velocity and accuracy. The touch/control boot protocol involved dribbling and passing assessment measuring time, number of touches and radial distance from cones during completion of a complex dribbling drill, ball velocity and offset from target during flat and airborne passes. The speed boot protocols involved combined agility and acceleration sprinting time and jump height before and after a 90 min match simulation protocol. Throughout the match simulation heart rate, player perceived exertion, perceived muscle fatigue, overall foot comfort and specific regional foot comfort.

The validated protocols were then applied to assess how boot parameters impact performance. For the power boot, boots with and without upper padding were compared

demonstrating a small favour for the non-padded boot. Similarly, boots with and without upper padding were compared for the touch/control boot scenario with no differences seen between the two designs. Finally, two commercially available speed boots were assessed for the speed boot scenario demonstrating significant differences in both comfort and performance measures. Indicating a potential link between decreased foot comfort and decreased ability to maintain performance throughout a 90 min game.

The boot performance conceptual framework was developed with component at each level but no interactive links between levels were added due to the lack of evidence in the literature. The boot performance conceptual framework offers researchers and the football boot industry a visualisation tool to aid the general overview when assessing or designing football boots. The three validations of protocols demonstrated strong test-retest reliability for most measures assessed and can therefore be applied to assess the impact of altering boot designs like demonstrated in this study.

PUBLICATIONS

Conference Presentations:

Okholm Kryger, K., Mitchell, S. and Forrester, S. (2017). Assessing the impact of upper padding thickness on passing and dribbling performance. In: World Conference of Science and Soccer. Rennes, France, p 109.

Okholm Kryger, K., Mitchell, S. and Forrester, S. (2017). Assessing the impact of upper padding thickness on kicking performance. In: World Conference of Science and Soccer. Rennes, France, p. 360.

Okholm Kryger, K., Mitchell, S. and Forrester, S. (2017). How upper padding affects shooting performance. In: Wolfson School of Mechanical, Electrical and Manufacturing Engineering PhD Research Conference. Loughborough, UK.
(Awarded 1st prize at 'Best Poster' competition)

Okholm Kryger, K., Mitchell, S. and Forrester, S. (2016). The speed-accuracy trade-off for football kicks. In: UK Footwear Science Meeting. Stoke on Trent, UK.

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CHAPTER 1

Introduction

1.1 Chapter Outline

This chapter provides details on the motivation and reasoning for the research conducted throughout the Ph.D. period. Explanation of main purpose is given in which the key research aims are stated. To finish, an overview of the general structure of the thesis is presented.

1.2 The Area of Study

Football is the world's most popular sport played by 265,000,000 people world-wide in 2000 including 110,000 professional male players (Fédération Internationale de Football Association, 2007). Footwear in football is a key element as it works as the connection between player and ball as well as player and surface. The football boot is therefore key equipment for the player in relation to performance, injury and comfort (Hennig, 2011). Bold marketing claims regarding enhancement of performance aspects are applied by the football boot industry today. Sporting goods companies need to frequently introduce technological innovations to distinguish themselves in an increasingly competitive, continually changing, global football footwear market (Xerfi 2XDIS04, 2013). It is common practice to market football boots with an emphasis on enhancing a single key performance characteristic (e.g. running speed, touch/control or shot power). Today, football boots are, therefore, subcategorised into four categories, of which three are linked to specific skill performance enhancing claims: The Power Boot for enhanced shooting performance, the Touch/Control Boot for ball control and the Speed Boot, designed for enhanced generation of speed. Despite the fundamental importance of football boot design when delivering advertised benefits, little research has been published on the impact of football boot design on performance, injury and comfort. Therefore, little is known about the importance and impact of changing boot design. Additionally, the studies assessing the impact of boot design on performance, injury and comfort have not applied validated test protocols. The field would therefore benefit from the development and validation of protocols designed specifically for assessment of football boots.

1.3 Statement of Purpose

The research conducted firstly aimed to understand the current football boot design. This includes the football player's fundamental demands from a football boot and how these are achieved through the design of the football boot. Based on the low level of research published and its varying quality, the second aim of this research project became development and validation of human test protocols to assess the impact of football boot design on the skill performance claims made by the industry. With the test-retest validated protocols available, the final aim of this research project involved the application of the validated protocols to assess a single comparison of boots with varying designs to obtain knowledge on specific impacts on performance whilst also demonstrating the applicability of the validated protocols.

1.4 Research Questions

In order to meet the purposes of this research project a number of research questions were proposed.

Q1. Which football boots does the current market contain and what are the claims and proofs for the benefits of these designs?

The football boot design has evolved over more than a century and the market continues to grow with market competition still growing today (Xerfi 2XDIS04, 2015). To answer this research question, a summary of the development of the football boot through history is made in Chapter 2 followed by a description of the current football boot market (last updated March 2018) with descriptions of the current design categories available: power, touch/control, speed and heritage. To understand how the evidence from research and marketing claims relate, the marketing claims associated with these football boot design categories were outlined and with reference to these claims a review of the published evidence behind the design specifications and their performance claims was performed.

Q2. How can a football player's demands from a football boot during match-play be logically presented?

To design a football boot, its required demands from the football player must be understood. As football is a multi-facets sport causing multiple demands from the player and hence the football boot then these complex interactions may benefit from being defined in a conceptual framework. This representation method allows users to visualise the potential interactions between boot design and performance, injury risk and perception. Chapter 3 describes the development of a generic football boot performance conceptual framework designed to highlight the possible links between the football player's demands during match-play and the football boot design (and vice versa) using conceptual framework strategies.

Q3. How does one reliably assess the impact of football boot design on the key performance aspects highlighted in the marketing of the main boots designs on the current market using human participants?

As discovered when reviewing the current evidence supporting manufacturer marketing claims on performance for their current football boot designs (Q1), limited research has been published and no validated assessments methods have previously been applied. Applying protocols where no level of validation has been performed lowers the strength of the research conducted. Validated protocols have been designed for player focused assessment, which is, however, not transferrable to the assessment of external impacting factors such as football boots. The development of football boot specific protocols assessing boot design related performance parameters was therefore performed (Chapter 5 for power boots, Chapter 9 for touch/control boots and Chapter 12 for speed boots). Validation was performed through test-retest reliability assessment and content validity assessment of equipment used. The football boot specific protocols were developed based on critical reviews of current literature methodologies (Chapter 4, 7, 8 and 11). Finally, the developed test protocols for each of the boot designs were applied to firstly highlight applicability of the protocols developed and secondly to bridge some of the gaps demonstrated in Q1 and Q2 between published research knowledge and marketing claims from football boot manufacturers.

1.5 Thesis Organisation

The content of each chapter is summarised briefly below, whilst the overall thesis structure is presented in Figure.

Chapter 2 provides a review of how the football boot design has developed through history, the football boot industry today and how the industry football boot divides designs into performance enhancing subcategories. Leading on from this, a thorough review of research published on how football design impacts the key performance enhancing claims made by the football boot industry.

Chapter 3 introduces a boot performance conceptual framework developed to visualise the link between the player demands during match-play and the properties of each football boot component. The spider diagram may act as a mind map for researchers or manufacturers to evaluate potential benefits but also risks from altering a component of the football boot design.

Section 1 - The Power Boot

- ***Chapter 4*** provides a review of assessment methods for analysing shooting performance in football. This chapter focuses both on test setup and tool to use for the assessment of shooting performance.
- ***Appendix B to D*** are small pilot studies performed to assess the quality of assessment tools used to measure ball velocity and ball accuracy.
- ***Appendix E*** discusses the current methods for validation of a test protocol for human testing to find a statistical assessment method for later use.
- ***Chapter 5*** applies the knowledge gained in Chapter 4 and Appendix 2 to 5 and describes the development and validation through equipment content validation and test-retest reliability of a novel protocol for assessment of how football boot design impacts shooting performance.
- ***Chapter 6*** applies the validated protocol from Chapter 5 to assess the impact of upper padding thickness on shooting performance.

Section 2 - The Touch/Control Boot

- ***Chapter 7*** provides a review of assessment methods for analysing dribbling performance. This chapter focuses both on test setup and tool to use for the assessment of dribbling performance.
- ***Chapter 8*** provides a review of assessment methods for analysing passing performance. This chapter focuses both on test setup and tool to use for the assessment of passing performance.
- ***Appendix F*** reviews typical passing lengths performed during match-play in the FA Premier League to obtain ecologically valid passing lengths for the test protocol.
- ***Appendix G*** is a pilot study to assess the quality of the assessment tool used for measuring offset from target in dribbling and passing.

- ***Chapter 9*** applies the knowledge gained in Chapter 7 and 8 and Appendix 6 and 7 and describes the development and validation through equipment content validation and test-retest reliability of a novel protocol for assessment of how football boot design impacts dribbling and passing performance.
- ***Chapter 10*** applies the validated protocol from Chapter 9 to assess the impact of upper padding thickness on dribbling and passing performance.

Section 4 - The Speed boot

- ***Chapter 11*** provides a review of assessment methods for analysing speed generation, comfort and fatigue. This chapter focuses both on test setup and tool to use for the assessment of speed generation, comfort and fatigue.
- ***Appendix H and J*** are pilot studies assessing the ecological validity of a football match simulation protocol by heart rate and exertion measures.
- ***Appendix K*** is a pilot study assessing the test-retest reliability of football specific speed protocols previously applied in the literature.
- ***Chapter 12*** applies the knowledge gained in Chapter 10 and appendix 8 to 10 and describes the development and validation through equipment content validation and test-retest reliability of a novel protocol for assessment of how football boot design impacts speed generation, fatigue and comfort during match-play.
- ***Chapter 13*** applies the validated protocol from Chapter 11 to two commercially available 'Speed Boot' designs on speed generation, fatigue and comfort during match-play.

Chapter 14 summarises the content of this thesis and identifies the perceived limitations present throughout. In brief, the results obtained from the research are used to address the aims stated in the Introduction chapter. Finally, the future directions from the new methods and knowledge obtained though this research project are addressed.

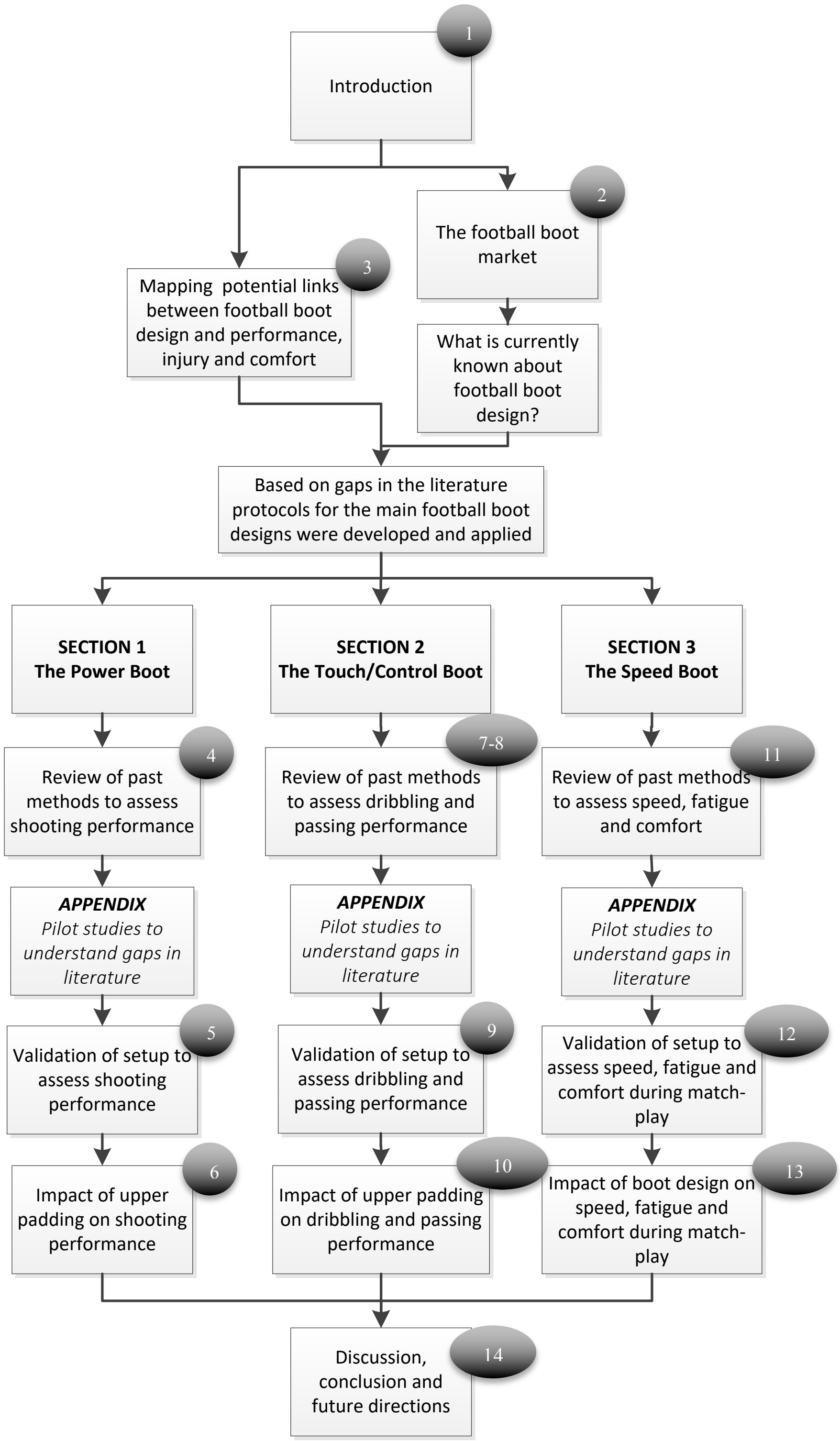


Figure 1.1. Visual outline of thesis content including chapter correspondence.

CHAPTER 2

General Literature Review

2.1 Chapter Outline

This chapter first outlines the development of the football boot through history up until today, including a description of the football current market and the current football boot designs and their associated marketing claims. This leads on to a review of published evidence of the impact of boot design on key design features the claimed benefits of the different football boot categories available on the current market.

2.2 History of Football Boot Design

Over the decades where football (soccer) has been played and advanced, the football boot design has been developing and still is today. In the 1800's, English factory workers used hard leather work boots for playing (Hennig, 2011). Up through the 1800's, football boots were a work boots with the addition of leather studs to the outsole for improved traction (McArthur, 1995). These early football boots had a mass of >500 g, or >1 kg under wet conditions (Hennig, 2011). Specific football boot producers only started to appear in the early 1900's (Gola (1905), Valsport (1920) and Hummel (1923)).

The Dassler brothers founded adidas and Puma in 1948. The brothers' personal rivalry started a design evolution of the football boot. In 1954, Addolf "Adi" Dassler, the founder of adidas, developed shoes for the German national team with screw in studs and, at that time, a low mass of only 380 g (Hennig, 2014). In the 1960's the below-the-ankle football boots were introduced, which allowed players improved agility (McArthur, 1995). With growing attention to design the boot mass was further reduced over the next two decades and colours other than the traditional black and white were introduced to the market. This was also the period where professional players started being paid by manufacturers to wear specific boots (McArthur, 1995).

In the 1990's the advances in technology and innovation rapidly increased, with new designs launched still increasing year by year. This was especially thanks to the entry of the wold's biggest sportswear producer, Nike, on the football boot market with the 200 g Nike Mercurial boot. The big focus of the 1990's decade was stud design and placement to generate speed (McArthur, 1995). With the entry of Nike, player sponsorship deals became essential for football boot marketing with Nike sponsoring

Ronaldinho and Thierry Henry and adidas sponsoring David Beckham. Today, new materials have been introduced, which bring the mass of a football boot down to as little as 150 g. Not only is the market today focused on the mass of the boot, many additional performance-enhancing aspects have been developed. These performance-enhancing aspects are used to classify football boots into categories and are developed to match specific playing styles and playing positions.

2.3 The Football Boot Industry Today

Football is the most popular team sport in the world. The Fédération Internationale de Football Association (FIFA) stated in their big count nine years back that there are 265 million active players worldwide of which 111,000 were registered professional footballers (Fédération Internationale de Football Association, 2006). The biggest football event, the World Cup, attracted an audience of 3.2 billion in 2010 (Fédération Internationale de Football Association, 2014), thus the number of football players and enthusiasts is huge on a global scale making the football market very attractive. Within the United Kingdom alone, football has seen an increase in the percentage of total sports apparel sales, rising from 14% to 17% between 2013 and 2014 (Mintel Reports, 2014) – a market with a turnover of £ 3.75 billion in 2014 and growth expectations over the next five years to be 19.8%, taking the market to £ 4.49 billion in 2019 (Mintel Reports, 2014). The market only represents a tiny part of the global sporting goods sales amounted to around € 246 billion in 2012, a 3% increase from the previous year 2011 (Xerfi 2XDIS04, 2013).

The global football market has grown at a healthy rate of +4% on average per year since 2006 with a total value in 2013 of £ 9.38 billion (NPD Group Data, 2014). All the major companies in the world sporting goods industry make their main revenue on footwear: Nike 53.7%, adidas 45.5% (Xerfi 2XDIS04, 2013). The two largest companies on the market Nike and adidas had a total revenue of $19.2 billion and $15.8 billion respectively in 2010 (28.7% and 43.3% were made in Europe) (Xerfi 2XDIS04, 2013). The global football footwear industry is becoming increasingly dominated by the growing market share of the leading sporting goods companies (from 18.9% in 2007 to 25,2% in 2012), driven by acquisitions of smaller brands and by marketing and advertising initiatives increasing the customers' brand value for those leading companies (Xerfi 2XDIS04, 2013). The high competition has led to many technological innovations, which allows sporting goods companies to differentiate themselves (Xerfi

2XDIS04, 2015). It has also become crucial for companies to produce a wide range of footwear products to satisfy ever increasing consumer demand, which puts even higher loads on the companies. Market analyses conclude that sporting goods companies will continue to focus on product innovation, consolidation (brand acquisitions to increase market share), marketing initiatives and greater use of digital technologies in the future (Xerfi 2XDIS04, 2013).

2.4 Football Boots Designs on the Market Today

To understand the range of football boots on the market today, an assessment of wording used by the official brands in their football boot marketing on their official website (Table 2.1). Football boot designs are today sub-categorised by the manufacturers based on specific performance aspects. These include 'speed' generating boots for faster running, ball 'touch/control' boots enhancing passing and dribbling ability and the 'power' boots claimed to enhance ball velocity and accuracy for shooting or long passing. In addition, classic 'heritage' boot designs can be grouped together. These are not produced with a specific performance claim but are instead re-launching of older popular models e.g. adidas Copa Mundial or Predator and have, therefore, not been considered within the remainder of this thesis.

Table 2.1. Football boots designs on the market today and their marketed key parameters

Category	Boot	Marketing headline	Mass	Fit/Shape	Traction	Outsole stiffness	Upper friction	Upper thickness	Upper texture	Stability	Plantar pressure	Material durability
Speed	Nike Mercurial	Explosive speed – Ultralight fit	■	■	■	■	■		■			
	Adidas X	Light up the pitch with electric speed	■	■	■		■	■	■	■		
	Puma EvoSpeed	Made for the explosive. Engineered for the attack.	■	■	■		■	■		■		
Control	Nike Magista	Amplified playmaking		■	■		■		■		■	
	Adidas Nemeziz	Supernatural agility just got more natural	■	■					■	■		
	Adidas Ace	Absolute control for the masters of the game.	■	■		■	■	■	■	■		
	Puma EvoTouch	Offers unprecedented touch to the ball in all conditions		■	■			■		■		
Power	Nike Hypervenom	Deadly finishing		■	■	■		■	■			
	Puma EvoPower	Optimizes the interaction between kicking velocity and accuracy	■	■			■	■	■	■		
Heritage	Nike Tiempo	Natural command	■	■				■	■	■		
	Adidas Copa	Elite-level touch meets the game's classiest player.		■	■				■			
	Puma King	Unparalleled experience in terms of comfort and control		■	■				■	■		■

Note: Category selection is based on content of football boot descriptions from the official websites; Only the professional versions of the different designs were assessed. Websites used were: www.nike.com; www.adidas.com; www.puma.com.

2.5 The Power Boot – Definition and Literature

Power boots have been developed to optimise a player's shooting ability through claimed improved ball velocity generation (normally described as power by boot manufacturers) and accuracy. On the market today, power boots are represented by the

Nike Hypervenom and Puma EvoPower. The Hypervenoms were first released in 2013, whilst Puma EvoPower made its way to the market in January 2014. The power boot design is therefore relatively new on the football boot market.

When assessing the marketing claims of performance enhancing design parameters behind power boots it becomes clear that only fit (which is mentioned for all boot design), upper thickness and upper texture are descriptive factors applied for both designs (Table 2.1). The first generations of Puma EvoPower contained an upper padded texture, which today has been modified into a dotted texture with localised pressure points, similar to the Nike Hypervenom design. The earlier generations of Puma EvoPower also contained a claimed energy storing outsole to optimise generation of higher ball velocity. These features are, however, not included in the latest Puma EvoPower design (released 2017). No obvious design similarities are therefore seen between power boot designs today. The following sections are reviews of the scientific literature on how football boot design impacts shooting performance.

Several aspects of the football boot have been researched in relation to ball velocity. The literature collected assessing football boot design on ball velocity generation is listed in Table 2.2. A total of nine studies were found.

Table 2.2. Summary of the studies investigating boot design features on ball velocity

Study	Boot parameter	Number of boots compared	Impact (P value)
Amos and Morag (2002)	Shoe mass	2	NS
Hennig and Zulbeck (1999)	Outsole stiffness	5	NS
	Shoe model	5	< 0.05
Ismail et al. (2010)	Shoe model	4	No stats
Moschini and Smith (2012)	Boot mass	3	NS
Sterzing et al. (2006)	Shod versus barefoot	5	0.05
Sterzing and Hennig (2007a)	Friction	4	0.07
Sterzing and Hennig (2007b)	Traction on stance leg	4	< 0.01
Sterzing and Hennig (2008)	Toe box height	4	< 0.05
Taha et al. (2013)	Shoe model	3	No stats

NS = Non-significant

Overall effects

Four studies compared different football boot models available on the market (Hennig and Zulbeck, 1999; Ismail et al., 2010; Sterzing et al., 2006; Taha et al., 2013). These studies were not able to report the effect of individual boot parameters due to the multifactorial effects occurring when comparing different boots with multiple variations in their designs. In other words, different boots most likely vary in multiple boot parameters, potentially impact performance differently. These studies can, however, be used to obtain a general understanding of whether, amongst the tested football boots, a performance difference can be achieved - in this case shooting ball velocity. The four studies do, however, all lack either ecological validity and/or standardised setups thus increasing the risk of other potential influencing factors affecting the results in addition to the football boots. These limitations are discussed further below.

Taha et al. (2013) compared maximum velocity achieved when wearing the Nike Mercurial Vapor VIII FG, the Adidas AdiPower Predator TRX FG, and the Puma King Finale SL I FG. The main downfall of this study was the shooting technique applied – a toe kick. This shooting method is rarely used in football due to its poor accuracy and minimal contact occurs between the football boot and ball (Althoff and Hennig, 2011). No argument was included of why this shooting style was chosen. With the lack of accuracy a toe kick produces, the ball-boot impact point has an increased risk of being located off centre (visible from photo figures included) and therefore produce differences in spin and thereby loss of energy, which is likely to have affected the outcomes of the study. Also, the results from this study cannot be transferred into real life football scenarios since these types of shots are rarely used by skilled players and variations in shooting velocity is therefore not relevant for the design of football boots. Additionally, no statistical comparison was performed.

In the study by Ismail et al. (2010) a two-step instep kick was used to compare four different football boots from the brands: Adidas, Puma, Nike, and Umbro (no model description given). A motion analysis system (200 Hz) was used to measure maximum ball velocity and force plates were used to measure maximum force generated by the support leg at the final instep, yet no information was given on whether this maximum force represents the total or the vertical force measured. The highest maximum velocity achieved across the 33 subjects was 17.75 $m.s^{-1}$, which is very low in comparison to mean maximum velocities obtained in the rest of the literature (Table 4.6). No comments on the low ball velocity measures were made by the authors. In addition, no statistics were performed on the results. The biggest variance in mean maximum velocities between boots was found to be 1.55 $m.s^{-1}$, suggesting a variation can be achieved using different boots. Yet, without standard deviations and statistical analysis these numbers should not be used to assert performance differences between boots.

Hennig and Zulbeck (1999) compared five masked football boots of difference designs. This was the first study to report that ball velocity during full-instep kicks may be significantly influenced by the boot design. The study demonstrated low intra-individual coefficients of variance (< 2%) during the repetitive trials for a given boot, which confirmed a high accuracy and repeatability of their test setup. The study also found a low correlation ($r^2 = 0.04$) between tibial acceleration and ball velocity, meaning that the other factors, and potentially the football boot, were more dominant as an impacting factor. Yet, the test setup was not clearly described in the study, which prevents other researchers from reproducing the study. Additionally, ball speed was measured using 15 laser diode photocells. The limitation to this measurement method is that the ball needs to be travelling close to ground level to register a ball speed reading. Also, the instrument only measures time to travel a set horizontal distance in the target direction reducing the accuracy. This is unfortunate as significant differences in ball velocity ($p < 0.01$) were seen between boot designs.

Finally, Sterzing et al. (2006) compared three different masked football boots in addition to barefoot and sock shooting conditions. The barefoot and sock conditions are described in the section below. No significant difference was found between boot designs. The actual test setup for this study was only published 3 years later in Sterzing and Hennig (2008), using six maximum velocity shots performed with a standardised three-step approach but no control was mentioned of shot type. Players may therefore not have used the same technique for each repetition and for each shoe condition.

In summary, research has been performed comparing ball velocities achieved using different football boots models. The quality of the research varies and key descriptions and/or statistical assessments are missing preventing future researchers reproducing the methods used. It is, however, interesting to note that the work by Hennig and Zulbeck (1999) found significant differences between boot designs.

Pressure distribution

In relation to overall boot design, Hennig et al. (2009) attempted to compare dorsal pressure distribution at ball impact of two boots demonstrating a significant difference in shooting accuracy. Pressure was assessed using a Pedar insole (Novel Inc., St. Paul, MN) attached on the dorsal side of the boot. Measurements showed that the more accurate shoe demonstrated more ‘homogenously’ distributed pressures as compared to the significantly less accurate model. What was meant by homogenous was not described further. Additionally, strapping a 0.6 mm thick Pedar insole (Novel Inc., St.

Paul, MN) on top of the football boot changes several of the boot characteristics e.g. the shape of the upper and friction properties.

Barefoot kicking

As mentioned previously, Sterzing et al. (2006) compared three different masked football boots as well as barefoot and sock shooting conditions when measuring shooting ball velocity. It was found that the use of football boots reduces ball velocity by up to 1.5% compared with barefoot shooting for players that are able to disregard pain during barefoot shooting (Sterzing et al., 2006). Subjects shot significantly faster ($p < 0.05$) barefooted despite the peak resultant shear force of the stance leg being significantly lower ($P < 0.05$), which indicates a more cautious approach to the shot (Sterzing et al., 2006). It should be mentioned that the same football boot was worn on the support leg for all trials. These results confirm an early observation of a football player shooting faster and further without shoes (Plagenhoef, 1971).

Pain perception

Pain level has been analysed by its effect on shooting velocity in relation to barefoot shooting in the study described above. It may appear obvious that a shod foot benefits from pain reduction at impact compared to an unshod shooting (Lees et al., 2010). Barefoot shooting conditions were proven to be perceived more painful than when wearing football boots, regardless of type ($p < 0.01$; Sterzing et al., 2006). Therefore, players' perception of ball velocity was related to their perceived pain and not to the actual ball velocity (Sterzing et al., 2006). The relationship was, however, not assessed for pain levels experienced between the different shod conditions. It is therefore unknown whether player perception of pain and perception of ball velocity is evident when wearing football boots with varying upper designs.

Outsole bending stiffness

Hennig and Zulbeck (1999) looked at the relationship between ball velocity and outsole bending stiffness and outsole deformation velocity. A regression analysis demonstrated low determination coefficients between ball velocity and outsole stiffness ($r^2 = 0.11$) as well as outsole deformation velocity ($r^2 = 0.04$). As the outsole stiffness values and method of measuring outsole stiffness were not explained, it is difficult to conclude whether the tendencies demonstrated in these studies are transferable and thereby outsole stiffness has been definitively shown to have no effect on optimising shooting velocity.

Shoe mass
The effect of football boot mass on ball velocity during shooting has been tested in the literature. Research found that boot mass significantly affects leg kinematics (knee angle at foot placement and just prior to ball impact (Moschini and Smith, 2012) and heavier boots have shown to significantly lower foot velocity (Amos and Morag, 2002). Despite having an effect on the leg kinematics, no significant difference was seen on ball velocity (Amos and Morag, 2002; Moschini and Smith, 2012; Sterzing and Hennig, 2008). Therefore, the assumption that a bigger mass may possibly enhance the momentum, yet also increase the moment of inertia, which may result in a slower movement transferring less energy does not seem applicable (Moschini and Smith, 2012). The mean foot mass for an adult male is 1.43 kg (Plagenhoef et al., 1983). With a modern football boot weighing roughly between 0.16 and 0.25 kg, the increase segment mass ranges between 11.2% and 17.5%. If this calculation is performed for the leg and foot together, the mean limb mass for males of 6.18 kg (Plagenhoef et al., 1983) would experience a 2.6% to 4.0% increase in mass. The limb mass is taken from the general population and it can only be assumed that football players have more dominant muscle mass and therefore an increased limb mass and smaller impact of boot mass in comparison to the general population. Based on the results from the literature and the calculation above it can be reasoned that the impact of shoe mass is minimal for modern football boots on ball velocity.

Toe box height
A single study has looked at how the anatomical fit of the upper through toe box height affects ball velocity. It was found that an increased toe box height can reduce ball velocity by up to 2.0% (Sterzing and Hennig, 2008). Four masked shoes were compared. It is not known whether the toe box height was the only varying factor or whether four different models with different toe heights were compare. If the last scenario is the actual case then other impacting factors could have affected the results. Hence, with the sparse amount of information available about the methods, the shoes tested as well as a minimal amount of information regarding the actual results then it is not possible to conclude on the actual effect of toe box height on shooting velocity.

Upper friction
Only a single study (Sterzing and Hennig, 2007) was found assessing the impact of friction properties of the upper shoe surface on ball velocity. Due to confidentiality

reasons this study did not define the actual friction properties. Instead the friction properties were defined as low friction, regular friction, high friction and very high friction. Whether these were within the range of normal boot design or not was not mentioned. ‘Regular friction’, which according to the paper demonstrated friction properties similar to currently used shoe upper friction, showed tendencies towards higher ball velocity compared to the assessed ‘low’ and ‘high’ friction conditions ($p < 0.07$). Ishii et al. (2014), however, assessed the impact of upper friction ($\mu = 0.1$, 0.2, 0.4 and 0.6) on ball velocity and spin through finite element modelling and concluded that the shoe upper does not significantly impact ball velocity. No conclusion can therefore be drawn based on the current literature.

Support foot traction

The stance leg and foot should not be neglected when a player is performing a shot. The typical run up motion followed by a sudden braking at the final foot plant (see Lees et al. (2010) for a full kinematical description) highlights the importance of traction properties for the support foot. It can be assumed that appropriate traction characteristics can increase the horizontal ground reaction forces acting on the support leg and provide a better start to the kinetic chain sequence. Previous research has shown significant differences in shooting velocity by altering the stud length (Sterzing and Hennig, 2007). The study included soft ground studs, firm ground studs, and 2 versions of trimmed stud lengths (50% and 0% of original length) all tested on artificial turf. Significantly higher ball velocities were seen using firm ground studs and 50% of original length studs. Unfortunately, no additional measures of actual traction properties were performed in the study. The results obtained suggest that stud length and thereby traction affects the player’s ability to improve shooting velocity.

Summary

Several studies have looked at the impact of football boot design on shooting velocity (Table 2.2). Four studies have attempted to look at the overall effects by using different boot designs yet every study lacks information in their methodology, use unrealistic designs (toe kicking) or have atypical outcome velocities, which makes their results questionable. A surprising discovery is that players obtain higher velocities when shooting barefooted compared to wearing football boots. The underlying mechanisms have, however, not been assessed in the past literate. The impact of outsole stiffness, shoe mass, toe box height, stance foot traction and upper friction have been tested. It appears that stance foot traction, upper friction and toe box height may be impacting ball velocity. Yet a general problem is the lack of standardisation and information delivered in the scientific publications on the topic.

2.6 Literature review of the impact of football boot design on shooting accuracy

In contrast to ball velocity, research on the effect of boot design on shooting accuracy is limited with only two studies found (Hennig et al., 2009; Kuo and Shiang, 2007; Table 2.3). Additionally, no study has assessed both performance parameters together.

Table 2.3. Summary of the studies investigating boot design features on shooting accuracy

Study	Boot parameter	Number of boots compared	Impact (P value)
Hennig et al. (2009)	Shoe model	5	< 0.01
	Pressure distribution	2	No stats
Kuo and Shiang (2007)	Lacing	4	< 0.05

Overall effects

Similar to the review of boot design on shooting velocity, the overall effects can offer indications as to whether differences are currently achievable in designs on the market (caused by a potential multifactorial impact). Such a study was performed by Hennig et al. (2009) who assessed radial offset from a target plate for five masked football boots and a barefoot condition. Barefoot shooting was shown to decrease accuracy compared with shod shooting by up to 20%. Additionally, the various types of football boots significantly varied in ball accuracy by up to 13%. Despite limitations in the masked boot designs, the lack of ball velocity control and shot technique used and target ecological validity, this study indicates that football boot design can be optimised for shooting accuracy.

Laces

Kuo and Shiang (2007) assessed the location of the lacing on shooting accuracy. Designs with laces located either inside or outside demonstrated to produce significantly more accurate shot compared to designs defined as 'lace on the side' and 'laces cowered'. No photo or additional design description was given. As only the lace location was mentioned and, unless specially manufactured uppers were designed for the same boot, then it is likely that different designs have been tested and that the outcome reflect the overall difference between different design due to multiple impacting factors.

Summary

Limited research has been done on the impact of football boot design on shooting accuracy. Only two studies were found on this topic. The comparison of five masked football boots has been performed showing up to 13% difference, which indicates that the design can affect shooting accuracy. The impact of lace location has also been assessed but due to lack of information on the boot designs tested then it is not currently possible to conclude on the impact of these parameters on shooting accuracy.

2.7 Touch/control boot – Description and literature review

The touch control boots have been developed to optimise a player's ball handling skills, especially focusing on dribbling and passing performance. On the market today, the touch/control boot is represented by boot designs from all three leading manufacturers (Table 2.1). The Nike Magista was launched in 2013 as a replacement to the Nike Total 90, which had appeared on the market since 2000. Touch/control boots are therefore not a new design focus style but the actual designs have changed through time. When assessing the marketing claims of performance enhancing design parameters behind touch/control boots it becomes clear that the key terms vary between designs (Table 2.1). Fit (which is mentioned for all boot design), stability and the texture of the upper are the three most used terms. Adidas focuses on mass additionally, whilst Nike and Puma focus on traction. The appearances of these designs also vary. Adidas have, for both Nemeziz and Ace, developed a laceless, thin synthetic upper, whilst Puma opted for a smooth, thin calf leather upper and Nike uses a stiffer, thicker and textured synthetic upper. All the designs do, however, share a round studded outsole design. The following section assesses the published literature on how football boot design impacts the claimed performance enhanced parameters of a touch control boot.

Literature review of the impact of football boot design on dribbling performance

Only a single study was found on how football boot design impacts any aspects of dribbling performance (Table 2.4). In the study by Sterzing et al. (2011) players completed a zig-zag dribbling drill in two football boots: Puma King and Puma V1.10. The designs were reported to vary in upper material, fit, lacing and mass. The study applied a non-validated setup and found significant differences for completion time of the drill, favouring the Puma V1.10 (Table 2.4), but no significant difference ($P = 0.13$) for total number of touches.

Table 2.4. Summary of the studies investigating boot design features on dribbling performance

Study	Boot parameter	Number of boots compared	Impact (P value)
Sterzing et al. (2011)	Boot design	2	Time: P < 0.05 Touches: P = 0.13

Literature review of the impact of football boot design on passing performance

Similarly to dribbling, only the study by Sterzing et al. (2011) was found including the assessment on how football boot design impacts any aspects of passing performance (Table 2.5). Lofted passes of stationary balls, one touch passes of rolling balls and one touch passes from aerial balls were assessed for four footwear conditions. The two boot designs mentioned above, in addition to an indoor court shoe and barefoot condition, were compared. No significant differences were obtained in radial offset from target between the four conditions (Table 2.5).

Table 2.5. Summary of the studies investigating boot design features on passing performance

Study	Boot parameter	Number of boots compared	Impact (P value)
Sterzing et al. (2011)	Boot design	4 (incl. barefoot)	Lofted pass, stationary start: P = 0.20 Flat pass, rolling start: P = 0.22 Lofted pass, areal start: P = 0.06

Summary

In summary, only a single study has assessed the impact of football boot design on both dribbling and passing performance. Determining of whether and how football boot design impacts passing and dribbling performance is therefore not possible.

2.8 Speed boot – Definition and literature review

The most frequently worn football boot on the market today is the speed boot design (Football Boots DB, 2017). The biggest player sponsorship deals for manufacturers are also seen for the leading speed boots on the market: Cristiano Ronaldo with Nike Mercurial and Lionel Messi with adidas X. The speed boot design started with the Nike Mercurial launching in 1998 focusing on both stud configuration (bladed studs) and mass (200 g) for claimed running speed enhancement. These claims are still seen today for the football boot designs available on the market (Table 2.1) with mass, fit, traction and upper friction are in focus when marketing speed boots. The different speed boot designs therefore have similarities in focus on being lightweight and therefore designed in thin synthetic upper materials but designs still vary in outsole designs through stud shape and placement. The relationship between boot mass and speed is also perceived by players. In a qualitative study of football players' perception of football boots and clothing, a connection between boot mass and player was generally shown and lightweight material of many football boots seemed to produce a positive experience (Berggren Torell, 2011). For example, one male footballer said: ‘You want a boot as light as possible. You feel a little faster and you feel it’s a little easier to run’ (Berggren Torell, 2011, p. 88). The quantification of how football boot mass impacts performance has not yet been performed. Frederick in the 1980’s demonstrated that the energy demand in running increases about 1% for every 100 g of additional mass on a foot (Frederick, 1984, 1986). Yet more recent research suggests that this is not relevant for lighter running shoes (<300 g) (Franz et al., 2012). With modern football boots weight around 200 g, then mass is unlikely to directly impact energy demands for football players. More research is, however, still needed to confirm whether mass has an impact on sprinting ability.

Two published studies applying the same test setup have assessed the impact of boot design on speed using a short slalom (agility) drill and a 6 m linear acceleration drill (Table 2.6). The drills were not validated and a pilot study performed within the relevance for this thesis (Appendix J) demonstrated poor test-retest reliability.

Table 2.6. Summary of the studies investigating boot design features on speed

Study	Boot parameter	Number of boots compared	Impact (P value)
Müller et al., (2009)	Stud length	3	Slalom: $P < 0.01$, sprint: $P < 0.01$
	Stud geometry	2	Slalom: $P < 0.05$, sprint: NS
Sterzing et al. (2009)	General boot design	2	Slalom: $P < 0.01$
	Stud (general boot design)	3	Dry: Slalom: $P < 0.01$, sprint: $P = 0.07$ Wet: Slalom: NS, sprint: NS
	Mass	2	Slalom: NS
	Heel counter stiffness	2	Slalom: NS

NS = non-significant

Overall boot design

Different designs were compared by Sterzing et al. (2009). Slalom sprints performed on artificial turf proved to be significantly faster in boots designed for artificial turf over boots designed for grass (Table 2.6).

Stud design (length, geometry and placement)

In the series of studies by Müller et al., (2009) and Sterzing et al. (2009) stud type, stud shape and stud length all showed to significantly impact the speed of players performing linear acceleration and slalom drills (Table 2.6). For stud length Müller et al., (2009) compared firm ground Nike Mercurial Vapor II (speed boots) with 100% stud length, 50% stud length and 0% stud length on an artificial LigaTurf 240 22/4 RPU brown pitch (Polytan, Burgheim/Germany). The players were significantly faster using longer studs ($p < 0.01$) compared to the trimmed stud conditions. Sterzing et al. (2009) compared four different designs with different stud types. Significantly disfavouring the boot design with soft ground studs on dry artificial surface whilst (with five subjects) no difference was seen under wet conditions. Whether stud design alone was the impacting factor when assessing different models cannot be concluded. For stud geometry Müller et al., (2009) compared two Nike Tiempo Premier boots with elliptic studs (8 front and 4 back) and bladed studs (9 front and 4 back). Significantly faster acceleration sprints were performed in the bladed boot ($p < 0.05$), whilst no difference was seen for acceleration sprints ($p = 0.89$).

Boot mass

Altering the mass by the addition of a 70 g insole had no significant effect on sprint time using the short slalom (agility) drill and 6 m linear acceleration drill (Sterzing et al., 2009). However, whether sprint ability would be impacted throughout match-play in a heavier boot due to fatigue has not yet been assessed.

Heel counter stiffness (Comfort)

By altering the stiffness of the heel counter, Sterzing et al. (2009) assessed the impact of comfort on speed. The stiffer heel counter was described as less comfortable than the softer heel counter design, although no participant data was included on perception of comfort. No significant difference was seen between high and low comfort scoring models. It was therefore concluded by the author that players can tolerate a certain level of shoe discomfort during relatively short motor performance testing situations. Whether two short sprint drills is sufficient to replicate the impact of comfort on sprint ability during a match and thereby obtain ecological validity is questionable.

Summary

Only two studies have previously assessed the impact of football boot design on running speed generation in football. However, the protocol used has within pilot research of this thesis demonstrated poor test-retest reliability. Additionally, optimal ecological validity would include the ability to generate speed throughout a 90 min match. In line with the power boot and touch/control boot reviews, more research is therefore needed to understand how football boot design impacts speed generation.

2.9 Chapter summary

The football boot has developed from self-made studded footwear to branded designs in the early 1900's to a competitive market with multiple releases of new, innovative designs annually. Today, football boots are sub-categorised by the manufacturers based on specific performance aspects. These include 'speed' generating boots for faster running, ball 'touch/control' boots enhancing passing and dribbling ability, the 'power' boots claimed to enhance ball velocity and accuracy for shooting or long passing and the classic 'heritage' boot designs. The last mentioned is not produced with a specific performance claim but are instead re-launching of older popular models. Despite the many releases and hence innovative designs linked to marketing claims of enhanced player performance, little research has been performed. No validated protocols have been applied to assess the football boot designs through human testing. The industry and research would therefore both benefit from the development of validated human test protocols. These were performed to assess objective performance as well as perception of comfort measure claims for the three performance focused boot designs: power, touch/control and speed.

Additionally, within the time constrain limitations of the research a single comparison study was performed for each of the boot designs to aim to bridge some of the gaps demonstrated between marketing claims and published literature. An assessment of the impact of upper padding was performed for both 'power' and 'touch control' boot designs. This was done as padding is a common design feature of power boots, however, the rationale behind this design strategy is not understood. For 'speed' boots a comparison of two available designs on the current market were compared to assess the overall impact of boots with multiple design variations on maintenance of speed performance and comfort during match-play. The two speed boots designs were chosen due to their previously demonstrated variations in plantar pressure (Okholm Kryger, 2014).

CHAPTER 3

Boot Performance Conceptual Framework of a Player's Demands from a Football Boot

3.1 Chapter Outline

This chapter aims to develop a boot performance conceptual framework and illustrate how the framework can help visualise a complex interaction system, such as the link between the player demands and the football boot design. Following the general introduction highlighting the relevance for structuring the relationship between the player and the football boot, the building process of the boot performance conceptual framework linking a football player's demands during match-play with the football boot (and vice versa) is described. Finally, a description of the validation method and suggestions to appropriate application methods are demonstrated.

3.2 The Relevance of a Boot Performance Conceptual Framework

As described in Chapter 2, the football boot industry is still growing and several new boot designs have been introduced into the market in recent years with claimed improvements for the player wearing them. Football boots are composed of multiple components and the different designs vary in shape, material and addition/removal of certain components. Also, football is a complex sport containing numerous demands for the boot to fulfil. It can, therefore, be challenging for the manufacturer or football boot researcher to have a clear overview of the complexity of how design parameters impact the player wearing them. Applying a boot performance conceptual framework design to link and visualise the interactions between components can, therefore, be advantageous. The framework is cross-disciplinary and manufacturers benefit from the framework to visually link desired performance enhancement to boot design and specific boot components but also how changes in design can impact boot performance. Researchers benefit from a clear visual overview to map overlooked potential factors for optimising performance, injury risk and player perception e.g. comfort.

3.3 Introduction to Rule Based Systems for Framework Development

The use of a framework serves several usages; principally to:

- Encapsulate knowledge,
- Ease the setup of experimental tests,
- Inspire/guide/ensure novel design activity,

- Ease the illustration of active and not active research areas,
- Allow to easily highlight important components to reflect on a specific player position, boot, surface, demographic design needs.

To critically verify and validate a framework, the theories of reliability, safety, and efficiency of rule based systems can be used. Rule based systems are most commonly used in computer science, especially when developing and testing artificial intelligence systems (Landauer, 1990). An example of this is the development and testing of control system for aircrafts (Ligeza, 2006). In this case, the relevance for using the methods of rule based systems to evaluate the boot performance conceptual framework is to ensure that all components in the framework are accurate, needed and to avoid unwanted and unneeded components. A traditional rule based system consists of four basic components:

(1) Rule base: The permanent data including rules and object of specific knowledge base.
(2) Inference engine or reasoned semantics: The processes linking the object in the rule base.
(3) Temporary working memory: computer storage memory.
(4) User interface: A device, which allows the outside to add input here to get output.

(Ireson-Paine, 1996)

The framework designed in this study does not contain the same level of complexity as typical rule based system design. The framework can therefore be evaluated with a full visual overview of the entire framework and therefore does not contain components (3) or (4). The following section will introduce how a rule base (1) and reasoned semantics (2) are traditionally evaluated in rule based systems.

3.4 Methods

Defining the aim

Initially, the problem to be mapped must be established. The aim should be clear and precise. If an aim is too broad then the chance of making the framework too wide and imprecise is likely. The aim for this boot performance conceptual framework was defined as follows:

'*To map the football player's match specific demands from a football boot and how these are influenced by different components and can be quantified or qualified through different research measures'.*

The choices of key components for the aim are discussed further:

"football player"	*The map could have focused on demands from others than the user alone. This could be the spectator or manufacturer etc. Yet the user was chosen since the main aim of the framework is to understand how the football boot affects the performance, comfort and injury risk of the player.*
"match specific"	*The sport specific demands were chosen to limit the content to match demands only. Additional demands have deliberately been avoided to simplify the model whilst still allowing the rule set used to be complete and consistent. These include cost, the ease of cleaning, the social standing evoked by wearing the boot - although the last mentioned is related to the aesthetics of the boot.*
"demands from a football boot"	*The demands of the football boot can be linked to its interactions during a football match. These include the connection with the user of the boot, the connection with the surface (grass or artificial turf), the ball and other players.*
"different components"	*The different components involve the design and construction of the boot. This is where the differences between boots can be seen/created to understand what produces an optimal football boot design for a certain aim. This involves the different components, the assembly of the components, the materials used and the conditioning.*
"quantified or qualified through different research measures"	*Measures can be quantified or qualified. These sections involve the measurable ways to determine the performance of the football boot.*

Rule based system process

Once the aim was established, the creation chain for a rule based system was used from the step by step guide described previously. The creation chain for a rule based system is shown in Figure 3.1. First step involves the acquirement of knowledge to generate the framework. Secondly, the framework is built. Thirdly, a verification and validation is performed. If any issues occur at this phase then a process returns to the acquirement of knowledge or building phase to correct the issue. This cyclic structure is repeated until a satisfactory verification and validation is achieved. Finally, the system is tested and, if needed, the cyclic structure of returning to a previous stage to correct any issues is performed until satisfaction is achieved.

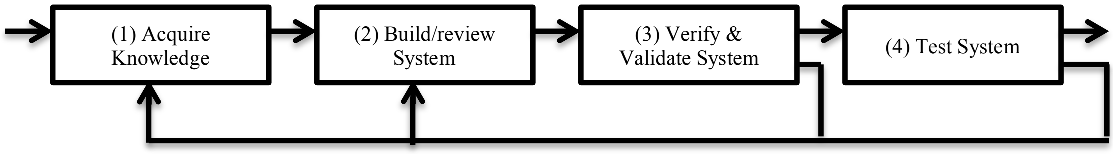


Figure 3.1. Creation chain for a rule based system.

Acquire our knowledge base

The first step in creating a system involves obtaining knowledge about the needs, the content and the rules needed in the system (Ligeza, 2006). A knowledge base was obtained through group discussions amongst academic and industrial researchers familiar with the design of studded footwear and a review of published literature and claims and focuses from manufacturer websites on studded footwear.

Building the system – (1) Defining desired levels

The second phase involves building the model. This involves the definition of the structure/style, planning the levels of information, sorting the objects into appropriate instances, and making appropriate links between objects at different levels (Ligeza, 2006). Levels should include the movements that a player performs during a football match scenario and what the player demands from the boot at each of these movements. The framework should also define how these demands can be tested and which boot components affect these demands. The framework should therefore easily allow a researcher or football boot producer to understand the desired football boot design for a certain football specific movement or vice versa, to understand which movements a certain football boot component affects (Figure 3.2). The different levels are described in the following sections.

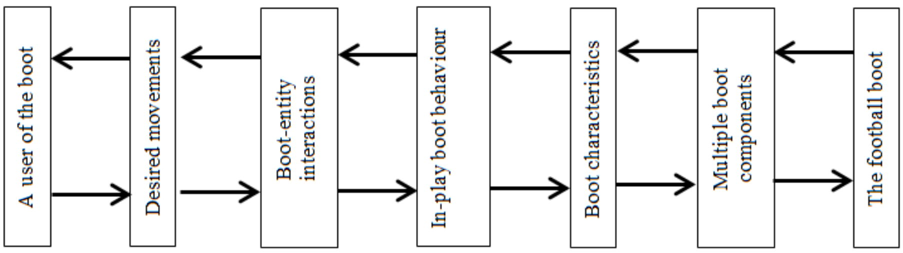


Figure 3.2. The desired levels of the boot performance conceptual framework.

Building the system – (2) Performance, injury and perception perspective

It is generally accepted that sports equipment, including footwear, should be designed with a focus on the optimal balance of performance, injury and perception (Figure 3.3). This involves trying to obtain maximal performance whilst still ensuring that the player is safe by aiming to minimise risk of injury and obtain an acceptable level player perception, e.g. comfort (Hennig, 2011). A football boot must perform in relation to the demands of the game, provide protection for the foot, and enable the foot to perform the functions demanded of it (Ismail et al., 2010). The boot performance conceptual framework is therefore built in three planes – a performance, an injury preventive, and a player perception plane.

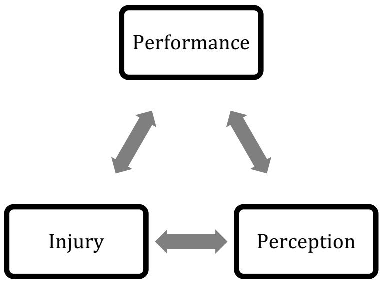


Figure 3.3. The focus areas when designing sports equipment.

Building the system – (3) A user of the boot

The user of the boot is logically, the person wearing or who is aimed to wear the football boot. This could be subcategorised into player positions, different geographic origins, genders, age groups, etc. to make the usage of the framework more case specific. This can be useful from a research perspective to analyse differences between different groupings of players or from an industrial perspective to ensure that the product is fitted to the targeted population.

Building the system – (4) Desired movements

This section contains all football specific movements performed during match-play. Key movements vary depending on their position, playing style or match scenario. It is therefore useful to first define these when aiming to understanding the boot requirements for this specific user. The football specific movements are based on the Bloomfield movement classification (Bloomfield et al., 2004). In addition to the movements described by Bloomfield et al. (2004), some additional movements were added, which were found by group discussions amongst academic and industrial researchers familiar with the design of studded footwear to be missing from the classification scheme (marked in red in Figure 3.4).

To optimise the readability, whilst still being redundant and obtaining a satisfying level of completeness then a single level was used. Yet motions in football can be subcategorised into the timed and therefore planned locomotion of the user, whilst instantaneous motion can be subcategorised into other and more unexpected movements, turns and on the ball activity (Figure 3.4). Each movement can also be described in more detail by several modifying factors (Figure 3.4). This sub-framework might be useful for users of the main framework to fully understand which movements should be the focus points in their usage of the framework.

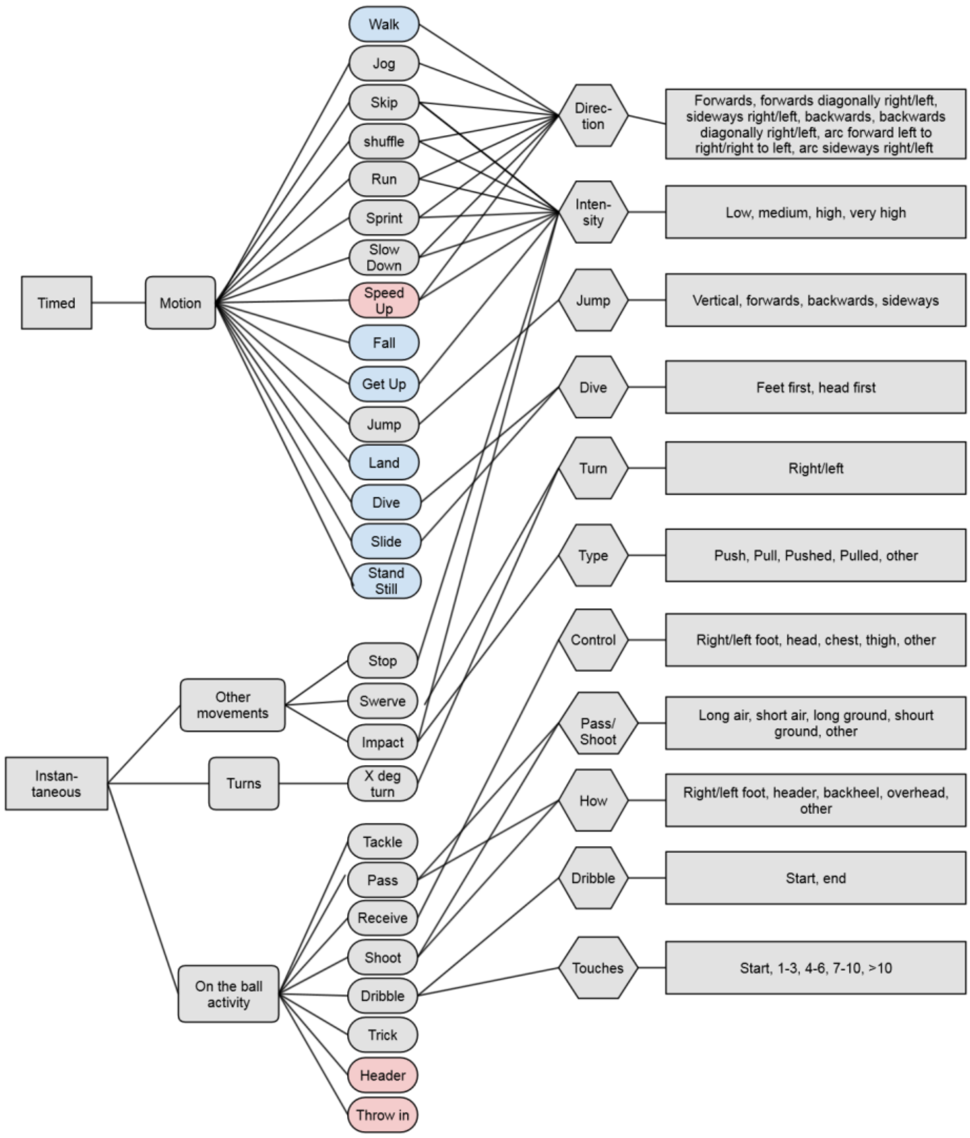


Figure 3.4. Classification of football specific movement.
Red = added football specific movements to the original classification. Blue = movements with decreased importance of football boots. (adjusted version of Bloomfield et al., 2004).

Building the system – (5) Boot-entity interactions

The boot/entity interactions level allows the user to highlight the interactions made with other objects during that specific movement. Four different interactions are possible in match-play. The player is naturally in contact with the boot at times but contact is also made with the surface, the ball and contact with other players may occur during tackles or unintended collision. A variation in surface types are used in football with a variation in mechanical properties and therefore demands from the boot will vary (Zanetti et al., 2013).

Building the system – (6) In-play boot behaviour

The in-play behaviour of the football boot when worn by the player includes measurable boot behaviour and therefore acts as the link between the boot and the player. These components include the claims used by manufacturers to define different boot designs. These measures include aspects of performance, injury risk and player perception and can both be assessed by objective measures and subjective players perception scores or interviews.

Building the system – (7) Boot characteristics

This level includes the mechanical features of a football boot which can be tested and therefore quantified. These can consequently be used to understand the property difference between differences in football boot component. From the opposite direction of the framework, the boot characteristic level can also be seen as the factors that the in-play performance is affected by.

For the usability of the framework then some instances have been split whilst others have not. This is the case for stiffness. The upper and the outer stiffness are both displayed since the two offer very different impact on the in-play performance. On the other hand, an instance such as 'mass' is not split into mass of each component, since the effect – unless extremely abnormal – does not have a large impact on the in-play performance. Once again the framework is therefore simplified to assure satisfactory completeness, whilst still allowing an acceptable level of reduction for the user-friendliness.

Building the system – (8) Multiple boot components

The football boot can vary in which components it contains but generally, the components can be divided into 3 main sections: the upper, the sole and the bonding applied (Figure 3.5). The upper involves the inner and outer panel, which also contain the linings, the brand logo and the tongue. Also laces and support component(s) are included in the upper structure. A heel counter is a normal support structure, with a varying design depending on the style. Finally, some boots contain a mid-panel with padding for support. The sole of the football boot is composed of two or three components. A Football boot always contains an insole and an outsole. The outsole is composed of the sole plate and studs. Some designs also contain a midsole, which is normally composed of a Texon board. The bonding method varies depending on the design and depending on the components bonded. These include glue, thermal bands, stitches, rivets, pins etc.

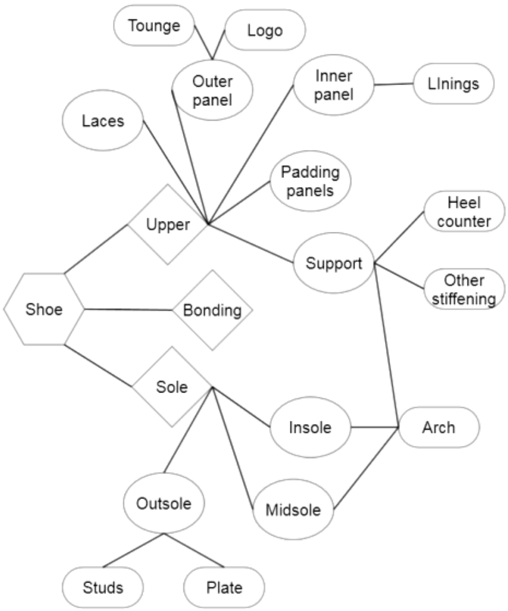


Figure 3.5. Football boot components.

Building the system – (9) The football boot

The football boot defines the final product or, if working the framework in reverse order, the design prototype, which is being tested for completeness from the framework. The football boot can be substituted by a more specific boot type. This could be a certain design or a type of football boot e.g. speed or power boot.

Building the system – (10) Levels not included in the framework

Selections have been made to create a simplified framework which gives relative completeness which fulfils the redundancy but still has an appropriate level of reduction to make it user friendly. Levels not included are listed below:

- *Impacting component:* Many measures included in the framework are relative to the parameters of another impacting component. The grip, which can both be in related to the outsole and surface interaction and the upper and ball interaction, is not only influenced by the football boot but also the condition and actual properties of the other impacting component. To keep the focus on the football boot then the properties of any other component than the boot was neglected. Yet the user should not neglect the importance of any other component and that a boot can be adjusted to different conditions (e.g. altered stud length).

- *Condition of boot:* It is generally assumed that the boot conditions are optimal when new. Yet a boot will change its parameters throughout its life cycle and more than likely decrease in performance in some of the in-play behaviours since the boot characteristics will alter.
- *Condition of player:* This can have several meanings. The condition of the player when performing the match is a strong impacting fact. The player's level, current condition, and whether the player is familiar with the football boot.

Building the system – (11) Connecting relevant objects from the different levels

The interlink between the user of the boot and the boots in the framework has been defined as follows: '*A user of the boot tries to execute desired movements which involves boot-entity interactions achieving in-play boot behaviour influenced by boot characteristics determined by multiple boot components of the football boot'* (shown in Figure 3.6 from top to bottom). Whilst the framework can also act in the reverse direction (bottom to top) interlining the boot with the user of the boot by: *'A football boot composed of multiple boot components giving certain boot characteristics affect the in-play boot behaviour at the different boot-entity interactions during the desired movement from the user of the boot'* (Figure 3.6).

These interlinks should be divided into two separate colour and line codes to distinguish between the needs and focus points of the dominant and non-dominant foot.

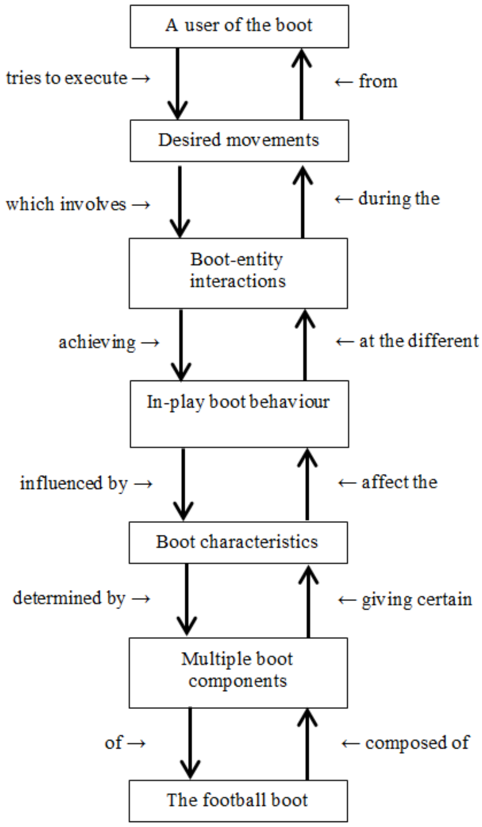


Figure 3.6. The desired levels and their two-way connections of the framework.

Based on the literature review performed (Chapter 2), it is evident that existing research on the effect of football boot design is unable to offer a broad, clear understanding of the football player's match specific demands from a football boot or how these are influenced by different components or can be quantified or qualified through different research measures. Additionally, the potential multifactorial impact of altering one or multiple boot, movements or player components is challenging to structure. Connections between levels were therefore not added in the generic version of the framework. Instead it was left open allowing users to apply the framework as a mind map, an inspiration or a control tool for the user.

Validation and verification through test of the framework

The third and fourth steps, verification and validation and testing of the system, were performed in one session using multiple case scenarios of usage completed by academic and industrial researchers familiar with the design of studded footwear.

Verification, validation and testing involve the comparison of a rule base to a specification of its desired behaviour, comparison of a rule base's specification to some external notion of correctness or propriety (Landauer, 1990). The most used method for validating and verifying rule based systems involves the detection of anomalies. Anomalies are strong indicators of errors in the system. The analysis can, as mentioned above, be performed at different levels depending on the specific system and its complexity. In this study, syntax and semantic logic were analysed, as the complexity level of this system did not require mathematical or programming analysis. The issues concerning anomalies which according to literature should be tested/evaluated can been grouped as demonstrated in Table 3.1.

Table 3.1. Anomalies occurring in rule based systems (Atzeni and Parker Jr., 1988; Landauer, 1990; Ligeza, 2006)

Completeness	- Are rules following a universal and logical applicability? - Is the content within the rule-set? - Detection of incompleteness. - Are some things not fully detailed or understood? - Identification of missing rules
Connectivity	- Addresses the inference system defined. - Involves evaluation of the used groups of rules and properties. - (hard to test as these are properties of the entire graph)
Consistency	- Addresses the logical consistency of the rules. - Looks at conflicting, ambivalent, indeterminism and ambiguous rules. - Are any rules bipolar or unclear? - (can be seen as the 'correctness' check)
Distribution	- Addresses the aesthetic criteria - Simplicity of rules, the distinctions they cause and values implied - Awkward rules can often be improved by adding several rules - Rules should be distributed evenly across variables
Order	- Priority/weighted or random?
Reduction	- Reduction/simplification of rules - Elimination of unnecessary attributes
Redundancy	- Everything must be there for a reason. - Detection of identical, subsumed, equivalent or unused variables and rules.

If any system anomalies are detected in the verification and validation phase then the developer must return to a previous phase to correct these before another verification and validation phase can be attempted.

The illustration type to distinguish different features of the system modelled was also done at this stage turning characteristics of the features into rules (Landauer, 1990).

It should be noted that the level of completeness of rule base should only be sufficient as it is impossible to fully cover every detail. Therefore, simplicity and efficiency in some reasonable incompletely defined sense are key elements for a good functioning rule base (Landauer, 1990; Ligeza, 2006).

How to navigate the boot performance conceptual framework

The final boot performance conceptual framework is shown in Figure 3.7. The user can choose to read the framework from left to right or vice versa. By working left to right the user can identify key desired movements performed by the player to assess and work their way in the right direction to understand which boot properties that may impact the performance, injury or comfort during this/these desired movements. The user can by working right to left visualise how a specific boot component may impact specific movement of the player.

As mentioned previously, the map is not designed with links between components in the different sections due to little knowledge being currently available about these connections and to allow the user the freedom to assess novel thoughts and ideas.

3.5 Chapter Summary

The boot performance conceptual framework presented in this chapter aims to link the demands of the football player with the football boot design. It is evident that the link is multifactorial due to both the multiple tasks and movements of a football player as well as the multiple boot components and hence design possibilities. It is evident from the review of literature performed in Chapter 2 and the boot performance conceptual framework that little knowledge exists on how to optimise boot performance.

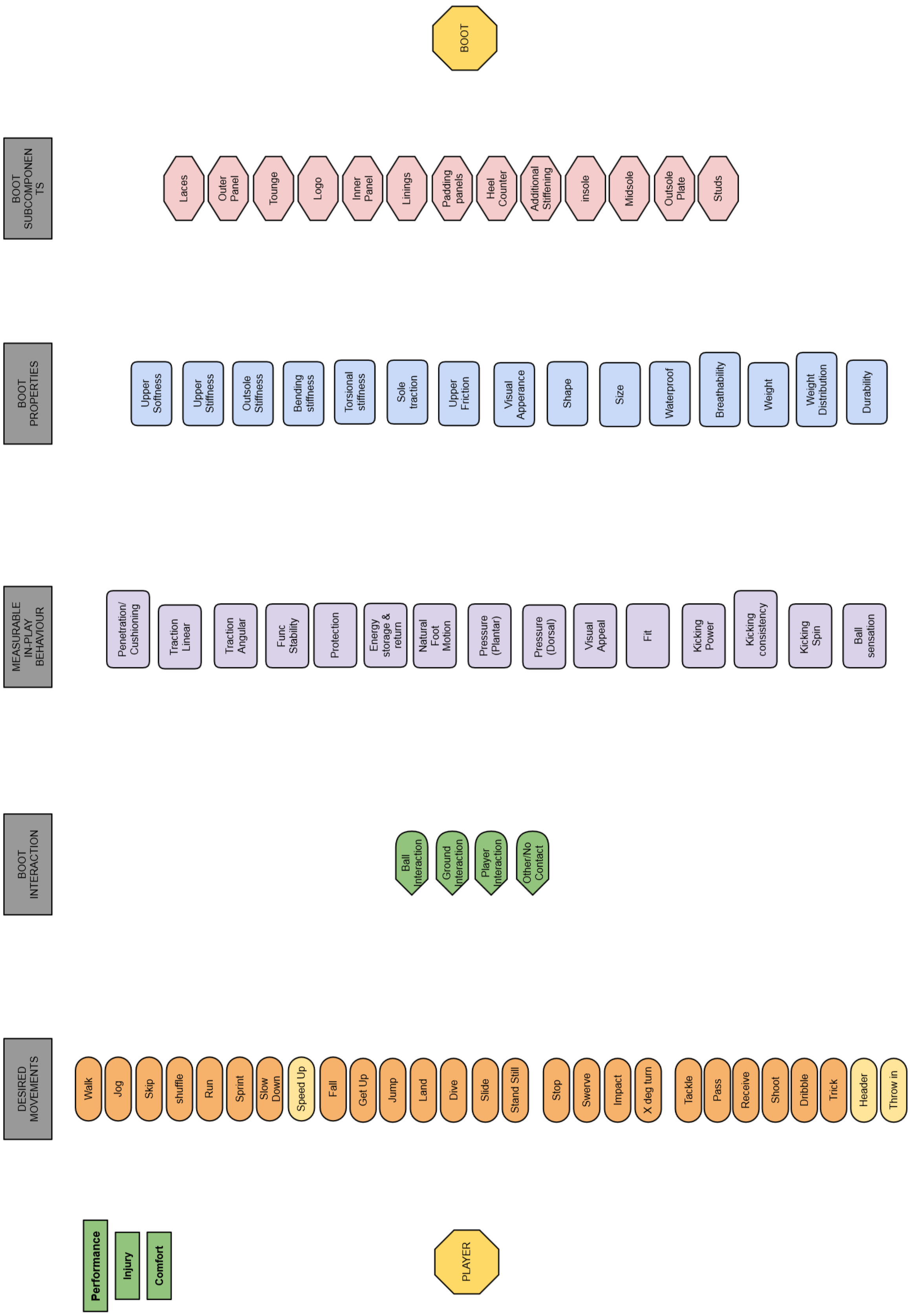


Figure 3.7. Final version of the boot performance conceptual framework

THE POWER BOOT

Introduction to Section

This section focuses on power football boots. These are, as described in Section 5 of Chapter 2, designed to optimise shooting performance. A critical review of the past literature has been conducted to evaluate how shooting performance has previously been assessed with regards to actual measures defining performance, as well as setup and measuring tools. Based on the knowledge gained in the literature review, validation study was developed to assess the test-retest reliability of a new, improved protocol specifically designed to assess the impact of football boot design on shooting performance. The validated protocol was then applied to compare football boot designs by assessing the impact of upper padding thickness on shooting performance. An outline of this power boot section is demonstrated in Figure I.

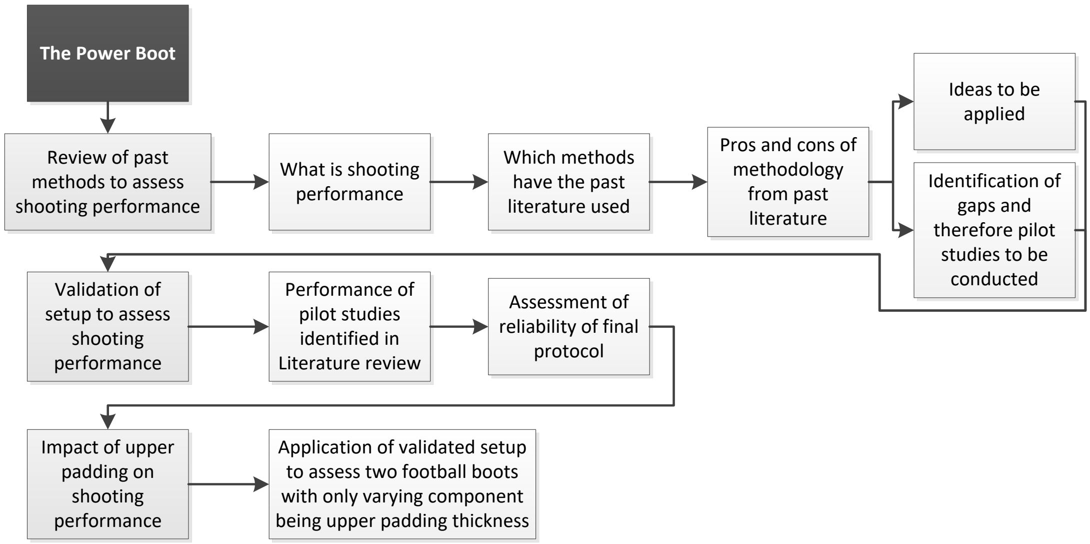


Figure I. Section outline

CHAPTER 4

Review of Assessment Methods for Shooting Performance

4.1 Chapter Outline

This chapter first aims to define shooting and shooting performance in football. Once established, a review of past literature assessing shooting performance in football is performed. The review focuses on test setups applied and measuring tools for the different performance aspects of shooting in football.

4.2 Understanding Shooting in Football

What is shooting in football

Shooting in football is when a player, with their foot, strikes the ball aiming for goal. To do so, different shooting techniques have been developed where players strikes the ball with specific parts of the foot on specific parts of the ball to alter predictability for the keeper, the swerve and the ball velocity (Lees et al., 2010).

Importance of shooting in football

The obvious aim of a football match is to score more goals than the opposing team. Consequently, one of the most valued and important player skills within the game is the ability to score goals. The vast majority of goals scored in football are the result of a shot on goal (Michailidis et al., 2013), making good shooting ability a desired aspect for football players. Skilful shooting is also important for the many dead ball situations in football (free-kicks and penalties). To put this into perspective, teams in the FA Premier League scored 31.2 ± 11.8 goals from open play, 10.9 ± 4.4 goals from set pieces, 3.2 ± 1.6 goals from penalties (84% success rate) per team (WhoScored, 2015), whilst a total of only 28-32 goals per season were scored directly from free kicks in the English Premier League over the seasons 2009/10 to 2013/14 (Coverdale, 2014).

What is shooting performance composed of

Ball velocity is a key performance component of shooting. A goalkeeper or defender will have to react quicker and move faster to block the ball, if the ball moves at a higher velocity. A powerful shot is, however, not always the optimal shot. It can be argued that a high velocity shot is not necessarily a successful one (Kellis and Katis, 2007; Lees and Nolan, 2002). Accuracy of the shot may be even more important than high velocity for scoring goals in football. Accuracy refers to the ability to vary precisely the parameters of movement production as measured by the absolute position

(Newell, 1985). Finnoff et al. (2002) argued that shooting accuracy is an important component of football performance and can be measured discretely, making it a good topic for performance research.

It is, however, important to assess the two performance aspects in relation to each other. Fitts (1954) was the first to suggest that both the speed and accuracy of motor skills can influence the overall quality of performance. Meaning, if a player focuses too much on generating high ball velocity then they will have to compensate by loss of accuracy and vice versa. Previous research has shown that when players are instructed to perform an accurate shot, then the speed-accuracy trade-off causes a reduction in ball velocity as well as in linear and angular joint velocities compared with a purely powerful shot (Kellis and Katis, 2007; Lees and Nolan, 1998; Teixeira, 1999).

Additionally, the player's decision making and technique are critical performance components in a match play scenario (Ali, 2011; McMorris et al., 1994). These, however, are influenced by the player and not the equipment, e.g. footwear, used. Assessing how football boot design impacts performance therefore should, therefore, focus on ball accuracy control and speed aspects.

4.3 Past Literature Assessing Shooting Performance

Fifty-two studies were collected with a focus on the factors influencing the ball velocity in football shots (Table 4.1) and twenty-three studies on how impacting factors affect shooting accuracy (Table 4.2) up until March 2018 from Google Scholar, MEDLINE, SPORTDiscuss and PubMed. Publication alerts were set up post literature search to minimise risk of missing papers published after the main search occurred. So, despite both shooting velocity and shooting accuracy both being important performance measures for shooting less than half as many studies focus on the accuracy aspect compared to velocity. Additionally, only four studies assess both ball velocity and ball accuracy, meaning that a holistic understanding of shooting performance has not been obtained in most studies.

Table 4.1. Literature assessing shooting ball velocity.

Research Study	N	Level	Sex	Based On	Validation
Ali et al., (2007b)	16	Semi-pro + University	Male	-	ICC: 0.33, SEM: ±5.1 $km.h^{-1}$, CV: 9.5%
Amos and Morag (2002)	14	Skilled	Male	-	-
Andersen et al. (2012)	50	2nd best league	Female	-	-
Apriantono et al. (2006)	7	Amateurs	Male	-	-
Asai et al. (2002)	6	University	N/A	-	-
Asami and Nolte (1983)	4	Professional	N/A	-	-
Barfield (1995)	18	Amateurs	Male	-	-
Barfield et al. (2002)	6	Elite	Female	-	-
	2	Elite	Male		
Chew-Bullock et al. (2012)	38	University	Male	-	-
Cometti et al. (2001)	63	Professional division 1	Male	-	-
	32	Amateurs	Male		
Dörge et al. (2002)	30	Skilled	N/A	-	-
Grgantov et al. (2013)	48	Youth	N/A	-	ICC = 0.59-0.83[#]
	24	N/A	N/A		
	18	N/A	N/A		
Hennig and Zulbeck (1999)	20	Experienced	Male	-	-
Hong et al. (2011)	5	University	Male	-	-
Hong et al. (2012)	5	University	Male	-	-
Hong et al. (2013)	5	University	Male	-	-
Ismail et al. (2010)	6	Amateurs	N/A	-	-
Isokawa and Lees (1988)	6	Trained	Male	-	-
Kellis et al. (2004)	10	Trained	Male	-	-
Kellis et al. (2006)	10	Amateurs	Male	-	-
Lees & Davies (1988)	5	Skilled	Male	-	-
Levanon and Dapena (1998)	6	Experienced	Male	-	-
Luthanen (1988)	29	Skilled	N/A	-	-
Majelan et al. (2011)	10	Skilled	N/A	-	-
Manolopoulos et al. (2006)	10	Amateurs	N/A	-	-
Markovic et al. (2006)	77	Students	Male	-	Standing kick: ICC: 0.95, CV = 3.3% Instep kick: ICC: 0.95, CV = 2.8% Drop kick: ICC: 0.95, CV = 2.6%
Moschini and Smith (2012)	10	Semi-professional	Male	-	-
Narici et al. (1988)	11	Amateurs	Male	-	-
Nunome et al. (2002)	5	Experienced	Male	-	-
Nunome et al. (2006a)	5	Skilled	N/A	-	-
Nunome et al. (2006b)	9	Experienced	Male	-	-
Opavsky (1988)	6	N/A	N/A	-	-
Poulmedis et al. (1988)	11	National	N/A	-	-
Roberts et al. (1974)	1	Experienced	Male	-	-
Rodano and Tavana (1993)	10	Professional	N/A	-	-
Russell et al. (2010)	15	English Championship	Male	-	ICC: 0.32, SEM: ±1.5 $m.s^{-1}$, SRD: 4.3%
Sakamoto et al. (2010)	17	University	Male	-	-
	17	University	Female		
Sakamoto et al. (2011)	17	University	Male	-	-
	17	University	Female		
Sakamoto et al. (2013)	13	University	Male	-	-
	13	University	Female		
Sakamoto et al. (2014)	13	University	Male	-	-
	13	University	Female		
Scurr and Hall (2009)	7	Amateurs	Male	-	-
Shan and Westerhoff (2005)	8	Novice	Male	-	-
	7	Skilled	Male		
Shinkai et al. (2007)	11	Skilled	Male	-	-
Sterzing et al. (2006)	19	N/A	N/A	-	-
Sterzing and Hennig (2007a)	18	Experienced	N/A	-	-
Sterzing and Hennig (2007b)	23	Experienced	N/A	-	-
Sterzing and Hennig (2008)	~20	N/A	N/A	-	-
Taha et al. (2013)	1	University	Male	-	-
Taïana et al. (1993)	15	4th division	N/A	-	-
Tol et al. (2002)	15	Amateurs	Male	-	-
Trolle et al. (1993)	24	Elite	Male	-	-
Tsaousidis and Zatsiorsky (1996)	2	Amateurs	Male	-	-

N = number of participants; Level = playing level as described by authors in publication; N/A = no information available; [#] = results range for different shooting techniques.

Table 4.2. Literature assessing shooting ball accuracy.

Research Study	N	Level	Sex	Based on	Validation
Abt et al. (1998)	6	Recreational	Male	Mod. Zelenka et al. (1967)	-
Ali et al., (2007b)	16	Semi-pro + University	Male	-	Points: ICC: 0.26, SEM: ±0.54, CV: 57.8%
Cox et al. (2002)	14	Elite	Female	-	-
Currell et al. (2009)	11	Recreational	Male	-	-
Figueiredo et al. (2011)	143	Players	Male	-	CoR: 0.71
Finnoff et al. (2002)	N/A	N/A	N/A	-	Radial offset: ICC: 0.99
Haaland and Hoff (2003)	47	Players	Male	-	Points: CV: 11.5%
Hennig et al. (2009)	20	N/A	Male	-	-
Katis et al. (2013)	21	Amateur	Male	-	-
Kuo and Shiang (2007)	3	University	Male	Finnoff et al. (2002)	
Majelan et al. (2011)	10	Skilled	N/A	-	-
Northcott et al. (1999)	10	Collegiate	Male	-	-
Reilly and Holmes (1983)	40	Players	Mare	-	-
Russell et al. (2010)	15	English Championship	Male	-	Radial offset: ICC: 0.38, SEM: ±39 cm, SRD: ±107 cm
Rösch et al. (2000)	588	High & low	N/A	-	-
Scurr and Hall (2009)	7	Amateur	Male	Finnoff et al. (2002)	-
Stone and Oliver (2009)	9	Semi-professional	Male	Ali et al., (2007b)	-
Vanderford et al. (2004)	59	U14-U16	Male	Mod. Zelenka et al. (1967)	-
Williams et al. (2010)	15	Amateur	Male	-	-

Note: Studies highlighted in ***bold/italic*** asses both ball velocity and accuracy; CoR = Coefficient of reliability; CV = coefficient of variance (%); ICC = intra-class correlation coefficients; Level = playing level as described by authors in publication; Mod. = modified; N = number of participants; N/A = no information available; SEM = standard error of measurement.

A large variation of participants has been researched, however, the vast majority have included only male players (Table 4.1 and Table 4.2). The large quantity and variety in the literature should therefore provide a broad understanding of external impacting factors of ball accuracy and velocity and quality of test methodologies to assess shooting in football. However, only four of the velocity assessment methods and six of the accuracy methods used have been reliability assessed which may decrease the reader's confidence in setup and assessment methods quality.

External factors, such as sex, player level or weather conditions, can impact results and should therefore be identified and controlled. These are described further in Appendix A.

Shot type

As mentioned previously, a shot can be subcategorised into different technique styles. These vary in player kinematics, angle and point of ball contact and the swing vector (direction of the swing) (Hong et al., 2013b). For example, in straight instep kicking the ankle joint displays a comparatively plantarflexion movement, whereas in a curve shot, the impact occurs with the ankle joint making an L-shaped dorsiflexion movement (Asai et al., 2002; Hong et al., 2013b). Differences in ball velocity and shooting kinematics when changing shot type has previously been studied in the literature (Asai et al., 2002; Hong et al., 2012, 2013b; Levanon and Dapena, 1998; Nunome et al., 2002; Sakamoto et al., 2010, 2011). Significant differences in ball velocity for different shot types have also been demonstrated (Sakamoto et al., 2011). Most studies have included information on shot technique used (Table 4.3). The most common shot technique applied is the instep kick. When other techniques have been used, then these have most commonly been used to compare technique on performance. Very few of these studies describe any control measures of technique. Changing shot type throughout testing could therefore impact results and should be controlled.

Table 4.3. Shot technique given to players as instruction and count of shots assessed.

Research Study	Shot	Count	Research Study	Shot	Count
Abt et al. (1998)	N/A	N/A	Manolopoulos et al. (2006)	Instep	N/A
Ali et al. (2007b)	N/A	10(6)	Markovic et al. (2006)	Standing kick	3
Amos et al. (2002)	N/A	3		Instep	3
Andersen et al. (2012)	Instep	5		Drop kick	3
Anderson et al. (1994)	Instep	15-20	Moschini et al. (2012)	Free	3
Apriantono et al. (2006)	Instep	5	Narici et al. (1988)	Powerful	N/A
Asai et al. (2002)	Instep	N/A	Northcott et al. (1999)	N/A	1
Asami et al. (1983)	Instep	4	Nunome et al. (2002)	Instep	>3
Barfield (1995)	Instep	10		Side-foot	>3
Barfield et al. (2002)	Instep	5	Nunome et al. (2006a)	Instep	2
Chew-Bullock et al. (2012)	Powerful	3	Nunome et al. (2006b)	Instep	9
Cometti et al. (2001)	Instep	5	Opavsky (1988)	Instep	N/A
Cox et al. (2002)	N/A	8	Poulmedis et al. (1988)	Instep	N/A
Currell et al. (2009)	N/A	10	Reilly et al. (1983)	Free	9
Dörge et al. (2002)	Instep	8	Roberts et al. (1974)	Toe	1
Figueiredo et al. (2011)	N/A	N/A	Rodano et al. (1993)	Instep	5
Finnoff et al. (2002)	N/A	10	Russell et al. (2010)	N/A	8
Grgantov et al. (2013)	Instep kick	3	Rösch et al. (2000)	N/A	N/A
	Side-foot kick				
	Instep kick				
Haaland et al. (2003)	N/A	15	Sakamoto et al. (2010)	Instep	N/A
Hennig et al. (1999)	N/A	5		In-front	N/A
Hennig et al. (2009)	N/A	5		Inside	N/A
Hong et al. (2011)	Knuckling	10	Sakamoto et al. (2011)	Instep	10
	Straight instep	10		Inside	10
	Curved instep	10	Sakamoto et al. (2013)	Instep	N/A
Hong et al. (2012)	Knuckling	10	Sakamoto et al. (2014)	Instep	N/A
	Straight instep	10	Scurr et al. (2009)	Instep	6
	Curved instep	10	Shan et al. (2005)	Instep	3
Hong et al. (2013)	Topspin drive shot	1	Shinkai et al. (2007)	Instep	2
	Straight instep	1	Sterzing et al. (2006)	Instep	6
	In-front curve kick	1	Sterzing et al. (2007a)	Instep	6
Ismail et al. (2010)	Instep	3	Sterzing et al. (2007b)	Instep	6
Isokawa et al. (1988)	Instep	1	Stone et al. (2009)	N/A	N/A
Katis et al. (2013)	Free	20	Taha et al. (2013)	Toe kick	3
Kellis et al. (2004)	Instep	5	Taïana et al. (1993)	Instep	5
Kellis et al. (2006)	Instep	3	Tol et al. (2002)	Free	10
Kuo et al. (2007)	N/A	10	Trolle et al. (1993)	Instep	≥20
Lees & Davies (1988)	Free	3	Tsaousidis et al. (1996)	Toe	N/A
Levanon et al. (1998)	Instep	N/A	Vanderford et al. (2004)	N/A	N/A
Luthanen (1988)	Instep	1	Williams et al. (2010)	N/A	6
Majelan et al. (2011)	Instep	24			

N/A = no information available; x(y) = where x is number of shots assessed and y is number of shots assessed

Number of shots

There has been a wide range in the number of shots used in data collection varying from 1 to 20 shots, whilst some studies omit this information (Table 4.3). It has previously been suggested that five consecutive shots are adequate to obtain consistency in the shot biomechanics (Amiri-Khorasani et al., 2010). The application of familiarisation shots was, however, not included or mentioned in most of the past literature. It can therefore be speculated that consistency of the first shots in studies not including familiarisation is lower. Additionally, the total number of shots performed must be restricted to minimise fatigue effects. No study has discussed the gradual increase in fatigue from continuous shooting repetition. Further research should therefore be done to gain understanding of this.

Target (type and distance)

A target is evidently needed if measuring accuracy of shooting performance. All studies assessing shooting accuracy included a target, however, the type, size and location in space and distance of the target varies between studies (Table 4.4). Studies solely assessing ball velocity of shots have, however, not always used a target (Table 4.4). Larger inconsistencies in player biomechanics, contact points between foot and ball and thereby also greater variation in shooting velocities obtained have been shown when no target is used (Lees and Nolan, 2002). Application of a target therefore improves reliability of ball velocity as well as ecological validity due to the nature of shots in football being aiming towards a goal (i.e. a target). A note should be added on the finding that research has shown that adding focus on accuracy to a shooting drill decreases the ball velocity (Lees and Nolan, 2002). However, due to the nature of the game and the importance of multifactorial performance of shooting, then it is believed that a target is beneficial.

The most common **type** of target being used in the literature is a standard 11-a-side goal (2.44 x 7.32 m; Table 4.4). Other targets, e.g. other goal sizes, a mat hanging on a wall or a large carbon coated plywood plate, have also been used. Although no research has assessed the impact of target type on performance, for ecological validity the use of a standard goal is favourable.

The **size** of the target has also varied in the literature. While some studies aim to place the ball inside a goal, others chose to divide the goal into point zones (Table 4.4). However, to allow quantification of accuracy as actual offset from target then a point in space must be chosen.

The **position** of the chosen target also varies widely in the literature (Table 4.4). Whether the target point is located in the air or closer to the ground has been shown to alter the shooting kinematics (Katis et al., 2013). It has been shown that players lean the body away from the ball (backward body lean) and use a lower contact point on the ball when a player shoots the ball to the top of the goal to enable the ball to follow a higher trajectory after release (Prassas et al., 1990). Muscle activation has also been shown to differ depending on the target position (Katis et al., 2013; Majelan et al., 2011). For example, successful ground target shots showed a significantly lower rectus femoris and tibialis anterior activation in comparison to successful shots targeting a 0.5 x 0.5 m area under the goal bar on a traditional 11-a-side goal (2.44 x 7.23 m) (Katis et al., 2013). It is therefore important that the target position is taken into consideration. Many researchers have chosen to position the target in the top corners as these are often seen as the most desired area to place the ball to avoid the goalkeeper from saving the ball, which has also been identified by researchers as an optimal ball placement location to beat the goalkeeper (Ali et al., 2007a; Table 4.4). Contrary, studies have also applied the centre of the goal as target, which is an area of goal easily covered by the goalkeeper and therefore rarely the targeted area for shots in football. To sum up, a point in space is needed as the target point for researchers to quantify accuracy by offset from target. In terms of target position, the extreme locations, i.e. top or bottom corners of the goal are generally optimal in football as these are the locations most difficult for the goalkeeper to protect.

The question of an appropriate **distance** also needs to be discussed. No study was found assessing the importance of the distance to the target. A single study (Zebas and Nelson, 1990) on American football analysed the consistency of kinematic variables from a highly skilled player when shooting an American football from different distances to goal. The player shot an American football from 20, 30 and 50 yards while being filmed in the sagittal plane. Ball velocity was reported showing that distance restriction had little effect on mean ball speed, which was found to be 33.9, 36.8 and 35.6 $m.s^{-1}$ from the three distances respectively. If transferrable, this result may indicate that shooting velocity, when advised to shoot with maximum effort, will be less affected by the target distance however this is yet to be confirmed in football.

In the literature, the approximate mean distance applied is 12 m from target, however, the range of distances has been large, ranging from 2 to 25 m. No study has argued for their distance chosen. Additionally, no data on common shooting distances in match-play was found. It is therefore difficult to argue for an optimal distance.

Initial ball motion
All studies on maximum ball velocity, apart from Tol et al. (2002), were performed, or assumed performed due to the lack of information, from a static 'dead ball' position, where the ball laid stationary on the ground at ball-boot contact (Table 4.5). Accuracy focused shots have, on the contrary, more cases of shots assessed with an initially moving ball, typically either rolling or bounding towards the player prior to ball-boot contact. One single study has looked at the difference between ball velocities when shooting a static ball and shots performed against a ball rolling at 2.2 $m.s^{-1}$ (Tol et al., 2002).The study did not identify any significant differences and authors did not include the standard deviation measures as it could be suspected that larger variations in shooting velocity would be seen when shooting the non-static ball due to larger variations in foot impact point on the ball.

Previous studies have argued that ecological validity of setup assessing shooting from a static ball start might be limiting and may examine the execution of 'technique' rather than 'skill' (Russell and Kingsley, 2011). However, the added ball controlling element created when the assessed player receives the ball in motion increases the impact of the player's technique on the shooting performance outcome scores. When assessing an external factor, e.g. football boot design, then the impact of a player's skill level should be minimised.

Run up approach
When assessing shooting, the run up approach also needs to be discussed. Opavsky (1988) showed that having a run up increases the ball velocity in comparison to shooting with no run up. This leads to the question of what an optimal run up is. The main run up components affecting the success of a football shot have been shown to be the distance, speed, and angle of the run up (Kellis et al., 2004; Kellis and Katis, 2007).

Table 4.4. Targets and shooting distances applied in previous research.

Research Study	Target	Distance (m)	Target position
Abt et al. (1998)	Goal	~15.6	Entire target
Ali et al. (2007b)	Goal	16.5-25	All 4 corners
Amos et al. (2002)	Forward direction	N/A	N/A
Andersen et al. (2012)	Net	4	N/A
Anderson et al. (1994)	$2m^2$ area	5	Entire target
Apriantono et al. (2006)	Middle of goal	11	Centre
Asai et al. (2002)	Mini goal	4	Entire target
Asami et al. (1983)	Handball goal	10	Centre
Barfield (1995)	Net	N/A	N/A
Barfield et al. (2002)	Net	N/A	N/A
Chew-Bullock et al. (2012)	Goal	6	0.3 m^2 centre
Cometti et al. (2001)	Goal	5.5	N/A
Cox et al. (2002)	Goal	7	Centre
Currell et al. (2009)	Goal	16.46	Centre
Dörge et al. (2002)	1m2 target	4	N/A
Figueiredo et al. (2011)	2x3 m goal	9	Top corners
Finnoff et al. (2002)	1.22x24.3 m carbon coated board	6.1	Centre
Grgantov et al. (2013)	Goal	16	N/A
Haaland et al. (2003)	Goal	10	Top corners
Hennig et al. (1999)	N/A	N/A	N/A
Hennig et al. (2009)	Circular electronic target	10	Centre
Hong et al. (2011)	Goal post	25	Entire target
Hong et al. (2012)	Goal post	25	Entire target
Hong et al. (2013)	Goal	25	Centre
Ismail et al. (2010)	N/A	N/A	N/A
Isokawa et al. (1988)	N/A	N/A	N/A
Katis et al. (2013)	2.44 x 7.23 m goal	11	Centre top & bottom 0.5 m2
Kellis et al. (2004)	Goal	11	N/A
Kellis et al. (2006)	Goal	11	N/A
Kuo et al. (2007)	1.22x24.3 m carbon coated board	6.1	N/A
Lees et al. (1988)	N/A	N/A	N/A
Levanon et al. (1998)	Goal	11	N/A
Luthanen (1988)	N/A	N/A	N/A
Majelan et al. (2011)	6x2 m Mat	7	0.6 m^2 corners
Manolopoulos et al. (2006)	Goal post	N/A	Entire target
Markovic et al. (2006)	Net	N/A	N/A
Moschini et al. (2012)	N/A	N/A	N/A
Narici et al. (1988)	$1.5m^2$ target	10	Entire target
Northcott et al. (1999)	Goal	15	Centre
Nunome et al. (2002)	Goal	11	Centre
Nunome et al. (2006a)	Goal	11	1 m^2 centre
Nunome et al. (2006b)	Goal	9	1 m^2 centre
Opavsky (1988)	N/A	N/A	N/A
Poulmedis et al. (1988)	N/A	N/A	N/A
Reilly et al. (1983)	Goal drawn on wall	8.23	Sides
Roberts et al. (1974)	N/A	N/A	N/A
Rodano et al. (1993)	N/A	N/A	N/A
Russell et al. (2010)	2.44x7.23 m goal	15	Corners
Rösch et al. (2000)	Goal	16	Corners
Sakamoto et al. (2010)	Goal	N/A	N/A
Sakamoto et al. (2011)	Goal	N/A	N/A
Sakamoto et al. (2013)	Goal	10	N/A
Sakamoto et al. (2014)	Goal	10	N/A
Scurr et al. (2009)	Goal	11	Lower right corner $0.6m^2$
Shan et al. (2005)	5x2m mat	N/A	N/A
Shinkai et al. (2007)	N/A	N/A	N/A
Sterzing et al. (2006)	N/A	N/A	N/A
Sterzing et al. (2007a)	N/A	N/A	N/A
Sterzing et al. (2007b)	No	N/A	N/A
Stone et al. (2009)	2.44x7.23 m goal	16.5-25	All 4 corners
Taha et al. (2013)	Net	2	Entire target
Taïana et al. (1993)	$1m^2$ target	10	Entire target
Tol et al. (2002)	Goal	11	Entire target
Trolle et al. (1993)	Goal	11.3	N/A
Tsaousidis et al. (1996)	N/A	N/A	N/A
Vanderford et al. (2004)	N/A	25	Entire target
Williams et al. (2010)	Goal	10	Either side

N/A = information not available

Table 4.5. The starting motion of the ball and run up approaches applied in past literature.

Research Study	Start	Step	Angle (°)	Research Study	Start	Step	Angle (°)
Abt et al. (1998)	Dynamic	Free	Free R_N	Manolopoulos et al. (2006)	Static	2	N/A
Ali et al. (2007b)	Dynamic	Free	Free R_N	Markovic et al. (2006)	Static	mixed	N/A
Amos et al. (2002)	Static	2	N/A	Moschini et al. (2012)	N/A	2-3	Free R_N
Andersen et al. (2012)	Static	3	22.5-45.0	Narici et al. (1988)	Static	N/A	N/A
Anderson et al. (1994)	Static	2	Behind	Northcott et al. (1999)	N/A	N/A	N/A
Apriantono et al. (2006)	Static	N/A	N/A	Nunome et al. (2002)	Static	N/A	N/A
Asai et al. (2002)	Static	N/A	N/A	Nunome et al. (2006a)	Static	N/A	N/A
Asami et al. (1983)	Static	N/A	N/A	Nunome et al. (2006b)	Static	N/A	N/A
Barfield (1995)	Static	2	45-60	Opavsky (1988)	Static	6-8	N/A
Barfield et al. (2002)	Static	2	45-60	Poulmedis et al. (1988)	Static	N/A	N/A
Chew-Bullock et al. (2012)	Static	N/A	N/A	Reilly and Holmes (1983)	Static	Free	Free R_N
Cometti et al. (2001)	N/A	Free	Free NC	Roberts et al. (1974)	N/A	2	N/A
Cox et al. (2002)	Dynamic	Free	N/A	Rodano et al. (1993)	N/A	2	N/A
Currell et al. (2009)	Static	N/A	N/A	Russell et al. (2010)	Dynamic	N/A	N/A
Dörge et al. (2002)	Static	3 m	30-45	Rösch et al. (2000)	Static	N/A	N/A
Figueiredo et al. (2011)	Static	N/A	N/A		Dynamic	N/A	N/A
Finnoff et al. (2002)	Static	N/A	6.1	Sakamoto et al. (2010)	Static	Free	Free R_N
Grgantov et al. (2013)	Static	N/A	Arbitary	Sakamoto et al. (2011)	Static	N/A	N/A
Haaland and Hoff (2003)	Dynamic	N/A	N/A	Sakamoto et al. (2013)	Static	N/A	N/A
Hennig et al. (1999)	N/A	N/A	N/A	Sakamoto et al. (2014)	Static	N/A	N/A
Hennig et al. (2009)	N/A	N/A	N/A	Scurr and Hall (2009)	Static	3-5	30, 45, 60
Hong et al. (2011)	Static	N/A	N/A	Shan et al. (2005)	Static	~3	0-30
Hong et al. (2012)	Static	N/A	N/A	Shinkai et al. (2007)	N/A	N/A	N/A
Hong et al. (2013)	Static	N/A	N/A	Sterzing et al. (2006)	N/A	N/A	N/A
Ismail et al. (2010)	Static	1-3	N/A	Sterzing et al. (2007a)	N/A	3	N/A
Isokawa et al. (1988)	Static	1	0, 15, 30, 45, 60, 90	Sterzing et al. (2007b)	N/A	3	N/A
Katis et al. (2013)	N/A	2	Free R_N	Stone and Oliver (2009)	Dynamic	Free	Free
Kellis et al. (2004)	Static	1.5 m	0, 45, 90	Taha et al. (2013)	N/A	3	N/A
Kellis et al. (2006)	Static	2	N/A	Taïana et al. (1993)	N/A	N/A	N/A
Kuo and Shiang (2007)	N/A	N/A	N/A	Tol et al. (2002)	Dynamic	N/A	N/A
Lees & Davies (1988)	Static	N/A	N/A	Trolle et al. (1993)	N/A	N/A	N/A
Levanon et al. (1998)	Static	N/A	N/A	Tsaousidis et al. (1996)	N/A	N/A	N/A
Luthanen (1988)	Static	2	N/A	Vanderford et al. (2004)	Dynamic	Free	Free R_N
Majelan et al. (2011)	Static	Free	0, 30, 45	Williams et al. (2010)	Dynamic	N/A	N/A

N/A = information not available; R_N = not repeated same self-selected run up; R_Y = repeated same self-selected run up; ~ = approximately.

The **distance** affects the number of steps taken and the step length in the run up. The exact difference of a one-step or multi-step run up on ball velocity does not appear to have been researched in the literature. Yet, reflection on real match scenarios, players seem to prefer a multi-step approach (Kellis and Katis, 2007; Lees et al., 2009, 2010; Majelan et al., 2011; Marqués-Bruna et al., 2007). It can also be speculated that players through training and match-play have obtained a personal preference, which is likely to vary between players. What is known is that the length of the last stride or step is important in maximal shooting (Lees and Nolan, 2002; Stoner and Ben-Sira, 1981). It was reported that professional players showed a longer stride length when performing a long-range shot compared with a medium-range shot. This may well be related to the speed of the run up performed, although not having been measured directly.

The run-up **speed** typically used by male players has been shown to be around 3-4 $m.s^{-1}$ (Kellis and Katis, 2007; Lees et al., 2005). Allowing players to use a self-selected run-up speed is favourable to optimise ecological validity.

The run up is normally performed from an **angle** as demonstrated in Figure 4.1 with a curved run up approach (Marqués-Bruna et al., 2007). A curved approach allows the player's body to incline towards the centre of rotation (Lees et al., 2010). Several explanatory factors exist as to why inclining body towards the centre of rotation is beneficial for the player. One purpose is that it is easier to get the foot of the inclined shooting leg under the ball to make better contact with it in these circumstances (Lees et al., 2010). A second purpose is that a more inclined lower body allows more knee extension of the shooting leg at impact and thus a higher foot velocity (Lees et al., 2009). A third purpose is that a curved approach provides a more stable position for executing the shot, consequently contributing to the consistency and accuracy of shooting performance (Lees et al., 2009). Research has shown that skilled players have a self-selected approach angle around 43° ± 12 (Egan et al., 2007). This angle relates well to what has previously been shown to be the optimal approach angle (45°) for generation of maximal velocity (Isokawa and Lees, 1988), although a recent study found no significant differences in maximum ball velocity by altering approach angle (Kellis et al., 2004). Scurr and Hall (2009) examined the effects of approach angle on penalty shooting accuracy. Seven male amateur recreational football players shot penalties at a 0.6 x 0.6 m target from a self-selected approach angle, 30º, 45º and 60º. They discovered no significant difference in shooting accuracy between the approach angles and no compensation was made by altering shooting velocity. Letting the player use their own preferred run up angle might therefore be beneficial but control measures ensuring a uniform approach between trials is however needed to ensure that a change in run up approach over time does not impact performance.

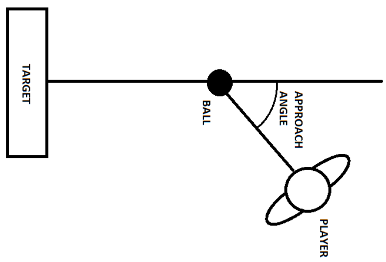


Figure 4.1. Definition of approach angle.

4.4 Methods for Measuring Ball Velocity in Shooting

Before reviewing the methods of assessing ball velocity in the literature, it is important to understand what velocity ranges a ball reaches during shooting in football. For male players the mean ball velocity across studies has been approximately 24 $m.s^{-1}$ with a range of 15.2 to 37.3 $m.s^{-1}$ (Table 4.6). The large range can be explained by the different shooting strategies applied and variation in population assessed. Not enough literature assessing women is available to gain a general perspective of typical ball velocities achieved.

Focus should be made on when during flight the ball velocity measure is made as ball velocity will decrease throughout flight (Asai and Seo, 2013; National Aeronautics and Space Administation, n.d.).

Test equipment

The past literature has used a wide range of tools to measure ball velocity (Table 4.6). Motion analysis systems and high-speed video analysis are the most commonly used in the research but radar guns, laser diodes and photo cells have also been used.

- Motion analysis is the analysis of consecutive images from image sequences, e.g., produced by video cameras or high-speed cameras. Markers on designated human body segments as well as the ball can be used to analyse the motion. Apart from Nunome et al. (2006a, 2006b), who used a frame rate of 1000 Hz to analyse ball velocity, researchers have used relatively slow frame rates of 60-500 Hz (see discussion on sampling frequency below). Some difficulty can occur when trying the stick markers to the ball as these are likely to be lost, during flight or at impact when bouncing/landing. The downfall of using motion analysis systems is the complexity in setting up the equipment when performing outdoor testing, its light and hence weather sensitivity.
- High speed video can be used to analyse motion in both 2-D and 3-D depending on the number of cameras used. Both methods have been used in the past literature to measure ball velocity (Table 4.7). Due to parallax error, 2-D motion capture may show lower ball velocities, if not shot directly in a perpendicular direction to the camera (Barber and Carré, 2010). The benefit of using high speed video as well as motion capture is visual data tracking the ball in the visible range of the ball flight. If measured with the appropriate frame rate the average ball velocity offers a good estimate of the ball velocity.
- Radar speed guns may be hand-held or mounted. These measures the velocity of the object at which it is pointed by sensing a change in frequency of the returned radar signal caused by the Doppler Effect. Since only a single measure is commonly given as output by a radar speed gun, it may be questioned whether

the measure is the peak velocity and at which moment in the flight path velocity is tracked and measured.

- Photo cells and laser diodes were used in an older publication (Hennig and Zulbeck, 1999). The problems with these measuring choices are that the ball cannot travel above the measured zone and therefore cannot be shot far above ground. Also, the instrument only measures time to travel a set horizontal distance in the target direction and therefore is inherently inaccurate.

Other equipment may also be relevant to assess ball velocity. Recently, Adidas launched the miCoach Smart Ball football (Adidas, Herzogenaurach, Germany). Through a smartphone application, this gives the ball velocity measured by a triaxial accelerometer integrated in the ball (Smith et al., 2017). If reliable and valid, the miCoach Smart Ball football could simplify testing and enhance ecological validity as no external test equipment would be needed beyond the ball itself. Thus, a wide range of options are available for the researcher to choose from when selecting an instrument to measure ball velocity. A comparison has not been reported in the literature on football to define which tools are reliable and valid to use.

Sampling frequency

Two thirds of the studies using video and high-speed video have captured ball (and lower limb) movements at rates between 50 and 500 Hz (Table 4.7), which for most cases were then again filtered before analysing at a common range of 6-18 Hz (Andersen et al., 1999; Dörge et al., 2002; Nunome et al., 2002; Teixeira, 1999). Video cameras should be able to capture an appropriate number of frames per second in relation to the ball velocity which, as seen in Table 4.6 has been measured to velocities up to 37 $m.s^{-1}$ for men. A calculation of the appropriate sampling for a ball velocity of 37 $m.s^{-1}$ can be seen in Table 4.8. With frame rates down to 60 Hz a large visual zone is needed in which the ball velocity may decrease and parallax error may increase. A frequency of ≥ 200 Hz will, with an appropriate camera distance to the

Table 4.6. Ball velocities obtained in past literature.

Research study	Ball velocity ($m.s^{-1}$)	SD ($m.s^{-1}$)	Research study	Ball velocity ($m.s^{-1}$)	SD ($m.s^{-1}$)
Amos et al. (2002)	~24.1-24.8	N/A	Moschini et al. (2012)	20	1.55
Andersen et al. (2012)	23.2	0.4		18.6	1.93
	22.4	0.3		18.2	1.97
Apriantono et al. (2006)	28.4	1.6	Narici et al. (1988)	20	3.6
	26.8	1.1	Nunome et al. (2002)	28	2.1
Asai et al. (2002)	25.44	0.8		23.4	1.7
Asami et al. (1983)	29.9	2.9	Nunome et al. (2006a)	32.1	1.7
Barfield (1995)	26.4	2.1	Nunome et al. (2006b)	26.3	3.4
Barfield et al. (2002)	25.3	1.5	Opavsky (1988)	23.5	N/A
	21.5	*2.44*		30.8	N/A
Chew-Bullock et al. (2012)	17.7	3.95	Poulmedis et al. (1988)	27.1	1.32
	15.2	3.44	Roberts et al. (1974)	24.1	N/A
Cometti et al. (2001)	29.5	12.89	Rodano et al. (1993)	22.3-30.0	N/A
	29.7	7.52	Russell et al. (2010)	16.8	2.0
	29.9	5.71		16.6	1.7
Dörge et al. (2002)	24.7	2.5	Sakamoto et al. (2010)	22	2
	21.5	2		21.3	2.5
Grgantov et al. (2013)	20.9-26.8	N/A		18.3	1.6
Hennig et al. (1999)	23.3-24.1	N/A		26.6	1.6
Hong et al. (2011)	25.8	1.07		26.6	1.6
	28.3	1.07		21.9	1.4
	26	1.05	Sakamoto et al. (2011)	22	*2.6*
Hong et al. (2013)	25.4	0.7		19	*2.1*
	26.8	0.4		26.6	2.6
	25.9	0.8		21.9	2
Ismail et al. (2010)	37.3	N/A	Sakamoto et al. (2013)	*22*	*1.4*
	36.8	N/A		26.4	2
	33.0	N/A	Sakamoto et al. (2014)	*22*	*1.4*
	34.6	N/A		26.4	2
Isokawa et al. (1988)	18.7	1	Scurr and Hall (2009)	25.1	2.07
	20.1	1.58		24.2	2.3
	19.1	1.64		24.5	2.12
Kellis et al. (2004)	19.8	1.5		23.5	N/A
	20.4	2.4	Shan et al. (2005)	24.2	N/A
	18.5	3.1		16.9	N/A
Kellis et al. (2006)	24.7	1.8	Sterzing et al. (2006)	26.1-26.5	N/A
	21.8	2.2	Sterzing et al. (2007a)	26.2-26.5	N/A
Levanon et al. (1998)	28.6	2.2	Sterzing et al. (2007b)	26.4	N/A
Luthanen (1988)	14.9-22.2	N/A		27.0	N/A
Majelan et al. (2011)	~30-33	N/A		27.1	N/A
Manolopoulos et al. (2006)	27.9	1.8		26.6	N/A
Markovic et al. (2006)	19.5	1.9	Taha et al. (2013)	20.8	N/A
	19.7	2.0		19.2	N/A
	19.8	1.9		16.2	N/A
	26.5	2.5	Taïana et al. (1993)	26.7	2.5
	26.6	2.5	Tol et al. (2002)	24.6	N/A
	26.7	2.7	Trolle et al. (1993)	27.6-28.8	N/A
	25	2.2	Tsaousidis et al. (1996)	24.9	1.1
	25.2	2.3			
	25.3	2.2			

Ball velocities in *italic* are measures of female performance; SD = standard deviation; N/A = information not available

Table 4.7. Previous literature – Test equipment used to measure ball velocity.

Research Study	Equipment	Hz	Resolution
Amos et al. (2002)	HSV	1000	N/A
Andersen et al. (2012)	Motion Analysis	500	.
Anderson et al. (1994)	2-D Video	60	N/A
Apriantono et al. (2006)	HSV	500	N/A
Asai et al. (2002)	2-D HSV	4500	256x256
Asami et al. (1983)	2-D HSV	500	N/A
Barfield (1995)	Motion Analysis	200	.
Barfield et al. (2002)	Video	120	N/A
Chew-Bullock et al. (2012)	Radar gun	.	.
Cometti et al. (2001)	Radar gun	.	.
Dörge et al. (2002)	2-D HSV	400	N/A
Grgantov et al. (2013)	Radar gun	.	.
Hennig et al. (1999)	Laser diodes	.	.
Hong et al. (2011)	3-D HSV	300	720x480
Hong et al. (2012)	2-D HSV	1000	1024x1024
Hong et al. (2013)	2-D HSV	1000	1024x1024
Ismail et al. (2010)	Motion Analysis	200	.
Isokawa et al. (1988)	Video	150	N/A
Kellis et al. (2004)	3-D HSV	120	N/A
Kellis et al. (2006)	3-D HSV	120	N/A
Lees et al. (1988)	2-D HSV	200	N/A
Levanon et al. (1998)	3-D HSV	200	N/A
Luthanen (1988)	2-D Video	65	N/A
Majelan et al. (2011)	Motion Analysis	60	.
Manolopoulos et al. (2006)	Motion Analysis	200	.
Markovic et al. (2006)	Radar gun	.	.
Moschini et al. (2012)	3-D HSV	200	N/A
Narici et al. (1988)	Sound recording	.	.
Nunome et al. (2002)	3-D HSV	200	N/A
Nunome et al. (2006a)	Motion Analysis	1000	.
Nunome et al. (2006b)	Motion Analysis	1000	.
Opavsky (1988)	2-D HSV	60	.
Poulmedis et al. (1988)	Photocells	.	.
Roberts et al. (1974)	2-D HSV	100	N/A
Rodano et al. (1993)	3-D HSV	100	N/A
Sakamoto et al. (2010)	3-D HSV	1000	1024x1024
Sakamoto et al. (2011)	Motion Analysis	250	.
Sakamoto et al. (2013)	Motion Analysis	250	.
Sakamoto et al. (2014)	3-D Video	50	N/A
Scurr and Hall (2009)	Motion Analysis	120	.
Shan et al. f (2005)	Motion Analysis	5000	.
Shinkai et al. (2007)	Radar gun	.	.
Sterzing et al. (2006)	Radar gun	.	.
Sterzing et al. (2007a)	Radar gun	.	.
Sterzing et al. (2007b)	Radar gun	.	.
Sterzing et al. (2008)	Radar gun	.	.
Taha et al. (2013)	Photo cells	.	.
Taïana et al. (1993)	Speedometer	.	.
Tol et al. (2002)	Radar gun	.	.
Trolle et al. (1993)	Doppler radar	.	.
Tsaousidis et al. (1996)	2-D HSV	4000	N/A

HSV = high speed video, N/A = information not available

Table 4.8. Estimate of sampling frequency needed.

Sampling Frequency (Hz)	Ball velocity ($m.s^{-1}$)	Distance travelled between frames (m)
50	37	0.74
100	37	0.37
200	37	0.18
500	37	0.07
1000	37	0.04
5000	37	<0.01

measuring zone, allow the research multiple frames for assessing ball velocity. For instance with a visual zone of 2 m will allow the researcher 11 frames, from which the central frames can be selected to minimise parallax error. Additionally, the majority of studies did not include shutter speed applied, which, although dependent on lighting settings, is relevant.

4.5 Methods for Measuring Ball Accuracy in Shooting

Different approaches have been applied to assess accuracy for shots in football (Table 4.9). Scoring offset by a point system depending on zones was the most frequently used method followed by measured radial offset distance using various methods and finally a hit/miss count method has been applied where count of successful hits was used as a measure of accuracy.

The point system is dependent on the zonal size, shapes and scoring value. Another issue with the point systems lies within the zonal setup. The goal is commonly divided into zones by the use of rope or other material to create square zones, each allocated a certain point-value. By using squares and not circles to define the offset then the point will not replicate the actual offset. Also, conclusions drawn from the use of point system may not necessarily reflect the relative difficulty of the tasks performed (Russell and Kingsley, 2011). For instance, the Loughborough Soccer Shooting Test assigned the greatest number of points to shots placed in the corners of a goal as this limits the chance of the shot being saved by the goalkeeper (Ali et al., 2007b). In contrast, a comparable shooting assessment by Currell et al. (2009) assigned the lowest number of points when shots were placed towards the corners. Consequently, conclusions derived from assessments based on criterion-based outcomes are dependent on the scoring criteria used and limit the like-for-like comparison of data between different tests that aim to assess the same variables of skilled performance (Russell and Kingsley, 2011).

Assessing the actual offset distance as a measure of accuracy has been applied less frequently than the point system method (Table 4.9). Finnoff et al. (2002) reported a mean deviation from their target point of approximately 0.90 m over a 6.1 m distance when ball impacts were measured manually. Kuo and Shiang (2007) found a smaller mean offset of 0.30-0.45 m when replicating the same method for comparing different football boots. Majelan et al. (2011), who use a relatively similar distance (7 m), found the mean distance varying between ~0.25 and ~0.40 m. Whilst Russell et al. (2010) who used a 15 m distance reported a 0.51 ± 0.06 m offset for both test and re-test over two separate days. As just illustrated, comparing actual distances in contrast to individual point systems make intra-study comparison easier.

Table 4.9. Previous shooting accuracy literature: Test setup and variable measured.

Study (year)	Methods	Equipment
Abt et al. (1998)	Points	Visual
Ali et al. (2007b)	Points & timed	Radar gun
Cox et al. (2002)	N/A	N/A
Currell et al. (2009)	Points	Visual
Figueiredo et al. (2011)	Points	Video
Finnoff et al. (2002)	Distance measured	Tape measure
Haaland and Hoff (2003)	Points	Visual
Hennig et al. (2009)	Distance measured	Electronic sensors
Katis et al. (2013)	Accurate><inaccurate	Visual
Kuo and Shiang (2007)	Distance measured	Tape measure
Majelan et al. (2011)	Distance measured	Video
Northcott et al. (1999)	Points	Visual
Reilly and Holmes (1983)	Points	N/A
Russell et al. (2010)	Distance measured	Video
Rösch et al. (2000)	Points	Visual
Scurr and Hall (2009)	Distance measured	Video
Stone and Oliver (2009)	Points & timed	Visual/video
Vanderford et al. (2004)	Points	Visual
Williams et al. (2010)	Points	Visual

The studies have, however, used different methods to measure radial offset. The Finnoff et al. (2002) test design involved a carbon sided paper and white paper covered plywood which, when being compressed at ball contact, would leave a carbon mark on the white paper (Table 4.4). The authors reported that the total cost of supplies was less than $150 and intra-class correlation coefficients for intra- and inter-rater reliability for measuring the offset distance were 0.99. Majelan et al. (2011) used a digital camera (Casio EX-F1, Casio Computer Co., Tokyo, Japan; 300 Hz, 720×576 pixels) located behind the shooter to measure radial offset. The camera angle applied was possible since the target used was a mat hanging on the wall (Table 4.4). The methods applied by Finnoff et al. (2002) and Majelan et al. (2011) can, however, not be applied in the ecological valid environment using a location within a football goal as target, as discussed previously. Russell et al. (2010) assessed radial offset using video analysis and Quintic Coaching 4.01 software version 14 (Quintic Consultancy Ltd., UK), which is a 2D assessment software assessing the goal from a single frontal facing camera. It is unclear whether assessment of radial offset was done as the ball crossed the goal line or approximated by the researcher. Furthermore, the software assesses video at 50-60 Hz and resulting in large frame-to-frame ball displacements (e.g. at 22 $m.s^{-1}$ the ball moves 0.37-0.44 m between frames). This review agrees with the outcome of the previous review of aerobic and skill assessment in football by O'Reilly and Wong (2012) that future research should continue to attempt to incorporate methods of analysis such as video digitization that can provide reliable measures of accuracy and success for shooting actions.

In conclusion, it is clear that measuring the radial offset distance with an appropriate, reliable and valid tool is a more accurate means of assessing shooting accuracy than using the popular point systems. In addition, by measuring the ball position relative to the target point further measures of accuracy than radial offset can be investigated, e.g. vertical and horizontal offset from the target and measures of spread and success.

4.5 Methods for Assessment of Perception of Shooting Performance

It is generally accepted that perception of performance does not always relate to objective performance measures. Still, only one study included measures of subject perception of shooting performance. Sterzing and Hennig (2008) asked players to rank perceived generation of velocity for different football boot designs from worst to best. Whether large variances were perceived was however masked when using a ranking scale. No relationship between actual and perceived performed was seen, which indicates the importance of measuring both aspects of performance. No study has assessed subjective perception of shooting accuracy. Future research may benefit from the use of rating scales for assessment of players' perception of accuracy and ball velocity performance.

CHAPTER 5

Validation of Human Test Protocol to Assess Shooting Performance in Football

5.1 Chapter Outline

The literature review (Chapter 4) highlighted that no validated protocol has been applied to assess the impact of football boot design on shooting performance in football. Based on the knowledge obtained from the literature review on optimal test setup and measuring tools for assessing shooting performance in football and pilot studies to fill gaps in the knowledge, a novel protocol was developed to assess the impact of football boot design on shooting performance in football. This chapter describes test-retest assessment of the reliability of this protocol using content validated of equipment (performed in Appendix B-D).

5.2 Aims

A better understanding of design requirements for optimal shooting would benefit both the industry and consumer. Hence, this study aimed to formulate and validate a new protocol for the assessment of shooting performance (i.e. ball velocity and accuracy) through a multi-factorial and controlled approach. The setup was structured to be easy to apply and demand no more than two researchers to run yet be ecologically valid and produce transferable results. Novel accuracy assessments offset measures were also investigated.

Additionally, an analysis of the relationship between perceived and actual performance as well as an analysis of the speed-accuracy trade-offs for shooting in football through the measures of ball velocity and shooting accuracy were performed.

5.3 Methods

Participants

Nine skilled male football players (age 22.8 ± 2.1 years, stature 1.77 ± 0.03 m, mass 71.1 ± 4.5 kg) were recruited from the University 1st football and futsal teams. All futsal players had a history as a football player prior to University and all players recruited had 8 ± 3 years experience of club level football. None of the subjects had suffered from match-preventive lower limb injuries in the six months prior to testing. All subjects were UK size 8 and right foot dominant, which was determined by asking subjects which side they preferred for shooting. During the test, subjects wore the same brand of new football socks to prevent the socks from altering the subjects' sensation of the boot and ball.

Ethics

The investigation received ethical clearance from the institutional ethics committee and each participant provided written informed consent in accordance with the requirements of the Helsinki Declaration for research using human participants.

Football boots

UK size 8 Umbro prototype football boots were developed for the test (Figure 5.1). Fit was ensured from verbal feedback and palpation prior to testing. The boots had a smooth white synthetic upper with no additional padding, central lacing and a black firm ground outsole similar to the Umbro UX2 firm ground.

Figure 5.1. Plantar and dorsal view of football boots used.

Experimental design

Subjects participated in two sessions each of 2 h duration separated by 7-14 days. Standardised warm up and five test shots were performed in the player's own football boots before testing started (Figure 5.2). Each session comprised assessment of the two different boot designs used for further comparison in Chapter 6. For validation purposes only one of these boot designs was used, the non-padded boot. In each session 10 shots focused on shooting accuracy followed by 10 shots focused on maximum ball velocity were completed – totalling 20 shots per participants per boot (Figure 5.2). Two subjects were tested in each session and alternated every 10^{th} successful shot to minimise fatigue (Figure 5.2). Shots where players evaluated their technique as not optimal or shorter were not recorded by any of the measuring tools were classified as non-successful.

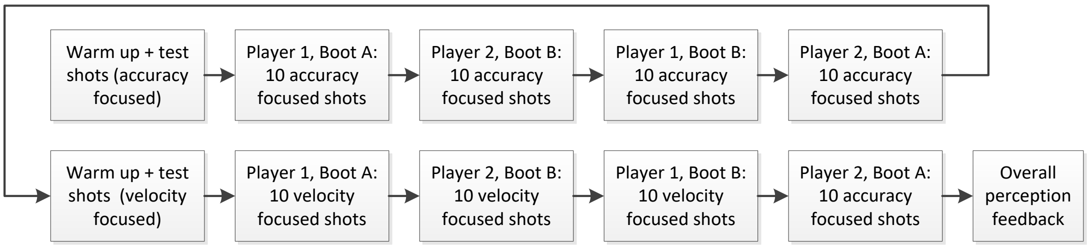


Figure 5.2. Session structure.

Tests were performed on an outdoor third generation artificial pitch (LigaTurf RS+ CoolPlus 260, Polytan, Burgheim, Germany). In brief, the pitch had a 25 mm in situ rubber shock pad, the carpet fibres were 60 mm monofilament polyethylene and the infill comprised 15 $kg.m^{-2}$ sand and 15 $kg.m^{-2}$ rubber crumb giving a total infill height of 41 mm. Pitch testing conducted immediately after this study using the FIFA Quality Concept methodologies (Fédération Internationale de Football Association, 2015a), gave a force reduction of 69.6 ± 1.5%, vertical deformation of 11.4 ± 0.5 mm and rotational resistance of 31.9 ± 1.3 Nm. Tests were only performed under dry conditions. A single Adidas miCoach football (Adidas, Herzogenaurach, Germany; 22 cm diameter, 0.43 kg, 0.9 bar) was used for the tests. Pressure was tested before and after each session with no measurable change during the session. The Adidas miCoach football was placed with the manufacturer specified orientation for each shooting instance (valve facing player; middle arrow facing towards centre of target). Using the same contact point on the ball for each shot limited the risk of the ball impacting the results (Neilson, 2003; Neilson and Jones, 2005).

The ball was placed for a free kick scenario 16 m from goal and directly behind the penalty spot (Figure 5.3). With no evidence in the literature on optimal or common shooting distances in football, this distance was chosen as it would represent a free kick scenario in football with a distance, where players could choose to shoot directly at goal. Players used a repeated but self-selected run up. The test shots were used to determine their preferred run up pattern for accuracy and another set of test shots were used to determine their preferred run up pattern for maximum ball velocity shots. The start position was marked with a cone and participants were instructed to repeat the same run up for every shot. The start positions were recorded and used again for the repeated session to prevent the run up impacting shooting performance (Kellis et al., 2004; Kellis and Katis, 2007). The top right corner of the goal was used as the target point for both accuracy and velocity focused shots and was approximated as 0.11 m lower than the bar and 0.11 m inside the post, based on the ball radius being 0.11 m). This target point location has been identified as an optimal ball placement location to beat a goalkeeper when shooting (Ali et al., 2007a).

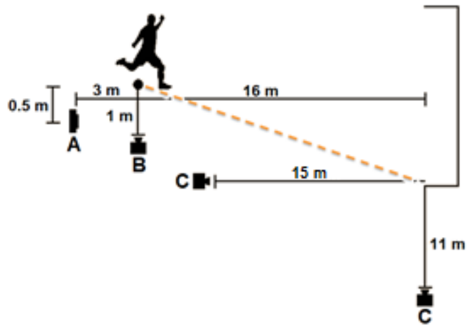


Figure 5.3. Aerial view of setup.
Note: Ball placed 16 m in front of centre of goal; Shots target top right corner of the goal;
A = TrackMan Football; B = CASIO EX-FH1000 camera; C = two GoPro HERO4 Black cameras.

Ball velocity was assessed with TrackMan Football (TrackMan Golf, Vedbaek, Denmark; validation performed in Appendix B) placed 3 m behind the ball with a 0.5 m offset at the opposite site to the run up (e.g. right for right-footed players). Offset from target was recorded using two GoPro HERO4 Black cameras (240 Hz, 1280x720 pixels; GoPro Inc., San Mateo, CA). One camera, tilted 90° to allow portrait view, was placed 9 m from the goal post, 1 m above the ground, and along the back line to record the moment when the ball passed the goal line (Figure 5.3). The second camera was placed 15 m directly in front of the target, and at the height of the target to capture ball offset from the target when the ball passed the goal line (Figure 5.3; placement of camera defined in Appendix C). A spirit level was used to ensure that the camera was level and a laser was used to ensure that the camera was facing the target point. Pilot studies demonstrated a pixel size of 0.008 $m.pixel^{-1}$ and a maximum barrel distortion of -2.1%. The two cameras were controlled wirelessly by a GoPro Smart Remote (GoPro Inc., San Mateo, CA). A manufactured light synchronisation device, with four light columns changing at different speeds (1 = 1 Hz, 2 = 10 Hz, 3 = 100 Hz, 4 = 1000 Hz) was placed in the vision of both cameras to allow synchronisation of the images. The synchronisation device was used due to poor synchronisation using the GoPro Smart Remote (Appendix D).

Players were instructed to apply the same shooting technique for every shot, as previous research found that changing technique can significantly impact performance (Sakamoto et al., 2011). Boot-ball impact was recorded using high-speed video recordings, CASIO EX-FH1000 (Casio Computer Co., Tokyo, Japan; 420 Hz, 224x168 pixels). Similarity of technique between all shots (accuracy and velocity) for an individual was visually assessed and any shot varying in technique was excluded. Additionally, after each shot players evaluated whether optimal technique was achieved. This was done by circling ‘yes’ or ‘no’ and, if ‘no’ was chosen, then participants were asked to make a note of the reason behind. These shots were repeated. To assess players’ subjective perception of performance, a questionnaire was included in the test. Players filled in a 7-point Likert scale after each shot evaluating the player’s perceived performance. For accuracy shots, participants were asked to score the accuracy of their shots (1 = ‘extremely accurate’ to 7 = ‘extremely inaccurate’) whilst for maximum velocity shots, participants were asked to score the ball speed achieved (1 = ‘extremely fast’ to 7 = ‘extremely slow’; Figure 5.4).

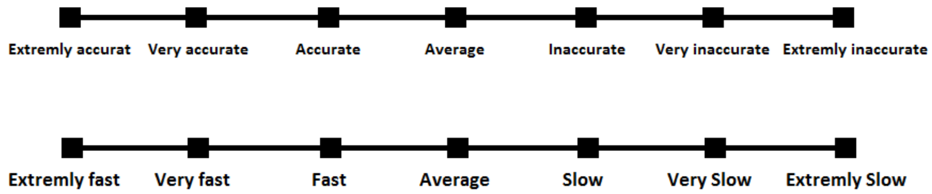


Figure 5.4. Examples of Likert scales used to assess players’ perceived accuracy and ball velocity.

Analysis of measures

Maximum ball velocity measures were presented as velocity in SI derived units of m.s^{-1} as well as percentage of the player’s fastest shot. For accuracy assessment, the video frame when the ball passed over the goal line was defined from the GoPro HERO4 Black camera placed on the goal line. This equivalent frame from the GoPro HERO4 Black camera placed in front of the goal was used for analysis of radial offset (Figure 5.3). The videos were analysed in Image-Pro Analyzer (Version 7.0, Media Cybernetics, Inc., Rockville, MD). Accuracy was assessed by radial offset, vertical offset (y-axis offset; Figure 5.5), horizontal offset (x-axis offset; Figure 5.5), success through goal/no goal and zonal offset spread (Figure 5.5) and spread through axis 95% confidence ellipses angle and major and minor axes lengths. Last mentioned measures were obtained by fitting 95% confidence ellipses to the 2-D data spread using MATLAB (The MathWorks Inc., Natick, MA). The 95% confidence ellipse angle was defined as the angle between the x-axis and the major axis measured counter clockwise.

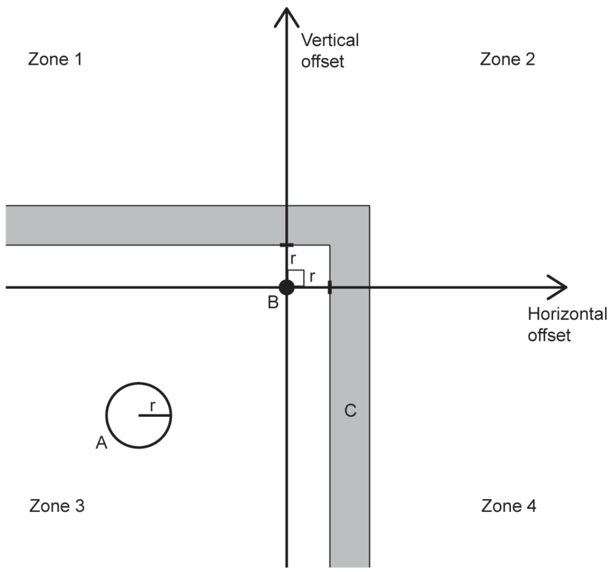


Figure 5.5. Zones used to organise offset of shots. Zones split area into four zones by separation lines vertically and horizontally through the target point.
A = Football with radius ‘r’; B = Target point with r distance to goal post and crossbar; C = Goal.

Statistical analysis

Statistical analysis was carried out using SPSS software (Version 23.0; SPSS Inc., Chicago, IL). Statistical significance was set at $P \leq 0.05$. Non-parametric tests were applied based on the violation of outliers in the differences between the two related groups for some variables. Systematic bias in the repeatability between sessions was analysed by Wilcoxon’s matched-pair tests for all measure apart from zonal offset which was assessed using Person’s chi^2. A post-hoc using z-score indicating difference at ≥1.96 was additionally applied for zonal offset.

The reliability assessment followed the suggested assessment methods from the review of validation methods performed in Appendix E. The magnitude of relative reliability was determined by two-way random intraclass correlation coefficient ($ICC_{2,1}$) two-way random effect model (absolute agreement definition) analyses of the mean subject scores for each session following clinical significance levels suggested by Cicchetti (1994). Data was log-transformed due to heteroscedasticity as suggested by Vaz et al. (2013) and Weir (2005a). The $ICC_{2,1}$ is commonly suggested as the preferred assessment method to quantify relative reliability of test-retest validation setups (Beckerman et al., 2001; Hopkins, 2000; Lexell and Downham, 2005; Vaz et al., 2013; Weir, 2005). Absolute reliability was derived using standard error of measurement (SEM) and the smallest real difference (SRD) necessary to be considered real were derived from the intra-class correlation coefficients following the methods explain by Weir (2005).

Due to the low number of shots per person, success and spread data was also assessed using all data grouped together. $ICC_{2,1}$, SEM and SRD scores cannot be obtained from grouped data. Comparison of success between sessions was therefore performed using Pearson's Chi^2 test for goal/no goal comparisons and Fisher's exact test for zonal offset. Frequencies below 5 in zone four violated the assumption for parametric test for zonal offset comparisons (Field, 2009), hence Fisher's exact test was chosen. Comparison of spread was performed through 95% confidence ellipse analysis of grouped data. Mean axis length, axis rations, area and ellipse angle were compared from a visual plot and mean scores for each condition. To further assess whether a saturation level (level at which addition/subtraction of one participant's data does alter results) of participants was obtained for assessment of grouped 95% confidence ellipse data, a comparison of mean differences between all data and data from which one player was excluded was performed.

An indirect analysis of the speed-accuracy trade-offs for shooting in football through the measures of ball velocity and shooting accuracy was assessed from the mean performance of the accuracy and velocity focused shots for each participant with non-parametric Wilcoxon's matched pair tests. Each players variation in performance (mean and standard deviation) when focusing on accuracy rather than ball velocity was assessed to underline the general tendency of the speed-accuracy trade-off in addition to the non-parametric Wilcoxon's matched pair.

A comparison analysis of the relationship between perceived (subjective) and actual (objective) performance was performed based on the raw outcome scores using Spearman's rank correlation coefficient tests between matching perceived and objective outcome measures.

9.4 Results

Performance scores and systematic bias between sessions

The means and standard deviations (SD) for all outcome measures are presented in Table 5.1 for both sessions. No significant difference was shown for ball velocity demonstrating 22.7 ± 2.6 $m.s^{-1}$ and 22.6 ± 2.1 $m.s^{-1}$ in the two sessions for accuracy focused shots. Non-significant but higher velocities with smaller standard deviations were found for velocity focused shots (28.9 ± 1.9 $m.s^{-1}$ and 29.0 ± 1.8 $m.s^{-1}$). Mean ball velocity as a percentage of maximum velocity for the individual demonstrated similar non-significant results. (Accuracy 72.6 ± 7.7% and 72.3 ± 8.0%; Velocity 92.2 ± 3.8% and 92.5 ± 3.5%).

Table 5.1. Systematic bias and relative reliability for test-retest validation of shooting outcome measures for the shooting protocol.

Variable	Session 1 Mean	±SD	Session 2 Mean	±SD	$ICC_{2,1}$	Mean difference	Bias (P-value)	Grouped mean	SEM	SRD
Velocity ($m.s^{-1}$)										
Accuracy	22.7	±2.6	22.6	±2.1	0.537	0.2	0.635	22.6	±1.1	±3.2
Velocity	28.9	±1.9	29.0	±1.8	0.944	-0.1	0.678	28.9	±0.4	±1.2
Velocity (% of max)										
Accuracy	72.6	±7.7	72.3	±8.0	0.640	0.3	0.635	72.4	±3.6	±10.1
Velocity	92.2	±3.8	92.5	±3.5	0.846	-0.3	0.678	92.4	±1.3	±3.6
Radial offset (m)										
Accuracy	1.76	±0.90	1.76	±1.03	0.824	0.07	0.214	1.82	±0.21	±0.58
Velocity	2.39	±1.17	2.41	±1.14	0.717	-0.14	0.314	2.39	±0.38	±1.06
Horizontal offset (m)										
Accuracy	-1.13	±1.24	-1.22	±1.40	0.900	0.02	0.106	-1.25	±0.20	±0.55
Velocity	-1.60	±1.68	-1.67	±1.61	0.612	0.09	0.314	-1.65	±0.56	±1.54
Vertical offset (m)										
Accuracy	-0.02	±1.05	-0.18	±0.85	0.653	0.20	0.906	-.011	±0.25	±0.70
Velocity	-0.04	±1.33	0.06	±1.34	0.714	-0.28	0.737	-0.02	±0.26	±0.73
Major axis (m)										
Accuracy	6.86	±2.89	6.27	±2.72	0.891	0.59	0.348	6.56	±0.91	±2.51
Velocity	6.95	±2.38	7.06	±2.25	0.927	-0.11	0.789	7.00	±0.61	±1.68
Minor axis (m)										
Accuracy	2.88	±0.90	2.50	±1.33	0.557	0.38	0.537	2.63	±0.73	±2.02
Velocity	3.68	±1.88	3.78	±1.44	0.784	-0.09	0.550	3.73	±0.76	±2.09
Ratio										
Accuracy	0.44	±0.11	0.46	±0.24	0.593	-0.21	0.827	0.45	±0.12	±0.32
Velocity	0.52	±0.22	0.57	±0.23	0.640	-0.05	0.550	0.55	±0.13	±0.36
Area (m^2)										
Accuracy	17.0	±13.0	11.6	±7.3	0.369	5.4	0.341	14.3	±8.4	±23.4
Velocity	22.2	±16.4	21.6	±12.1	0.909	0.7	0.825	21.9	±4.2	±11.7
Angle (°)										
Accuracy	45	±17	29	±25	0.541	16	0.066	37	±15	±42
Velocity	51	±19	50	±16	0.778	1	0.825	51	±8	±23
Success (%)										
Accuracy	58	±21	58	±26	0.925	2	0.588	56	±4	±12
Velocity	65	±22	55	±17	0.527	-1	0.820	57	±7	±20
Zonal offset (%)										
Accuracy (z1)	30	±17	25	±17	0.603	-1	0.955	31	±6	±17
Accuracy (z2)	12	±13	16	±15	0.460	-1	0.949	12	±5	±14
Accuracy (z3)	58	±21	58	±26	0.925	2	0.588	56	±4	±12
Accuracy (z4)	<1	±0	1	±4	0.000	-1	0.347	1	±2	±7
Velocity (z1)	25	±17	29	±8	0.377	2	0.669	28	±7	±19
Velocity (z2)	8	±14	16	±13	0.471	-2	0.550	15	±5	±14
Velocity (z3)	65	±22	55	±17	0.527	-1	0.820	57	±7	±20
Velocity (z4)	1	±4	<1	±0	0.000	1	0.347	1	±2	±7
Perceived accuracy										
Accuracy	3.5	±0.9	3.3	±0.6	0.490	0.3	0.314	3.4	±0.00	±0.01
Perceived velocity										
Velocity	2.7	±0.5	2.7	±0.7	0.161	-0.1	1.000	2.7	±0.00	±0.01

MD = mean difference; $ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition); SD = standard deviation; SEM = Standard error of measurement = SD × $\sqrt{1 - ICC}$. SRD = Smallest real difference at 95% confidence intervals = SEM × 1.96 × $\sqrt{2}$.; z1-z4 = zone 1-4

Mean radial offsets were not significantly different between sessions for both shooting conditions with higher offset shown for velocity focused shots (Table 5.1). Mean horizontal offset (Accuracy -1.13 ± 1.24 m and -1.22 ± 1.40 m; Velocity -1.60 ± 1.68

m and -1.67 ± 1.67 m) as well as mean vertical offset (Accuracy -0.02 ± 1.05 m and -0.18 ± 0.85 m; Velocity -0.04 ± 1.33 m and 0.06 ± 1.34 m) demonstrated good similarities between sessions and no significant differences.

The majority of shots were placed inside goal with no significant difference between sessions for both accuracy (58 ± 21% and 58 ± 26%; P = 0.588) and velocity focused shots (65 ± 22% and 55 ± 17%; P = 0.820). Zonal offset revealed that the second most shots ended in zone 1 (right above goal; Table 5.1). No significant difference and small mean differences were shown for all zones for both shot types (≤ 2%; Table 5.1).

The 95% confidence ellipse area showed a large yet non-significant mean difference (5.4 m^2) for accuracy focused shots. Velocity focused shots did, however, show good consistency in area (22.2 ± 16.4 m^2 and 21.6 ± 12.1 m^2) and therefore low mean difference (0.7 m^2). The 95% confidence ellipse angle also demonstrated larger variation of accuracy focused shots (45 ± 17˚ and 29 ± 25˚) than velocity focused shots (51 ± 19˚ and 50 ± 16˚). The ratio between minor and major axis of the 95% confidence ellipse demonstrated good consistency between session for both accuracy (0.44 ± 0.11 and 0.46 ± 0.24) and velocity focused shots (0.52 ± 0.22 and 0.57 ± 0.23). Large standard deviations for all 95% confidence ellipse measures do, however, indicate large variations between subjects. Perceived accuracy and velocity measures also demonstrated no significant differences between sessions (Accuracy 3.5 ± 0.9 and 3.3 ± 0.6; Velocity 2.7 ± 0.5 and 2.7 ± 0.7).

Relative Reliability

The degree of subject consistency and agreement between sessions as assessed by the intraclass correlation coefficients ($ICC_{2,1}$) was shown to be excellent for ball velocity measures for velocity focused shots ($ICC_{2,1}$ = 0.944; $ICC_{2,1}$ = 0.846) and fair to good for all velocity measures for accuracy focused shots ($ICC_{2,1}$ = 0.537; $ICC_{2,1}$ = 0.640; Table 1). Single planar accuracy measures of radial, horizontal and vertical offset demonstrated good or excellent $ICC_{2,1}$ scores ($ICC_{2,1}$ = 0.612-0.900). Success demonstrated excellent relative test-retest reliability for accuracy focused shots (0.925), whilst velocity focused shots demonstrated fair relative test-retest reliability. Zonal offset showed a wide variation in $ICC_{2,1}$ scores ranging from < 0.000 due to the low number of cases in zone 4 to 0.925 for zone 3 for accuracy focused short (Table 5.1). The measures related to the 95% confidence ellipse analysis demonstrated poor to fair ($ICC_{2,1}$ = 0.369-0.593) scores for accuracy focused shots and good to excellent ($ICC_{2,1}$

= 0.640-0.909) scores for velocity focused shots. Perceived accuracy and velocity demonstrated poor to fair scores ($ICC_{2,1}$ = 0.490; $ICC_{2,1}$ = 0.161).

Absolute Reliability

The 68% confidence interval represented by standard error of measurement (SEM) and 95% confidence interval represented by smallest real difference (SRD) expressed in both the measurement unit and as a percentage of the mean. A small SRD ranges were shown for ball velocity measures for velocity focused shots (SRD = ±1.2 $m.s^{-1}$) while a larger SRD range was obtained for accuracy focused shots (SEM = ±1.1 $m.s^{-1}$; SRD = ±3.2 $m.s^{-1}$). Similar trends were seen when converting ball velocity into percentage of the subject's maximum velocity (Accuracy SRD = ±10.1%; Velocity SRD = ±3.6%). Reversely, single planar accuracy measures showed a tighter SRD band for accuracy focused shot (radial SEM = ±0.58 m; horizontal SEM = ±0.55 m, vertical SEM = ±0.70 m) than velocity focused shots (radial SEM = ±1.06 m; horizontal SEM = ±1.54 m, vertical SEM = ±0.73 m). Success SRD ranges demonstrated to be ±12% for accuracy focused shots and ±20% for velocity focused shots. Zonal offset did, likewise, demonstrate large SRD absolute reliability bands ranging from ±7% to ±20%. The measures related to the 95% confidence ellipse analysis and zonal offset both demonstrated large SEM and SRD bands (Table 5.1). For the Likert scores of perceived accuracy and perceived velocity tight SRD bands were seen (Accuracy SRD = ±0.01, Velocity SRD = ±0.01).

Success assessed from grouped data

Success assessed from grouped data from all participants to obtain a larger data set demonstrated high similarities between sessions (Accuracy P = 1.000; Velocity P = 0.887; Table 5.2)

Table 5.2. Grouped data comparison of success between sessions.

Success	Session 1 (%)	Session 2 (%)	P-level
Accuracy focused			
Goal	57.1	57.1	1.000
No Goal	42.9	42.9	
Velocity focused			
Goal	56.6	55.2	0.887
No Goal	43.4	44.8	

Pearson's Chi^2 test. Significance level set at $P \leq 0.05$.

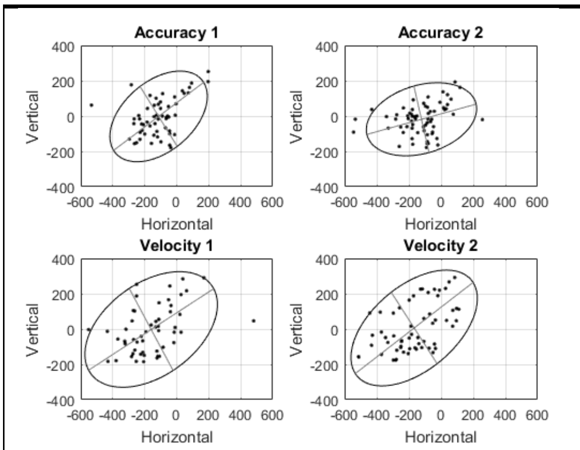
Zonal offset assessed from grouped data
Zonal offset assessed from grouped data from all participants to obtain a larger data set demonstrated high similarities between sessions (Accuracy P = 0.447; Velocity P = 0.867; Table 5.3).

Table 5.3. Grouped data comparison of zonal offset between sessions.

Offset Zone	Session 1 (%)	Session 2 (%)	P-level	z-score
Accuracy focused			0.447	
Zone1	30.4	25.4		0.1
Zone2	12.5	15.9		-0.6
Zone3	57.1	57.1		0.2
Zone4	0.0	1.6		1.1
Velocity focused			0.869	
Zone1	30.2	29.3		0.2
Zone2	11.3	15.5		-1.0
Zone3	56.6	55.2		0.3
Zone4	1.9	0.0		1.4

Significance level set at P ≤ 0.05; z-score indicating significant difference at ≥1.96.

Spread assessed from grouped data
Zonal offset assessed from grouped data from all participants to obtain a larger data set demonstrated relatively large variations between sessions (Figure 5.6). The variance is both visible when plotted and from mean axes lengths, axis ratios, areas and angles (Figure 5.6).



Variable	Session 1	Session 2
Minor axis (m)		
Accuracy	1.32	1.64
Velocity	1.73	1.32
Major axis (m)		
Accuracy	4.42	4.72
Velocity	6.00	5.92
Axis ratio		
Accuracy	0.30	0.34
Velocity	0.29	0.23
Area		
Accuracy	18.33	24.32
Velocity	32.61	24.55
Angle (˚)		
Accuracy	34	14
Velocity	31	35

Figure 5.6. 95% confidence ellipses and given centre points, radiuses, and angle.

To further assess whether a saturation level of participants was obtained for assessment of grouped 95% confidence ellipse data, a comparison of mean differences between all data and data from which one player was excluded was performed (Table 5.4). The major axis demonstrated the smallest mean maximum variation in results when excluding a player from the data set with a variation of up to 5.8% for any shooting condition over the two sessions (Table 5.4). Any other variable assessed demonstrated large mean maximum variation when excluding a player from the data set (19.4-27.3%; Table 5.4). The player and shooting condition producing the large variations varied between variables assessed.

Table 5.4. Absolute mean difference of all data and data excluding a player.

Variable	Mean	Minimum	Maximum
Major axis (%)			
Accuracy S1	2.0	0.5	5.8
Accuracy S2	1.1	0.3	2.7
Velocity S1	1.3	0.4	2.9
Velocity S2	1.9	0.7	3.0
Minor axis (%)			
Accuracy S1	1.3	0.3	2.8
Accuracy S2	3.9	1.3	9.5
Velocity S1	4.7	0.9	19.4
Velocity S2	2.4	0.3	6.7
Ratio (%)			
Accuracy S1	2.8	0.2	6.6
Accuracy S2	4.5	1.8	9.7
Velocity S1	4.7	0.2	20.0
Velocity S2	3.6	0.8	9.4
Area (%)			
Accuracy S1	2.1	0.2	6.3
Accuracy S2	8.2	0.1	27.3
Velocity S1	3.9	1.3	9.5
Velocity S2	1.1	0.3	2.7
Angle (%)			
Accuracy S1	4.7	1.1	9.8
Accuracy S2	8.2	0.1	27.3
Velocity S1	8.1	4.1	14.7
Velocity S2	7.8	1.8	12.7

Indirect analysis of the speed-accuracy trade-off

Point (0;0) on Figure 5.7A and B represents the target point of the top right goal corner. No variation in zonal offset was seen between accuracy and velocity focused shots (Figure 5.7A and B).

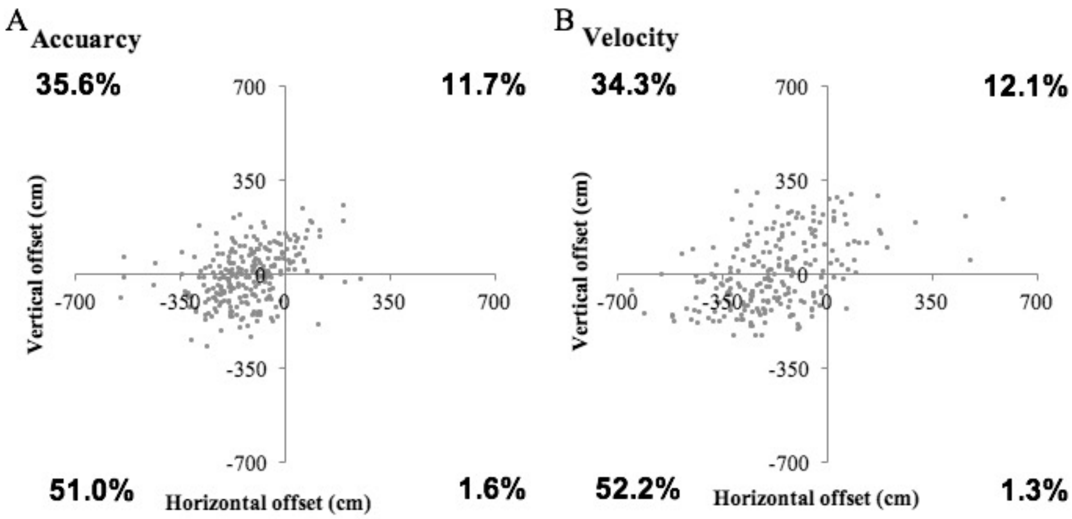


Figure 5.7A and B. Offset for accuracy and velocity shots around the target point (0;0).

Velocity focused shots demonstrated significantly higher ball velocity (P < 0.001), larger radial offset (P < 0.001) and larger horizontal offset (P < 0.05) compared to accuracy focused shots (Table 5.5). An increase spread for velocity shots related to the larger offset scores are also visually detectable when plotted as seen Figure 5.7A and B.

Table 5.5. Differences in ball velocity and offset between accuracy and velocity focused shots.

Skill	Variable	Mean ± SD		Sig.
Accuracy focused	Velocity (%)	72.4	±7.8	
	Radial offset (m)	1.82	±0.97	
	Horizontal offset (m)	-1.25	±1.31	
	Vertical offset (m)	-0.11	±0.93	
Velocity focused	Velocity (%)	92.4	±3.6	<0.001***
	Radial offset (m)	2.39	±1.16	<0.001***
	Horizontal offset (m)	-1.68	±1.65	0.012*
	Vertical offset (m)	-0.02	±1.33	0.621*

* = P ≤ 0.05; *** = P ≤ 0.001.

Comparison analysis of the relationship between perceived (subjective) and actual (objective) performance

Table 5.6 demonstrates the correlation between perceived performance measure and objective performance measures. Subjective perception of accuracy recorded on a 7-point Likert scale demonstrated moderate correlation with horizontal and vertical offset in the 8 mm boot (horizontal r = 0.516, P = 0.028; vertical r = 0.492, P = 0.038). Comparing the questionnaire outcome of perceived ball velocity with TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) measured ball velocity showed no correlation. This indicates that participants were unable to detect velocity.

Table 5.6. Correlation between subjective and objective measures of performance.

		Perceived accuracy		Perceived velocity	
		r_s	p-value	r_s	p-value
Radial offset	Session 1	0.330	0.181		
	Session 2	0.107	0.672		
Horizontal offset	Session 1	0.155	0.540		
	Session 2	0.516	0.028*		
Vertical offset	Session 1	0.225	0.369		
	Session 2	0.492	0.038*		
Velocity (% of max)	Session 1			-0.332	0.135
	Session 2			0.246	0.593

r_s = Spearman's correlation coefficient; * = P ≤ 0.05.

5.5 Discussion

This study aimed to validate a new test setup for the assessment of shooting performance through objective and subjective ball velocity and accuracy measures. The test setup aimed to assess the impact of football boot design on shooting performance, varying from past literature aiming to assess performance differences evoked by the subject due to, for example, playing level.

In all cases ball velocity measures were not significantly different in all cases between session. Better ICC and SRD scores were shown for velocity kicks where a difference of ±1.2 m.s^{-1} or ±3.6% was shown to be detectable, whilst a difference of ±3.2 m.s^{-1} or ±10.1% change was detectable for accuracy focused kicks. There was no difference between assessing ball velocity in SI units or as a percentage of player's maximum ball velocity achieved. The test-retest reliability demonstrated the ability to detect smaller differences in performance than the past literature. Ali et al. (2007) obtained an ICC of 0.33 and SEM of ±1.4 m.s^{-1} and Russell et al. (2010) obtained an ICC of 0.32 and SRD of ±4.3 m.s^{-1}. Similar shooting distances were used in the three studies (16 m in the current study, 15 m in Russell et al. (2010) and 16.5 m in Ali et al. (2007)). Differences may lie within the run up, shot type and ball impact point, which have all been shown to impact shooting performance (Asai et al., 2002; Hong et al., 2012, 2013b; Kellis et al., 2004; Kellis and Katis, 2007; Levanon and Dapena, 1998; Nunome et al., 2002; Sakamoto et al., 2010, 2011). Balls were placed statically on the ground in this study whilst both Ali et al. (2007) and Russell et al. (2010) assessed player skill level and therefore applied setups with a ball in motion. The run up and shot types were not controlled in these studies whilst these were free but kept consistent within an induvidual in this study.

Ball accuracy measures were not significant different in all cases between session. Better ICC and SRD scores were shown for accuracy kicks for radial and horizontal offset, whilst no difference between kick types was seen for vertical offset in ability to detect differences in performance. The test-retest reliability of radial offset demonstrated the ability to detect smaller differences in performance than the past literature. Past literature has only assessed radial offset and therefore the other accuracy performance detectability measures cannot be compared. Ali et al. (2007) obtained an ICC of 0.26 and SEM of ±0.54 m and Russell et al. (2010) obtained an ICC of 0.38, SEM of ±0.39 m and SRD of ±1.07 m. In addition to the variations mentioned above between the past literature and this study then it is difficult to compare accuracy measures with Ali et al. (2007) since a point system was used instead of an actual measurement of offset from the target.

In addition to the single plane accuracy assessment, two new assessment methods were attempted focusing on success and spread. Success, measured as goals scored and zonal offset, were included as shooting performance in football is dependent on whether the shot is on or off target. An on target shot creates a goal scoring opportunity. The comparison of zonal offset demonstrated no difference between sessions but SRD scores of up to 20% were seen for both goals scored and zonal offset which is large to detect differences. Offset spread was assessed through 95% confidence ellipses assessments. Spread is a relevant assessment addition where centre point represents systematic offset bias from target, major-minor axes ratio indicates the magnitude of directional bias and the angle the dimension of directional bias. Similar to success, offset spread demonstrated no difference between sessions but large SRD scores. The reason behind the large SRD scores is likely due to the low number of shots performed per participant. Assessments of grouped data from all subjects were performed to overcome the low number of repetitions per participant. Validation using the $ICC_{2,1}$, SEM and SRD could therefore not be performed. Both goals scores and zonal offset demonstrated high similarities between sessions when grouped. An attempt of performing 95% confidence ellipses with grouped offset spread data from all participants also was performed. Through visual inspection and comparison of mean scores a large variance was seen between sessions. To further assess the reason behind these differences an assessment of participant saturation was performed. The assessment indicated that saturation was not met. If offset spread should be assessed from 95% confidence ellipses in future research then a participant saturation level must be reached.

In addition to objective measures of performance, the player's perception of performance was assessed for each shot. Literature has shown that objective measures of performance and players perception of performance can vary (Roberts et al., 2001). Yet perception data is an important tool for boot manufacturers and researchers to obtain a more holistic understanding of the boot. Perceived measures demonstrated poor and fair relative reliabilities due to small variance in scores between subjects but demonstrated small SRDs (±0.01), which indicates that the perceived accuracy and velocity tools are applicable for assessing subjective perception of performance to offer another level of understanding of the boot performance.

In addition to the validation assessments, an attempt to demonstrate the speed-accuracy trade-off for shooting in football was performed. Although tendencies similar to the speed-accuracy trade-off have been seen for shooting in football (Lees and Nolan, 2002), no assessment has previously been performed. Significant differences between accuracy focused shots and velocity focused shots were shown by accuracy focused shots being performed with significantly lower ball velocity yet significantly higher accuracy. This tendency was present for eight out of the nine players. The results underline the importance of controlling the ball velocity and accuracy focus of shots assessed.

Finally, the strength of correlation between subjective and objective measures of performance was assessed. For ball velocity, no correlation was seen between measured and perceived ball velocity performance. Similar results were seen for ball offset from target assessments. It could be assumed that players could visually observe the offset from target, yet the best correlations demonstrated to be moderate correlation for one boot condition whilst performing accuracy focused shoots. This indicates that objective measures of performance do offer good indication of players' perception of performance and vice versa. Subjective feedback on a boot design may therefore be just as important as objective performance measures, as players may perceive differences and thereby favour buying one boot over another. Assessment of both perceived and actual performance should therefore be assessed individually.

Limitations

Players performed the tests in the boots without an adaptation period to 'break in' the boots. If boots are compared using this setup then it is difficult to allow players the time to adapt to all boots tested. If significant differences are shown when comparing boots with this setup then the lack of adaptation should be acknowledged as a potential impacting factor on results.

When developing a protocol to assess the impact of a small adjustment like football boot design then it is essential to control any other impacting factor. This includes a control of the human subject to minimise the level of human error. Within this study the aim was to allow natural movement in a repeatable pattern. This study included more control than past literature exploring the effect of boot design on kicking performance (Chapter 4). It was therefore important to listen to the feedback from the players throughout the test to sense whether the kicking and defined run up are natural and well set for the individual subject. Players reported throughout the test that once their preferred run up was found that the kicking appeared to be a natural movement for them. By controlling run up and kick type it is believed that ecological validity can be achieved despite actively trying to minimise human error.

Atkinson and Nevill (1998) proposed a minimum of 40 participants is required to assess the reliability of a test protocol. This suggestion was based on the determination of limits of agreement, where sample data are used to extrapolate to a given population. Though, given the difficulties in obtaining participation rates of homogenous participant samples, a sample size of 40 is not always possible. Therefore, the reliability of football kicking tests have, like in this study, been determined with fewer individuals (e.g. Ali et al., 2007; Russell et al., 2010).

This study used TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) to assess ball velocity. It is recognised by the researchers that the TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) is not available for usage by other research labs and it is therefore suggested that researchers validate their ball velocity instrument prior to testing and that the pilot test performed in relation to this study suggested that 2-D high speed video camera could be an alternative solution.

5.6 Conclusion

The protocol assessed in this study demonstrated good test-retest reliability for shooting performance measures for especially ball velocity, radial, horizontal and vertical offset and player perceived performance by demonstrating small SRD scores. Poor test-retest scores were seen for offset measures as success and spread due to the low number of shot per participant. Through grouped player data assessment success demonstrated high similarities between sessions. Offset spread did, due to an insufficient number of participants, demonstrate poor consistency between sessions. If offset is desired as an outcome for future research then more participants will need to be tested.

Finally, the study also demonstrated the importance of subdividing shots by focus (i.e. accuracy or ball velocity) as well as the importance of assessing both objective and subjective measures of performance to obtain a holistic understanding of performance.

CHAPTER 6

Impact of Football Boot Upper Padding on Shooting Performance

6.1 Chapter Outline

This chapter applies the validated protocol (Chapter 5) to assess shooting performance differences between two football boots of similar designs but varying upper thickness. Chapter 2 and 3 highlights the lack of current knowledge and potential impacting factors on performance. To demonstrate the application of the validated protocol (Chapter 5) the impact of upper thickness through additional padding on shooting performance was chosen as this design parameter was a current design feature of the Puma EvoPower boot.

6.2 Introduction

The obvious aim for a football team during a match is to score more goals than the opposing team. Consequently, one of the most valued and important player skills within the game is the ability to score goals. Michailidis et al. (2013) found that goals in the European Championship 2012 were predominantly scored by shooting (40.8%). Optimal shooting performance in unquestionably based on technique but may also be influenced by the support from the equipment i.e. the ball and the player's football boots.

Football boots are created by manufacturers with a specific performance feature (e.g. running speed, ball control or shooting power) which is used in the buying guidelines and when choosing which type of player to sponsor (adidas, 2015; Nike Inc., 2015; Puma SE, 2015). It has also become crucial for companies to produce a wide range of footwear products to satisfy ever-increasing consumer demand. The high market competition has led to many technological innovations, which allow sporting goods companies to differentiate themselves (Xerfi 2XDIS04, 2015). Two football boots claiming to optimise shooting performance through improved ball velocity and accuracy have been released by leading manufacturers. The first generations of Puma EvoPower contained an upper padded texture, which today has been modified into a dotted texture with localised pressure points, similar to the Nike Hypervenom design. An understanding of how padding impacts shooting performance was therefore desired.

6.3 Aims

The aims of this study were to:

- Analyse the impact of boot upper thickness on accuracy and ball velocity for shooting.
- Analyse the impact of boot upper thickness on perceived shooting accuracy and velocity performance.

6.4 Methods

Participants

Nine skilled male football players (age 22.8 ± 2.1 years, stature 1.77 ± 0.03 m, mass 71.1 ± 4.5 kg) were recruited from the University 1st football and futsal teams. All futsal players had a history as a football player prior to University and all players recruited had 10 ± 6 years experience of club level football. None of the subjects had suffered from match-preventive lower limb injuries in the six months prior to testing. All subjects were UK size 8 and right foot dominant, which was determined by asking subjects which side they preferred for shooting. During the test, subjects wore the same brand of new football socks to prevent the socks from altering the subjects' sensation of the boot and ball.

Ethics

The investigation received ethical clearance from the institution's human research ethics committee, and each participant provided written informed consent in accordance with the requirements of the Helsinki Declaration for research using human participants.

Football boots

Two UK size 8 Umbro football boot prototype models were developed for the test (Figure 6.1). Fit was ensured from verbal feedback and palpation prior to testing. Both prototypes had the same firm ground outsole similar to the Umbro UX Accuro Pro. The uppers were also the same in terms of central lacing and the smooth white synthetic material. The boots only differed in upper padding thickness; one boot had no padding (0 mm) and the other had 8 mm of Poron Memory foam padding (density 80 P, hardness 83 ± 2, spring back 3-5 s; Figure 6.1).

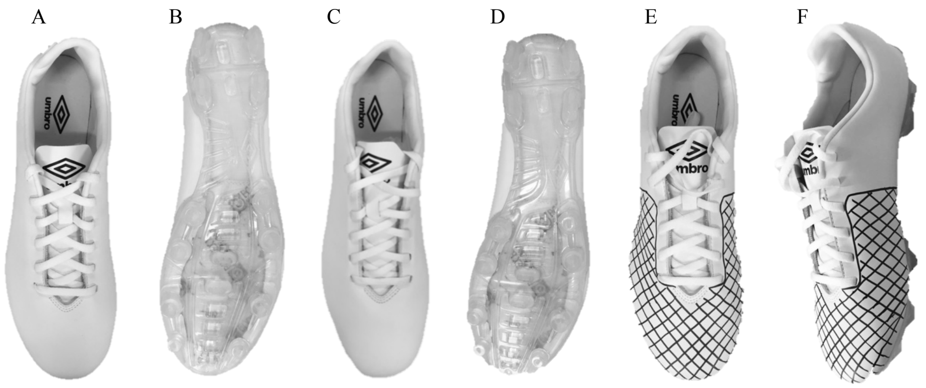


Figure 6.1. Plantar and dorsal views of the (A–B): 0 mm padded boot; and (C–F) 8 mm Poron Memory foam padded boot where (E-F) is the dorsal and medial view with the upper padding zone highlighted.

Experimental design

The protocol used was the same as for the test-retest comparison (Chapter 5). Subjects participated in two sessions each of 2 h duration separated by 7-14 days. Standardised warm up and five test shots were performed in the player's own football boots before testing started (Figure 5.2). Each session comprised assessment of the same two boot designs. The two football boots were masked and tested in a randomised order. For comparison purposes results from the 0 mm and 8 mm boot was assessed from one session each. The order picked was randomised for boot order within session and boot order between sessions. In each session 10 shots focused on shooting accuracy followed by 10 shots focused on maximum ball velocity were completed – totalling 20 shots per participants per boot (Figure 5.2). Two subjects were tested in each session and alternated every 10th successful shot to minimise fatigue (Figure 5.2). Shot where players evaluated their technique as not optimal or short were not recorded by any of the measuring tools were classified as non-successful.

Test setup and analysis of measures

The study followed the protocol validated in Chapter 5. All tests were performed on the goal on the same outdoor third generation artificial pitch (LigaTurf RS+ CoolPlus 260, Polytan, Burgheim, Germany)**.** In brief, the pitch had a 25 mm in situ rubber shock pad, the carpet fibres were 60 mm monofilament polyethylene and the infill comprised 15 kg/m^2 sand and 15 kg/m^2 rubber crumb giving a total infill height of 41 mm. Pitch testing of the player-surface interaction conducted immediately after this study using the FIFA Quality Concept methodologies (Fédération Internationale de Football

Association, 2015a), gave a force reduction of 69.6 ± 1.5%, vertical deformation of 11.4 ± 0.5 mm and rotational resistance of 31.9 ± 1.3 Nm. All measures apart from vertical deformation (advised rage 4-11 mm) were within the FIFA Quality Concept requirements. Tests were only performed under dry conditions to minimise the impact of the surface on the outcome. A single Adidas miCoach football (Adidas, Herzogenaurach, Germany) (22 cm diameter, 0.43 kg, pressure = 0.9 bar) was used for the tests. Pressure was tested before and after each test and did not change during any trial. The Adidas miCoach football was placed with the manufacturer specified orientation for each shooting instance (valve facing kicker; middle arrow facing towards centre of target) to minimise (Neilson and Jones, 2005).

Following the validated human test protocol, players used a repeated but self-chosen run up determined during the familiarisation shots. Players were instructed to repeat the same run up for every attempt. Setup was replicated from the validated human test protocol with a shooting position 16 m in front of the centre of the goal and targeting the top right corner (measured as 0.11 m lower than the bar and 0.11 m inside the post). TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) was used to measure ball velocity, which offer instant results. Accuracy was assessed using two GoPro HERO4 Black cameras (GoPro Inc., San Mateo, CA) (240 Hz, 1280x720). One camera assessed the ball passing the goal line and one assessed the ball offset from target when passing the goal line. The same synchronisation devised was used as described in Chapter 5. Radial, vertical and horizontal offsets were assessed by trigonometry from points obtained using Image-Pro Analyzer (Version 7.0, Media Cybernetics, Inc., Rockville, MD) as described in Chapter 5. Accuracy was assessed though radial offset, horizontal offset, vertical offset, success and spread. Shots were additionally assessed through offset in zones (see Chapter 5). Players' subjective perception of shooting accuracy and ball velocity were assessed on the 7-point Likert scales validated in Chapter 5.

Statistical analysis

Statistical analysis was carried out using SPSS software (Version 22.0; SPSS Inc., Chicago, IL). Results are reported as means ± standard deviations and statistical significance was set at $P \leq 0.05$. Assessment of assumptions for parametric tests were performed and based on the violation of outliers in the differences between the two related groups for some variables then non-parametric tests were applied. To analyse the effect of boot upper thickness data was split between accuracy and velocity focused shots the mean performance for each participant was used for statistical assessment. Difference in ball velocity measures (measured as actual and % of maximum ball velocity achieved) and accuracy measured by radial offset, vertical offset and horizontal offset as well as perceived performance between the 0 mm non-padded and 8 mm padded boot were assessed using non-parametric Wilcoxon's matched pair tests. Success was assessed using Fischer's exact test. Non-parametric assessment was performed due to violation of assumption that frequencies must be >5 in >20% of expected frequencies.

6.5 Results

Impact of boot upper thickness on objective and subjective ball velocity and accuracy performance

Ball velocity assessed as percentage of maximum and actual speed showed no significant difference between boot types for both accuracy and velocity focused shots (Table 6.1).

Table 6.1. Ball velocity and accuracy difference between 0 mm and 8 mm padded boots.

Skill	Variable	Boot	Mean	±SD	P-value
Accuracy	Velocity (%)	0 mm	73.0	±9.2	0.908
		8 mm	73.1	±6.7	
	Velocity ($m.s^{-1}$)	0 mm	22.7	±4.4	0.862
		8 mm	22.6	±2.7	
	Radial offset (m)	0 mm	2.31	±0.61	0.896
		8 mm	2.04	±0.45	
	Horizontal offset (m)	0 mm	-1.35	±0.71	0.983
		8 mm	-1.34	±0.62	
	Vertical offset (m)	0 mm	0.13	±0.50	0.031*
		8 mm	0.48	±0.65	
	Perceived accuracy	0 mm	3.0	±0.8	0.678
		8 mm	2.9	±0.7	
Velocity	Velocity (%)	0 mm	93.8	±2.7	0.742
		8 mm	93.0	±2.8	
	Velocity ($m.s^{-1}$)	0 mm	28.9	±2.4	0.744
		8 mm	29.0	±2.2	
	Radial offset (m)	0 mm	2.78	±1.02	0.372
		8 mm	2.94	±0.80	
	Horizontal offset (m)	0 mm	-1.81	±1.30	0.557
		8 mm	-1.98	±1.47	
	Vertical offset (m)	0 mm	0.25	±0.72	0.050*
		8 mm	0.41	±0.71	
	Perceived velocity	0 mm	2.5	±0.6	0.392
		8 mm	2.6	±0.5	

Likewise, no significant different was shown for radial offset outcomes between the two conditions for accuracy focused shots (0 mm 2.31 ± 0.61 m, 8 mm 2.04 ± 0.45 m, P = 0.896) or velocity focused shots (0 mm 2.78 ± 1.02 m, 8 mm 2.94 ± 0.80 m, P = 0.372; Table 6.1). Again, no difference was seen for the horizontal offset for accuracy focused shots (0 mm -1.35 ± 0.71 m, 8 mm -1.34 ± 0.62 m, P = 0.983) or velocity focused shots (0 mm -1.81 ± 1.30 m, 8 mm -1.98 ± 1.47 m, P = 0.557; Table 6.1). Vertical offset did, however, demonstrate significantly higher for shots above target performed in the 8 mm padded boot for both accuracy focused shots (0 mm 0.13 ± 0.50 m, 8 mm 0.48 ± 0.65 m, P = 0.031) and velocity focused kicks (0 mm 0.25 ± 0.72 m, 8 mm 0.41 ± 0.71 m, P = 0.050; Table 6.1). Players' perception of accuracy and ball velocity performance was not significantly difference between boot conditions. For the 0 mm non-padded boot, 57.8% and 58.1% of all attempts were in zone 3 (goal zone) for accuracy and velocity focused kicks respectively, whilst 28.1% and 28.2% of the attempts were in zone 1 for accuracy and velocity shots respectively (Figure 6.2). For shots performed in the 8 mm padded boot, 43.7% and 46.0% of shots were in zone 3, meaning 14.1 and 12.1 percentage points less than the 0 mm condition. Likewise, 43% and 40.7% were shot into zone 1, being 14.9 and 12.5 percentage points more than the 0 mm boot. Although not statistically different, tendencies towards differences were seen for accuracy focused shots (P = 0.069; Table 6.2) whilst no significant difference was seen for velocity focused shots (P = 0.248; Table 6.2).

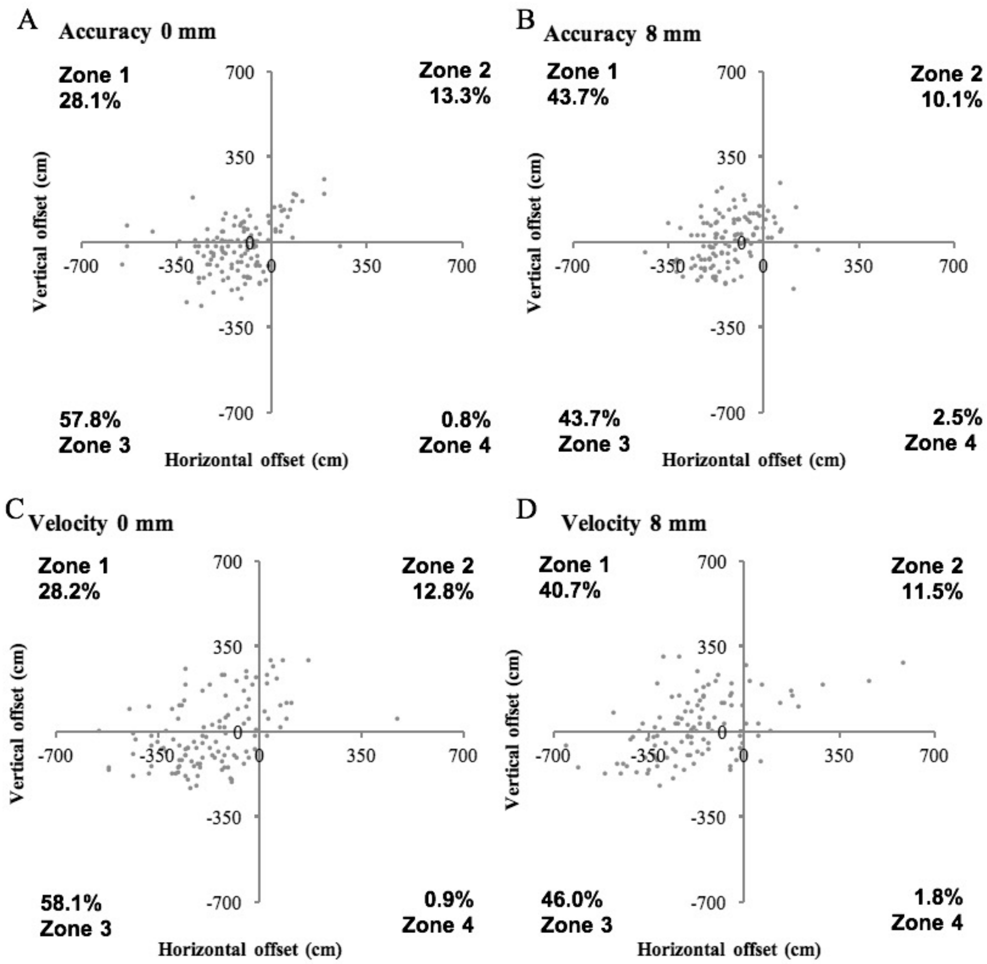


Figure 6.2A-D. Offset for Accuracy and Velocity shots split in boot type with frequency of hits within the four designated zones around the target point (0;0).

Success measured by goals scored was significantly higher for accuracy focused shot in the 0 mm non-padded football boot (P = 0.033; Table 6.3), whilst a tendency towards more goal scored in the 0 mm non-padded boot was seen for velocity focused shots (P = 0.060; Table 6.3).

Table 6.2. Grouped data comparison of success between boots.

Skill	Boot	Success	Percentage	P-value
Accuracy kick	0mm	Goal	57.8	0.033*
		No goal	42.2	
	8 mm	Goal	43.7	
		No goal	56.3	
Velocity kick	0mm	Goal	58.1	0.060
		No goal	41.9	
	8 mm	Goal	46.0	
		No goal	54.0	

Pearson's Chi^2 test. P-value significance level set at 0.05.

Table 6.3. Grouped data comparison of zonal offset between boots.

Skill	Boot	Zone	Percentage	P-value	z-score
Accuracy kick	0mm	1	28.1	0.069	1.3
		2	13.3		-0.5
		3	57.8		-1.0
		4	0.8		0.7
	8 mm	1	43.7		
		2	10.1		
		3	43.7		
		4	2.5		
Velocity kick	0mm	1	28.2	0.248	1.1
		2	12.8		-0.2
		3	58.1		-0.9
		4	0.9		0.4
	8 mm	1	40.7		
		2	11.5		
		3	46.0		
		4	1.8		

Pearson's Chi^2 test. P-value significance level set at 0.05. Z-score for post hoc significance level set at 1.96

6.6 Discussion

The aim of this study was by apply the validated protocol (Chapter 5) to assess of impact of upper padding in the football boot design on shooting performance, assessed though objective and subjective measures of accuracy and ball velocity.

Ball velocity assessed both as actual velocity and as a percentage of maximum velocity of the player demonstrated high similarities. Mean ball velocities only varied 0.1 $m.s^{-1}$ between the 0 mm non-padded boot and the 8 mm padded boot designs. Players did not perceive any differences in ball velocity either. This result is in disagreement with the theory presented by Sterzing et al. (2006), where a relationship between decreased pain and perceived improved performance was suggested. In relation to this padding was suggested to decrease discomfort and thereby improve the player's perception of performance.

When assessing single planar offset scores, no significant difference was found for radial or horizontal offset using both accuracy and velocity focused shots in the two boot models. Only vertical offset during accuracy and velocity focused shots demonstrated a significant difference. Shots in the 0 mm non-padded boot were significantly closer to target than shots performed in the 8 mm boot for both types of shots. Indeed, for the 8 mm boots the shots were, on average, placed higher above the target.

As an example, 57.8% of shots went inside the goal (zone 3), whilst the majority of misses (28.1%) went directly over the goal (zone 1) and the minority (0.8%) were wide at goal height (zone 4). This demonstrates that players do not miss in a random distribution around the target point. The offset plots suggest that, although not significant (Accuracy P = 0.069 and velocity 0.248), more shots were misplaced over the goal instead of inside the goal with the 8 mm boots compared to the 0 mm boot. When assessing success as goal/no goal comparison significantly (P = 0.033) more goals were scored in the 0 mm non-padded boot for accuracy focused shots, whilst tendencies towards a difference (P = 0.060) for velocity focused kicks. Whilst past literature has assessed accuracy through measures of radial offset, the results from this study underline the importance of assessing accuracy from multiple aspects to get a holistic perspective of accuracy. The observed increase in vertical offset and thereby increased missed chances of scoring with the padded boot is likely due to the padding causing decreased control of the contact point on the ball and foot angle at contact. Whether this is caused by the small changes in upper surface shape, decreased ability to sense the ball, or both is, however, unknown.

Only Sterzing et al. (2006) have previously assessed perception of performance. Their discovery of discrepancy between actual and perceived performance underlines the importance of assessing both aspects individually. No significant difference in perceived performance was found between boot designs in this study. It should also be added that players did not perceive any differences between designs in comfort or fit. Most players did not notice the design difference and a few players asked whether one boot was smaller than the other due to the slightly stiffer and tighter fit of the 8 mm padded boot.

The impact of upper thickness on shooting accuracy and ball velocity has not previously been assessed in the literature. Past literature have found a potential impact of boot design in particular boot brands/designs, outsole stiffness, upper friction, traction on stance leg or the toe box height parameters on ball velocity (Hennig and Zulbeck, 1999; Sterzing et al., 2006; Sterzing and Hennig, 2007b, 2007a, 2008) and by comparing boot brands/designs and maybe lacing for accuracy (Hennig et al., 2009; Kuo and Shiang, 2007). The only aspect of the design that has previously been concluded in several and more robust studies is the boot weight, which according to the research does not impact ball velocity (Amos and Morag, 2002; Moschini and Smith, 2012) as these used high speed motion analysis to track the ball velocity. Yet both studies lacked control of run up, a target, kick type and kick quality control, and no assessment of protocol reliability or validity was demonstrated. Both accuracy focused studies used accurate offset measures (pressure sensitive boards) but again, control measures were lacking. The previous literature investigating shooting accuracy has also only defined accuracy as a radial offset measure (Hennig et al., 2009; Kuo and Shiang, 2007). Yet in football the direction of the offset is crucial. Delivering above target is worse for goal shooting than attempts that are too low, as a miss above target would risk missing the goal and the goal scoring opportunity. Radial offset as well and vertical as horizontal offsets were therefore assessed in this study. Therefore, although previously studies have assessed the impact of various aspects of boot design on shooting performance, no conclusions can currently be reached. Additionally, no published research has assessed both velocity and accuracy in the same study setup. Players maybe therefore have compensated by altering the not measured performance aspect which, therefore, could act as an impacting factor and thereby altered the outcome.

Limitations

Whether longer adaptation period to the extreme boot condition could have altered the results can be speculated, as the football boot with no padding would be closer to the design players normally wore.

When altering a specific boot parameter, multiple properties of the boot are likely to change, e.g. upper stiffness for upper padding addition (Chapter 3). Additionally, altering a single boot parameter for enhancement of a single performance aspect, e.g. shooting, may have a reverse effect on other aspects of the game, e.g. performance of passing and dribbling where a more sensitive ball sensation may benefit performance. Last mentioned is assessed further in Chapter 10.

6.7 Conclusion

The results of the two boot models with varying upper thickness (no foam and 8 mm memory foam) in this study indicate that upper padding negatively impacts accuracy by increasing the vertical offset of ball flight making the play miss goal more frequently. In contrast to marketing claims of padded power boot designs, no impact was seen on ball velocity performance and the players' perceived performance. As the non-padded boot is more related to the boot design worn by most players then the lack of familiarisation to the boot may have negatively impacted the performance in the padded boot.

Finally, this study only focuses on one of many potential impacting factors. The football boot spider diagram created in Chapter 3 demonstrated the many design features which impact on performance that are still to be understood. Future research may look into the impact of outsole stiffness in relation to energy storage and therefore improved energy return during ball impact, as applied the in Puma EvoPower boot design. Another hypothesised impacting factor is outsole/stud traction of the support leg. Optimal traction can be hypothesised to improve kicking performance by minimising sliding but allowing natural foot deceleration at contact and rotation of the foot during the swing phase.

THE TOUCH/CONTROL BOOT

Introduction to Section

This section focuses on touch/control football boots. These are, as described in Chapter 2, Section 7, designed to optimise ball handling situations, especially marketed with a focus on dribbling and passing performance. A critical review of the past football literature has been conducted to evaluate how dribbling and passing performance have previously been assessed with regards to actual measures defining performance, setup and measuring tools. Based on the knowledge gained in the literature review, a validation study was developed to assess the test-retest reliability of a new, improved protocol specifically designed to assess the impact of football boot design on dribbling and passing performance. The validated protocol was then applied to compare football boot designs by assessing the impact of upper padding thickness on dribbling and passing. An outline of this touch/control boot section is demonstrated in Figure II.

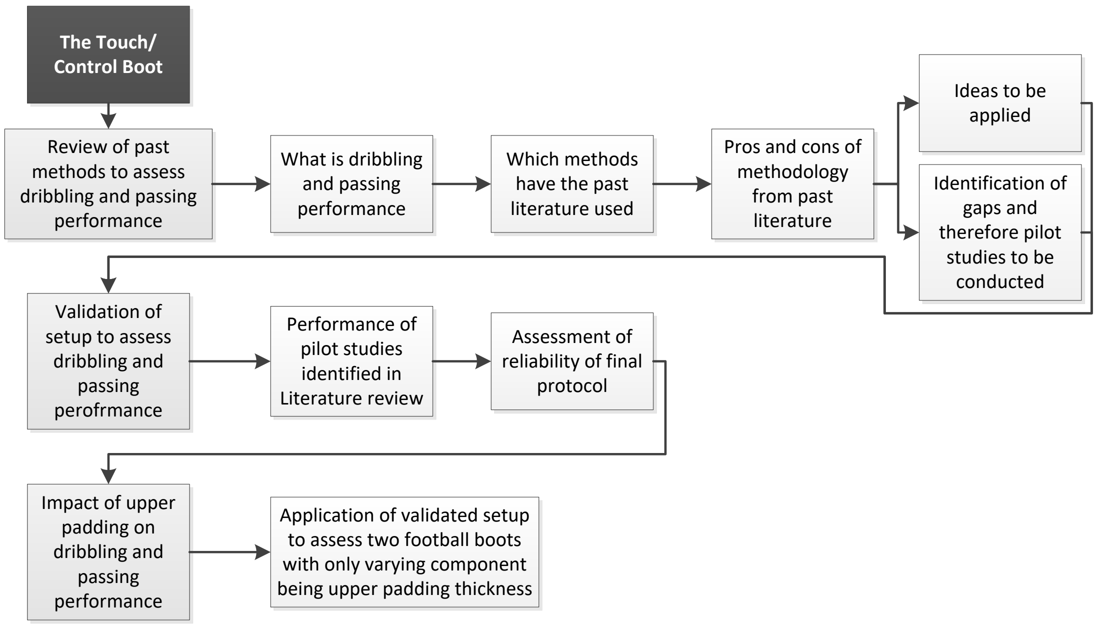


Figure II. Section outline.

CHAPTER 7

Review of Assessment Methods for Dribbling Performance

7.1 Chapter Outline

This chapter first describes dribbling in football and what defines what dribbling performance is composed of. This is followed by an assessment of past literature assessing dribbling performance in football. The assessment focuses on appropriate setup and measuring tools for the different performance aspects of dribbling in football.

7.2 Understanding Dribbling in Football

What is dribbling in football

Dribbling is when a single player in motion manoeuvres the ball with multiple touches to either avoid an opponent attempting to intercept the ball or gain territory on the pitch. The dribbling path is therefore often multidirectional.

Importance of dribbling in football

Dribbling is a fundamental aspect in football match-play. Analysis of individual actions in professional match-play has highlighted that together with short passes dribbling is the most frequently performed skills during match play. Furthermore, no significant difference was seen between defenders, midfielders and forwards in the number of dribbling sequences during a game (Bloomfield et al., 2007). The ability to dribble the ball past opposing players is a hallmark of talented players and hence is often seen to reflect a player's level skill (Haaland and Hoff, 2003; Hoare and Warr, 2000; Malina et al., 2005; Reilly and Holmes, 1983; Rösch et al., 2000). No studies have assessed the link between match outcome and dribbling success in football. Yet, it is clear that a player's ability to perform optimal dribbling sequences is essential for the team success.

What is dribbling performance composed of?

Skilful dribbling is composed of multiple performance aspects. Firstly, the player must possess a high level of ball control to be able to manoeuvre the ball close to the body and in the desired direction (Russell and Kingsley, 2011). Unlike most other sports specific skills, dribbling skill involves more freedom, which is seen by larger intra- and inter-player variation. As example, the skill of performing specific stoke types in tennis or shooting in football are related to specific biomechanics characteristics. Dribbling is, however, highly individual and should be assessed in relation to this. With an increase in player dribbling skill level, ball-boot interaction type, i.e. contact points applied on ball and boot, may vary more due to a larger repertoire of touch types managed. With larger repertoire of touch types, it can be assumed that consistency in touch types and number of touches apples decreases. Hence, variation caused by natural variation in human performance rather than poor assessment methods is likely to be seen. This is, however, yet to be confirmed through test-retest assessment.

Secondly, the player must be able to perform the dribbling sequence at high speed to prevent interception by the opponent or to rapidly gain territory (Huijgen et al., 2010; Mohr et al., 2003). Finally, the player's decision making is a critical performance component in a match play scenario where the player's dribbling performance depends on the right touch, right body position and right motion direction of the ball (Ali, 2011; McMorris et al., 1994). Last mentioned is, however, influenced by the player and not the equipment, e.g. footwear, used. Assessing how football boot design impacts performance therefore should only assess the ball control and speed aspects and these measures are described as the 'technique' of dribbling rather than the 'skill' performance per se (Ali, 2011).

7.3 Past Literature Assessing Dribbling Performance

Studies assessing any aspect of dribbling performance in football were gathered from the literature. Studies where outcome scores was grouped into general scores with other football performance aspects (e.g. passing) were not included. Twenty-two studies assessing dribbling performance in football were collected up until March 2018 from Google Scholar, MEDLINE, SPORTDiscuss and PubMed. Publication alerts were set up post literature search to minimise risk of missing papers published after the main search occurred (Table 7.1).

The majority of studies were conducted using male players and a wide range of playing levels have been assessed (Table 7.1). The studies gathered have varied test setup design s. Two studies based their setup on Zelenka et al. (1967), which is a non-validated setup originally assessing general performance in a drill containing multiple components and scored as a grouped performance score. One study applied the non-validated Reilly and Holmes (1983) setup and one the non-validated McGregor et al. (1999) setup. The only study applying a previously validated setup was based on a field hockey validated test setup by Lemmink et al. (2004) where reliability was assessed as ICC solely (ICC = 0.78). No studies applying a previously developed protocol can therefore be assumed to offer valid or reliable results. Four studies included some level of test setup validation statistics (Table 7.1). These were all developed to assess player performance. Strong absolute reliability were seen for each of these setups.

Table 7.1. Literature assessing dribbling performance.

Study (year)	N	Level	Sex	Based On	Validated (test-retest statistics)
Abt et al. (1998)	6	Recreational	Male	Mod. Zelenka et al. (1967)	-
Currell et al. (2009)	11	Recreational	Male	-	Time: P = 0.568
Figueiredo et al. (2011)	143	Players	Male	-	-
Gelen (2010)	26	Professional	Male	-	-
Haaland and Hoff (2003)	47	Players	Male	-	Time: CV = 4.3%
Hoare and Warr (2000)	17	Players	Female	-	-
Huijgen et al. (2010)	519	Academy	N/A	Lemmink et al. (2004)	-
Koltai et al. (2016)	97	N/A	Both	-	-
Mathavan (2015)	N/A	University	N/A	-	-
McGregor et al. (1999)	9	Semi-professional	Male	-	-
Mirkov et al. (2008)	20	Professional	Male	-	Time: ICC = 0.81; CV = 3.3%
Ostojic and Mazic (2002)	22	Professional	Male	McGregor et al. (1999)	-
Reilly and Holmes (1983)	40	PE students	Male	-	-
Russell et al. (2010)	15	English Championship	Male	McGregor et al. (1999)	Speed: ICC = 0.78**; CV = 2.4% Accuracy: ICC = 0.77**; CV = 4.6% Success: ICC = 0.40*; CV = 2.2%
Rösch et al. (2000)	588	Mixed	N/A	-	-
Santhosh and Sivakumar (2015)	120	University league	Male	-	-
Silassie and Demena (2016)	52	Club	Male	-	-
Sterzing et al. (2011)	19	4^{th}-10^{th} league Germany	Male	-	-
Stone and Oliver (2009)	9	Semi-professional	Male	Reilly and Holmes (1983)	-
Vanderford et al. (2004)	59	U14-U16	Male	Mod. Zelenka et al. (1967)	-
Vänttinen et al. (2010)	36	Players	Male	-	-
Zago et al. (2016)	10	U13 sub-elite	Male	-	-

Level = playing level as described by authors in publication; PE = physical education; N = number of participants; N/A = no information available; P = p-level; ICC = intraclass correlation coefficient; CV = coefficient of variance.

External factors can impact results and should therefore be identified and controlled. These are described further in Appendix F. Other more specific test setups to assess dribbling are described in more details in the following sections.

Dribbling movements performed

Most studies apply slalom or zig-zag dribbling sequences around cones placed with varying distance from each other, comparable to classic coaching techniques of dribbling (Table 7.2). This movement pattern demands many touches to maintain control due to the constant change in direction. Other studies have used primarily linear movements with occasional sharp turns (Figueiredo et al., 2011; Hoare and Warr, 2000). More linear movement may replicate common in-play dribbling scenarios but not challenge the player's ball control as linear movements allow players to decrease the number of touches by allowing the ball to roll longer between touches, which is not a typical action during match-play as such movements are commonly intercepted by the opponent. Therefore, drills should be testing the players' technique by involving changes in direction forcing players to keep the ball close to the body. These changes in direction can be of various designs instead of just a continuous slalom or zig-zag movement.

Length of drill

The drill length applied varies in the literature and none of the studies have argued why the applied length was chosen (Table 7.2). Dribbling sequences during match-play are normally short, however, to collect the desired amount of data and improve quality of dribbling time measure then a higher number of touches and a longer dribbling distance is needed. The increased length should, however, not induce fatigue and adequate rest period between repetitions of these longer dribbling sequences should be addressed (Russell and Kingsley, 2011).

Running velocity

Bate (1996) argued that ability to perform at high speed rather than facets of perceptual, cognitive and motor skill make up soccer skill. A player with good ball control will be at higher risk of losing the ball if a high speed is not generated. Instructing players to complete the drill in minimal time is therefore desirable to stress players when assessing dribbling performance.

Table 7.2. Drill type applied in previous literature.

Study (year)	Drill type	Length	Touch control
Abt et al. (1998)	Slalom	4 cones – line – 12 m	N/A
Currell et al. (2009)	Slalom	5 cones – line – 9.14 m x2	N/A
Figueiredo et al. (2011)	9x9 m square	4 cones – Square – 36 m	Foot
Gelen (2010)	Zig-zag	4 cones – line – 10 m	N/A
Haaland and Hoff (2003)	Slalom	5 cones – line - 6 m x2	Inside & outside foot
Hoare and Warr (2000)	Slalom	12 cones – line – 17 m x2	N/A
	T test	4 cones – T shape – 5 m	N/A
Huijgen et al. (2010)	Linear	Line – 30 m	N/A
	Slalom	12 cones – 2 parallel lines (2 m width) – 15 m	N/A
Koltai et al. (2016)	Complex slalom	8 cones – complex – N/A	N/A
Mathavan (2015)	Circular slalom	12 cones – circle – N/A	N/A
McGregor et al. (1999)	Slalom	7 cones – line – 18 m x2	N/A
Mirkov et al. (2008)	100° zig-zag	5 cones – zig-zag – 20 m	N/A
Ostojic and Mazic (2002)	Slalom	7 cones – line – 18 m x2	N/A
Reilly and Holmes (1983)	Slalom	5 cones – line – 0.91-1.83 m	N/A
	Zig-zag	6 cones – zig-zag – 5 x 4.88 m + 7.32 m & 9.14 m linear run	N/A
Russell et al. (2010)	Slalom	7 cones – line – 20 m	N/A
Rösch et al. (2000)	Complex slalom	10 come – complex – N/A	N/A
Santhosh and Sivakumar (2015)	Circular slalom	12 cones – circle – N/A	N/A
Silassie and Demena (2016)	Zigzag	N/A	N/A
Sterzing et al. (2011)	Slalom	6 cones – complex – 8.5 m	N/A
Stone and Oliver (2009)	Complex	8 cones – complex – ~40 m	N/A
Vanderford et al. (2004)	N/A	N/A	N/A
Vänttinen et al. (2010)	Slalom	8 cones – line – 20 m x2	N/A
Zago et al. (2016)	Figure 8 shape	3 cones – line – 4.3 m	Single foot

N/A = no information available; x2 = twice.

Touch control

Only two study gave players instructions on how they were allowed to touch the ball throughout the drill (Table 7.2). It can be argued that restricting touch types would restrict the player from performing what may appear natural and thereby lower the ecological validity of the test. Allowing players the freedom to touch the ball as appears natural to them is therefore desired.

7.4 Methods to Measure Dribbling Time

Measures

All studies apart from Russell et al. (2010) and Zago et al. (2016) used completion time as a single measure of dribbling performance (Table 7.3). The result from timed dribbling drills with speed as the only outcome measure offers no understanding of the quality of the technique, i.e. ball control (Russell and Kingsley, 2011). A player with high dribbling skills can keep the ball close to the desired position whilst moving at high speed without focusing on ball control will increase the steps and likelihood of losing possession of the ball. Assessing completion time is one performance measure but should not be the only measure of performance

Table 7.3. Measures and measuring tools used applied in past literature.

Study (year)	Measure	Measuring tool
Abt et al. (1998)	Time	Stopwatch
Currell et al. (2009)	Time	Electronic time gates
Figueiredo et al. (2011)	Time	Stop watch
Gelen (2010)	Time	Electronic time gates
Haaland and Hoff (2003)	Time	Stop watch
Hoare and Warr (2000)	N/A	N/A
Huijgen et al. (2010)	Time	Electronic time gates (linear)
		Stopwatch (zig-zag)
Koltai et al. (2016)	Time	Electronic time gates
Mathavan (2015)	Time	N/A
McGregor et al. (1999)	Time	Stopwatch
Mirkov et al. (2008)	Time	Electronic time gates
Ostojic and Mazic (2002)	Time	N/A
Reilly and Holmes (1983)	Time	N/A
Russell et al. (2010)	Ball velocity	50 Hz video
	Accuracy	50 Hz video
	Success	50 Hz video
Rösch et al. (2000)	Time	Stopwatch
Santhosh and Sivakumar (2015)	Time	N/A
Silassie and Demena (2016)	Time	Stopwatch
Sterzing et al. (2011)	Time	Electronic time gates
Stone and Oliver (2009)	Time	Electronic time gates
Vanderford et al. (2004)	Time	N/A
Vänttinen et al. (2010)	Time	Electronic time gates
Zago et al. (2016)	Time,	Motion capture
	Ball contacts	Motion capture
	Stride length	Motion capture
	Centre of mass	Motion capture

Drill is indicated in brackets where several tool have been applied depending on drill type; N/A = no information available.

Equipment

Drill completion time has been assessed using multiple timing measuring tools (Table 7.3). Some studies do not include the measuring tool, which blocks readers from understanding the level of accuracy that time was assessed with. Seven studies assessed time with a stopwatch which allows a large level of human error. Human reaction time is typically 0.15-0.30 s (Fischer and Rogal, 1986) and previous research has suggested both systematic and random error when comparing handheld stopwatch timing with electronic timing (Haugen and Buchheit, 2016; Hetzler et al., 2008; Moore et al., 2007). The potential level of measuring error using stopwatch is therefore large. This lowers the quality of the data published applying the stopwatch measuring method and applying an alternative measuring tool can therefore only be recommended. The second most applied tool to assess time was electronic time gates. With these the human error level based on the examiner is eliminated, however electronic time gates assess the first body part crossing the line. With a commonly used height of ~1.0 m above the ground then gates will capture either leg, hip or arm movement. However this will vary depending on the height of the runner and where runner is in the gate cycle when passing the line (Altmann et al., 2017; Cronin and Templeton, 2008). Applying electronic time gates therefore allow research to assess time without the impact of human error but the potential inconsistency in body part measured decreases the reliability of measured obtained. The International Association of Athletics Federations apply high speed video as their "gold standard" measuring tool (Haugen and Buchheit, 2016). Zago et al. (2016) applied motion capture system which is a reliable tool for assessing speed as well (Dorociak and Cuddeford, 1995; Whiteside et al., 2013; Windolf et al., 2008) and useful if already applied for kinematic or dynamics assessment. The setup is however complex and time consuming whilst high speed video analysis is less demanding to apply. Russell et al. (2010) assessed the ball speed rather than player completion time using 50 Hz video recordings. A method which, if the ball is controlled close to the body when crossing the measuring finish line can be used as a time performance measuring tool. Additionally, the way the time data is treated varies. For example, McGregor et al. (1999) used the sum of the times from all trials whilst the majority used the best or mean of all trials as the outcome. Also Mirkov et al. (2008) used a unique calculation method: a ratio between time to finish drill with and without ball as their outcome measure.

Application of a reliable and valid measuring tool assessing completion time is needed. The majority of studies apply methods identified by literature to lack reliability. High speed video assessment, also used to assess professional athletics sprint times, is an easily applicable tool to reliably assess time. Other more demanding methods can also be assessed e.g. an motion capture system.

7.5 Methods to Measure Dribbling Ball Control

Measures

Being largely neglected in dribbling performance research (Table 7.3), the assessment of ball control is still an important performance aspect. The lack of understanding of performance from solely time/speed measures has been highlighted in past literature (O'Reilly and Wong, 2012; Russell and Kingsley, 2011). Two studies included measures of ball control performance. Russell et al. (2010) and Zago et al. (2016) were the only studies assessing direct measures of ball control in addition to the time performance measure. Precision (offset from cone) and success rate (passing cones without the ball touching the cone or lost control) were assessed by Russell et al. (2010) and count of ball-boot contacts, player stride length and player centre of mass in the Zago et al. (2016) study. Number of touches and offset from cones describe the player's ability to navigate the ball through the drill and hence provide measures of ball control. Success as a count of successfully navigating around a cone without losing or touching the ball is a relative score. It must be clearly identified when a ball is classified as 'lost', which was lacking in the Russell et al. (2010) study. Player stride length is highly individual and has, to the author's knowledge, not been identified as a measure of dribbling performance. Additionally, centre of mass is more a measure of the player's performance than how external factors, e.g. footwear, impacts performance.

Equipment

A motion capture system was used by Zago et al. (2016) and 2-D video (50 Hz) was applied by Russell et al. (2010). Both offer an objective method to assess ball control measures. However, an motion capture system is expensive and therefore might not be accessible, especially to the football boot industry. It is additionally a complex setup and sensitive when performing testing outdoor. Alternatively, 2-D video analysis is an affordable, portable and easily applicable assessment tool. The application of 2-D high speed video analysis was also validated in the Russell et al. (2010) setup (Table 7.1). 2-D high speed video analysis may additionally be applied to assess number of touches. A 2-D high speed video may however not be able to assess player stride length and player centre of mass, if desired.

7.6 Methods for Assessment of Perception of Dribbling Performance

No studies on passing performance included assessment of the players' perception of performance (Table 7.3). It is generally accepted that perception of performance does not always relate to objective performance measures. It is also appreciated that perception may be subjective or dependent on footwear fit, which varies with foot and football boot shape (Kinchington, 2003; Kinchington et al., 2012). More research is, however, needed to fully understand this matter. With the knowledge available today it may therefore still be important to assess both, in order to gain a holistic understanding of perception, performance and for the industry to better understand their consumers.

7.7 Summary

The majority of studies gathered in this review partially assessed performance by solely assessing completion time. Lacking a holistic assessment of performance, applying single measures of time can mask compensation in ball control and therefore not represent true match-play performance. It must therefore be emphasised that performance is multifactorial and should be assessed as such. Completion time should therefore be measured in line with ball handling measures. These include number of touches and offset from cones. It is important that compensation in one measure can improve performance in another and performance therefore should be assessed from a holistic perspective of all measure.

It was already evident from the review in Chapter 2 that no study has focused on assessing the impact of external factors such as football boot design. Additionally, the review discovered that the minority of studies applied a validated setup and the setup applied varied on a broad range of parameters. This review concluded that when assessing dribbling performance, the dribbling drill has to stress player but be accomplishable. The drill length has to be long enough to achieve a satisfactory number of measures but not fatigue subject. Pilot testing should identify whether a drill structure is satisfactory within these parameters. Ecological validity would benefit from subjects not being restricted by ball-boot interactive restrictions. Subject perception of performance has been neglected and may add an additional dimension for the industry to understand the consumers.

Football boot research would benefit from a validated test setup from which the impact of football boot design on performance can be understood. These then potentially impacting design variations can be determined from the spider diagram presented in Chapter 3.

CHAPTER 8

Review of Assessment Methods for Passing Performance

8.1 Chapter Outline

This chapter first describes passing in football and what defines what passing performance is composed of. This is followed by an assessment of past literature assessing passing performance in football. The assessment focuses on appropriate setup and measuring tools for the different performance aspects of passing in football.

8.2 Understanding Passing in Football

What is passing in football

Passing is when the player delivers the ball to another player by either rolling it along the ground or delivering it through the air. Bloomfield et al. (2007) defined passing to involve a spectrum of types (long air, short air, long ground, short ground, other) and how they are performed (right/left foot, header, backheel, overhead, other). The most common types being either rolling it along the ground or delivering it through the air both performed with the foot. To simplify and to relate the research to football boots, the studies reviewed will only involve passes performed with the foot.

Importance of passing in football

Analysis of individual actions in professional football games has highlighted that, together with dribbling, short passes are the most frequently performed skills during match play (Bloomfield et al., 2007). With midfield players performing significantly more passes during a match than strikers and defenders (number of passes: midfielders 27.3 ± 28.8, strikers 13.9 ± 9.6, defenders 9.0 ± 7.8) and strikers performing significantly fewer long air passes (1.3 ± 2.5 per match) than midfielders and defenders (7.0 ± 6.9, 9.7 ± 6.9 per match; Bloomfield et al., 2007).

Differences in number of passes have shown to be related to success in football. It has been reported that the top five teams in the Italian Serie A league complete more short passes (< 37 m) than their less successful counterparts (Rampinini et al., 2009). It has also been demonstrated that longer passing sequences are associated with an increased number of goals per possession in successful teams (Hughes and Franks, 2005) and an early study assessing passing proficiency in international competitions found that 57% of goals were scored after a period of play that includes short passes (Olsen, 1988). It is therefore evident that optimal passing performance is crucial in football.

What is passing performance composed of

Skilful passing in football is composed of multiple performance aspects. It must be appreciated that several types of passing exist but general to performance for them all is the demand of accuracy in the pass. A pass is typically performed towards a teammate standing still or moving into space and the ball therefore needs to reach the player without the receiver having to move/change running path to receive the ball to prevent the receiver to miss the ball, struggle to control the ball or interception by an opponent player. Additionally, the ball speed is essential for passing performance. A slow ball is likely to be intercepted before reaching the target player. Conversely, a fast ball might not be controllable for the target player and if the target player is in motion then the interception point is critical for success. Additionally, the player's decision making and technique are critical performance components in a match play scenario (Ali, 2011; McMorris et al., 1994). Assessing how football boot design should therefore primarily evaluate the ball control and speed aspects of performance.

8.3 Past Literature Assessing Passing Performance

Studies assessing any aspect of passing performance with outcome scores not grouped into general scores with other football performance aspects (e.g. dribbling) were gathered from the literature. Thirteen studies assessing passing performance in football were obtained up until March 2018 from Google Scholar, MEDLINE, SPORTDiscuss and PubMed. Publication alerts were set up post literature search to minimise risk of missing papers published after the main search occurred (Table 7.4). The majority of studies were conducted using male players and a wide range of playing levels have been assessed (Table 7.4). The studies gathered have a varied test setups design. Five studies included some level of test setup validation statistics and five studies applied the validated test setup by (Ali et al., 2007a; Table 7.4).

External factors can impact results and should therefore be identified and controlled. These are described further in Appendix F. Other more specific test setups to assess passing are described in more details in the following sections.

Type of pass

None of the studies gathered included any specification on instructions given to the players on technique (Table 7.5). This means that players may have used any part of the foot as the contact point with the ball. Seven studies instructed players to perform flat passes rolling over ground, one applied airborne passing, and five did not include any description of the assessed pass type. A different technique is used when passing the ball by the ground or in the air and the application of these pass types vary depending on the game scenario. It is therefore firstly important to include description of the type of pass and to assess both flat and airborne passes when defining passing performance.

Table 7.4. Literature assessing passing performance.

Study (year)	N	Level	Sex	Based on	Validated/Re-validated
Ali et al. (2007a)	48	University	Male	-	Time: ICC = 0.70**, CV = 4.7% Penalty time: ICC = 0.58** Perform. time: ICC = 0.64**, CV = 14.4%
Ali et al. (2007b)	16	Semi-professional & University	Male	Ali et al. (2007a)	-
Bullock et al. (2012)	42	Amateur	Male	Mod. Ali et al. (2007a)	Time: CV = 3.5% Points: CV = 2.4%
Foskett et al. (2009)	12	N/A	Male	Ali et al. (2007a)	-
Gant et al. (2010)	15	Premier-grade	Male	Ali et al. (2007a)	-
Haaland and Hoff (2003)	47	Players	Male	-	CV = 11.3%
Hoare and Warr (2000)	17	Players	Female	-	-
Lyons et al. (2006)	20	College	Male	Ali et al. (2007a)	-
Northcott et al. (1999)	10	Collegiate	Male	-	-
Rostgaard et al. (2008)	14	Elite	Male	-	-
	7	Sub-elite	Male		
Russell et al. (2010)	15	English Championship	Male	-	Speed: ICC = 0.76**; CV = 6.5% Accuracy: ICC = 0.51**; CV = 10.0% Success: ICC = 0.43*; CV = 11.7%
Rösch et al. (2000)	588	High & low	N/A	-	-
Sterzing et al. (2011)	19	4th-10th league Germany	Male	-	-
Vänttinen et al. (2010)	12	Players	Male	-	R assessed for full battery
	12	Players	Male		
	12	Players	Male		

N = number of participants; Level = playing level as described by authors in publication; N/A = no information available, Perform. = Performance; ICC = intraclass correlation coefficient; CV = coefficient of variance; R = Pearson correlation coefficient.

Length of pass

A large variance of distances has been used when assessing passing performance (Table 7.5). The mean ± standard deviation for passing length assessed was 10.3±10.0 m, but a range of 3.5 m to 36 m underlines a large variance in assessment method used. Additionally, none of the studies added any argumentation for their chosen passing length. To enhance ecological validity and optimise the assessment then typical passing lengths in football need to be understood. Additionally, passing length should be defined in relation to target size to challenge the players at an appropriate level, meaning to test the player whilst being possible with a target evaluation zone size large enough to not miss any attempts.

Table 7.5. Pass type, passing distance and target used in past literature.

Study (year)	N	Type of pass	Air/ground	Distance (m)	Target	Size (m)	Start
Ali et al. (2007a)	8 short + 8 long	N/A	Ground	3.5 & 4.0	Plate	0.1	Dynamic
Ali et al. (2007b)	8 short + 8 long	N/A	Ground	3.5 & 4.0	Plate	0.1	Dynamic
Bullock et al. (2012)	5 right + 5 left	N/A	Ground	2.5	Plate	0.1	Dynamic
Foskett et al. (2009)	8 short + 8 long	N/A	Ground	3.5 & 4.0	Plate	0.1	Dynamic
Gant et al. (2010)	8 short + 8 long	N/A	Ground	3.5 & 4.0	Plate	0.1	Dynamic
Haaland and Hoff (2003)	15 right + 15 left	N/A	Ground	10	Mini goal	1 x 0.4	Dynamic
Hoare and Warr (2000)	15 min x2	N/A	N/A	5 + 10	Player	-	Dynamic
Lyons et al. (2006)	8 short	N/A	Ground	4.25 & 5.0	Plate	0.1	Dynamic
Northcott et al. (1999)	2	N/A	N/A	10	Plate	3.33	N/A
	1	N/A	N/A	20	Plate	3.33	N/A
	1	N/A	N/A	30	Plate	3.33	N/A
Rostgaard et al. (2008)	10	N/A	Air	30	Test leader	6 x 3	Dynamic
Russell et al. (2010)	28	N/A	N/A	4.2 + 7.9	Plate	0.50 x 0.25	Dynamic
Rösch et al. (2000)	5	N/A	N/A	11	Hockey goal	N/A	Dynamic
	5	N/A	N/A	36	Circle on floor	r = 2	Static
Vänttinen et al. (2010)	5 successful	N/A	N/A	7	Between 2 lights	1	Dynamic

N = Number of passes completed; r = radius; N/A = No information available.

Target type and size

No consensus is present in the literature on the target type or size (Table 7.5). The Ali et al. (2007b) setup, which was applied in several studies (Table 7.5) defined targets as a square of plates on which the player would bounce the ball on whilst targeting the centre (0.1 m zone). Others applied a mini goal (Haaland and Hoff, 2003; Rösch et al., 2000), one study applied the test leader as the target, who is allowed to move within a small zone to receive the ball (Rostgaard et al., 2008), one study applied passing between players who are standing in from of each other (Hoare and Warr, 2000), one study applied a random sequence of 1 m wide flashing light gates to introduce a level of surprise. It is therefore evident that many different target setups have been with varying target sizes, which may be related to the large variation in distance (mentioned above). Applying a mini goal, zone or person as target does not allow the assessor to quantify the offset from target but instead either score accuracy as a pass/fail or zonal point score. The issues with scoring system like these will be discussed further under appropriate methods for measuring ball accuracy in passing. Finally, the target should be large enough to be able to assess all passes performed. This can only be established through pilot testing once an appropriate passing distance has been identified.

Start position

Many studies replicated the methods by Ali et al. (2007b) where the player bounces the ball off a wall after which the player must turn and pass the ball. This together with setups where the player receives the ball (Haaland and Hoff, 2003; Hoare and Warr, 2000; Russell et al., 2010) all involve a level of control before performing the pass. The accuracy of the pass is therefore affected by the ability to control the ball appropriately and the accuracy of the ball path. Other studies allow the player to start with the ball but from an active start (Bullock et al., 2012; Rösch et al., 2000; Rostgaard et al., 2008; Vänttinen et al., 2010; Zelenka et al., 1967). By doing so the passing performance is dependent on the player's dribbling ability and ball control prior to the pass. These setups allow the researcher to analyse the players' skill level but whether an inaccurate pass is caused by a poor passing technique or by another factor such as poor control of the ball is not measurable with this setup. To avoid impacting factors and purely test passing ability, the a 'dead ball' scenario like Rösch et al. (2000) performed should be used.

8.4 Appropriate Methods for Measuring Ball Accuracy in Passing

The two main ways of dividing the offset measure is by splitting the methods into indirect measures of offset through point scoring systems or count systems and direct measures of offset assessing the actual offset distance from target.

The majority of studies have applied indirect measures of offset (Table 7.6). The Ali et al. (2007a) based studies used a point system. These were subsequently converted into penalty seconds and then added to the total completion time of the passing drill. By doing so, several factors influence the total score. This may be beneficial when analysing a player's skill level but the Ali et al. (2007a) protocol is not beneficial to obtain information on single parameters such as passing accuracy. And despite its popularity in the research (Table 7.4) then their methodology and measuring technique has already met some critique in the literature for providing outcomes that have limited practical application due to the point-second conversion methodology (O'Reilly and Wong, 2012; Russell and Kingsley, 2011). Hoare and Warr (2000) used a subjective evaluation from the observers to score the accuracy of passes. Players were instructed to pass the ball over distances of 5 m for 15 min. Experienced coaches would then decide on performance ability. This type of methodology has many inherent errors including the subjective opinions of coaches. Northcott et al. (1999), Rostgaard et al. (2008), Rösch et al. (2000) and Vänttinen et al. (2010) all used a point system to quantify the offset. This was done by adding point zones around the target. This improves the understanding of the offset but is still not a precise measure. Also, when comparing scores then it should be mentioned that some use lower points when being closer to the target (Northcott et al., 1999; Rostgaard et al., 2008) whilst others used higher points (Rösch et al., 2000). The reader should therefore be cautious when interpreting point scores from different studies. Finally, Haaland and Hoff (2003) simply counted the number of successful attempts to place the ball in a mini goal. Accuracy is, however, difficult to quantify objectively no matter which point scoring system applied. When individuals define a penalty score or dimensions of a point zones, results will be impacted. There is, therefore, no optimal method to quantify offset using these systems. Only a single study (Russell et al., 2010) applied direct measure offset by assessing the actual offset distance (Table 7.6).

A study trying to measure the effect of an impacting factor on a player's passing accuracy should try to make the measure as accurate and precise as possible. It is therefore surprising that many methods have been used but only one study used the actual offset distance to measure the accuracy of the pass.

Table 7.6. Measures and measuring tools used applied in past literature.

Study (year)	Measure	Measuring tool
Ali et al. (2007a)	Accuracy (time)	Visual + hand-held stopwatch
Ali et al. (2007b)	Accuracy (time)	N/A
Bullock et al. (2012)	Accuracy (time)	N/A
Foskett et al. (2009)	Accuracy (time)	N/A
Gant et al. (2010)	Accuracy (time)	N/A
Haaland and Hoff (2003)	Success (count)	
Hoare and Warr (2000)	Quality	Subjective
Lyons et al. (2006)	Accuracy (time)	N/A
Northcott et al. (1999)	Accuracy (points)	N/A
Rostgaard et al. (2008)	Success (points)	N/A
Russell et al. (2010)	Speed	50 Hz video
	Accuracy	50 Hz video
	Success (count)	50 Hz video
Rösch et al. (2000)	Success (points)	N/A
Vänttinen et al. (2010)	Time	Motion capture system
	Accuracy (points)	Motion capture system

N/A = no information available.

Equipment

In addition to most studies applying points or count systems then little information on equipment used in the previous literature is available. Half the studies did not include a description of the measuring tool used (Table 7.6). Only Russell et al. (2010) and Vänttinen et al. (2010) described the application of systems to measure passing accuracy performance. Vänttinen et al. (2010), however, applied a simplified zonal measuring technique despite obtaining data of the actual offset. Russell et al. (2010) applied 2-D video recording and direct linear transformation method to assess the actual distance from target. This is the most accurate method applied in the literature but still demonstrated a coefficient of variance of 10.0%. The motion capture systems applied by Vänttinen et al. (2010) is, therefore, applicable however complex and time consuming whilst high speed video analysis is therefore a less demanding assessment method.

8.5 Appropriate Methods for Measuring Ball Velocity in Passing

Only a single study collected any measure of the ball velocity (Table 7.6). According to the speed-accuracy trade-off theory, an increase in velocity causes a decrease in accuracy, meaning a decrease level of ball control and vice versa (Fitts, 1954; Okholm Kryger et al., 2016). A player could therefore benefit from lowering the ball velocity to improve the accuracy of the passing during testing.

Equipment

A single study used a marked circle on the floor with a marked radius of 2 m (Rösch et al., 2000). The aim for the player was to place the ball within the circle like a curling scenario. The player therefore had to adjust both the accuracy of the direction as well as the velocity. This is a simple method to take velocity in to consideration. A quantitative measure of ball velocity is however accurate and ecologically valid, as passes are normally received and controlled by the receiving team mate whilst still in motion, which controverts the setup applied by Rösch et al. (2000). Vänttinen et al., 2010 applied a motion capture system (50 Hz) to assess the time from the moment passing impact occurred to the moment when the ball entered the accuracy zone. This is, however, not a measure of ball velocity but rather the length of time taken and cannot be applied as a measure of velocity as the distance travelled varied with offset to target. Russell et al. (2010) assessed ball velocity using direct linear transformed 2-D video (50Hz). Ball velocity measures were demonstrated to have a coefficient of variance of 6.5% and standard error of mean of ± 1.0 m.s^{-1}. It was, however, not clear where during the pass that the ball velocity was recorded. Friction will slow down the ball as it rolls over the grass and for study comparison purposes then it is important to identify at what point the pass of the ball velocity is recorded.

8.6 Methods for Assessment of Perception of Passing Performance

No studies on passing performance included assessment of the players' perception of performance (Table 7.6). As discussed in Chapter 4, more research is needed on player perception but it is still important to assess both to get a holistic understanding of perception, performance and for the industry to better understand their consumers.

8.7 Summary

Similar to dribbling research, the majority of studies gathered for this review on assessment of passing performance only partially assessed performance. It must be emphasised, again, that performance is multifactorial. Assessing passing solely from offset from target allows subjects to compensate and decrease offset by lowering the ball velocity, which in match-play would lower performance and the pass would have an increased risk of being intercepted by the opponent or slow down the game. Measures of ball velocity should therefore not be neglected when assessing passing performance.

It was already evident from the review made in Chapter 2 that no study has focused on assessing the impact of external factors such as football boot design. Additionally, the review discovered that the minority of studies applied a validated setup and the setup applied varied on a broad range of parameters. This review concluded that it is important to be clearer on type of pass performed and the technique applied for this pass. A better understanding of typical pass length in football for both flat and airborne passes is needed. There needs to be an acknowledgement and distinct separation between flat passes and airborne passes and the technique used for the two.

Start position was often dynamic, which is useful when assessing the skill level of a subject but when assessing external factors such as football boot testing then the impact of skill level should be minimised. Static starting position is therefore suggested, despite a level of ecological validity lost.

As mentioned in the dribbling review, football boot research would benefit from a validated test setup from which the impact of football boot design on performance can be understood. These then potentially impacting design variations can be determined from the spider diagram presented in Chapter 3.

CHAPTER 9

Validation of Human Testing Protocol for Assessing Performance of Football Boot Design through Dribbling, Short Passing and Long Passing

9.1 Chapter Outline

The literature review (Chapter 2) highlighted that no validated protocol has been applied to assess the impact football boot design on dribbling and passing performance in football. Through the knowledge obtained from a literature review on previous methods applied to assess dribbling and passing performance in football and pilot studies to fill gaps in the knowledge a novel protocol was developed. This chapter describes test-retest assessment of the reliability of this protocol using content validated of equipment (performed in Appendix H).

9.2 Aim

This study aimed to formulate and validate a new protocol for the assessment of passing and dribbling performance through a multi-factorial and controlled approach. The setup was structured to be easy to apply and demand no more than two researchers to run yet be ecologically valid and produce transferable results.

9.3 Methods

Participants

Eight skilled male football players (age 20.7 ± 1.2 years, height 1.74 ± 0.03 m, mass 71.8 ± 7.9 kg) were recruited from the University 1st football and futsal teams. All futsal players had a history as a football player prior to University and all players recruited had 9 ± 4 years experience of club level football. None of the subjects had suffered from match-preventive lower limb injuries in the six months prior to testing. All subjects were UK size 8 and right foot dominant, which was determined by asking subjects which side they preferred for kicking. During the test, subjects wore the same brand of new football socks to prevent the socks from altering the subjects' sensation of the boot and ball.

Ethics

The investigation received ethical clearance from the institution's human research ethics committee, and each participant provided written informed consent in accordance with the requirements of the Helsinki Declaration for research using human participants.

Football boots

UK size 8 Umbro prototype football boots were developed for the test (Figure 9.1). Fit was ensured from verbal feedback and palpation prior to testing. The boots had a smooth white synthetic upper with no additional padding, central lacing and a black firm ground outsole similar to the Umbro UX Accuro Pro.

Figure 9.1. Plantar and dorsal view of football boots used.

Experimental design

Subjects participated in two sessions, each of 2 h duration, separated by 5-7 days. Standardised warm up and familiarisation of each drill were performed in their own football boots prior to testing. The testing involved three drills - dribbling, short passing and long passing, which were completed in this order throughout. Two familiarisation runs and six recorded trials of the dribbling drill were completed. Five familiarisation passes and eight recorded trials were performed for both short and long passes. Two subjects were tested in each session and alternated trials throughout to minimise fatigue.

Test setup

The same ball, an Adidas Brazuca football (Adidas, Herzogenaurach, Germany; 22 cm diameter, 0.43 kg mass, 0.9 bar pressure), was used in all sessions. Pressure was tested before and after each session with no measurable change during the session. Tests were performed on the same outdoor third generation artificial pitch (LigaTurf RS+ CoolPlus 260, Polytan, Burgheim, Germany)**.** In brief, the pitch had a 25 mm in situ rubber shock pad, the carpet fibres were 60 mm monofilament polyethylene and the infill comprised 15 kg.m^{-2} sand and 15 kg.m^{-2} rubber crumb giving a total infill height of 41 mm. Pitch testing using the FIFA Quality Concept methodologies (Fédération Internationale de Football Association, 2015), gave a force reduction of 69.6 ± 1.5%, vertical deformation of 11.4 ± 0.5 mm and rotational resistance of 31.9 ± 1.3 Nm. Tests were only performed under dry conditions.

The dribbling test setup incorporated two tasks: loop turn dribbling and zig-zag dribbling (Figure 9.2). Subjects started by performing eight loop dribbles. After the loop turns the path carried on into eight zig-zag cuts. Cones were placed in two parallel lines 1.6 m apart. Cones within each line were placed 3 m apart. The dimensions were chosen based on pilot testing; with sufficient turns to gather repeated data sets for analysis without inducing fatigue to subjects and appropriately narrow turns to challenge the subject's dribbling ability. Subjects were instructed to complete the drill as fast as possible without losing ball control. They were free to use any part of either foot to control the ball.

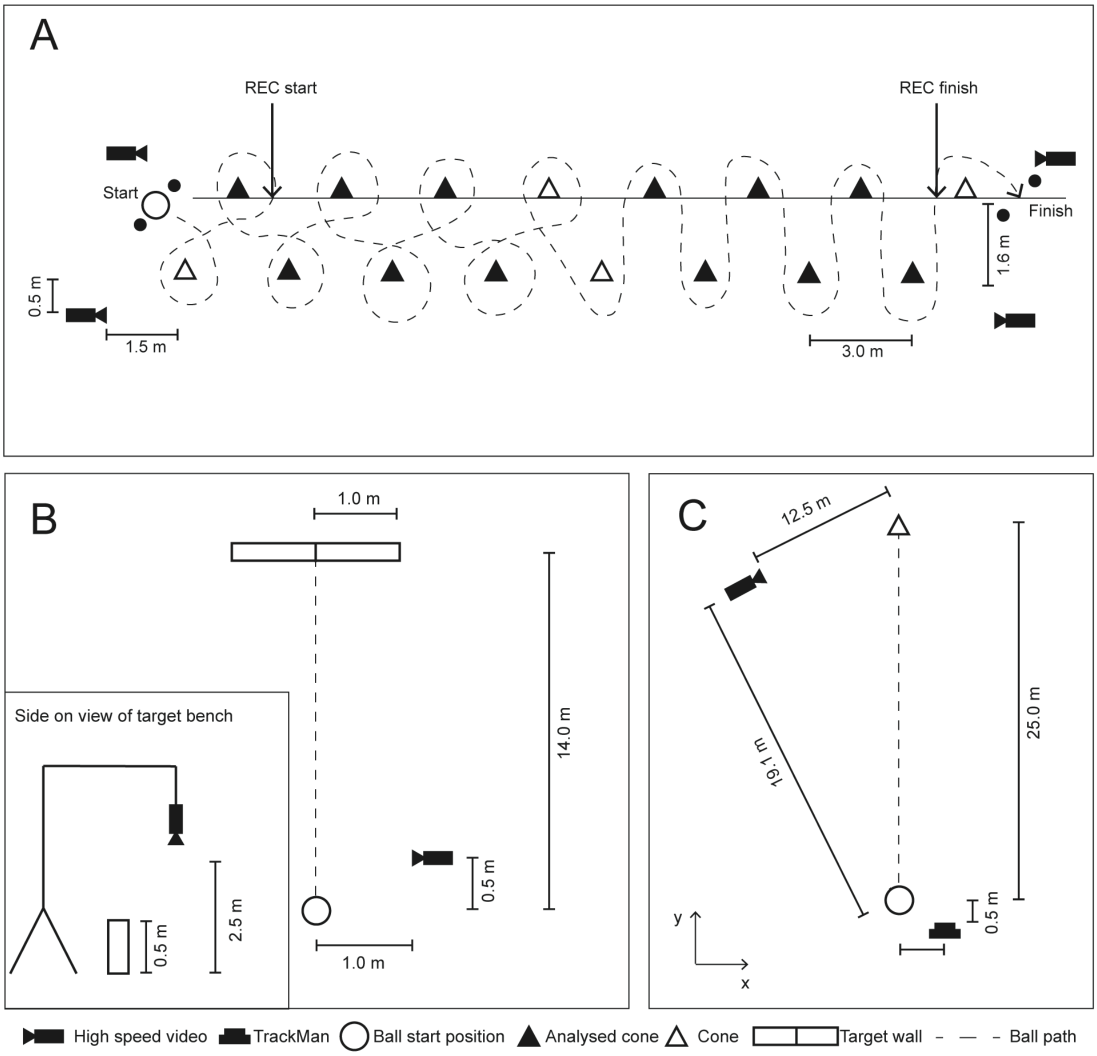


Figure 9.2. Planar view test setup for (A) dribbling drill, (B) short passing drill, and (C) long passing drill.

Subjects would only complete a dribbling trial when their heart rate (SUUNTO X6HR and Memory Belt chest straps; SUUNTO, Vantaa, Finland) fell below 110 beats.min^{-1} (within their recovery zone according to Fox & Haskell, 1968) and they reported themselves ready. If subjects rated a dribbling trial poor or very poor on a 5-point Likert scale then the trial was repeated (Figure 9.3). The number of trials required to achieve the six successful dribbling trials was recorded.

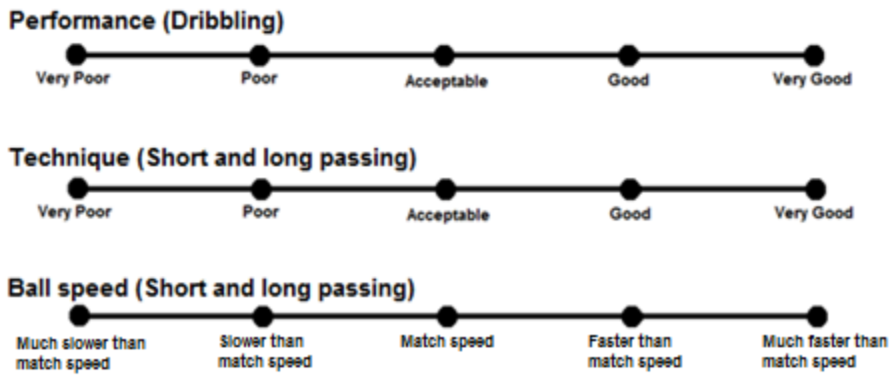


Figure 9.3. Likert scales used to assess players' perceived performance.

For short passing, subjects passed a stationary ball towards the centre of a 2 m wide and 0.5 m high wall located 14 m from the initial ball position (Figure 9.2). The passing distance was chosen based on match analysis data discussed in Appendix G. Subjects were instructed to 'pass the ball with the inside of the foot along the ground with no bounce imagining passing to a teammate in the centre mid of the pitch to maintain ball position. The ball therefore needs to be passed at a match realistic speed'.

For long passing, subjects performed an airborne pass from a stationary ball starting position to a cone placed 25 m away (Figure 9.2). The passing distance was chosen based on match analysis data discussed in Appendix G. Subjects were instructed to 'pass an airborne ball (≥1 m above the ground during flight) with the instep of the foot to reach the marked spot when first bouncing on the ground'. The imitated game scenario explained to the subject was 'the midfielders deep pass to the winger/striker running in behind the opponent defence'. Subjects used a repeated but self-selected run up. The five practise passes were used to determine their preferred run up pattern.

After each pass trial (short and long passing), subjects were asked to rate their technique and the ball speed on 5-point Likert scales ranging from very poor to very good and much lower than match speed to much faster than match speed (Figure 9.3). If technique was rated poor or very poor or ball velocity was not rated as match speed then the trial was retaken. The total number of trials required to achieve eight successful passing trials was recorded.

Post session subjective analysis
At the end of the test session, subjects were asked to rate their perception of the boot. This included a 5-point Likert scale for perception of ball control (1 = very inaccurate to 5 = very accurate), a 7-point Likert scale for ball sensation (1 = barely detectable to 7 = strongest imaginable) and a 10 cm visual analog scale for comfort (0 = very uncomfortable to 10 = very comfortable; Figure 9.4).

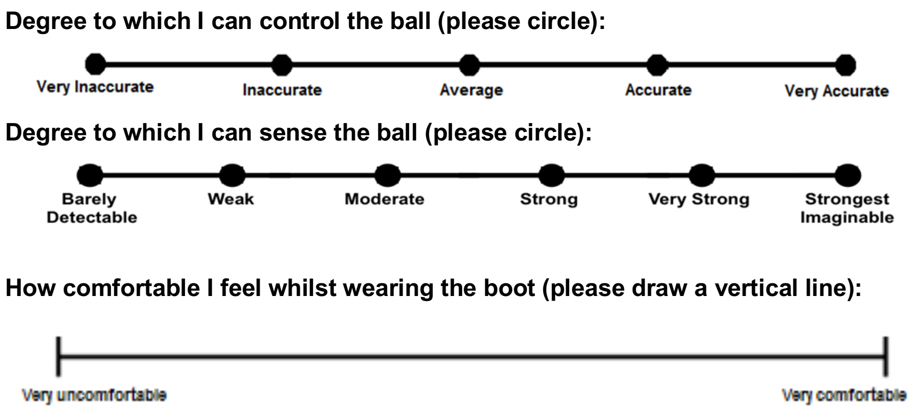


Figure 9.4. Likert and visual analogue scales used to assess players' overall perceived control, ball sensation and comfort of the boot.

Analysis of measures
To assess dribbling performance number of touches, total time to complete drill and maximum lateral deviation from the cones were analysed. Number of touches and time to complete drill were determined using a chest mounted GoPro HERO4 Black camera (120 Hz, 1280x720 pixels). The number of touches was manually determined in GoPro Studio (Version 2.5.7, GoPro Inc., San Mateo, CA). By placing the left row of cones on the side line (white line on the ground), it allowed start and finish point to be assessed between first passing the white line (2^{nd} cone) and first passing the white line at the final cone (16^{th} cone). Using alternative start and finish points was chosen to avoid acceleration into the drill and deceleration out of the drill to impact the scores. Subjects were, however, told that the entire drill was examined.
Maximum lateral ball deviation from the cone when turning was assessed using four GoPro HERO4 Black cameras (240 Hz, 1280x720 pixels, barrel distortion = 2.1%)

positioned perpendicular to and 0.5 m wider than the cone line and 1.5 m behind the first cone (Figure 9.2). Mean pixel size for the furthest cones assessed demonstrated a resolution of 1.0 ± 0.1 mm.pixels^{-1}. Videos were analysed in Image-Pro Analyzer (Version 7.0, Media Cybernetics, Inc., Rockville, MD). Direct linear transformation (DLT) was applied to the lateral deviation point measures to convert points from the image plane reference to the object space reference frame to obtain the real world offset distance. DLT accuracy levels were 0.012 ± 0.009 m along the x-axis (perpendicular to the row of cones) and 0.051 ± 0.038 m along the y-axis (following the row of cones). DLT analysis was performed in MATLAB (The MathWorks, Inc., Natick, MA) based on the method of Woltring & Huiskes (1990) for 2-D camera recordings (http://isbweb.org/software/movanal.html).

To assess short passing performance ball velocity and offset from target were measured. Ball velocity was assessed using 2-D high-speed video of the initial ball movement after foot contact using a CASIO EX-FH1000 camera (Casio Computer Co., Tokyo, Japan) (420 Hz, 230x170 pixels, barrel distortion = <0.1%). The camera was placed 0.5 m in front of the initial ball position with 1 m setback to record ball velocity (Figure 9.2) allowing a resolution of 4 ± 1 mm.pixels^{-1}. Passing accuracy for short passing was assessed using a GoPro HERO4 Black camera (240 Hz, 1280x720 pixels) placed on a tripod allowing aerial view of the ball impact on the bench (Figure 9.2). The camera was placed 3 m above the centred target line on the bench allowing a resolution of 1.0 ± 0.1 mm.pixels^{-1}. All video analysis was conducted using Image-Pro Analyzer.

To assess long passing performance ball velocity, radial offset, x-axis offset (perpendicular to passing direction; Figure 9.2) and y-axis offset (passing direction; Figure 9.2) from the target were measured. Ball velocity was assessed using a TrackMan Football system (TrackMan Golf, Vedbaek, Denmark). The TrackMan system was positioned 3 m behind and 0.5 m to the right as all subjects were right foot dominant. Accuracy was assessed with a GoPro HERO4 Black camera (240 Hz, 1280x720 pixels) placed on a tripod 1.6 m above the ground at a 15˚ tilt with the target cone in the centre point of the camera. Videos were analysed in Image-Pro Analyzer. DLT was then applied to the offset point measures to convert points from the image plane reference to the object space reference frame to obtain the real world offset distance. DLT accuracy was 0.045 ± 0.036 m along the x-axis and 0.041 ± 0.036 m along the y-axis (Appendix H).

Statistical analysis

Statistical analysis was carried out using SPSS software (Version 23.0; SPSS Inc., Chicago, IL). Statistical significance was set at $P \leq 0.05$. Non-parametric tests were applied based on the violation of outliers in the differences between the two related groups for some variables. Systematic bias in the repeatability between sessions was analysed by Wilcoxon's matched-pair tests. The magnitude of relative reliability was determined by two-way random intraclass correlation coefficient ($ICC_{2,1}$) two-way random effect model (absolute agreement definition) analyses of the mean subject scores for each session following clinical significance levels suggested by Cicchetti (1994). Data was log-transformed due to heteroscedasticity as suggested by Vaz et al. (2013) and Weir (2005). The $ICC_{2,1}$ is commonly suggested as the preferred assessment method to quantify relative reliability of test-retest validation setups (Beckerman et al., 2001; Hopkins, 2000; Lexell and Downham, 2005; Vaz et al., 2013; Weir, 2005). Absolute reliability was derived using standard error of measurement (SEM) and the smallest real difference (SRD) necessary to be considered real were derived from the intra-class correlation coefficients following the methods explain by (Weir, 2005).

9.4 Results

Elimination of data

Number of excluded trials and turns for dribbling in either test session are shown in Table 9.1. No trials were repeated but 10 turns were excluded from assessment of session 1 and 12 turns from assessment of session 2. The turns excluded were randomly distributed between players assessed and no significant difference was seen between sessions.

Table 9.1. Excluded and repeated sessions for dribbling.

		Excluded due to			Excluded due to		
Boot	**Total trials completed**	**Questionnaire response**	**Total trial assessed**	**Total turns completed**	**Ball bouncing off cone**	**Ball leaving calibrated zone**	**Total turns assessed**
S1	48	0	48	576	9	1	566
S2	48	0	48	576	12	0	564

S1 = session 1; S2 = session 2

One pass was repeated in session 1 for short passing due to the player reporting not obtaining match-related ball speed (Table 9.2). For long passing, three passes were repeated in in both sessions. No significant difference was therefore seen in number of trials repeated between sessions for both short and long passing.

Table 9.2. Excluded and repeated sessions for short and long passing.

Drill	Boot	Total passes completed	Excluded due to: Ball leaving calibrated zone	Excluded due to: Questionnaire response	Total passes assessed
Short passing	S1	65	0	1	64
	S2	64	0	0	64
Long passing	S1	67	0	3	64
	S2	67	0	3	64

S1 = session 1; S2 = session 2

Performance scores and systematic bias between trials

The means and standard deviations (SD) as well as the median and range for all outcome measures are presented in Table 9.3 for both sessions. The mean dribbling time demonstrated to be very similar for the two sessions (session 1 = 29.4 ± 1.7 s; session 2 = 29.1 ± 1.5 s) with a mean difference of 0.3 s. Individual subjects were consistent between sessions giving a mean difference of 0.2 touches between sessions (session 1 = 54.3 ± 6.0 touches; session 2 = 54.7 ± 8.4 touches). Lateral ball deviation from cone for the four types of turns assessed in the dribbling drill showed a mean difference of 0.04-0.06 m between sessions. For short passing the assessed performance measures of ball velocity and offset from target showed small mean differences of 0.19 $m.s^{-1}$ and 0.04 m respectively. Of the 64 passes, 28 passes ended right of target in session 1 and 30 passes in session 2 and therefore 36 and 34 ended left of target in the session 1 and session 2 boot respectively (Figure 9.5). Smaller mean difference was seen for ball velocity in the long passing (0.02 $m.s^{-1}$). Offset measures demonstrated larger mean differences in comparison to the ones seen for short passing (radial offset = 0.31 m; x-axis offset left = 0.10 m; y-axis offset left = 0.11 m). Systematic bias was rejected since no significant differences were observed and the mean differences between session were small for all of the measures of performance assessed (Table 9.3).

Table 9.3. Systematic bias, relative reliability and absolute reliability between trials for the dribbling and passing tests.

	Trial 1				Trial 2									
Variable	Mean ± SD	Median	25% Q	75% Q	Mean ± SD	Median	25% Q	75% Q	$ICC_{2,1}$	MD	Bias (P-value)	Grouped Mean	SEM	SRD
Dribbling														
Time (s)	29.4 ± 1.7	28.8	28.3	30.2	30.2 ± 1.5	28.9	28.0	29.2	.879	0.3	.428	29.5	± 0.5	± 1.4
Total touches	54.3 ± 6.0	55.3	49.8	57.2	57.2 ± 8.4	57.3	49.6	58.6	.965	0.2	.797	54.1	± 1.2	± 3.4
Turn offset R (m)	0.64 ± 0.10	0.65	0.60	0.68	0.68 ± 0.08	0.60	0.56	0.65	.453	0.05	.347	0.63	± 0.03	± 0.08
Turn offset L (m)	0.78 ± 0.11	0.78	0.68	0.81	0.81 ± 0.08	0.79	0.78	0.86	.679	-0.04	.349	0.77	± 0.04	± 0.12
Zigzag offset R (m)	0.84 ± 0.23	0.85	0.61	1.07	1.07 ± 0.16	0.75	0.63	0.86	.220	0.06	.589	0.81	± 0.08	± 0.23
Zigzag offset L (m)	0.69 ± 0.23	0.58	0.53	0.77	0.77 ± 0.26	0.63	0.54	0.73	.518	-0.04	.694	0.67	± 0.12	± 0.33
Short passing														
Velocity ($m.s^{-1}$)	20.8 ± 1.2	21.1	19.7	21.7	21.7 ± 1.6	21.2	19.2	21.3	.853	0.2	.598	20.7	± 0.5	± 1.3
Offset (m)	0.07 ± 0.22	-0.02	-0.08	0.25	0.25 ± 0.15	0.10	-0.01	0.15	.765	-0.04	.497	0.08	± 0.08	± 0.22
Long passing														
Velocity ($m.s^{-1}$)	19.3 ±1.2	19.3	18.5	19.9	19.2 ± 1.2	19.3	18.9	19.5	.957	0.0	.361	19.2	± 0.2	± 0.6
Offset radial (m)	2.52 ±0.78	2.65	2.33	3.11	2.74 ± 0.63	2.65	2.10	3.64	.303	-0.31	.901	2.8	± 0.31	± 0.86
Offset x-axis (m)	-0.15 ±1.73	-0.23	-0.39	0.07	-0.18 ± 1.80	-0.25	-0.18	1.29	.339	-0.10	.537	-0.41	± 0.35	± 0.97
Offset y-axis (m)	0.51 ±1.52	0.27	-1.44	-1.69	0.61 ± 1.72	0.27	-0.36	1.07	.414	-0.11	.778	-0.03	± 0.68	± 1.89
Subjective				7.1	8.1									
Control	4.0 ±0.5	4.0	4.0	4.0	3.4 ± 1.1	3.5	2.8	4.0	.504	0.6	.102	3.7	± 0.0	± 1.0
Sense	4.8 ±0.7	5.0	4.0	5.0	4.4 ± 0.9	4.0	4.0	5.0	.851	0.4	.083	4.6	± 0.3	± 0.8
Comfort	7.6 ±0.6	7.4	7.1	8.1	7.6 ± 0.8	7.2	7.0	8.0	.562	0.2	1.000	7.6	± 0.4	± 1.2

$ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition); MD = mean difference. Bias is determined from test-retest data using Wilcoxon matched-paired test for the mean outcomes for the 8 subjects; Grouped mean = average mean for both sessions; SEM = Standard error of measurement = SD × $\sqrt{1 - ICC_{2,1}}$; SRD = Smallest real difference at 95% confidence intervals = SEM × 1.96 × $\sqrt{2}$. SEM% and SRD% = SRD expressed as percentage of mean; Q = quartile.

Relative Reliability

The degree of subject consistency and agreement between sessions as assessed by the intraclass correlation coefficients ($ICC_{2,1}$) was shown to be excellent (>0.750) for dribbling outcome measures time and touches (Table 9.3). Turn offset and left zigzag offset measures demonstrated a fair to good relative reliability (turn offset right $ICC_{2,1}$ = 0.093; turn offset left $ICC_{2,1}$ = 0.679; zigzag offset left $ICC_{2,1}$ = 0.518), whilst poor relative reliability was seen for the right zigzag turns (zigzag offset right $ICC_{2,1}$ = 0.220). For short passing excellent relative reliability (>0.750) was demonstrated for both velocity and offset measures. Excellent relative reliability (>0.750) was also demonstrated for velocity for long passes, whilst offset measures showed poor to fair correlation (radial offset $ICC_{2,1}$ = 0.303; x-axis offset left $ICC_{2,1}$ = 0.339; y-axis offset left $ICC_{2,1}$ = 0.414). For subjective measures, overall comfort the $ICC_{2,1}$ was excellent for ability to sense the ball ($ICC_{2,1}$ = 0.851) and fair for ball control ($ICC_{2,1}$ = 0.504) and comfort ($ICC_{2,1}$ = 0.562).

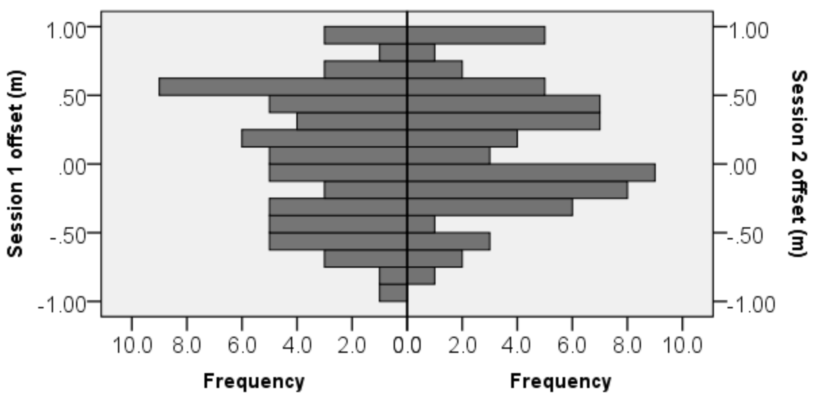


Figure 9.5. Histograms of offset for session 1 (left) and session 2 (right).

Absolute Reliability

The 68% confidence interval represented by standard error of measurement (SEM) and 95% confidence interval represented by smallest detectable change (SRD) expressed in both the measurement unit and as a percentage of the mean are demonstrated in Table 9.3. For dribbling time the SRD from the absolute mean showed to be ± 1.4 s, which is 4.7% of the absolute mean value. Number of touches demonstrated a SEM of ± 1.2 touches and SRD of ± 3.4 touches, which is 6.3% change in the absolute mean for SRD. The SEM and SRD were smaller for lateral ball offset from cones for the loop turns in comparison to the zigzag cut (Table 9.3) and varied between 0.03 m and 0.12 m in SEM and 0.08 m and 0.33 m in SRD. Ball velocity for both long and short passes demonstrated small SEMs (short pass SEM = ± 0.5 m.s^{-1}; long pass SEM = ± 0.2 m.s^{-1}) and SRDs (short pass SRD = ± 1.3 m.s^{-1}; long pass SEM = ± 0.6 m.s^{-1}), which is <7% of the absolute mean for SRD. Small SRDs were also shown for both short and long passing for the offset measures applied (Figure 9.6). Radial offset showed the smallest SEM and SRD of the offset measures for long passing (Figure 9.6). Subjective measures also showed SRD scores ranging from 0.8 to 1.2.

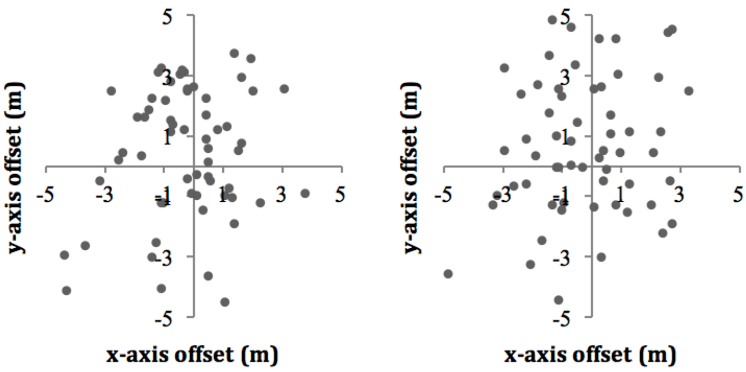


Figure 9.6. Offset for long passes in session 1 (A) and session 2 (B).

9.5 Discussion

This study aimed to validate a new test setup for the assessment of passing and dribbling performance. The setup was developed with the aim of assessing the impact of football boot design on performance, varying from past literature aiming to assess performance difference evoked by the subject due to, for example, playing level. The magnitude of the test–retest mean bias was small in all cases. Excellent relative reliability scores were confirmed for more than one objective measure for each drill and for all subjective measures. Absolute reliability scores showed small SRDs around the mean demonstrating good ability to detect significant differences in performance between football boots. Validation of the absolute reliability scores is discussed further in this section.

Passing measures of accuracy by distance to target is easily assessed between boots and players for optimal performance. Dribbling performance is, as mentioned in Chapter 7, not a straightforward measure due to the highly subjective skillset applied by players and the possibility of increased complexity in types of touches applied through natural intra- and inter-player variability which therefore potentially the number of touches applies and distance to cones during turns. Small mean differences were observed for dribbling, however, larger variations were seen in distance to cone when turning. A large repertoire in ball-boot interactions when changing direction observed on the videos assessed is the likely reason why poor to good test-retest ICC2,1 scores were seen for both turns and zig-zag change in direction movements. Hence, variation is believed to be caused by natural variation in human performance rather than poor assessment methods. Additionally, it is important to assess factors in relation to one another as improved performance of one factor may cause worsening of another and therefore neutralise the overall performance. When assessing dribbling performance, completion time and number of touches used are both highly subjective. This test setup was shown to be able to detect a change in performance of 1.4 s, (4.7% of the mean drill completion time) and 3.4 touches (6.4% of the mean count of touches) in defining difference in dribbling performance. The measure of lateral deviation from cones was more sensitive for change in performance when assessing loop turns (>16% change) over zigzag turns (>47% change). Understanding performance of dribbling is multifactorial (Russell and Kingsley, 2011). It is therefore important that all factors are taken into consideration when evaluating performance changes. No previous studies have attempted to assess the impact of football boot design on dribbling performance and it is not possible to indicate the exact sensitivity levels needed for each performance factor individually. It should instead be an overall multifactorial analysis of change in performance, which defines whether design parameters can impact performance.

This study is the first to critically assess the passing distances applied. Past literature has used widely varying distances without arguing for their passing length chosen. Today, companies record detailed match data including passing distances and future research should, like this study, aim to perform ecologically relevant setups. The key performance measure of passing is offset from target player – given that ball velocity is appropriate. This study demonstrated the ability to detect differences between boot designs of 0.22 m for short passes. When performing a 14 m flat pass to a team mate, then an offset of 0.4 m from the player should be within the reach of the team mate and a sensitivity level of 0.22 m is therefore able to detect performance impacting changes to performance of short passing accuracy whilst variance in ball velocity is detectable by a 6.4% change.

For long airborne passes the ball travelling time is longer and the receiving player commonly performs a run into space to receive the ball, allowing time for adjusting run up based on ball path. Regardless, avoiding opponents by optimising ball velocity and accuracy is still critical for match performance**.** The ball is received in motion and direction of pass inaccuracy will therefore impact performance outcome of the pass. Lateral inaccuracy is more likely to impact performance. A lateral inaccuracy may be adjusted for by a change in run up velocity but is likely to decrease performance from the receiver having to compromise velocity to handle the ball. Balls inaccurately landing shorter or longer than target can be handled by the receiver by controlling the ball with a different body part and may, therefore, allow more inconsistency before performance in compromised. This study demonstrated sensitivity to detect differences in radial offset of 0.86 m (28.7% change) and ball velocity of 0.6 $m.s^{-1}$ (3.3% change), whilst lateral and length offset sensitivity proved to be 0.97 m and 1.89 m respectively. Radial offset and ball velocity should be applied over lateral and length offset, although the latter should be included in the performance evaluation to understand any directional offset, whilst offset tendencies smaller than 0.97 m laterally and 1.89 m in length are likely to occur by chance.

When compared to past literature, only a few studies have validated their test setup for dribbling or passing. These used different setups (e.g. passing and dribbling distances) and, in contrast to this study, aimed to assess performance through the level of human error provoked and therefore included less controlling restrictions in their test setups. It is, therefore, inappropriate to compare the validations of these protocols to the current results.

Whilst focusing on objective measures, no past literature has included subjective feedback. Literature has shown that objective measures of performance and players perception of performance can vary (Roberts et al., 2001). Subjective feedback on perceived comfort and performance of a boot design may be just as important as objective performance measures for the holistic understanding of performance. If players sense differences and thereby favour one boot over another then this can impact the decision of buying including the word of mouth marketing of the product. This study included subjective measures of overall perception of comfort, ball sensation and ball control. The scale sensitivity demonstrated an ability to detect changes within one mark of the Likert scales for ball control and sensation and 1.2 cm change on the comfort visual analog scale.

Limitations

An important factor, which will highly impact the outcome of human testing, is the subjects' technical level (Anderson and Sidaway, 1994; Manolopoulos et al., 2006). Improved technique will minimise the level of human error and thereby intra-subject standard deviations. This study assessed skilled university players and future research should aim to include subjects with equivalent or higher level to maintain reliability scores within the values obtained in this study.

No adaptation period or 'break in' experience for players was included. It should be acknowledged that adaptation and changes in performance can occur over time yet these are two different scenarios and should not be confused.

This study used TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) to assess ball velocity. It is recognised by the researchers that the TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) is not available for usage by other research labs and it is therefore suggested that researchers validate their ball velocity instrument prior to testing and that the pilot test performed in relation to this study suggested that 2-D high speed video camera could be an alternative solution.

9.6 Conclusion

The protocol assessed in this study demonstrated acceptable test-retest reliability for a multifactorial assessment for performance for dribbling, short passing and long passing for skilled male players. The protocol offers researchers and football boot manufacturers a tool to test/validate football boot designs.

CHAPTER 10

Impact of Upper Thickness on Dribbling and Passing Performance

10.1 Chapter Outline

This chapter applies the validated protocol (Chapter 9) to assess dribbling and passing performance differences between two football boots of similar designs but varying upper thickness. Chapter 2 and 3 highlights the lack of current knowledge and potential impacting factors on performance. To demonstrate the application of the validated protocol (Chapter 5) the impact of upper thickness through additional padding on shooting performance was chosen. The impact of upper padding was selection similarly to Chapter 6 to highlight that football and therefore also the football boot demands multifactorial performance. Altering e.g. upper thickness for shooting performance may cause an adverse effect on the softer ball-boot impacting movement of dribbling and passing.

10.2 Introduction

As described in Chapter 2, football boots designed for optimal passing and dribbling are classified as the touch or control boots. One of the typically highlighted design features of football boot designs is the upper design (Chapter 2; adidas, 2017; Nike Inc., 2017; Puma SE, 2017). The upper, however, varies between touch/control boot designs. The PUMA EvoTouch Pro is designed with “Ultra-thin K-Touch leather upper” using kangaroo leather (Puma SE, 2017). The Nike Magista models have a thicker, stiffer textured upper by adding localised pressure points or uneven surface with All Conditions Control (ACC) technology (Nike Inc., 2017). The Adidas Ace 17+ are designed with a thinner, smoother laceless sock forefoot coated with a thin layer of raised NON STOP GRIP (NSG) dots (adidas, 2017).

Touch/control boots are mainly marketed towards midfield players, which were shown in the literature to perform significantly more passes during a match than strikers and defenders (Bloomfield et al., 2007). Yet professional players from all positions are wearing these designs (e.g. the French national team for the 2016 UEFA European Championship, all apart from two players wore one of the designs listed above). In football, a player’s dribbling and passing performances are fundamental for the player’s performance and key for a team’s success and important for any position on the pitch.

Obtaining optimal touch and control on the ball is therefore important for any player regardless of position.

Additionally, as described in Chapter 6, the currently applied additional padding on power boot designs may cause reverse effect on other aspects of the game, e.g. performance of passing and dribbling where a more sensitive ball sensation may benefit performance. Understanding the impact of padding on passing and dribbling performance is therefore relevant in relation to current football boot deigns on the market and despite large interest from the industry, no studies have analysed how different boot design parameters affect a player's ability to perform passes or dribble. With the validated protocol available it is possible to assess the impact of boot design on passing and dribbling performance.

10.3 Aims

- Analyse the impact of boot upper thickness on accuracy and ball velocity for dribbling, short passing and long passing.
- Analyse the impact of boot upper thickness on perceived differences in comfort, ball control and sensation of the ball.

10.4 Methods

Participants

Eight skilled male football players (age 20.7 ± 1.2 years, height 1.74 ± 0.03 m, mass 71.8 ± 7.9 kg) were recruited from the University 1st football and futsal teams. All futsal players had a history as a football player prior to University and all players recruited had 9 ± 4 years experience of club level football. None of the subjects had suffered from match-preventive lower limb injuries in the six months prior to testing. All subjects were UK size 8 and right foot dominant, which was determined by asking subjects which side they preferred for kicking. During the test, subjects wore the same brand of new football socks to prevent the socks from altering the subjects' sensation of the boot and ball.

Ethics

The investigation received ethical clearance from the institution's human research ethics committee, and each participant provided written informed consent in accordance with the requirements of the Helsinki Declaration for research using human participants.

Football boots
Two UK size 8 Umbro football boot prototype models were developed for the test (Figure 10.1). Fit was ensured from verbal feedback and palpation prior to testing. Both prototypes had the same firm ground outsole similar to the Umbro UX Accuro Pro. The uppers were also the same in terms of central lacing and the smooth white synthetic material. The boots only differed in upper padding thickness; one boot had no padding (0 mm) and the other had 6 mm of Poron foam padding (6 mm, XRD 12236; Algeos (n.d.); Figure 10.1).

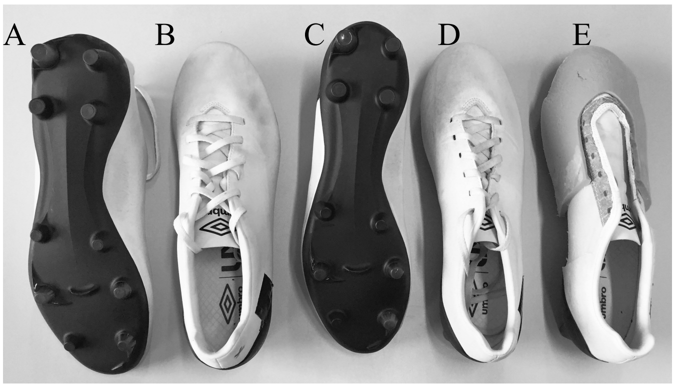


Figure 10.1. Plantar and dorsal views of the (A–B): 0 mm padded boot; and (C–E) 6 mm Poron foam padded boot where (E) is the dorsal view with the upper padding exposed to illustrate its extent.

Experimental design
The results were collected during a larger study setup. Subjects participated in three sessions of 2 h duration separated by 5-7 days. Players were blinded to which boots they wore and performed the session in 0 mm boots twice, for test-retest comparison (Chapter 9), and once in the 6 mm boots for comparison with the 0 mm boots. The boot order was randomised. Standardised warm up and familiarisation of each drill were performed in their own football boots before testing started. Subjects went through three drills (dribbling, short passing and long passing) in that set order for all test sessions. The two football boots were masked and tested in a randomised order.

Test setup and analysis of measures
The study followed the protocol validated in Chapter 9. The same ball, an Adidas Brazuca football (Adidas, Herzogenaurach, Germany; 22 cm diameter, 0.43 kg mass, 0.9 bar pressure) was used for the tests. Pressure was tested before and after each test and did not change during the session. Tests were performed on the same outdoor third generation artificial pitch (LigaTurf RS+ CoolPlus 260, Polytan, Burgheim, Germany).

In brief, the pitch had a 25 mm in situ rubber shock pad, the carpet fibres were 60 mm monofilament polyethylene and the infill comprised 15 $kg.m^{-2}$ sand and 15 $kg.m^{-2}$ rubber crumb giving a total infill height of 41 mm. Pitch testing conducted immediately after this study using the FIFA Quality Concept methodologies (Fédération Internationale de Football Association, 2015), gave a force reduction of 69.6 ± 1.5%, vertical deformation of 11.4 ± 0.5 mm and rotational resistance of 31.9 ± 1.3 Nm. Tests were only performed under dry conditions.

Following the validated protocol, subjects completed the multidirectional dribbling drill composed of loop turn dribbling and zig-zig dribbling. The measures of time, number of touches and radial offset from cones were assessed with GoPro HERO4 Black cameras (GoPro Inc., San Mateo, CA) following the setup and analysis instructions given in Chapter 9. Short passing were performed with players passing a stationary ball with the inside of the foot along the ground with no bounce towards the centre of a 2 m wide bench located 14 m from the initial ball position. A high-speed CASIO EX-FH1000 video following was applied to assess ball velocity and a GoPro HERO4 Black camera (GoPro Inc., San Mateo, CA) located above the target giving an aerial view of the target zone was applied to assess offset from target. Both instruments followed the suggested setup and results were assessed as shown in Chapter 9. Finally, long airborne instep passes were assessed with the suggest pass length of 25 m targeting a cone plane on the ground. TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) was used to assess ball velocity whilst a GoPro HERO4 Black camera (GoPro Inc., San Mateo, CA) was applied to assess offset from the target. Both instruments followed the suggested setup and results were assessed as shown in Chapter 9. Subjective control measures were used throughout the tests and an overall perception of the boots were included also following the validated test protocol.

Post session subjective analysis

At the end of the test session, subjects were asked to rate their perception of the boot. This included a 5-point Likert scale for perception of ball control (1 = very inaccurate to 5 = very accurate), a 7-point Likert scale for ball sensation (1 = barely detectable to 7 = strongest imaginable) and a 10 cm visual analog scale for comfort (0 = very uncomfortable to 10 = very comfortable; Figure 9.4).

Statistical analysis
Statistical analysis was carried out using SPSS software (Version 22.0; SPSS Inc., Chicago, IL). Results are reported as means ± standard deviations and statistical significance was set at $P \leq 0.05$. Assessment of assumptions for parametric tests were performed and based on the violation of outliers in the differences between the two related groups for some variables then non-parametric tests were applied. To analyse the effect of boot upper thickness on dribbling, short passing and long passing the mean performance for each participant was used for statistical assessment. Difference in objective measures of dribbling (time, number of touches and radial offset from the cones for each turn type), short passing (ball velocity and offset) and long passing (ball velocity and radial offset, horizontal (x-axis) offset, vertical (y-axis) offset and subjective scores on comfort, control and sense were assessed using non-parametric Wilcoxon's matched pair tests.

10.5 Results

Trials Excluded
Table 10.1 and 10.2 described the number of repeated trials and excluded turns for each condition assessed. No significant difference was seen between padding condition in number of trials repeated or number of turns excluded.

Table 10.1. Excluded and repeated sessions for dribbling.

Boot	Total trials completed	Excluded due to: Questionnaire response	Total trial assessed	Total turns completed	Excluded due to: Ball bouncing off cone	Excluded due to: Ball leaving calibrated zone	Total turns assessed
0 mm	48	0	48	576	10	0	566
6 mm	48	0	48	576	12	0	564

S1 = session 1; S2 = session 2

Table 10.2. Excluded and repeated sessions for short and long passing.

Drill	Boot	Total passes completed	Excluded due to: Ball leaving calibrated zone	Excluded due to: Questionnaire response	Total passes assessed
Short passing	0 mm	66	0	2	64
	6 mm	65	0	1	64
Long passing	0 mm	66	0	2	64
	6 mm	68	0	4	64

S1 = session 1; S2 = session 2

Effect of upper thickness on objective performance measures dribbling

The total time that it took players to complete the dribbling drill showed no significant difference between boot types (0 mm 29.2 ± 1.5 s, 6 mm 29.1 ± 1.7 s, P = 0.649). Total number of touches did not vary significantly either between boots (0 mm 54.4 ± 7.0, 6 mm 54.1 ± 5.8, P = 0.652). Similarly, radial offset demonstrated no significant differences for each of the turn types assessed (Figure 10.3).

Table 10.3. Comparison of performance for the 0 mm and 6 mm padded boots.

Skill	Variable	Boot	Mean ± SD		P-value
Dribbling	Time (s)	0 mm	29.2	±1.5	0.649
		6 mm	29.1	±1.7	
	Total touches (n)	0 mm	54.4	±7.0	0.652
		6 mm	54.1	±5.8	
	Turn offset R (m)	0 mm	0.62	±0.10	0.632
		6 mm	0.60	±0.10	
	Turn offset L (m)	0 mm	0.79	±0.10	0.694
		6 mm	0.78	±0.09	
	Zigzag offset R (m)	0 mm	0.81	±0.20	0.373
		6 mm	0.78	±0.15	
	Zigzag offset L (m)	0 mm	0.71	±0.24	0.580
		6 mm	0.69	±0.21	
Short passing	Velocity ($m.s^{-1}$)	0 mm	20.6	±1.3	0.139
		6 mm	20.5	±1.3	
	Offset directional (m)	0 mm	-0.20	±0.18	0.627
		6 mm	-0.36	±0.22	
Long passing	Velocity ($m.s^{-1}$)	0 mm	19.3	±1.1	0.731
		6 mm	19.2	±0.7	
	Radial offset (m)	0 mm	2.42	±0.46	0.547
		6 mm	2.53	±0.66	
	Horizontal offset (m)	0 mm	-0.26	±1.03	0.260
		6 mm	-0.03	±1.00	
	Vertical offset (m)	0 mm	0.35	±1.38	0.335
		6 mm	0.09	±1.31	
Subjective	Comfort	0 mm	7.6	±0.7	<0.001
		6 mm	3.7	±2.4	
	Control ball	0 mm	3.4	±1.1	0.053
		6 mm	3.0	±1.0	
	Sense ball	0 mm	4.5	±0.9	0.486
		6 mm	3.9	±1.2	

SD = Standard Deviation; n = count

Effect of upper thickness on objective performance measures short passing

There was no significant difference in ball velocity for the short passing between padding conditions (0 mm 20.6 ± 1.3 $m.s^{-1}$, 6 mm 20.5 ± 1.3 $m.s^{-1}$, P = 0.139). No balls missed the target. Offset from target is demonstrated in Figure 10.2. A total of 64 passes were performed in each boot. 29 passes ended right of target in the 0 mm boot and 30 passes in the 6 mm and therefore 35 and 34 ended left of target in the 0 mm and 6 mm boot respectively. The mean offset was not significantly different between padding condition (0 mm -0.20 ± 0.18 m, 6 mm -0.36 ± 0.22 m, P = 0.627).

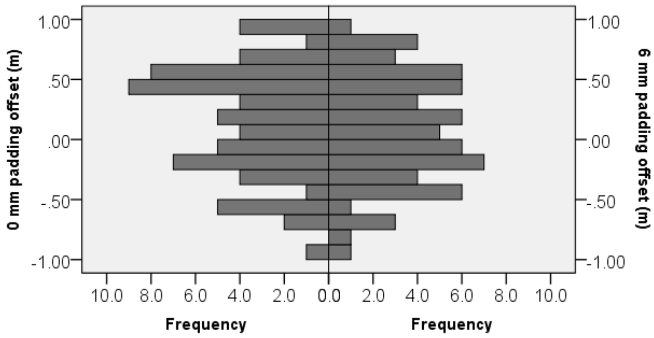


Figure 10.2. The offset (m) of short passes for the 0 mm (left) and 6 mm (right) boot. Right of target is represented by negative offset score and left of target is represented by positive offset score.

Effect of upper thickness on objective performance measures long passing

Similarly, there were no significant differences in any of the three offset measures (radial, horizontal and vertical) between padding conditions for the long passing (Table 10.3). Plots of the offsets for the 0 mm and 6 mm boots are shown in Figure 10.3A and Figure 10.3B. A wide spread is seen for both boots with no obvious visual tendencies or variance. Again, there was no significant difference in ball velocity between padding conditions (0 mm 19.3 ± 1.1 $m.s^{-1}$, 6 mm 19.2 ± 0.7 $m.s^{-1}$, P = 0.731).

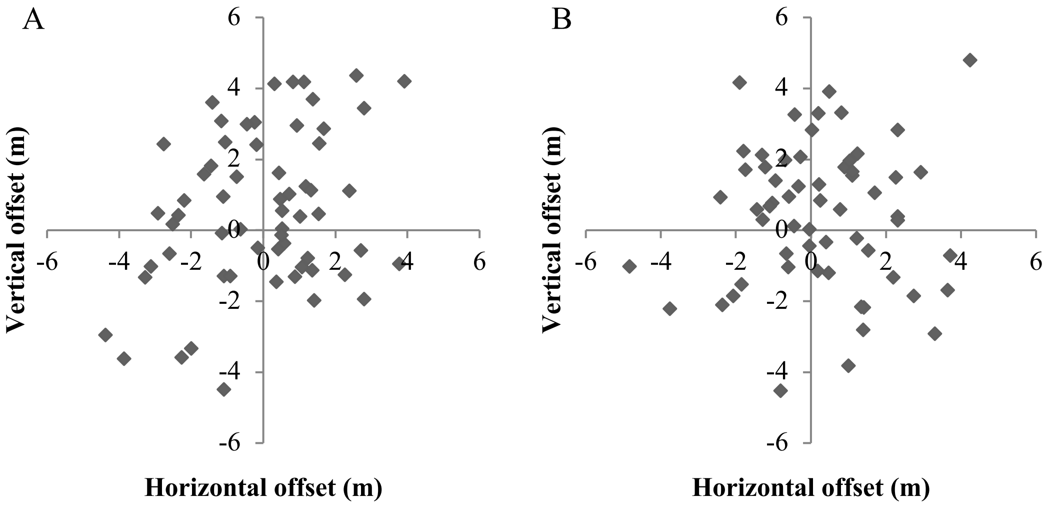


Figure 10.3A and B. Offset plot of long passes within calibration zone for 0 mm (A) and 6 mm (B).

Effect of upper thickness on overall perceived difference of comfort, control and ball sensation

Three passes landed outside the 5 by 5 m calibration zone. These were excluded from the study. The 0 mm boot was rated as significantly more comfortable (0 mm 7.6 ± 0.7, 6 mm 3.7 ± 2.4, P<0.001). The degree to which the subjects perceived they were able to control the ball demonstrated tendencies towards favouring the 0 mm boot for controlling the ball (0 mm 3.4 ± 1.1, 6 mm 3.0 ± 1.0, P = 0.053). Finally, no significant difference was shown for the players' perceived degree to which they could sense the ball on a 6-point Likert scale (0 mm 4.5 ± 0.9, 6 mm 3.9 ± 1.2, P = 0.486).

10.6 Discussion

The aim of this study was to assess the impact of upper padding thickness in football boot design on a player's dribbling and passing performance applying the protocol validated in Chapter 9. Dribbling performance was assessed through measures of time, number of touches and radial offset from cones and short and long passing from measures of ball velocity and offset from target. Players also rated boots on perceived comfort, perceived ball control and perceived ability to sense the ball. A total of 192 dribbling sequences, 256 short passes and 256 long passes were assessed from eight subjects. No significant difference was seen between boot designs with no or 6 mm upper padding for any of the 12 performance measures. Perceived ball control showed tendencies to difference (P = 0.053), favouring the non-padded boot, whilst no difference was seen for perceived ability to sense the ball. Finally, comfort was shown to be perceived significantly less comfortable (P < 0.001) in the 6 mm padded boot.

This study therefore offers new insight into the impact of design on passing and dribbling performance. No significant performance variation was shown between a smooth 6 mm Poron foam upper padding and a similarly designed boot without added upper padding. The thicker padding could have been hypothesised to decrease the player's ability to sense the ball and therefore decrease the control of the ball when dribbling and accuracy when passing the ball. However, this was not the case, which indicates that designers can produce boots with added padding of at least 6 mm without impacting dribbling or passing performance. Although no performance measures proved different between the two designs, significant difference (P < 0.01) was shown for the player's overall perceived comfort and tendencies towards significance (P = 0.053) for the player's perceived ability to control the ball. The two boot designs only differed in upper thickness yet a large variation was seen for perception of comfort in the two boots. Every player mentioned the comfort difference when testing the second boot. Both boots were shaped on the same last and the upper was not adjusted in fit when adding the 6 mm foam to the design, which caused a stretch of the upper and compression of the padding, which is believed to be the cause a tighter fit and therefore decreased perceived comfort. This highlights the complexity of controlling the alterations the impact of altering a single football boot design parameter. This complexity should be acknowledged by both researchers and manufacturers when introducing new design alterations. Footwear comfort is important for football players. It has been shown to be the most desirable property for football boots in user surveys from 1998, 2006 and 2013 (Hennig, 2011, 2014) and should therefore not be neglected. Previous studies have even linked footwear discomfort to altered lower extremity loading, which consequently triggered muscular fatigue and thereby decreased performance in football and rugby (Kinchington et al., 2011, 2012; Luo et al., 2009). Nevertheless, football boots are heavily marketed on their performance features whilst injury prevention and comfort are mostly neglected.

Additionally, that subjects rated perception of ability to control the ball demonstrated tendencies towards favouring the non-padded and significantly more comfortable boot may be a result of the padding, the comfort or a combination of the two. What can be determined, however, is the discrepancy between actual performance, where no significant difference was present and the perceived performance with tendencies towards favouring the non-padded boot for perceived ability to control the ball. This underlines the importance of assessing the boot from both actual performance measures and from the subjects' perceptions of performance.

Three long passes recorded landed outside the calibrated 5-by-5 m zone for direct linear transformation. To ensure all offset data can be reliably assessed then future studies would benefitting from applying a larger offset zone. Size should be determined from a pilot trial using subject from the population to be assessed to ensure that the zone fit the accuracy level.

10.7 Conclusion

By applying the validated protocol from Chapter 9, the impact of upper thickness (no padding and 6 mm Poron foam padding) on dribbling, short passing and long passing was compared. No significant difference was seen for any of the objective measures of performance for dribbling, short passing or long passing between the two boot designs. The non-padded boot was rated as significantly more comfortable and tendencies, although not significant ($P = 0.053$), were seen for players favouring the non-padded football boot for ball control.

Finally, this study only focuses on one of many potential impacting factors. The football boot spider diagram developed in Chapter 3 demonstrated the many design features which impact on performance that are still to be understood. Future research may look into the impact of other aspects of the boot designs which can be hypothesised to impact passing and dribbling performance. Common marketing claims involve both upper texture through increased of friction properties. These may also benefit from tests during different weather conditions. Additionally, outsole traction and thereby ability to generate optimal multidirectional movements as well at obtaining optimal support foot stability during passes can, amongst others, be hypothesised as important boot component designs for dribbling and passing.

THE SPEED BOOT

Introduction to Section

This section focuses on speed football boots. These are, as described in Chapter 2, designed to optimise speed generation. It is desired throughout this section to broaden the understanding of speed boot performance. The minimal mass of speed boot designs may impact the foot comfort experienced throughout match-play. This section therefore investigates the ability to maintain football specific performance as well as foot comfort during match-play for speed boots. A critical review of the past football literature is conducted to evaluate how a player's ability to maintain running and sprinting performance and foot comfort have been assessed previously. Based on the knowledge gained in the literature review and validation studies developed to bridge gaps a test protocol was developed. The assessment of test-retest reliability was performed. The validated protocol was then applied to compare two commercially available football boot designs. An outline of this speed boot section is demonstrated in Figure III.

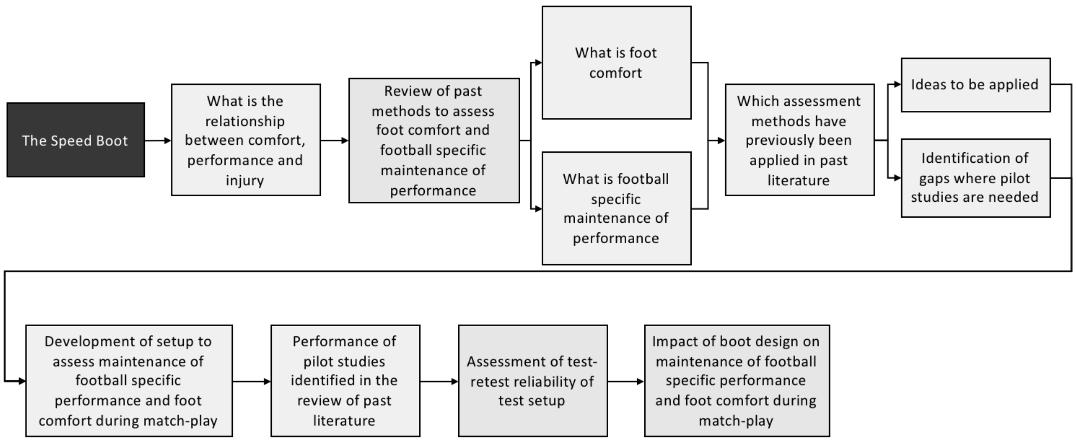


Figure III. Section outline.

CHAPTER 11

Review of Assessment Methods for Maintenance of Football Specific Performance and Foot Comfort

11.1 Chapter Outline

This chapter first describes how a relationship between footwear comfort and maintenance of performance in football can be hypothesised. Foot comfort is defined as a subjective perception experienced by the player. Football specific performance is in this section defining the player's ability to maintain running and sprinting performance during match-play. A review of assessment methods previously applied to assess football specific performance and foot comfort related match-performance is performed. The assessment focuses on appropriate setup and measuring tools for the different performance aspects of football specific performance layer's ability to maintain running and sprinting performance and foot comfort in football.

11.2 Relationship between Speed Performance and Foot Comfort in Football

Potential compromises/risks when focusing on speed

Technological advances have occurred in footwear development and use of biomechanical modelling and gait analysis techniques to understand quantitative foot-shoe interaction (Kinchington, 2003). Still the multifactorial needs make it challenging for athletes to find the "perfect shoe". Three multifactorial needs are commonly applied when grouping design requirements for sports footwear (Figure 11.1). Performance (e.g. speed), perception (e.g. comfort), and injury prevention (e.g. metatarsalgia) are all key factors and alterations to improve one component may lead to worsening of a second, which underlines the complexity of football boot designs. One example is the increase in traction through an aggravated stud design to optimise acceleration and deceleration (Bowers and Martin, 1975; Cawley et al., 2003; Hennig, 2011; McGhie and Ettema, 2012). Research has shown that that injury risk is compromised when traction levels are too high or too low (Alentorn-Geli et al., 2009; Cawley et al., 2003; Griffin et al., 2000; Lambson et al., 1996; Waldén et al., 2005), which underlines the complexity of football boot design.

Speed is a performance aspect of the football boot and a key marketing selling point for classified 'speed boots' (Chapter 2). The main design feature for speed boots is their lightweight properties. Whilst traction has been demonstrated to impact speed then mass has not. The multifactorial complexity issue may exist when attempting to improve performance by decreasing football boot mass by changing materials and trimming off protective factors. It can be hypothesised that decreased comfort may increase injury risk and decrease ability to maintain football specific performance. The following chapters will discuss the relationship between performance and comfort in more details.

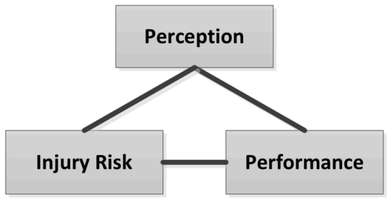


Figure 11.1. Design requirements for football boots.

The impact of comfort on performance

The connection between improved ability to maintain performance and appropriate foot comfort is widely assumed in the field of sports (Miller et al., 2000; Nigg et al., 1999; Schubert et al., 2011) and football specifically (Sterzing et al., 2009; Sterzing and Hennig, 2008). Yet the role of neurophysiology through neuromuscular responses and pain inhibition as a factor of performance is still not well understood (Kinchington et al., 2012). Short time exposure to different comfort levels, by varying heel counter stiffness, did not impact sprint performance in football (Sterzing et al., 2009). It was thereby concluded by the authors that players are capable of tolerating a certain amount of shoe discomfort during relatively short motor performance testing situations. Yet, the short exposure time seen when completing a 6 m acceleration sprint drill and short agility side cutting drill makes the outcome of little relevance to match-related impact of discomfort.

For long term exposure, it has, however, been demonstrated that footwear comfort is related to performance through reduced energy expenditure in running (Luo et al., 2009). Previous studies of footwear discomfort also suggest an alteration evoked by discomfort of the lower extremity muscle loading during running may cause muscular fatigue and be detrimental to subsequent performance (Nurse et al., 2005; Wakeling et al., 2002). Furthermore, fatigue and disruption to the usual movement patterns may provoke compensatory musculoskeletal mechanisms which compromise performance and increases the risk of injury (Cheung et al., 2003). It has therefore been suggested that optimal footwear condition is required to improve performance and decrease injury by reducing muscle activity (Kinchington et al., 2011) In sports where performance must be sustained for a prolonged period, e.g. football, decreased performance is represented by the inability to sustain the required work-rate (Reilly et al., 2008). One of the consequences of sustaining exercise for 90 min during football match-play is a decrease in the ability of muscles to generate force (Knicker et al., 2011; Polito et al., 2017). It has been shown that irrespective of the level of play and physical fitness of participants, the fall in work-rate in the second half is a consistent finding (Bangsbo et al., 1991; Di Salvo et al., 2007; Mohr et al., 2003; Reilly and Thomas, 1976). Research has also shown significant decrease in shooting ball velocity due to the lack of coordination disturbing the energy transfer between upper and lower leg, negatively affecting timing and leading to a poor impact position of the foot on the ball in the football fatigued state (Apriantono et al., 2006; Lees and Davies, 1988). Additionally, football specific fatiguing has also been shown to decrease protection normally maintained by muscle force around joints due to electromechanical delay, which has been shown to increase the risk of ligamentous sprain injury (Gleeson et al., 1998), joint injury (Mair et al., 1996) and muscle strain injury (Gehring et al., 2009; Greig and Walker-Johnson, 2007; Worrell and Perrin, 1992).

Decreased comfort has, to sum up, been found to increase energy expenditure, alter muscle loading and movement pattern which thereby decrease the ability of the player to maintain performance and potentially increase the risk of injury and therefore negatively impacts performance throughout a football match.

11.3 Understanding Foot Comfort in Football

What is foot comfort in football

Comfort has been defined as an ever-changing individual perception influenced by mechanical, neurophysiological, and psychological factors (Chen et al., 1995; Miller et al., 2000; Mündermann et al., 2001; Nigg et al., 1999; Reinschmidt and Nigg, 2000; Williams and Nester, 2006). The sensory function of the human foot permits the perception of different mechanical stimuli. Through mechanoreceptors, the foot can recognize different stimuli such as touch and vibration (Schlee et al., 2009). Footwear comfort has shown to be related to the fit, aesthetics, passive support, dynamic stability, muscle work to stabilise and thereby fatiguing, possible mobility, and the foot and leg alignment (Miller et al., 2000; Mündermann et al., 2001; Nigg et al., 1999; Reinschmidt and Nigg, 2000; Williams and Nester, 2006). Footwear comfort may therefore be impacted by a combination of mechanical, neuro-physiological and psychological factors (Miller et al., 2000).

Comfort has shown to be a highly individual measure depending on past experience, gender, age, culture, body mass, and skeletal alignment (Che et al., 1994; Goonetilleke and Luximon, 2001; Kong and Bagdon, 2010; Miller et al., 2000; Schubert et al., 2011). Footwear comfort has also shown to be multifactorial. Many shoe parameters such as size, shape, style, mass, flexibility, inside shoe climate (temperature, humidity), cushioning, materials, tread and aesthetics are all known to affect footwear comfort (Goonetilleke and Luximon, 2001). Comfort is therefore a sum of multiple impressions and therefore complex and specific to the subject wearing the footwear.

It is broadly believed that footwear fit is related to footwear comfort (Au and Goonetilleke, 2007; Hennig and Sterzing, 2010; Lam et al., 2011; Luximon et al., 2003). When we try on footwear, we are attempting to fit an irregular shaped object into a more regularly shaped shoe (Goonetilleke and Luximon, 2001). Footwear fit can be described as a functional geometrical match between shoe and foot (Lam et al., 2011). Different sport categories may have specific functional and thus geometrical demands on shoe fit (Lam et al., 2011). Research on football boots has demonstrated that players prefer a tighter boot (Kunde et al., 2009; Olaso Melis et al., 2016). A tight fit allow players optimal ball control and multidirectional motion with minimal discomfort from foot sliding within the shoe (Hennig, 2014; Hennig and Sterzing, 2010; Sterzing et al., 2011). The tighter fit has, however, shown to significantly increase plantar pressures in comparison to running shoes (Santos et al., 2001). Therefore, if exposed for longer periods, excessive pressures on the foot may lead to overuse injuries and foot pain (Chuckpaiwong et al., 2008; Fernández-Seguín et al., 2014; Weist et al., 2004).

Footwear comfort has been recognised in surveys as one of the most important variables for sport shoes design (Lucas-Cuevas et al., 2014; Nigg, 2010) and for football players specifically (Hennig, 2011). Longitudinal studies have shown significant correlations between decrease in comfort and increase in injury rate (Kinchington et al., 2010a, 2012), whilst optimal footwear condition is required to improve performance and decrease injury by reducing muscle activity (Kinchington et al., 2011).

What is foot comfort in football boots composed of?

Perception of comfort is a dynamic process depending on current, recent and expected stimuli as well as exposure time (Miller et al., 2000). Therefore, two scenarios of comfort can be discussed. Firstly, the 'try on in store scenario', as seen in football boot comfort studies like Olaso Melis et al. (2016) or where only short exposure is experienced. Secondly, long term exposure such as a full 90 min football match or a full season, as seen in football boot comfort studies like Kinchington et al. (2012, 2011).

11.4 Past Literature assessing Foot Comfort in Football Boots

Studies assessing foot comfort in football boots were gathered from the literature. Six studies were found (Table 11.3). Only one of the studies included the participant sex (Table 11.3) but from height, mass and shoe sizes described then it can be assumed that all studies were performed on male participants. One study validated a novel comfort scale (Kinchington et al., 2010b), whilst Okholm Kryger et al. (2016) applied scales previously validated in non-football footwear assessments (Table 11.3). Nunns et al. (2015) and Sterzing et al. (2009) did not validate nor apply previously validated questionnaires and Hennig (2014) did not describe the assessment tool used. Additionally, only Kinchington et al. (2010b) applied scales validated for studded footwear (rugby league and Australian rules). No studies therefore applied scales validated for football boots worn during football specific activity.

Table 11.1. Literature assessing foot comfort in football boots.

Study (year)	N	Level	Sex	Based On	Validated (test-retest)
Hennig (2014)	N/A	N/A	N/A	N/A	N/A
Kinchington et al. (2010b)	41	Rugby league & Australian rules	N/A	-	Week day = ICC 0.994-0.999 Match day = ICC 0.974 and 0.998
Okholm Kryger et al. (2016)	8	University	M	VAS Scale: Hong et al. (2005), Lam et al. (2011), Mündermann et al. (2001) Foot map: -	VAS Scale: High heel walking = ICC 0.876 Basketball footwear = ICC 0.62–0.78 Foot map: -
Nunns et al. (2015)	9	Youth academy	N/A	-	-
Sterzing et al. (2009)	20	Amateur to sub-elite	N/A	-	N/A

Level = playing level as described by authors in publication; N = number of participants; N/A = no information available; ICC = intraclass correlation coefficient.

11.5 Methods for Assessing Foot Comfort in Football Boots

Adaptation period needed

Comfort is, as previously mentioned, a multifactorial subjective sensation, which varies between people due to multiple factors (Che et al., 1994; Kong and Bagdon, 2010; Schubert et al., 2011). As perception is a dynamic process, exposure time has shown to alter perception of comfort (Miller et al., 2000). Generally, two scenarios of comfort can be discussed: the 'try on in store scenario' and the comfort felt 'during match-play or training', where the boot is worn for a longer period of time. Footwear comfort levels have shown to alter over time when wearing running shoes (Hintzy et al., 2015) Perception of comfort experienced 'during match-play or training' should therefore be assessed continuously for changes in comfort.

Methods previously applied to assess footwear comfort for football boots include single measures of comfort during short sports specific movement testing (Nunns et al., 2015; Okholm Kryger et al., 2016; Sterzing et al., 2009) and longitudinal observations throughout rugby and football seasons (Kinchington et al., 2010b, 2010a, 2012, 2011; Table 11.4). Hence, neither 'try on' comfort nor change in comfort 'during match-play or training'. As the majority of studies involve short term exposure, which gives an understanding of the 'try on in store scenario', then it is important to underline the potential change in perception of comfort over time. Caution to not generalise comfort results from the short-term exposure studies into long term exposure comfort should therefore be made.

Table 11.2. Drills performed for assessment of foot comfort in football boots.

Study (year)	Drill
Hennig (2014)	N/A
Kinchington et al. (2010b)	Match or training
Okholm Kryger et al. (2016)	Football specific movements
Nunns et al. (2015)	Football specific movements
Sterzing et al. (2009)	Football specific movements

N/A = no information available.

Scale type and wording

Studies have assessed foot comfort with Likert and Visual Analog Scales as well as discomfort foot maps (Table 11.5). All scales additionally varied in the wording used (Table 11.5). Without any comfort scales validated for football specific footwear comfort then future research will benefit from the design and validation of a relevant comfort assessment tool.

Table 11.3. Measuring tool applied to assess foot comfort in football boots.

Study (year)	Measuring	Scale	Range
Hennig (2014)	N/A	N/A	N/A
Kinchington et al. (2010b)	Lower limb comfort (incl. foot and footwear)	7-point Likert	Extremely uncomfortable (unable to run or jump; 0) - Zero discomfort (extremely comfortable; best ever feel; 6)
Okholm Kryger et al. (2016)	Global plantar foot comfort	100 mm VAS	Not comfortable at all (0) – most comfortable condition imaginable (10)
	Plantar foot discomfort map	Count	Yes - No
Nunns et al. (2015)	Perception of general comfort	7-point Likert	Uncomfortable - Comfortable
Sterzing et al. (2009)	Comfort perception	N/A	N/A

N/A = no information available; VAS = Visual Analog Scale.

11.6 Summary on Test Setup for Foot Comfort in Football Boots

Although previously applied, no tool for measuring foot comfort for football has been validated. A large variation is seen between tools applied in scale style and wording. Future research may therefore develop and validate a novel, test specific comfort assessment tool.

11.7 Understanding Maintenance of Football Specific Performance

Performance in sports depends on the athlete's ability to generate and maintain high physical, technical, decision-making and psychological skill levels during competition. Decline in any of these skill levels may appear as a symptom of football specific fatiguing (Knicker et al., 2011). The signs, symptoms and causes of muscular inability to maintain football specific performance are multifactorial (Knicker et al., 2011; Mohr et al., 2005).

Relevance of maintenance of performance in football

Through the assessment of time-motion analyses of football matches, studies have demonstrated a typical total distance of 9-12 km of intermittent exercise which has been demonstrated to include 1-3 km high intensity running, change in activity has been shown to occur every 4-6 s resulting in the execution of ~1350 activities throughout a game, including ~220 high intensity runs during a match for elite male football players (Bangsbo, 1994; Bangsbo et al., 1991; Bradley et al., 2009; Bradley and Noakes, 2013; Mohr et al., 2005, 2003; Reilly and Thomas, 1976; Rienzi et al., 2000). As football is an intermittent exercise, the average aerobic loading during match-play has shown to be ~75% of maximal oxygen uptake (Bangsbo, 1994; Bradley and Noakes, 2013; Mohr et al., 2005), whilst, during intense periods of a game, the anaerobic system is applied (Bangsbo, 1994; Ekblom, 1986; Hawley and Reilly, 1997; Mohr et al., 2005). However, the sum of high-intensity running, sprints and total distance covered have shown to decrease in second half compared to the first half of match-play and declines towards the end of the match (Bangsbo et al., 1991; Bangsbo, 1994; Di Salvo et al., 2009; Mohr et al., 2003; Reilly and Thomas, 1976). This tendency is believed to be related to fatigue, which, amongst other factors, inhibits maintenance of performance in latter stages of a game (Bradley and Noakes, 2013; Mohr et al., 2005). The sign of fatigue is also evident from studies reporting depleted muscle glycogen stores at the end of a match (Bendiksen et al., 2012; Krustrup et al., 2006). Minimisation of football specific fatiguing is therefore likely to be an important factor to maintain high level performance throughout a 90 min match (Barte et al., 2017; Knicker et al., 2011). In relation to injury risk, prolonged match-play related deficiency in muscle strength, has also been proposed to increase injury susceptibility (Greig, 2008; Rahnama et al., 2003; Small et al., 2009, 2010), including muscle activation alteration during running, resulting in increased forefoot loading, which may explain the incidence of stress fractures of the metatarsals (Weist et al., 2004).

In summary, football is an intermittent exercise causing the player to fatigue during the match. Minimisation of fatigue is beneficial for both performance maintenance and injury prevention.

11.8 Methods for Introducing Football Match-play Intensity Work-Rate

Performing research assessing an external impacting factor during actual match-play raises issues in controlling for variance in e.g. intensity and distance covered. Researchers have therefore developed field-based and laboratory match-play simulations to examine the impact of interventions (e.g. nutrition, pitch type or half time strategy) on performance (Table 11.6). These match-play simulations have been developed based on match analysis data from real match-play simulating high level football (Table 11.6). Validation has, however, often been performed using lower level football players, from which a lower level of fitness could be expected (Aziz et al., 2008; O'Donoghue et al., 2001; Table 11.6). The simulations vary largely in design. The strengths and weaknesses of these match-play simulations are therefore discussed further in this section.

The motorised treadmill match-play simulations protocol by Drust et al. (2000) lacks ability to imitate the change of movement intensity activities seen during match-play (~1,400 per match; Barrett et al., 2013), hence changes in velocity from acceleration and deceleration movements are not integrated characteristics of many simulations. This is a key limitation since these movements are frequently occurring in match-play and more energetically demanding than running at constant velocity (Osgnach et al., 2010). The non-motorised treadmill match-play simulations protocol by Thatcher and Batterham (2004) had more success in including as acceleration and deceleration actions. Yet the linear nature of treadmill running, which impedes change in direction, non-uniform locomotor patterns and utility movements, all of which significantly increase the energetic cost (Drust et al., 2007) and thereby lowers the ecological validity of such match-play simulations. Additionally, applying treadmill running does not offer same surface properties (e.g. hardness and friction) as a typical football pitch and assessment of running performance in studded footwear is not achievable.

The Loughborough Intermittent Shuttle Test protocol by Nicholas et al. (2000) requires the participants to cover more total and high speed running distances than those typically observed in match-play (Barrett et al., 2013; Williams et al., 2010). The protocol is developed to simulate the work-rate of a football match based on match analysis from the 1970s and 1980s (Reilly and Thomas, 1976; Withers et al., 1982). Football has developed and changed since the 1970s and 1980s match analysis studies. A larger number of high-intensity actions, especially seen by increased emphasis on "off the ball" movements, are seen today causing a reduction is average recovery time (Bradley et al., 2009). Additionally, the lack of sports specific movements (Bloomfield et al., 2007) negatively impacts the ecological validity of the Loughborough Intermittent Shuttle Test for reproducing football specific fatigue (Barrett et al., 2013).

Both the Copenhagen Soccer Test for men and women (Bendiksen et al., 2012, 2013) as well as the Ball sport Endurance and Sprint Test by Williams et al. (2010) contain match relevant changes in intensity, direction and drills. The complexity, however, restricts the number of participants able to complete the drill within a test session, increases the number of assessors needed and the familiarisation time of the drill. To be cost-effective then assessment of multiple subjects in one session would be preferable. Additionally, the Ball sport Endurance and Sprint Test does not control the total distance covered over the 90 minutes. This is ideal for assessment of player fitness level but when assessing external factors, e.g. football boots, then the lack of control is a disadvantage for the researcher.

Finally, the Soccer-specific Aerobic Field Test (SAFT90) by Lovell et al. (2008) is a shuttle run match-play simulation around a multidirectional agility course with intermittent exercise demands given by audio dictated commands (Barrett et al., 2013). The match-play simulation protocol is based on time-motion analysis data obtained from 2007 English Championship Level match-play (Prozone, Leeds, UK) (Lovell et al., 2008; Small et al., 2010). SAFT90 was validated by Lovell et al. (2008) to replicate football match-play specific fatigue responses through heart rate, blood lactate level, oxygen consumption, reduced sprint performance, decrease in body fluids and muscle specific fatigue (Lovell et al., 2008; Small et al., 2010). Throughout the 90 min match-play simulation, players cover 10.78 km, including frequent changes in intensity (1,269 changes, every 4.3 seconds) and multi-directional activities (1,350 changes in direction), producing similar internal loads to those reported from competitive match-play (Lovell et al., 2008). The protocol is therefore both multi-directional, requiring different, intermittent movement patterns, which simulates match-play better than treadmill and Loughborough Intermittent Shuttle Test protocols. Additionally, the SAFT90 is designed in a linear pattern with minimal equipment needed (six cones per participant) allowing researchers to include multiple players in the same test session. This makes the protocol easily applicable, which is the likely reason why the protocol has been used in several research papers assessing the impact of soccer specific fatigue (Azidin et al., 2015; Lovell et al., 2013; Nédélec et al., 2013; Small et al., 2009, 2010). Limitations to the SAFT90 lie in the generalisation in running effort over player positions, which, however, is a general limitation to all match-play simulation drills in the literature today. Di Salvo et al. (2007) and Bloomfield et al. (2007) demonstrated that player position affects the total distance and a variation in the total number of the sports specific movements performed. However, today the SAFT90 appears to be the match-play simulation drill with the highest ecological validity available and satisfactory for inducing football specific fatigue in a controlled research setup.

The SAFT90 drill setup is demonstrated in Figure 11.4. The player first moves around the 2 m cone and back to the finish line. This is either performed as side cutting or forward and backwards running. The following forward run and mid-way side cutting is altered in pace between runs. The same is the case for the final movement from the 20 m cone to the 0 m cone. Four different speeds are used: standing (0.0 km·hr^{-1}), walking (4.0 km·hr^{-1}), jogging (10.3 km·hr^{-1}), striding (15.0 km·hr^{-1}) and sprinting (≥20.4 km·hr^{-1}) in a randomised and intermittent fashion (Lovell et al., 2008).

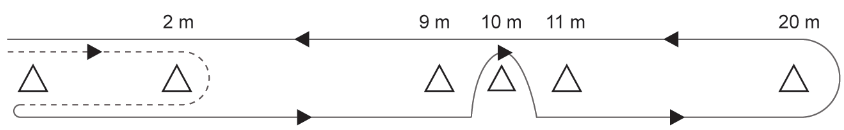


Figure 11.2. Diagram of the SAFT90 field course adapted from Lovell et al. (2008).
Stippled line = alternating utility movement; Dense line = forwards running; Triangle = cone.

Table 11.4. Players used to validated protocol on and source of time-motion match-play analysis data used for simulation in protocol.

			Time-motion simulation			Time-motion match-play source			
Study (year)	**Drill Name**	**Drill type**	**N**	**Level**	**Sex**	**Level**	**Sex**	**Source**	**Year**
Bendiksen et al. (2012)	Copenhagen Soccer Test for Men	Complex multidirectional drill performed at varying intensities including ball handling	12	2nd & 3rd Danish division	M	Professional	M	Mohr et al. (2003)	
Bendiksen et al. (2013)	Copenhagen Soccer Test for Women	Complex multidirectional drill performed at varying intensities including ball handling	19	1st division Sweden & Norway	F	International Danish Premier League Danish Premier League Top class & high level	F F F F	Andersson et al. (2010) Krustrup et al. (2005), Krustrup et al. (2010) Mohr et al. (2008)	
Drust et al. (2000)	-	Motorised treadmill drill with varying speed	7	University	M	Professional	M	Reilly et al. (1976)	
Lovell et al. (2008)	Soccer-specific Aerobic Field Test (SAFT90)	Multidirectional drill performed at varying intensities	8	Semi-professional	M	English Championship	M	Time-motion match analysis	2007
Nicholas et al. (2000)	Loughborough Intermittent Shuttle Test (LIST)	Shuttle running (20 m track) performed at varying intensities	7	Football and rugby players	M	Professional Australian professional	M M	Reilly et al. (1976) Withers et al. (1982)	
Russell et al. (2011)	Soccer Match Simulation (SMS)	Modified LIST including ball handling	10	Youth development	N/A	-	-	-	
Thatcher et al. (2004)	Soccer Specific Exercise Protocol (SSEP)	Non-motorised treadmill with varying speed	6	Professional	M	English premiership English premiership U19	M M	Time-motion match analysis	1998-1999
Williams et al. (2010)	Ball sport Endurance and Sprint Test (BEAST90)	Complex multidirectional drill performed at varying intensities including ball handling	15	Amateur	M	Top-level Professional Professional and elite Australian professional	M M M M	Bangsbo et al. (1991) Mayhew et al. (1985) Reilly et al. (2003) Withers et al. (1982)	

F = Female; M = Male; N = Number of participants; Y = Year.

11.9 Methods for Assessing Football Specific Fatiguing through Ability to Maintain Football Specific Performance

As fatigue is multifactorial occurring at both a physical, technical, physiological and mental level, no gold standard measure exists. A large amount of assessment methods have, however, been validated and applied in the literature (Table 11.7, Aaronson et al., 1999; Knicker et al., 2011). Despite the large range of fatigue measures available, some studies assessing the impact of sports specific fatiguing following football match simulating protocols solely assume that football specific fatiguing has occurred whilst no actual measure of fatigue is performed (e.g. Greig and Walker-Johnson, 2007; Small et al., 2010). This can be problematic when assessing multiple participants with a natural variation in fitness level.

Measures of football specific fatiguing during exercise

The following section introduces existing fatigue measuring methods and their applicability to assess fatigue throughout an outdoor match simulation drill.

In laboratory based tests, direct measures of fatigue include maximal voluntary force generation, power output, tetanic force and low frequency fatigue, whilst indirect measures include biomarkers, twitch interpolation, endurance time and electromyography (Finsterer, 2012; Vøllestad, 1997). Yet these parameters demand laboratory-based equipment and time whilst others are invasive. They are therefore challenging and unpractical to use during field tests. Additionally, some of these methods apply stress levels to the muscle not usually occurring during the sporting activity replicated and may therefore impact the ecological validity of the test (Enoka and Duchateau, 2008; Knicker et al., 2011).

A less invasive and more accessible objective physiological measure is heart rate, which can be assessed with a sensory chest belt. Heart rate has shown to exhibit strong correlations with the ventilatory and metabolic thresholds that determine the main metabolic pathway for energy production during exertion resulting in metabolic acidosis and subsequently muscle fatigue in football (De Nardi et al., 2011; Gant et al., 2010; Goedecke et al., 2013; Polito et al., 2017). Heart rate has also shown strong correlation with the psychophysiological stress associated with practicing sports (Lucía et al., 2000). Applying heart rate measures is therefore an appropriate objective measure which can be obtained without decreasing ecological validity.

Table 11.5. Common measures of fatigue during physical activity (Knicker et al., 2011).

Performance symptoms
↓ Whole-body work rate/velocity, inability to surge, ↑ rest periods, cessation of exercise
↓ Technique execution (tired looking movements)
↓ Hitting, Shooting or throwing velocity
↑ Error rate (e.g. fl accuracy of hitting, shooting or passing, missed catches or tackles)
↑ Mental lapses (i.e. ↓ concentration, ↑tiredness, slower/inaccurate decisions)[a]
Test measures
Physical exercise
↓muscle force (e.g. peak maximum voluntary contraction, isokinetic, or tetanic forces),
↓muscle, limb/joint, or whole-body power,
↑time (endurance, sprint, agility, repeated sprint),
↓stride frequency, ↓ stroke length, ↓pedal rate, ↓range of motion.
Technique
↓motor skill execution (e.g. ↓ foot or hand speed),
↓motor skill outcome (e.g. ↓ ball velocity or accuracy).
Subjective sensation[b]
↑ sense of effort (i.e. ↑ rating of perceived exertion),
↑ sense of generalised fatigue/tiredness,
↑ sense of force (includes ↑ sense of heaviness),
↑ ratings of muscle soreness, ↑ discomfort, ↑ pain.
Decision making[c]
Simple and choice reaction times, visual recognition tests, Stroop test, mental concentration.
Sport-related anticipant tests.
Psychological aspects
Motivation, self-efficacy, anxiety

[a] = anecdotal only; [b] = assessed using rating scales or questionnaires; [c] = are often improved or unchanged; ↑ = increase; ↓ = decrease.

Another commonly applied and non-invasive method is the use of player perception assessments. The perception of fatigue involves the conscious sensation of increasing effort needed to sustain a submaximal task meaning that the exercise feels harder, together with weakening muscles and symptoms that persist at rest (Enoka and Stuart, 1992; Knicker et al., 2011). Fatigue and tiredness measures have been performed for athletes (e.g. Baker et al., 2007; Montgomery et al., 2008; Winnick et al., 2005), but the rating of perceived exertion (RPE) is the most commonly applied method (Baron et al., 2011; Polito et al., 2017). The scale ranges from 6 to 20, denoting heart rates ranging from 60 to 200 beats.min^{-1}. RPE is quantified by the use of the Borg scale (Borg, 1982). RPE consist of recognition of sensations originating from muscles, joints, chest (i.e. pounding heart and laboured breathing), circulating factors, skin, and higher brain centre inputs (Borg, 1982; Hampson et al., 2001; Kayser, 2003; St Clair Gibson et al., 2003). All these perceptions, experiences, and signals are incorporated into a player's configuration of perceived exertion (Borg, 1982). The Borg scale is today used as a standard tool for American College of Sports Medicine (Utter, 2011) due to its strong link between RPE and physical performance (See evidence from literature in Table 11.8). Obtaining RPE scores as a subjective measure is therefore a well assessed and validated method commonly used to assess fatigue in football match-play simulations (e.g. Azidin et al., 2015; Lovell et al., 2013, 2008; Nédélec et al., 2013).

Table 11.6. Relationship between RPE and physical performance.

Time to exhaustion is closely associated with the rate of rise of RPE	e.g. Crewe et al. (2008), Marcora et al., 2009, Presland et al. (2005).
Exhaustion only occurs when individuals reach maximal RPE and exercise becomes intolerable and therefore impossible	e.g. Crewe et al. (2008), Enoka and Duchateau (2008), Enoka and Stuart, (1992), Marcora et al. (2009), Noakes and St Clair Gibson (2004)
Interventions known to enhance endurance time have also shown to improve RPE	e.g. glucose (Burgess et al., 1991; Winnick et al., 2005), bicarbonate (Nielsen et al., 2002; Swank and Robertson, 1989) or fluid ingestion (Baker et al., 2007; McGregor et al., 1999) and oxygen supplementation (Amann et al., 2006))
Interventions known to decrease endurance time have also shown to worsen RPE	e.g. muscular strain (Baron et al., 2011), hyperthermia (Crewe et al., 2008; Nielsen et al., 2001; Nybo and Nielsen, 2001), hypoxia (Amann et al., 2006; Noakes and St Clair Gibson, 2004), serotonin agonists (Marvin et al., 1997) and mental fatigue (Marcora et al., 2009))
RPE has shown strong positive correlations with physiological measures	e.g. heart rate (Borg and Linderholm, 1967; Borg, 1973; Skinner et al., 1973; Stamford, 1976), oxygen consumption (Skinner et al., 1973), respiratory rates (Noble et al., 1973) and blood lactate consumption (Hetzler et al., 1991))

Assessment of ability to perform physical exercise is also a common, non-invasive method to assess fatigue (Knicker et al., 2011; Mohr et al., 2005). Sprint drills assess both muscular and neural fatigue and can therefore be applied to assess change in performance due to fatigue before and after an outdoor match simulation drill. Additionally, a commonly applied method to assess decrease in power generation, more specifically neural fatigue (Rodacki et al., 2002), after a match simulation drill is the counter movement jump (e.g. Krustrup et al., 2010; Mohr et al., 2010; Nédélec et al., 2013). The propulsive motion of the lower limb during a counter movement jump has been advocated as particularly suited for evaluating explosive characteristics of sedentary individuals and elite athletes (Bosco and Komi, 1979; Markovic et al., 2004; Slinde et al., 2008). The motion uses a combined eccentric/concentric muscle action defined as a stretch-shortening cycle (Komi, 2000; Komi and Bosco, 1978). The subject starts the counter movement jump by standing in an upright position. A fast downward movement to about 90° knee flexion immediately followed by a fast upward vertical movement as high as possible, all in one sequence (Slinde et al., 2008). Variations in hand position technique used for the counter movement jump exist. The counter movement jump can be executed with arm swing or with the hands placed on the hips. Jumps with arm swing have shown to contribute with 8–11% of the jumping height and thus give a more positive effect on the outcome (Harman et al., 1990). Markovic et al. (2004) assessed seven explosive strength field tests. Counter movement jump without arm swing showed to be the most reliable and valid test for assessment of explosive power of the lower limbs in physically active men. The test-retest reliability has been validated in past literature (Table 11.9). Different statistical methods have been applied to validate test-retest reliability in the past literature. All studies included intraclass correlation coefficient (ICC) scores for relative reliability, which all showed to be excellent (≥0.750) according to the guidelines introduced by Cicchetti (1994). A variance in absolute reliability scores have been found in the literature, which is likely to be caused by variance in statistical assessment approaches and different populations and techniques assessed (Table 11.9). Slinde et al. (2008) assessed male athletes using the jump technique without arm swing and found SRD scores of 4.77 cm.

Measures of fatigue post exercise

Fatigue impacts the player during exercise but the impact of fatigue exceeds the time of the actual activity. Muscle soreness, decreased energy amongst other parameters will exist for hours and potentially days after the completion of the exercise (Hooper and Mackinnon, 1995). The Hooper's index, which was first proposed by Hooper and Mackinnon (1995) to aid detection of the overtraining syndrome, as it exhibited a correlation with parameters, such as creatine kinase, total white-blood-cell-count, red-blood-cell-count and catecholamines (Haddad et al., 2013; Hooper and Mackinnon, 1995; Polito et al., 2017) The Hooper's index contains four self-report numerical scales rating sleep, stress, fatigue and muscle soreness on a scale of 1 to 7 and calculated by adding up the four ratings (Haddad et al., 2013). The Hooper's index is commonly used in the literature for assessing football related fatigue following exercise (e.g. Chamari et al., 2012; Haddad et al., 2013; Nédélec et al., 2013), although not currently validated. Additionally, muscle soreness is commonly experienced after exercise. Thompson et al. (1999) suggested using a visual muscle diagram to assess change in muscle soreness post exercise by rating soreness on an 11-point Likert Scale for the major muscle groups. The diagram subdivides the lower limb into muscle groups (tibialis anterior group, calf group, hamstring group, glute group, quadriceps group and adductor group). The model has previously been applied to assess football related fatigue following exercise (Nédélec et al., 2013) but is not yet validated. Including both The Hooper's Index and The visual muscle diagram by Thompson et al. (1999) in the setup would offer the opportunity to validate the test-retest reliability of these.

Validation of both questionnaires as a control measure for players upon arrival to ensure that assessment is not impacted by pre-existing fatigue may be beneficial. Applying the visual muscle diagram to assess change in muscle soreness post exercise may additionally be useful to validate for application in the hours after testing.

Table 11.9. Validation of counter movement jump in past literature.

Reference	Hachana et al. (2013)	Markovic et al. (2004)	Richter et al. (2012)	Pagaduan et al. (2013)	Slinde et al. (2008)
Population	89 athletes age: 20.33±0.83 y, height: 179 ± 6.3 cm, mass: 73.11±5.65 kg	93 male PE students age: 19.6 ± 2.1 y, height: 180 ± 7 cm, mass: 77.1 ± 7.5 kg	127 female and 197 male school students age: 10-18 years, height 162 ± 12 cm, mass: 49.7 ± 13.3 kg	17 male age: 22 ± 2 y, height: 180 ± 6 cm, mass: 77 ± 8 kg	11 male elite athletes age: 31.0 ± 5.97 y, height: 174.3 ± 5.2 cm, mass: 77.5 ± 8.3 kg
Instructions	CMJ with arm swing	CMJ without arm swing	(1) CMJ with arm swing (2) CMJ without arm swing	(1) CMJ with arm swing (2) CMJ without arm swing	CMJ without arm swing
Test score (cm)	40.37 ± 5.20	35.2 ± 4.4	(1) 27.1 ± 7.2 (2) 23.8 ± 6.1	(1) median = 39 (2) median = 35	40.7 ± 1.1
Re-test score (cm)		35.3 ± 4.4 35.4 ± 4.7	(1) 27.8 ± 6.8 (1) 27.9 ± 6.8 (2) 24.1 ± 6.2 (2) 24.1 ± 6.2		40.9 ± 4.2
ICC	0.96	0.98	0.93	(1) 0.88 (2) 0.80	0.86
SEM	2.9 cm				1.72 cm
SRD/MDC					4.77 cm
Cronbach's alpha		0.98		(1) 0.94 (2) 0.89	(1) 0.94 (2) 0.89
CV (%)		2.8	(1) 5.5 (2) 4.4		

Note: test score times are reported as mean ± standard deviation unless reported otherwise; ICC = intraclass correlation coefficient; SEM = standard error of measurement; SRD = smallest real difference; MDC minimal detectable change; α = Cronbach's alpha reliability coefficients; CV = coefficients of variation; PE = physical education.

11.10 Understanding Speed in Football

What is speed in football

Performance in sports depends on the athlete's ability to generate and then maintain high physical, technical, decision-making and psycho
logical skill levels during competition and is therefore multifactorial and assessment can be performed in multiple ways (Knicker et al., 2011). Speed is an important performance factor in football and the key performance improvement claim of speed boots. Football players, along with many other athletes from different sports, execute multiple sprints along rapid acceleration or deceleration which are often related to multidirectional high intensity turns, during the course of a match (Bloomfield et al., 2007; Kaplan et al., 2009; Little and Williams, 2005; Newman et al., 2004).

Importance of speed in football

The ability of football players to perform varied high-speed actions is known to impact the overall football match performance (Kaplan et al., 2009; Little and Williams, 2005; Luthanen, 1988). Despite high-speed activities only contributing to around 11% of the total distance covered, they create the more decisive instances of the match and thereby directly contribute to obtaining ball possession and to scoring goals (Kaplan et al., 2009; Reilly et al., 2000).

Percentage of high intensity movement largely varies between playing position in the FA Premier League, although positions were separated into rough groups of strikers, midfielders and defender, then it was evident that defenders perform significantly fewer sprints in comparison to strikers and midfielders (Bloomfield et al., 2007). Still, the playing style of full backs is largely different to the one of centre backs, especially in the modern football, and cannot be classified as the same playing style category (Dellal et al., 2011). Consequently, total high intensity running distance covered in La Liga and FA Premier League showed to be higher for full backs (La Liga 226 ± 54 m; FAPL 241 ± 64 m) in comparison to centre backs (La Liga 285 ± 55 m; FAPL 270 ± 55 m), yet not reaching the distance covered by wide midfielders (La Liga 311 ± 67 m; FAPL 298 ± 62 m) and strikers (La Liga 289 ± 56 m; FAPL 300 ± 64 m; Dellal et al., 2011).

What is speed in football composed of

Speed is multifactorial and sports specific. Applying similar morphological (i.e., fibre type proportion) and biochemical determinants, research demonstrated that high speed actions can be subcategorised into: acceleration, maximal speed, and agility, which have shown to be relatively unrelated to one another (Little and Williams, 2005).

- Acceleration - the rate of change in velocity which allows a player to reach maximum velocity in a minimum amount of time.
- Maximum speed - the maximal velocity at which a player can sprint.
- Agility - often described as the ability to change direction and start and stop quickly but does not have a global definition.

And it has been suggested that the subdivision should be applied in the field of sports science when addressing high speed actions in football (Little and Williams, 2005). Football is a multidirectional sport and agility is therefore an important performance factor. In professional football outfield players have been shown to change direction 727 ± 203 times during one match (Bloomfield et al., 2007). Therefore, both acceleration and agility are key sprint motions for football players. Game analysis showed straight and oblique acceleration to be the most frequent football specific movements observed in actual matches (Sterzing and Hennig, 2005). These high speed actions are most frequently short (<10 m), normally lasting 2-4 s and take up 3-5% of the total match-play time and 10% of the total distance covered in professional male matches (Bloomfield et al., 2007; Osgnach et al., 2010) and therefore mostly include acceleration rather than maintenance of maximum speed.

11.12 Past Literature assessing Speed Performance in Football

Sprint time is a common performance measure in the literature. Due to a broad extent of studies applying sprint performance assessment in the literature, a focus on methods applied to assess football boot specific impact on sprint performance and sprint setups validated for football in the literature was chosen. However, the application of non-validated sprint protocols setups is common in the literature (e.g. Andersson et al., 2008; Ascensão et al., 2008; Krustrup et al., 2006). Of these, a single football specific sprint protocol including both agility and linear acceleration sprints was developed by Sterzing et al. (2009). The protocol was applied to assess the impact of boot design on sprint ability. However, no validation of the setup has yet been made.

It is still believed that speed should be accessed both in linear (acceleration and sprint) and multidirectional (agility), as both demonstrate different components of speed in football (Little and Williams, 2005) and have shown to be poorly correlated indicating that these are different skills that should not be interchanged (Hachana et al., 2013;

Little and Williams, 2005). Drills containing components of both linear acceleration and change in direction have previously been validated. Of these, the most commonly applied and validated protocols are the T-test and the Illinois agility test (Figure 11.3A and B).

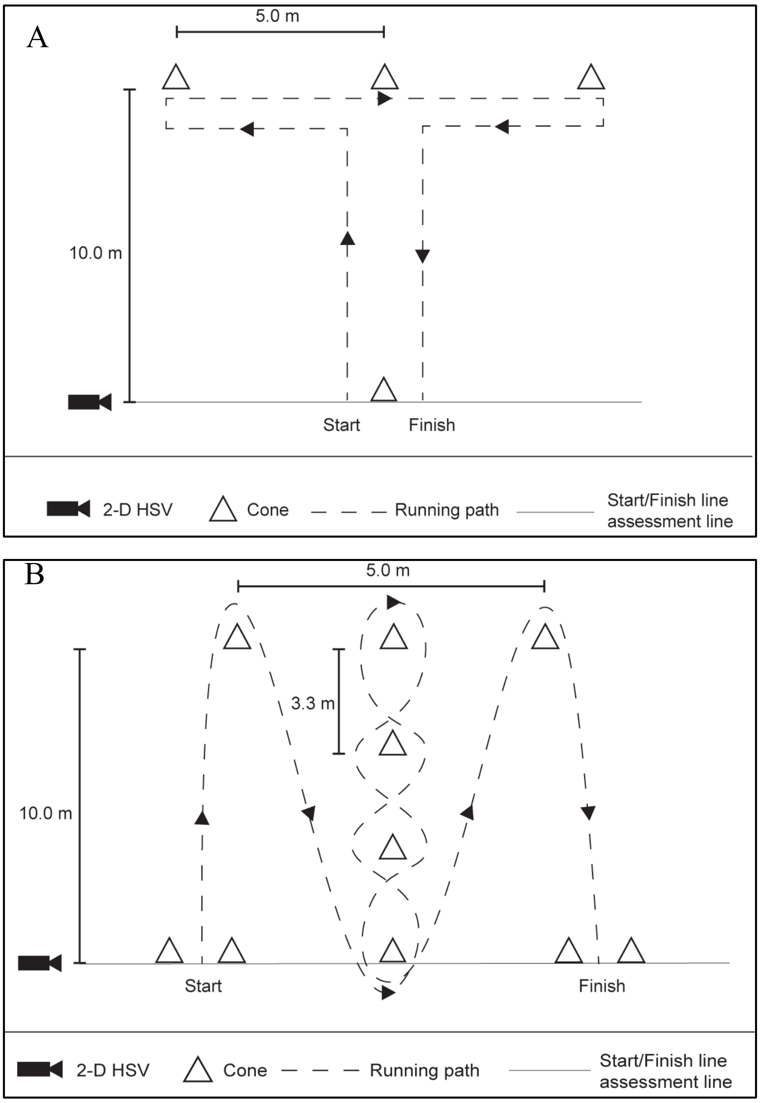


Figure 11.3A and B. Schematic representation of T-test (A) and Illinois agility test (B).

At present no 'gold standard' test of agility exists but both the T-test and Illinois drill have been validated in past literature. The application of the T-test has been inconsistent in the drill size (distances between cones) and procedure (i.e. touching cone or running around it; Hachana et al., 2013; Sporis et al., 2010; Stewart et al., 2014). Despite the variances in application, the T-test has shown excellent relative reliability (ICC $\geq$ 0.86; Table 11.1) and, although assessed using a variance of statistical tools, small absolute reliability bands (CV = 3.3%, Sporis et al. (2010); CV = 1.69%, Stewart et al. (2014); Table 11.1).

Table 11.1. Validation of T-test in past literature.

	Hachana et al. (2013)	Sporis et al. (2010)	Stewart et al. (2014)
Population	89 male team sports athletes, age: 20.8 ± 1.1 years, height: 1.80 ± 0.07 m, mass: 72.3 ± 8.8 kg	150 elite male junior footballers, age: 19.1 ± 0.6 years, height: 1.77 ± 0.06 cm, mass: 71.2 ± 5.7 kg	24 male PE students, Age: 16.7 ± 0.6 years
Measuring tool	Electronic time gates (1 m height)	Electronic time gates (0.75 m height)	Electronic time gates (0.8 m height)
Test score (s)	10.30 ± 0.61 (grouped)	8.20 ± 0.27	10.59 ± 0.61
Re-test score (s)		8.09 ± 0.26	10.48 ± 0.58
		8.09 ± 0.28	10.35 ± 0.57
ICC	0.95	0.928	0.86
SEM	0.18s		0.23
α		0.932	
CV (%)		3.3	1.69

Note: test score times are reported as mean ± standard deviation unless reported otehrwise; α = Crombach's alpha reliability coefficient; ICC = intraclass correlation coefficient; SEM = standard error of measurement; CV = coefficients of variation; PE = physical education

The Illinois agility test has, likewise, been applied with inconsistent distances and running procedures (Hachana et al., 2013, 2014; Lockie et al., 2013; Stewart et al., 2014). Despite the variances in application, the Illinois agility test has also shown excellent relative reliability (ICC ≥ 0.80; Table 11.2) and, although assessed using a variance of statistical tools, small absolute reliability bands (e.g. SRD = 0.52 s, Hachana et al. (2013), SRD = 0.64 s, Hachana et al. (2014); Table 11.1). Both the T-test and the Illinois agility test therefore demonstrate high test-retest reliability and may therefore be applied to assess a combination of acceleration and agility sprint performance.

11.13 Methods for Assessing Speed Performance in Football

The measure of completion time to quantify speed was in every validation study performed using electronic time gates (height 0.75-1.2 m), which according to the statistics appeared to be a reliable assessment methods. Past literature has, as mentioned in Section 11.4, criticised this assessment methods for its inconsistency in body part triggering the timing. With a commonly used height of ~1.0 m above the ground then gates will capture either leg, hip or arm movement. However this will vary depending on the height of the runner and where runner is in the gaitcycle when passing the line (Altmann et al., 2017; Cronin and Templeton, 2008). The International Association of Athletics Federations apply high speed video assessing when the chest passes the finish line as their "gold standard" measuring tool (Haugen and Buchheit, 2016).

Table 11.2. Validation of Illinois agility test in past literature.

	Hachana et al. (2013)	Hachana et al. (2014)	Lockie et al. (2013)	Stewart et al. (2014)
Participants	89 male team sports athletes, age: 20.8 ± 1.1 years, height: 1.80 ± 0.07 m, mass: 72.3 ± 8.8 kg	U-14 academy footballers,	18 male Australian footballers, age = 23.8 ± 7.0 years; height = 1.79 ± 0.06 m; mass = 85.4 ± 13.2 kg	24 male PE students, ($\bar{M}$ age = 16.7)
Measuring tool	Electronic time gates (1 m height)	Electronic time gates (1 m height)	Electronic time gates (1.2 m height)	Electronic time gates (0.8 m height)
Test score (s)	16.30 ± 0.77 s		14.19 ± 0.76 s	16.21 ±1.26 s
Re-test score (s)			14.02 ± 0.90 s	16.07 ± 0.97 s 15.97 ± 0.86 s
ICC	0.96	0.94	0.91	0.80
SEM	0.19 s	1.24%		0.55 s
SRD	0.52 s	0.64 s		
SWC			0.17 s	
CV (%)			2.5	2.21

Note: test score times are reported as mean ± standard deviation unless reported otehrwise; CV = coefficients of variation; ICC = intraclass correlation coefficient; PE = physical education; SEM = standard error of measurement; SRD = smallest real difference; SWC = smallest worthwhile change.

11.10 Summary on Test Setup for Ability to Maintain Football Specific Performance

Maintenance of football specific performance is multifactorial. The cause as well as signs and symptoms of inability to maintain football specific performance are multifactorial. Hence, multiple assessment methods but no gold standard exists. This review highlighted a number of non-invasive assessment tools that can be applied during field tests (i.e. no laboratory equipment needed). Measures of perceived exertion and ability to generate power and agility speed have previously been applied and validated for football relevant measures of maintenance of performance and can easily be applied during field test with multiple subjects and limited laboratory access. The agility speed assessment protocols would, however, benefit from validation of the Sterzing et al. (2009) football boot specific agility test prior to application.

CHAPTER 12

Test-Retest Reliability of Human Testing Protocol for the Impact of Football Boot Design on Maintainance of Performance and Foot Comfort throughout a Football Specific Match Simulation Drill

12.1 Chapter Outline

The literature review (Chapter 2) highlighted how the impact of football boot design on speed generation has only been assessed through short term exposure. Additionally, no validated protocol has been applied to assess the impact of football boot design on maintenance of performance through perceived exertion and ability to generate power and speed and foot comfort during football specific match-play simulation. Through the knowledge obtained from the literature review on previous methods applied to assess these in football and pilot studies to fill gaps in the knowledge a novel protocol was developed (Appendix J-L). This chapter describes a test-retest assessment of the reliability of this protocol.

12.2 Aims

This study aimed to validate a new test setup for the assessment of maintenance of performance through perceived exertion and ability to generate power and speed and foot comfort during a football specific match simulation drill. The setup was structured to be easy to apply and demand no more than two researchers to utilise it yet be ecological valid and produce transferable results. This was done by test-retest reliability assessment of the protocol.

12.3 Methods

Participants

Eleven skilled male university football players (age 20.1 ± 2.3 years, stature 1.83 ± 0.06 m, mass 74.2 ± 5.6 kg) volunteered for this study. Players had 8 ± 3 years of experience playing club level football. None of the subjects had suffered from match-preventive lower limb injuries in the six months prior to testing. All subjects were shoe size UK 8 to 10 and both right and left foot dominant players were included. A small range in shoe sizes was chosen to minimise changes in mechanical properties between shoe sizes impacting outcomes. During the test, subjects wore the same brand of new football socks to prevent the socks from altering the subjects' sensation of the boot and ball.

Ethics
The investigation received ethical clearance from the institutional ethics committee and each participant provided written informed consent in accordance with the requirements of the Helsinki Declaration for research using human participants.

Football boots
Players wore first generation Umbro Velocita football boots (Figure 12.1). The boots had firm ground outsoles suitable for the artificial pitch used in testing. All boots were dyed black using shoe dye recommended for football boots to minimise the impact of the colour scheme on the players' perception of the football boots.

Figure 12.1. Plantar, medial and dorsal view of Umbro Velocity.

Experimental design
Subjects participated in two sessions of 3 h duration separated by 7 days. Participants completed the session at the same time of day for both sessions.
Prior to the start of each session, the players readiness to complete the test was assessed though the Hooper's index (Haddad et al., 2013), muscle soreness felt in the main lower limb muscle groups using the muscle map suggested by Thompson et al. (1999) and overall perceived foot comfort was ranked on a novel 7-point Likert scale ranging from 1 = unbearable discomfort to 7 = extremely comfortable and a foot comfort map was used to identify and score any discomforts felt (Appendix I). Any player that rated sleep below "neither good nor bad", stress above "neither good nor bad", fatigue below "neither good nor bad", muscle sureness above "neither good nor bad" on the Hooper's index (Haddad et al., 2013; Hooper and Mackinnon, 1995), muscle soreness >3 on the muscle map, overall perceived foot comfort below "neither comfortable nor uncomfortable" or marked any discomforting locations on the foot map was assessed on that day.

Each session was initialised by a standardised warm up (Figure 12.2). Before and after completion of the match simulation drill, subjects completed two repetitions of the Illinois change of direction speed test (Getchell, 1979; Figure 12.2), which has been validated for assessment sports specific agility speed (Hachana et al., 2013, 2014; Lockie et al., 2013; Stewart et al., 2014; Chapter 11). The Illinois change of direction speed test was chosen over the football specific sprint tests by Sterzing et al. (2009) based on the poor test-retest reliability demonstrated in Appendix J. Directly after, three repetitions of maximal counter movement jump height (with hands on hips) were completed, which has been validated to assess lower limb power generation (Bosco and Komi, 1979; Markovic et al., 2004; Slinde et al., 2008). Both were executed to assess change in ability to generate speed over time. For the match simulation drill, players completed two 45 min match simulation halves separated by a 15 min break following the official instructions for the Soccer-specific Aerobic Field Test (SAFT90; Lovell et al., 2008) but at the modified length of 22 m to obtain appropriate and match-related fatigue (see Appendix K-L). Before, during and after the match simulation drill players were asked to complete a questionnaire assessing the player's perceived performance, fatigue and comfort measures (Appendix I). The match simulation drill was paused every 15th minute the match simulation stopped for <2 min to allow players to fill in a questionnaire, which has previously been performed by (e.g. Azidin et al., 2015; Nédélec et al., 2013; Small et al., 2009).

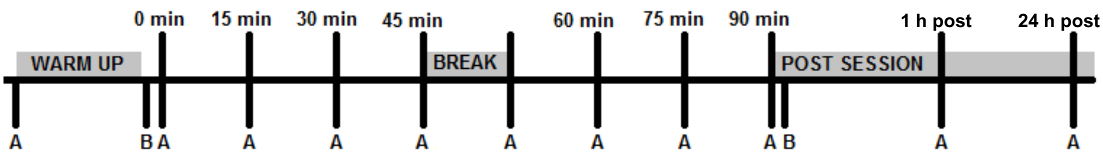


Figure 12.2. Schematic of the study design.
A = complete questionnaire, B = agility sprint and counter movement jump assessments.

For every 15th minute of the match simulation drill, subjects were asked to complete Borg's rated perceived exertion (RPE) scale (Borg, 1970; Appendix I). The use of RPE has been found reliable to use in football (Alexiou and Coutts, 2008; Impellizzeri et al., 2004). To assess perceived foot comfort level the novel 7-point Likert scale on overall foot comfort and the foot comfort map to circle and score any discomforts felt were completed (Appendix I). Finally, players were asked to rate any muscle fatigue felt in the main lower limb muscle groups follow the muscle map suggested by Thompson et al. (1999; Appendix I). Heart rate was recorded for each 15 min SAFT90 interval using a Polar Team Pro system (Polar Electronic, Kempele, Finland).

To assess impact of fatigue after completion of the match simulation drill, players were asked to rate muscle soreness felt in the main lower limb muscle groups following the muscle map suggested by Thompson et al. (1999) both 1 h and 24 h post session completion (Appendix I).

Test setup

Tests were performed on the same outdoor third generation artificial pitch (LigaTurf RS+ 265, Polytan, Burgheim, Germany). In brief, the pitch had a Polytan EL 25 shockpad, the carpet fibres were 65 mm monofilament polyethylene and infill comprised of sand and rubber crumb. The surface was FIFA 2 Star accredited 2 months prior to testing (Fédération Internationale de Football Association, 2017). Pitch testing using the FIFA Quality Concept methodologies (Fédération Internationale de Football Association, 2015), gave a maximum shock absorption of 69.75 ± 4.21%, maximum vertical deformation of 10.94 ± 1.75 mm and maximum rotational resistance of 44.8 ± 1.22 Nm. A modified version of Small et al.'s (2010) SAFT90 setup was applied as match simulation (Figure 12.3), with a placement of 22 m distance for the furthest cone instead of the original 20 m. The modified drill length increased the speed and thereby heart rate, which was found necessary to induce match-related fatigue (Appendix K-L). Initial movement involved 2 m forwards followed by a 2 m backwards movement around a tall cone which was either performed as forwards, then backwards running or by sidestepping. The second part involved a 22 m forward motion split halfway by a cutting action between three tall cones to the far cone followed by linear motion back to the starting position. Instructions followed the original audio recording. Players were at the start cone instructed on which movements (side stepping or forwards/backwards running) were to be performed around the cone placed 2 m form start and the intensity the drill was to be performed at up until the 22 m cone. At the 22 m cone a follow on instruction on the intensity of the motion back to the starting cone was given. This routine was repeated for each 15 min interval.

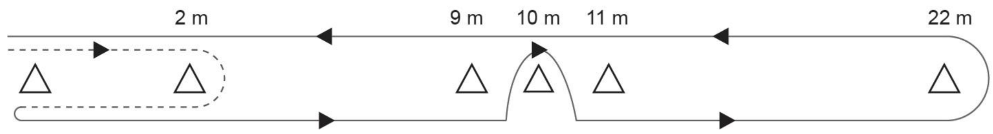


Figure 12.3. Diagram of the modified 22m SAFT90 field course adapted from original SAFT90 by Lovell et al. (2008))

Stippled line = alternating utility movement; Dense line = forwards running; Triangle = cone

To assess agility sprint ability, players completed the Illinois change of direction speed test (Figure 12.4). Setup followed the instructions given by Hachana et al. (2013). The subject started at the far left cone on the starting line. Sprint times were obtained using GoPro HERO4 Black cameras (240 Hz, 1280x720 pixels, barrel distortion = 2.1%) placed on the start/finish line (Figure 12.4). Time was measured in accordance to chest passing start and finish line. The best performance of the two trials was recorded for statistical analyses.

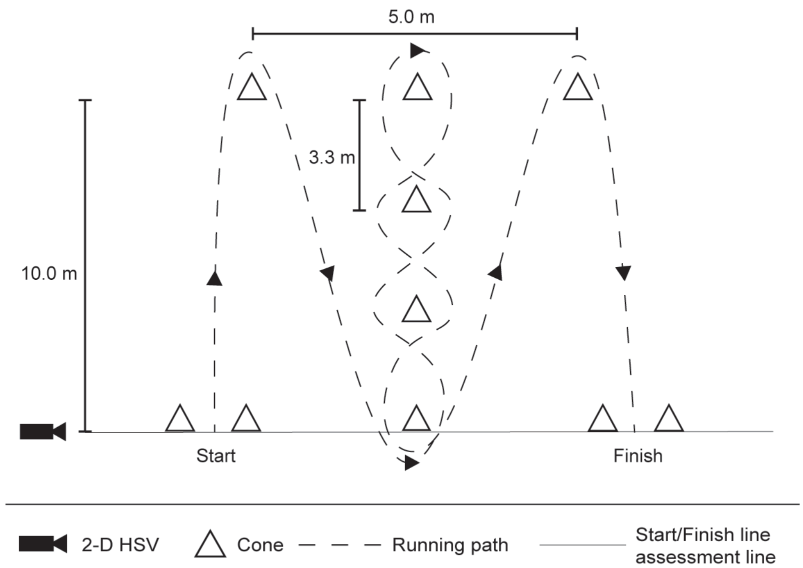


Figure 12.4. Schematic representation of Illinois change of direction speed test.

Maximal counter movement jump height was assessed using a Quattro Jump portable uniaxial force plate (Type 9290AD; Kistler Group, Winterthur, Switzerland), recording at 500 Hz. The plate was placed on a hard level surface next to the football pitch. Players performed the jumps without football boots on and followed the instructions given by Slinde et al. (2008) with hands kept on the waist whilst the jumps were performed. The researcher visually observed jumps and any jumps where players landed at a different location to take-off or altering landing technique were repeated. Data was analysed to give jump height using Quattro Jump Software (V1.1.1.4; Kistler Group, Winterthur, Switzerland).

Statistical analysis
Statistical analysis was carried out using SPSS software (Version 23.0; SPSS Inc., Chicago, IL). Statistical significance was set at $P \leq 0.05$. The reliability assessment followed the suggested assessment methods from the review of validation methods performed in Appendix E. Non-parametric tests were applied based on the violation of outliers in the differences between the two related groups for some variables. Systematic bias in the repeatability between sessions was analysed by Wilcoxon's matched-pair tests. The magnitude of relative reliability was determined by two-way random intraclass correlation coefficient ($ICC_{2,1}$) two-way random effect model (absolute agreement definition) analyses of the mean subject scores for each session following clinical significance levels suggested by Cicchetti (1994). Data was log-transformed due to heteroscedasticity as suggested by Vaz et al. (2013) and Weir (2005a). The $ICC_{2,1}$ is commonly suggested as the preferred assessment method to quantify relative reliability of test-retest validation setups (Beckerman et al., 2001; Hopkins, 2000; Lexell and Downham, 2005; Vaz et al., 2013; Weir, 2005). Absolute reliability was derived using standard error of measurement (SEM) and the smallest real difference (SRD) necessary to be considered real were derived from the intra-class correlation coefficients following the methods explain by (Weir, 2005).
Comparison of grouped count of discomforts and grouped regional discomforts marked on the foot map were assessed using Pearson's Chi^2 test for between session similarities. Relationships between the performance measures RPE and heart rate and comfort measures of overall discomfort score as well as count/sum of discomfort measures were assessed using Pearson's correlations.

12.4 Results

Test-retest reliability of performance intensity measures
Mean heart rate ranged from 148 ± 13 to 157 ± 12 beats per minute (bpm) during the 15 min intervals and showed a tendency to decrease over the 90 min session (Table 12.1). Mean difference between sessions varied from 0 to 3 bpm for each time interval and high P-values were obtained when assessing for bias apart from in the first 15 min interval ($P = 0.099$). Relative reliability assessed through $ICC_{2,1}$ measures demonstrated excellent reliability ($ICC_{2.1} \geq 0.950$) for any 15 min time interval throughout the 90 min match simulation drill. The 68% confidence interval represented by standard error of measurement (SEM) and 95% confidence interval represented by smallest detectable

change (SRD) expressed in both the measurement unit and as a percentage of the mean are demonstrated in Table 12.1. For mean heart rate the SRD from the absolute mean decreased from ±7 in the 0 to 15 min time interval to ±5 bpm for any time interval after 30 min.

Maximum heart rate measures ranged from 167 ± 10 to 176 ± 9 bpm and demonstrated to be consistent between sessions (mean difference = -2 to 4 bpm). Maximum heart rate measures demonstrated low bias apart from the first 15 min interval (0-15 min P = 0.078; Table 12.1). Relative reliability demonstrated excellent reliability ($ICC_{2.1} \geq 0.795$) for any 15 min time interval throughout the 90 min match simulation drill. Absolute reliability was shown to be less accurate than mean heart rate with SRDs detectable of ±9 to ±14 bpm (Table 12.1).

Table 12.1. Systematic bias, relative reliability and absolute reliability for performance intensity measures.

Variable	Session 1 Mean ± SD		Session 2 Mean ± SD		$ICC_{2,1}$	MD	Bias (P-value)	Grouped mean	SEM	SRD
Mean HR (bpm)										
0-15 min	157	±12	154	±13	0.950	3	0.099	156	±3	±7
15-30 min	154	±13	153	±13	0.965	0	0.810	153	±2	±6
30-45 min	153	±11	152	±13	0.969	1	0.554	152	±2	±5
45-60 min	147	±14	147	±14	0.982	0	1.000	147	±2	±5
60-75 min	151	±10	150	±11	0.969	1	0.509	150	±2	±5
75-90 min	149	±12	148	±13	0.980	1	0.228	149	±2	±5
Max HR (bpm)										
0-15 min	176	±9	172	±11	0.894	4	0.078	174	±3	±9
15-30 min	171	±11	173	±9	0.823	-2	0.520	172	±4	±11
30-45 min	173	±7	169	±10	0.843	4	0.106	171	±4	±10
45-60 min	171	±10	168	±14	0.814	4	0.299	169	±5	±14
60-75 min	169	±10	167	±10	0.795	2	0.515	168	±4	±12
75-90 min	172	±10	168	±11	0.824	4	0.189	170	±4	±12
RPE										
15 min	12	±3	12	±2	0.614	0	0.594	12	±1	±4
30 min	13	±2	13	±2	0.785	0	1.000	13	±1	±2
45 min	14	±2	14	±2	0.831	0	0.545	14	±1	±2
60 min	14	±2	14	±2	0.810	0	0.594	14	±1	±2
75 min	15	±3	15	±2	0.851	0	0.719	15	±1	±2
90 min	16	±2	16	±2	0.836	-1	0.729	16	±1	±3

MD = mean difference; Significantly difference between sessions set to $P \leq 0.05$; $ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition); SEM = Standard error of measurement = SD × $\sqrt{1 - ICC}$; SRD = Smallest real difference at 95% confidence intervals = SEM × 1.96 × $\sqrt{2}$.

Although heart rate showed a tendency to decrease over time, RPE gradually increased over the 90 min starting at a mean score of 12 ± 2 in session 1 and 12 ± 3 in session 2 and finishing at 16 ± 2 in both sessions. Mean difference was 0 for all time intervals apart from the last 15 min, with a small mean difference of -1. High P-values were also obtained between sessions ($P \geq 0.545$; Table 12.1). Good relative reliability was seen for the for 15 min interval ($ICC_{2.1} = 0.614$) whilst excellent relative reliability was seen for the following 75 min of match simulation ($ICC_{2.1} \geq 0.785$; Table 12.1). RPE scores demonstrated a SRD detectable of ±2-3 scores for any time interval aside from the first 15 min interval, which demonstrated a worse SRD of ±4 (Table 12.1).

Test-retest reliability of fatigue measures

Illinois agility test times assessed before completion of the 90 min match simulation drill demonstrated were significantly faster than sprint times performed after the completion of the 90 min match simulation drill for session 2 (grouped sprint times P = 0.010). However, a significant difference was seen between sprint times performed before completion of the 90 min match simulation drill is sessions 1 and 2 (P = 0.007; Table 12.2) and a low, although not significant, P-value was seen for sprint times performed after completion of the 90 min match simulation drill (P = 0.191; Table 12.2). If sprint performance instead is assessed as change in sprint time the violation of bias can be controlled (P = 0.576; Table 12.2). However, relative reliability demonstrated poor test-retest reliability whilst the SRD detectable was ±3.7% change, which is higher than the actual change seen for both sessions (Table 12.2).

Maximum counter movement jump height did not significantly change after completion of the 90 min match simulation drill (grouped jump heights P = 0.916). The jumps did, however, demonstrate small mean differences (pre MD = 0.9 cm, post MD = 1.9 cm) and high P-values (pre P = 0.483, post P = 0.861), indicating no violation of bias. Excellent relative reliability scores were seen between sessions ($ICC_{2.1} \geq 0.900$) and SRD prior to start was ±4 cm, whilst post session SRD demonstrated to be ±7 cm.

Table 12.2. Systematic bias, relative reliability and absolute reliability for performance intensity measures.

Variable	Session 1 Mean ± SD		Session 2 Mean ± SD		$ICC_{2,1}$	MD	Bias (P-value)	Grouped mean	SEM	SRD
Sprint time (s)										
0 min	15.95	±0.53	16.49	±0.27	0.451	-0.54	0.007	16.22	±0.39	±1.07
90 min	16.36	±0.46	16.78	±0.62	0.299	-0.42	0.191	16.57	±0.45	±1.25
Difference (%)	2.6	±2.0	1.8	±2.6	0.206	-0.8	0.576	2.2	±1.3	±3.7
CMJ (cm)										
0 min	48.7	±6.7	47.6	±7.6	0.965	0.9	0.483	48.2	±1	±4
90 min	49.3	±6.8	46.8	±9.4	0.900	1.9	0.861	48.0	±3	±7

MD = mean difference; $ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition); SEM = Standard error of measurement = SD × $\sqrt{1 - ICC}$; Significantly difference between sessions set to P ≤ 0.05; SRD = Smallest real difference at 95% confidence intervals = SEM × 1.96 × $\sqrt{2}$.

Self-reporting of muscle fatigue of the main muscle groups of the lower limb assessed on a 10-point Likert scale gradually increased throughout the match simulation drill from 1.4-2.7 at the 15th minute to 2.7-4.1 after 90 min for the different muscle groups, equalling a small increase in fatigue from "no muscle fatigue"/"a little muscle fatigue" to "a little muscle fatigue" (Table 12.3). Small mean differences were seen for any muscle group throughout the match simulation drill (≤ ±0.6) and no significant differences were observed when assessing for between session biases (Table 12.3). Self-reporting of muscle fatigue of the main muscle groups of the lower limb demonstrated excellent relative reliability for all muscle groups for the 30 min mark onwards (Table 12.3). For the first fatigue measure after 15 min of drill completion the gluteal, adductor and quadriceps regions demonstrated excellent relative reliability whilst the hamstring, calf and anterior lower leg regions demonstrated good relative reliability (Table 12.3). All SRDs for the self-reported main muscle groups of the lower limb muscle fatigue were ≤ ±1.4 for anterior lower leg, ≤ ±2.1 for gluteal and calf regions, ≤ ±2.5 for adductors and quadriceps regions and ≤ ±2.9 for hamstrings (Table 12.3).

Perceived muscle soreness scores obtained 1 h and 24 h after completion of the test session demonstrated highest muscle fatigue 1 h post-session with highest fatigue scores reaching 4.4 ± 2.1 for the quadriceps muscle group equalling between "little muscle soreness" and "quite sore" (Table 12.4). Mean difference again showed small differences between sessions (≤ ± 0.6) and no between-session biases were observed. Self-reporting of muscle soreness demonstrated poor to good relative reliability for pre-session scores (Table 12.4). Muscle soreness 1 h and 24 h after completion of the match simulation did, however, demonstrated good (in one case) and excellent relative reliability scores for all muscle groups ($ICC_{2,1}$ ≥ 0.698; Table 12.4). Self-reported muscle soreness on arrival (start) demonstrated small SRDs ranging from ±0.7 to ±1.2. One hour and 24 h post testing SRDs for each muscle group ranged from ±0.7 to ±2.1 depending on muscle group assessed.

Table 12.3. Systematic bias, relative reliability and absolute reliability for test-retest validation of muscle fatigue assessments (1-2 = no muscle fatigue to 9-10 very,very fatigued).

Variable	Session 1 Mean ± SD		Session 2 Mean ± SD		$ICC_{2,1}$	MD	Bias (P-value)	Grouped mean	SEM	SRD
Glute fatigue										
15 min	2.0	±1.2	2.0	±1.2	0.783	0.4	0.225	2.0	±0.6	±0.8
30 min	2.3	±1.2	2.5	±1.7	0.726	-0.3	0.500	2.4	±0.8	±1.4
45 min	2.2	±1.9	2.5	±2.1	0.687	-0.4	0.502	2.3	±0.9	±2.0
Post break	2.3	±1.9	2.8	±1.7	0.815	-0.4	0.381	2.6	±0.8	±2.1
60 min	2.6	±2.1	3.0	±1.9	0.857	-0.4	0.377	2.8	±0.7	±2.1
75 min	3.0	±2.2	3.2	±2.0	0.931	-0.2	0.559	3.1	±0.5	±1.5
90 min	3.4	±2.5	3.2	±2.2	0.980	0.2	0.347	3.3	±0.3	±0.9
Adductor fatigue										
15 min	2.1	±0.6	2.0	±1.0	0.849	0.1	0.782	2.1	±0.3	±0.9
30 min	2.1	±0.8	2.4	±1.0	0.782	-0.3	0.347	2.3	±0.4	±1.2
45 min	2.3	±1.5	2.2	±1.2	0.952	0.1	0.594	2.3	±0.3	±0.8
Post break	2.3	±1.5	2.8	±1.8	0.703	-0.4	0.430	2.6	±0.9	±2.4
60 min	2.4	±1.9	3.0	±2.1	0.783	-0.6	0.347	2.7	±0.9	±2.5
75 min	2.8	±1.9	3.2	±2.0	0.954	-0.4	0.104	3.0	±0.4	±1.1
90 min	3.3	±2.4	3.4	±2.3	0.953	-0.1	0.760	3.4	±0.5	±1.4
Quadriceps fatigue										
15 min	2.1	±0.6	2.0	±1.0	0.849	0.1	0.782	2.1	±0.3	±0.9
30 min	2.1	±0.8	2.4	±1.0	0.782	-0.3	0.347	2.3	±0.4	±1.2
45 min	2.3	±1.5	2.2	±1.2	0.952	0.1	0.594	2.3	±0.3	±0.8
Post break	2.3	±1.5	2.8	±1.8	0.703	-0.4	0.430	2.6	±0.9	±2.4
60 min	2.4	±1.9	3.0	±2.1	0.783	-0.6	0.347	2.7	±0.9	±2.5
75 min	2.8	±1.9	3.2	±2.0	0.954	-0.4	0.104	3.0	±0.4	±1.1
90 min	3.3	±2.4	3.4	±2.3	0.953	-0.1	0.760	3.4	±0.5	±1.4
Hamstring fatigue										
15 min	2.0	±1.0	2.0	±1.0	0.600	0.2	0.669	2.0	±0.8	±1.2
30 min	2.8	±1.6	3.0	±2.3	0.921	-0.2	0.559	2.9	±0.5	±1.5
45 min	2.1	±1.5	2.7	±2.2	0.782	-0.6	0.325	2.4	±0.9	±2.4
Post break	2.8	±2.0	3.0	±1.9	0.781	-0.2	0.708	2.9	±0.9	±2.5
60 min	3.4	±2.4	3.5	±2.3	0.783	0.3	0.871	3.5	±1.1	±2.9
75 min	3.6	±2.4	3.4	±2.4	0.812	0.1	0.870	3.5	±1.0	±2.8
90 min	4.1	±2.6	4.0	±2.7	0.848	0.1	0.873	4.1	±1.0	±2.8
Calf fatigue										
15 min	2.1	±0.6	2.3	±1.4	0.677	-0.2	0.559	2.2	±0.6	±1.7
30 min	2.7	±1.5	2.4	±1.7	0.843	0.2	0.594	2.6	±0.6	±1.7
45 min	2.7	±2.5	2.6	±1.5	0.859	0.1	0.834	2.6	±0.8	±2.1
Post break	2.3	±2.0	2.8	±1.7	0.951	-0.4	0.104	2.6	±0.4	±1.1
60 min	3.1	±2.3	2.9	±1.8	0.913	0.2	0.594	3.0	±0.6	±1.6
75 min	3.4	±2.1	3.2	±1.6	0.850	0.2	0.645	3.3	±0.7	±1.9
90 min	4.0	±2.5	3.8	±2.1	0.908	0.2	0.645	3.9	±0.7	±1.9
Ant. Lower leg fatigue										
15 min	1.4	±0.5	1.7	±1.0	0.636	-0.2	0.447	1.6	±0.5	±1.3
30 min	1.7	±0.7	1.8	±1.0	0.867	-0.1	0.594	1.7	±0.3	±0.8
45 min	2.2	±1.6	1.9	±1.4	0.901	0.3	0.282	2.1	±0.5	±1.3
Post break	2.0	±1.7	2.0	±1.3	0.887	0.0	1.000	2.0	±0.5	±1.4
60 min	2.3	±1.9	2.1	±1.4	0.933	0.2	0.447	2.2	±0.4	±1.1
75 min	2.7	±2.0	2.6	±1.7	0.975	0.1	0.594	2.6	±0.3	±0.8
90 min	3.0	±2.2	2.7	±1.7	0.947	0.3	0.282	2.8	±0.4	±1.2

MD = mean difference; Significantly difference between sessions set to $P \leq 0.05$; $ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition); SEM = Standard error of measurement = SD × $\sqrt{1 - \text{ICC}}$; SRD = Smallest real difference at 95% confidence intervals = SEM × 1.96 × $\sqrt{2}$.

Table 12.4. Systematic bias, relative reliability and absolute reliability for test-retest validation for post session muscle soreness assessed (1-2 = no muscle soreness to 9-10 very, very sore).

Variable	Session 1 Mean ± SD		Session 2 Mean ± SD		$ICC_{2,1}$	MD	Bias (P-value)	Grouped mean	SEM	SRD
Glute soreness										
1 h post	2.3	±1.7	2.6	±2.6	0.960	-0.2	0.449	2.4	±0.4	±1.1
24 h post	2.2	±1.7	2.2	±2.2	0.942	0.0	1.000	2.2	±0.4	±1.1
Adductor soreness										
1 h post	3.4	±1.5	4.0	±2.1	0.818	-0.6	0.276	3.7	±0.8	±2.1
24 h post	2.8	±1.1	2.9	±2.0	0.698	-0.1	0.842	2.8	±0.9	±2.0
Quadriceps soreness										
1 h post	4.4	±2.1	4.4	±2.1	0.949	0.0	0.729	4.4	±0.5	±1.3
24 h post	3.2	±1.3	3.0	±1.7	0.969	0.2	0.169	3.1	±0.3	±0.7
Hamstring soreness										
1 h post	3.8	±1.9	3.9	±2.1	0.949	-0.1	0.729	3.8	±0.4	±1.2
24 h post	3.0	±1.4	2.8	±1.3	0.969	0.2	0.169	2.9	±0.2	±0.6
Calf soreness										
1 h post	4.1	±1.9	4.2	±2.5	0.891	-0.1	0.824	4.2	±0.7	±2.0
24 h post	3.3	±1.7	3.0	±1.7	0.855	0.3	0.438	3.2	±0.6	±1.7
Ant. Lower leg soreness										
1 h post	2.4	±1.2	2.0	±1.7	0.854	0.4	0.225	2.2	±0.5	±1.5
24 h post	2.3	±1.3	1.9	±1.6	0.857	0.4	0.225	2.1	±0.5	±1.5

MD = mean difference; Significantly difference between sessions set to $P \leq 0.05$; $ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition); SEM = Standard error of measurement = $SD \times \sqrt{1-ICC}$; SRD = Smallest real difference at 95% confidence intervals = $SEM \times 1.96 \times \sqrt{2}$.

Test-retest reliability of comfort measures

The overall perceived foot comfort 7-point Likert scale demonstrated a decrease in mean comfort over time from 4.0 ± 0.9 and 3.9 ± 0.8 in session 1 and 2 respectively to 2.9 ± 0.9 and 2.7 ± 1.4 (Table 12.5). High P-values (P-value ≥ 0.311) and low mean differences (MD ≤ 0.3) was seen for any time interval (Table 12.5). The overall perceived foot comfort 7-point Likert scale demonstrated poor to good $ICC_{2,1}$ scores, which was due to small variance in outcome measures between participants making their change in ranking more likely to change. Overall perceived foot comfort revealed a SRD when trying the boot on at the start of session of ±0.9, SRD then dropped from ±1.8 at the start of the match simulation to ±1.5 at half time. After half time SRD increased to ±2.0 at the 60^{th} and 75^{th} minute assessment point and ±2.4 after 90 min (Table 12.5).

The foot discomfort map was assessed using both count and sum of discomforts. Last mentioned included the severity of discomfort marked by players (Table 12.5). Both sum and count of discomfort increased throughout the 90 minutes. Small mean differences (MD ≤ ±0.8) and no violation of bias (P ≥ 0.416) were seen for both assessment types. Relative reliability for sum of discomforts ranged from poor to good ($ICC_{2,1}$ 0.064-0.600) whilst count of discomforts ranged from poor to excellent (($ICC_{2,1}$ 0.061-0.960). No consistency was seen with regards to time periods with high and low score tendencies between count and sum measurements. The SRD detectable for discomforts measured as the sum ranged from ±2.4 to ±10.2 whilst SRD for count of discomforts ranged from ±0.8 to ±4.8. For count of discomforts the plantar foot region was the most affected foot region followed by the dorsal side (Table 12.5). Mean difference varied between foot regions but no violation of bias was seen for any of the regions (Table 12.5). Relative reliability ranged from good to excellent between the different regions ($ICC_{2,1}$ 0.667-0.833) and absolute reliability ranged from ±3.6 for the heel region to ±11.1 for the plantar region.

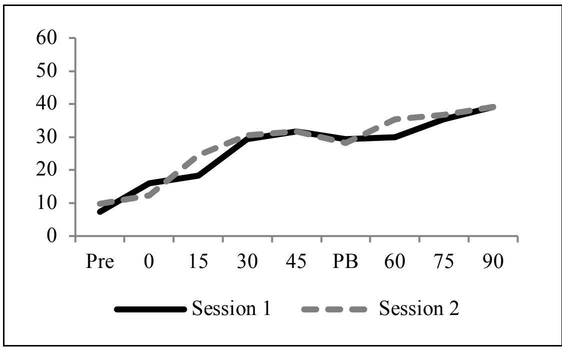
Table 12.5. Systematic bias, relative reliability and absolute reliability for test-retest validation of perceived comfort (1 = unbearable discomfort, 7 = extremely comfortable) and foot map discomforts.

Variable	Session 1 Mean ± SD		Session 2 Mean ± SD		$ICC_{2,1}$	MD	Bias (P-value)	Grouped mean	SEM	SRD
Perceived comfort										
Pre	4.0	±0.6	4.1	±0.6	0.746	0.0	0.845	4.0	±0.3	±0.9
0 min	4.0	±0.9	3.9	±0.8	0.311	0.1	0.782	3.9	±0.7	±1.8
15 min	3.7	±1.0	3.6	±0.9	0.447	0.1	0.782	3.6	±0.7	±1.9
30 min	3.2	±1.2	3.2	±1.0	0.672	0.0	1.000	3.2	±0.6	±1.7
45 min	3.2	±1.1	3.0	±1.0	0.735	0.2	0.512	3.1	±0.5	±1.5
60 min	3.3	±1.4	3.0	±1.1	0.680	0.3	0.619	3.2	±0.7	±2.0
75 min	3.1	±1.1	2.8	±1.3	0.597	0.3	0.397	2.9	±0.7	±2.0
90 min	2.9	±0.9	2.7	±1.4	0.471	0.2	0.645	2.8	±0.8	±2.4
Sum of discomforts										
Pre	1.1	±1.7	0.9	±1.4	0.450	-0.2	0.738	0.8	±0.9	±2.4
0 min	2.5	±3.4	1.3	±1.1	0.111	0.1	0.813	1.4	±0.9	±2.4
15 min	3.1	±2.3	2.8	±2.3	0.064	0.3	0.760	2.9	±2.1	±5.9
30 min	4.3	±2.7	3.9	±4.0	0.432	0.4	0.755	4.1	±2.5	±6.9
45min	3.9	±2.2	4.1	±4.4	0.243	-0.2	0.888	4.0	±2.9	±8.1
Post break	3.7	±2.0	3.3	±3.6	0.600	0.3	0.760	3.5	±1.8	±4.9
60 min	4.3	±2.4	5.0	±5.9	0.580	-0.7	0.698	4.7	±2.8	±7.8
75 min	5.3	±3.8	5.8	±6.4	0.593	-0.4	0.823	5.6	±3.2	±9.0
90 min	5.0	±3.1	5.8	±5.1	0.215	-0.8	0.698	5.4	±3.7	±10.2
Count of discomforts										
Pre	1.2	±1.9	0.3	±0.7	0.675	-0.2	0.738	0.8	±0.7	±1.8
0 min	2.6	±3.7	0.9	±1.4	0.350	0.3	0.438	1.3	±0.8	±2.1
15 min	1.7	±1.1	1.1	±1.1	0.960	-0.6	0.508	1.9	±0.3	±0.8
30 min	2.7	±1.3	2.2	±1.8	0.302	-0.1	0.892	2.7	±1.5	±4.1
45min	2.9	±1.6	2.8	±2.2	0.503	0.0	1.000	2.9	±1.4	±3.8
Post break	2.7	±1.7	2.9	±2.3	0.442	0.1	0.902	2.6	±1.6	±4.3
60 min	2.7	±1.3	2.6	±2.5	0.061	-0.6	0.416	2.9	±1.7	±4.8
75 min	3.2	±2.0	3.2	±2.2	0.665	-0.1	0.880	3.3	±1.2	±3.2
90 min	3.2	±1.9	3.3	±2.2	0.457	0.0	1.000	3.6	±1.4	±3.9
Count of discomfort per foot region										
Plantar	10.9	±6.4	9.1	±8.5	0.704	1.8	0.137	10.0	±4.0	±11.1
Dorsal	5.0	±3.4	5.8	±5.7	0.709	-0.8	0.482	5.4	±2.5	±6.9
Medial	1.6	±2.0	2.0	±3.5	0.667	-0.4	0.641	1.8	±1.6	±4.4
Lateral	3.3	±3.7	2.1	±3.5	0.692	1.2	0.650	2.7	±2.0	±5.5
Heel	1.4	±2.4	3.9	±3.5	0.833	-2.4	0.202	2.7	±1.3	±3.6

MD = mean difference; Significantly difference between sessions set to $P \leq 0.05$; $ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition); SEM = Standard error of measurement = SD × $\sqrt{1 - ICC}$; SRD = Smallest real difference at 95% confidence intervals = SEM × 1.96 × $\sqrt{2}$.

Assessment of grouped foot discomfort map measures

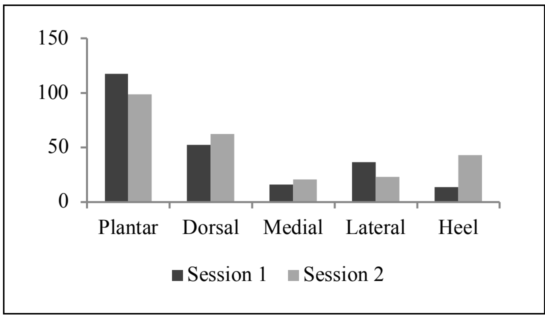
Foot map count from grouped data from all participants demonstrated high similarities between sessions (Figure 12.5). The lowest similarities were seen when trying on up until the 15th min in (P = 0.424-0.623) and 60 min into the drill (0.509).



Time	Session 1	Session 2	P-value
Pre	7	10	0.623
0 min	16	12	0.561
15 min	18	24	0.424
30 min	29	31	0.892
45 min	32	32	1.000
PB	29	28	1.000
60 min	30	35	0.509
75 min	35	37	0.900
90 min	39	39	1.000

Figure 12.5. Count of discomforts marked on the foot map over the 90 min.
Pre = prior to start of test session when first trying on boot; PB = post break.

Foot map count for each foot region was also assessed from grouped data demonstrating high similarities between sessions (Figure 12.6) with the most exposed regions being the plantar (session 1 = 113, session 2 = 109; Figure 12.6).



Time	Session 1	Session 2	P-value
Plantar	113	109	0.830
Dorsal	59	64	0.703
Medial	15	18	0.721
Lateral	27	30	0.781
Heel	23	27	0.650

Figure 12.6. Total count of discomforts per foot region marked in the two sessions.
Pearson's Chi^2 test. P-value significance level set at 0.05.

Relationship between performance and comfort factors

The correlation between objective measures of heart rate and subjective measures using RPE scores with measures of comfort through overall comfort score and count and sum of discomforts marked on the foot map demonstrated significant correlations for all interactions apart from RPE and sum of discomforts (Table 12.6). Count of discomforts demonstrated the highest correlation with both RPE (r = 0.873) and mean heart rate (r = -0.758; Table 12.6).

Table 12.6. Correlation between measures of performance and comfort level.

	RPE	Mean HR
Overall comfort	-0.830**	0.691*
Count of discomforts	0.873***	-0.758**
Sum of discomforts	0.537	0.622*

Note: Person's Correlation coefficient. $P \leq 0.05$ = *, $P \leq 0.01$ = **, $P \leq 0.001$ = ***.

12.5 Discussion

This study aimed to validate a new test setup for the assessment of change in foot comfort, ability to perform and fatigue over a full 90 min match simulation using both objective and subjective measures. A large number of objective and subjective measures were applied to understand the most reliable measures of performance, fatigue and comfort level.

Measures of maintenance of performance

Heart rate was assessed throughout the 90 min match simulation by the mean and maximum heart rate for each 15 min SAFT90 interval. Mean heart rate was shown to be a reliable tool with excellent $ICC_{2,1}$ scores and a SRD of ±5-7 bpm needed to detect significant changes in heart rate. Application of maximum heart rate also showed excellent $ICC_{2,1}$ scores but larger SRD were needed to obtain significant differences (±9-12 bpm), which makes maximum heart rate a less reliable performance assessment tool. Heart rates were, despite the extended drill length, below heart rate data from most 90 min real match-play studies (Table K3, Appendix K) as well as the original validation study by (Lovell et al., 2008) but closer to match-play heart rates compared to heart rate levels obtained with the original setup (Table K3, Appendix K). However, assessed individually, six of the 11 players reached the typical heart rate level seen from match-play data (player with lowest mean heart rate = 133 bpm; player with highest mean heart rate = 171 bpm).

RPE was demonstrated to be a reliable measure with a change of ±2 from 30th to 75th min and ±3 at the 90th minute demonstrated to be detectable. The RPE scores were higher in this study compared to applying the original SAFT90 protocol length (Table K5, Appendix K). The RPE scores therefore better replicated RPE scores seen in the past literature during SAFT90 completion (Table K3, Appendix K) as well as real match-play measures (Los Arcos et al., 2016; Rampinini et al., 2008, 2011). RPE scores were lower than Azidin et al. (2015) testing amateur players with the SAFT90 but slightly higher than Nédélec et al. (2013), who tested professional football players using SAFT90. Mean heart rate and RPE, therefore, both demonstrated to be reliable between sessions, to detect changes in performance and more ecologically valid than scores obtained using the traditional SAFT90 protocol (Appendix K).

Although both mean heart rate and RPE scores demonstrated excellent reliability, the two measures did not follow similar trends over the full 90 min match simulation. Studies have previously established a strong relationship between heart rate and RPE (Borg, 1982). RPE does, however, also consist of recognition of sensations originating from muscles, joints, chest (i.e. pounding heart and laboured breathing), circulating factors, skin, and higher brain centre inputs, which can give discrepancies over long term exercise (Borg, 1982; Hampson et al., 2001; Kayser, 2003; St Clair Gibson et al., 2003). Similar tendencies were observed in other studies applying the SAFT90 match simulation drill (Azidin et al., 2015; Nédélec et al., 2013), indicating that players may not push themselves as hard at the end of the match simulation drill.

As muscle cells are activated by electrical impulses from the brain through the nervous system signalling intramuscular release of calcium by the sarcoplasmic reticulum, muscle fatigue can occur at nerve or muscle cell level (Enoka and Duchateau, 2008; Enoka and Stuart, 1992). Sprint performance assesses a mixture of the two whilst counter movement jump is an indicator of neurological fatigue by decreased power generation and thereby a decreased jump height (Rodacki et al., 2002).

Sprint time assessed by the commonly used Illinois agility test (Hachana et al., 2013, 2014; Lockie et al., 2013; Stewart et al., 2014) demonstrated higher sprint times, i.e. slower performance, after 90 min, in both sessions though only significant in session 2. Violation of bias, poor $ICC_{2,1}$ scores and large SRDs were, however, seen for sprint times between sessions. To overcome the poor reliability when comparing actual performance then test-retest reliability of percentage of change between pre- and post-session was assessed. Bias was no longer violated, $ICC_{2,1}$ scores were still poor due to small differences between subjects and therefore players' ranking in the group being more likely to change (Weir, 2005) but small SRDs of 3.7% were obtained. Assessment of sprint times should therefore be assessed as a percentage of change in performance instead of actual sprint time.

The jump heights obtained in this study were higher than heights measured in the past literature (e.g. 35.4 ± 4.7 cm to 35.2 ± 4.4 cm in Markovic et al. (2004), who assessed male physical education students). The players used in this study were therefore higher level athletes and most players had undergone pre-season testing within a month prior to this testing and reported similar scores obtained for counter movement heights measured using a stationary force plate. The counter movement jumps, demonstrated excellent relative reliability scores ($ICC_{2,1} \geq 0.900$) and absolute reliability levels able to detect differences of 4 cm pre-session and 7 cm post session. $ICC_{2,1}$ scores were similar to relative reliability assessment results from previous studies (ICC = 0.86-0.98, Table 11.9). Previous literature correspondingly demonstrated similar test-retest absolute reliability (SRD = 4.77 cm, Slinde et al. (2008); SEM 2.9 cm, Hachana et al.

(2013); Table 11.9). Although a 7 cm SRD band post exercise may be large, counter movement jump height appears to be a better measure of change in power generation due to fatigue in comparison to the Illinois sprint agility running.

Additionally, no significant decrease (grouped jump heights P = 0.916) in jump height was seen between pre- and post-session. Similar results were obtained by Nédélec et al. (2013). Whether a football boot causing a higher level of discomfort may change this is unknown and further assessment of change in jump height pre- and post-session should therefore not be excluded before further research has been made.

Players' perception of muscle specific fatigue was assessed using a 10-point Likert scale for the major muscle groups of the lower limb. Each muscle group increased in fatigue throughout the 90 min match simulation drill from "no muscle fatigue" to "a little muscle fatigue". The highest increase was seen in the posterior muscle groups (hamstring and calf regions). With good and excellent relative reliability and detectable of SRDs ranging from ±0.8 to ±2.9, muscle fatigue assessment may be a reliable tool. The broadest SRD detectable were seen for glutes, adductors, quadriceps and hamstring regions post half time break and at 60th minute, indicating a less reliable period. This may be due to the rest period during half time and re-adaptation to exercise causing a larger variance in perception.

Likewise, players' perception of muscle soreness was assessed before and after completion of the match simulation drill. Prior to assessment, muscle soreness was used as a control measure of readiness to participate in the study. Any players scoring >2 did not take part in the test session on that day. Post-session the highest levels of soreness were seen 1 h after completion in comparison to 24 h after. The most affected muscle regions of perceived muscle soreness were the adductor, quadriceps, hamstring and calf regions. Excellent relative reliability was seen for all post-session assessment measures and with SRD bands within a range of 2. Fatigue and soreness therefore appear to be relevant and relatively sensitive measures to assess perceived impact of match-play simulation on muscular ability to maintain performance.

Measures of foot comfort

Comfort and discomfort are subjective measures and therefore individual to the subject's experience. Comfort has previously been described as an ever-changing individual perception influenced by mechanical, neurophysiological and psychological factors (Chen et al., 1995; Miller et al., 2000; Mündermann et al., 2001; Nigg et al., 1999). Foot comfort is additionally subjective due to variations in foot shape. Assessing foot comfort and discomfort is therefore challenging. Research has shown a discrepancy between objective plantar pressure and subjective perception of comfort during short term exposure (Okholm Kryger et al., 2016) despite the high plantar pressures experienced in football boots (Santos et al., 2001). Change in comfort level has, however, never been assessed over a full 90 min football match.

This study assessed the test-retest reliability of two comfort tools: an overall foot comfort 7-point Likert scale and a discomfort foot map. Overall foot comfort demonstrated SRDs detectable of ≤ ±2 until the 90th minute where a difference of ±2.4 is needed to prove significantly different. Applying the overall foot comfort 7-point Likert scale therefore appears to be useful when aiming to detect changes in comfort, especially, as no other tool have been validated and demonstrated to be more sensitive. 'Trying on' perception of comfort and 'wearing' are generally accepted as different comfort perceptions (Olaso Melis et al., 2016). It is, however, not clear how long boots should be worn to gain a full understanding of 'wearing' comfort. Overall foot comfort at the start was rated as 4, corresponding to 'neither comfortable nor uncomfortable'. The comfort then gradually decreased to < 3, corresponding to 'noticeable discomfort', after completion of the 90 min match simulation drill. No clear change therefore occurred in overall comfort level to define a difference between 'trying on' and 'wearing' comfort perception but wearing boots over time did decrease comfort. As a remark on the level of comfort scored, comfort level started at 'neither comfortable nor uncomfortable'. This is not surprising as football boots are not designed with a key focus on comfort but instead a level of compensation of comfort for optimal performance and safety. The tighter fit preventing foot sliding during multidirectional change of direction and minimal cushioning, especially in the lightweight speed boot designs, naturally increase planter pressure on the planter surface of the foot (Santos et al., 2001).

The foot map was included to understand whether looking at local discomfort is a reliable assessment method of foot discomfort. Firstly, comfort map was assessed using mean player scores of both sum of discomfort scores and count of discomforts marked. Applying the sum demonstrated a larger SRD detectable than the count of discomforts. This may indicate that subjects were not able to grade the discomfort reliably in contrast to their ability to distinguish between discomfort and no discomfort. Count demonstrated better relative and absolute reliability scores but varied by as much as ±4.8 in SRD. This is likely due to the low number of individual discomforts marked and error in statistical assessments are therefore likely to occur (Weir, 2005). The assessment of discomfort map data was therefore assessed through grouping of all players. The total count of discomforts demonstrated high similarities from the 30th minute onwards (P-value $\geq$ 0.892). This result indicates that grouping comfort map data is a good method to assess comfort throughout the 90 min match simulation drill. It also highlights the time it takes for players to adapt to the footwear and thereby potentially overcome the inconsistencies seen in past literature for short term exposure and perception of comfort (Okholm Kryger et al., 2016). More research is, however, needed to confirm this.

Subdividing the map into count of discomforts per foot region as a mean per individual did, as with sum and count of discomforts over time, demonstrate broad SRD bands, although $ICC_{2,1}$ scores were all good or excellent. Instead, total count of discomforts per foot regions was therefore assessed. The majority of discomforts were felt on the plantar aspect of the foot. The plantar aspect is the key area in relation to injury concerns, as high plantar pressure exposure has been related with increased risk of metatarsalgia and metatarsal stress fractures (Ekstrand and van Dijk, 2013; Hinz et al., 2008). The second most and approximately half as commonly marked as discomforting foot region was the dorsal side. This was, as reported by players, due to the tight fit and synthetic material rubbing against the dorsal side of their foot. Strong similarities between sessions were seen when all player data was grouped together for plantar and dorsal discomfort levels. With lower number of discomforts, medial, lateral and heel regions of the foot still demonstrated similarities, although not as strong as the plantar and dorsal side.

The results indicate that quantifying discomfort is challenging but achievable. One of the challenging factors when assessing discomfort over time is the likely change in locomotion. It is broadly accepted that discomfort can lead to changed locomotion patterns (Kibler et al., 1991; Van Mechelen, 1992) changing loading patterns of the foot which can then cause a shift in discomforts and thereby alter, or spread, discomforts felt from the original location to other foot regions or regions up through the kinetic chain (Weist et al., 2004).

Correlation between performance and comfort

The relationship between comfort measures and performance measures were additionally assessed. A strong negative correlation was seen between RPE and overall foot comfort and strong positive correlation with count of discomforts measured over the 90 min. indicating an increase in overall discomfort and more discomforts marked on the foot map when an increase in RPE was seen. A weaker but still significant positive correlation was also shown between mean heart rate and overall comfort, whilst a stronger negative correlation was seen for mean heart rate and count of discomforts, indicating a decrease in overall comfort and increase in discomforts marked when heart rate decreased. This indicates an interesting relationship between ability to perform and comfort level. More research is still needed to strengthen the theory of causation.

Limitations

Heart rate levels seen in the past match-play assessing literature were not completely achieved. It is unknown why heart rates were lower than what has previously been reported by Lovell et al. (2008) for the SAFT90 match simulation drill. The lower heart rate may be related to the lack of mental challenge when completing a match simulation drill in comparison to real match-play. More research into how match related heart rates can be achieved is, however, still needed.

An important factor, which will highly impact the outcome of human testing, is the subjects' technical level (Anderson and Sidaway, 1994; Manolopoulos et al., 2006). Improved technique will minimise the level of human error and thereby intra-subject standard deviations due to impression caused by technique. This study assessed skilled university players and future research should aim to include subjects with equivalent or higher level to maintain reliability scores within the values obtained in this study.

12.6 Conclusion

The protocol assessed in this study demonstrated acceptable test-retest reliability for heart rate, RPE, counter movement jump height, muscle fatigue and muscle soreness, overall comfort assessed on a 7-point Likert scale and grouped count of discomforts through a discomfort map measures throughout the 90-min match simulation drill. Sprint times did not show good test-retest reliability. Previous studies have, however, assessed test-retest reliability of the Illinois sprint test and found high reliability between trials. The difference may be due to the validation occurring over two different days in the study. Sprint assessment, however, demonstrated low SRDs when assessed as percentage of change over the session.

The setup was created to be applicable for two researchers to assess multiple participants in a single test session to optimise efficiency and decrease cost and time needed to perform the test, making it more attractive for research.

CHAPTER 13

Impact of Boot Design on Maintainance of Performance and Foot Comfort throughout a 90 min Football Specific Match Simulation Drill

13.1 Chapter Outline

This chapter applies the validated protocol developed in chapter Chapter 12 to assess the impact of two different football boot designs (Umbro Velocita and Nike Mecurial Vapor) on performance and comfort throughout a 90 min match simulation drill. In contrast to the past comparison chapters, comparison of currently available boot designs offers a more generic understanding of whether differences are seen between boots currently available on the market. Chapter 2 and 3 highlights the lack of current knowledge and potential impacting factors on performance. To demonstrate the application of the validated protocol (Chapter 12) two different currently available speed boots designs were therefore chosen due to their previously demonstrated variations in plantar pressure (Okholm Kryger, 2014).

13.2 Introduction

Speed design football boots are usually lightweight to help in optimising in-game performance, e.g. to optimise speed generation (Chapter 2). Compared to running shoes, no cushioning support is provided, the outsole studs distribute pressures differently and the soles are usually cut narrow to permit better sensation of the ball along the instep. These differences in footwear design have been shown to create around 35% higher forefoot plantar pressures when walking in football boots in comparison to running shoes (Santos et al., 2001). The high plantar pressures seen in football boots are believed to cause an increased risk of metatarsalgia and metatarsal stress fractures (Debiasio et al., 2013; Eils et al., 2004; Queen et al., 2007; Sims et al., 2008; Warden et al., 2007). The incidence rate of metatarsal stress fractures in male professional football was shown to be 0.04 injuries per 1000 h (Ekstrand and van Dijk, 2013) – the rate for amateurs is yet unknown. A squad of 25 professional players can therefore expect one stress fracture every third season.

Comfort has been shown to be the most desirable property for football boots in user surveys from 1998, 2006 and 2013 (Hennig, 2011, 2014). Interestingly, injury protection was one of the lowest scoring desired properties (Hennig, 2011, 2014), despite evidence that overuse injuries and footwear comfort in football and rugby are interlinked (Kinchington et al., 2011). Not only has discomfort been related to increased injury risk, previous studies have linked footwear discomfort to altered lower extremity loading, which consequently triggered muscular fatigue and thereby decreased performance (Kinchington et al., 2011, 2012; Luo et al., 2009).

To address the potential relationship between decreased comfort and increased fatigue this study assessed speed generation, comfort and the overall performance/fatigue throughout a 90 min match simulation drill to understand whether variations in these parameters are seen by varying the football boot design.

13.3 Aims

Analyse the impact of football boot design on performance, fatigue and comfort during a 90 min match simulation drill. Two different speed boot models available on the marked were compared.

13.4 Methods

Participants

Eleven skilled male university football players (age 20.6 ± 2.2 years, stature 1.78 ± 0.05 m, mass 70.1 ± 4.7 kg) volunteered for this study. Players had 7 ± 3 years of experience playing club level football. None of the subjects had suffered from match-preventive lower limb injuries in the six months prior to testing. All subjects were shoe size UK 8 to 10 and both right and left foot dominant players were included. A small range in shoe sizes was chosen to minimise changes in mechanical properties between shoe sizes to impact outcome. During the test, subjects wore the same brand of new football socks to prevent the socks from altering the subjects' sensation of the boot.

Ethics

The investigation received ethical clearance from the institutional ethics committee and each participant provided written informed consent in accordance with the requirements of the Helsinki Declaration for research using human participants.

Football boots

Two commercially available 'speed design' football boot models were included. These were the first generation Umbro Velocita football boots and Nike Mercurial Vapor X (Figure 13.1). Both models were firm ground stud models to match the artificial surface used for testing. The Umbro Velocita football boot was constructed o a synthetic upper, four heel studs, seven studs on the forefoot of which one was place centrally, central lacing and a mass of 160 g (size UK8). The Nike Mercurial Vapor X was constructed of a leather upper, four bladed heel studs, six bladed studs on the forefoot of which three were placed below hallux and one was centrally, central lacing and a mass of 180 g (size UK8). The plantar pressure of the two boot designs have previously been assessing demonstrating significantly higher plantar pressures for the Nike Mercurial Vapor X in the medial and lateral forefoot as well as the heel region during football specific movements (acceleration, sprint, deceleration, side cutting, cross cutting, landing and running; Okholm Kryger, 2014). All boots were dyed black using shoe dye recommended for football boots to minimise the impact of design on the players' perception of the football boots.

Figure 13.1. Plantar, medial and dorsal view of Umbro Velocita (left) and Nike Mercurial Vapor (right).

Experimental design

Subjects participated in two sessions of 3 h duration separated by 7 days. Participants completed the session at the same time of the day for both sessions. Each session was initialised by a standardised warm up. Players completed two 45 min match simulation halves separated by a 15 min break following the official instructions for the Soccer-specific Aerobic Field Test (SAFT90; Lovell et al., 2008) but at the modified length of 22 m to obtain appropriate and match-related fatigue (see Appendix K-L).

Every 15th minute the match simulation stops to allow players to fill in a questionnaire of rated perceived exertion (RPE) and perceived comfort. The RPE Scale was created by (Borg, 1970). The scale is based on the linear relationship between oxygen consumption and heart rate with workload and ranges from 6-20, which denotes heart rates ranging from 60-200 beats.min^{-1}. The use of RPE has been found reliable to use in football (Alexiou and Coutts, 2008; Impellizzeri et al., 2004). To assess perceived comfort level the validated overall foot comfort Likert scale and a foot map to mark discomforts were used. Speed was assessed between warm up and familiarisation to the match simulation drill, as well as just when reaching half time and when completing the full drill. To assess agility sprint ability, players completed the Illinois change of direction speed test (Figure 12.4) whilst ability to generate lower limb power was assessed using maximal counter movement jump height using a Quattro Jump portable uniaxial force plate (Type 9290AD; Kistler Group, Winterthur, Switzerland), recording at 500 Hz.

Test setup and analysis of measures

The study followed the protocol validated in Chapter 12. Tests were performed on the same outdoor third generation artificial pitch (LigaTurf RS+ 265, Polytan, Burgheim, Germany). In brief, the pitch had a Polytan EL 25 shockpad, the carpet fibres were 65 mm monofilament polyethylene and infill comprised of sand and rubber crumb. The surface was FIFA 2 Star accredited 2 months prior to testing (Fédération Internationale de Football Association, 2017). Pitch testing using the FIFA Quality Concept methodologies (Fédération Internationale de Football Association, 2015), gave a maximum shock absorption of 69.75 ± 4.21%, maximum vertical deformation of 10.94 ± 1.75 mm and maximum rotational resistance of 44.8 ± 1.22 Nm. Tests were only performed under dry conditions to minimise the impact of varying surface conditions on the outcome.

Prior to the start of each session, the players readiness to complete the test was assessed though the Hooper's index (Haddad et al., 2013), muscle soreness felt in the main lower limb muscle groups using the muscle map suggested by Thompson et al. (1999) and overall perceived foot comfort was ranked on a novel 7-point Likert scale ranging from 1 = unbearable discomfort to 7 = extremely comfortable and a foot comfort map was used to identify and score any discomforts felt (Appendix I). Any player that rated sleep below "neither good nor bad", stress above "neither good nor bad", fatigue below "neither good nor bad", muscle sureness above "neither good nor bad" on the Hooper's index (Haddad et al., 2013; Hooper and Mackinnon, 1995), muscle soreness >3 on the muscle map, overall perceived foot comfort below "neither comfortable nor uncomfortable" or marked any discomforting locations on the foot map was assessed on that day.

Following the validated human test protocol, subjects performed a standardised warm up followed by assessment of Illinois sprint ability and counter movement jump height (Chapter 12). Players then completed two 45 min match simulation halves separated by a 15 min break following the official instructions for the Soccer-specific Aerobic Field Test (SAFT90; Lovell et al., 2008) but at the modified length of 22 m to obtain appropriate and match-related fatigue. Before, during and after the match simulation drill players were asked to complete a questionnaire assessing the player's perceived exertion and foot comfort measures (Appendix I). Heart rate for each 15 min SAFT90 interval using a Polar Team Pro system (Polar Electronic, Kempele, Finland).
To assess impact of fatigue after completion of the match simulation drill, players were asked to rate muscle soreness felt in the main lower limb muscle groups following the muscle map suggested by Thompson et al. (1999) 1 h and 24 h post session completions (Appendix I).

Statistical analysis
Statistical analysis was carried out using SPSS software (version 23, SPSS Inc., Chicago, IL, USA). Assessment of assumptions for parametric tests were performed and based on the violation of outliers in the differences between the two related groups for some variables then non-parametric tests were applied. Mean and maximum heart rates for each 15 min interval, the best performance of counter movement jump height, the fastest sprint time and the score of subjective measures, apart from comfort map scores, were assessed using non-parametric paired t-tests and Wilcoxon's matched pair tests, when assumption violations were seen. Count of discomforts split over time and for the different foot regions was assessed from grouped data using Pearson's Chi^2 tests.

13.5 Results

Measures of ability to maintain performance
A significantly higher mean heart rate was seen when wearing the Umbro football boot between the 60^{th} and 75^{th} minute (Nike 152 ± 4 bpm, Umbro 160 ± 9 bpm, P = 0.017) as well as between the 75^{th} and 90^{th} minute (Nike 151 ± 6 bpm, Umbro 159 ± 7 bpm, P = 0.012); Figure 13.2A). Maximum heart rate experienced within each interval was also assessed without demonstrating any significant differences or tendencies between the Nike and Umbro football boots (Figure 13.2B).

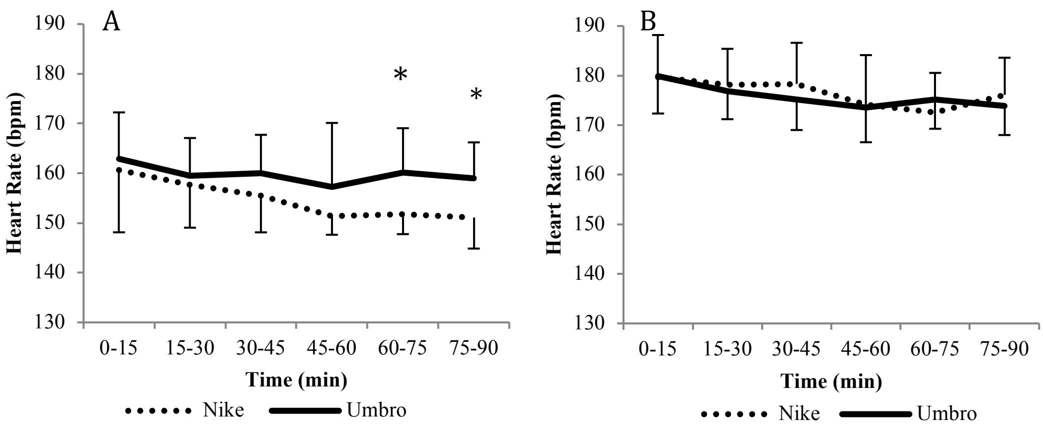


Figure 13.2A and B. Mean and maximum heart rate for each 15 min interval.

Subjects' perceived exertion assessed using the Borg RPE scale (Borg, 1982) did, despite variations in heart rate, demonstrate strong similarities between boot models and consequently no significant differences were seen between boots ($P \geq 0.302$; Figure 13.3). RPE did increase throughout the 90 min match simulation session from a start of mean 11.4 ± 2.0 in the Nike boot and 12.3 ± 2.1 in the Umbro boot, equalling an exertion level between 'light' (11) and 'somewhat hard' (13) to a final RPE score of 14.7 ± 0.9 in the Nike boot and 14.1 ± 1.1 in the Umbro boot, equalling in between 'somewhat hard' (13) and 'hard' (15; Figure 13.3).

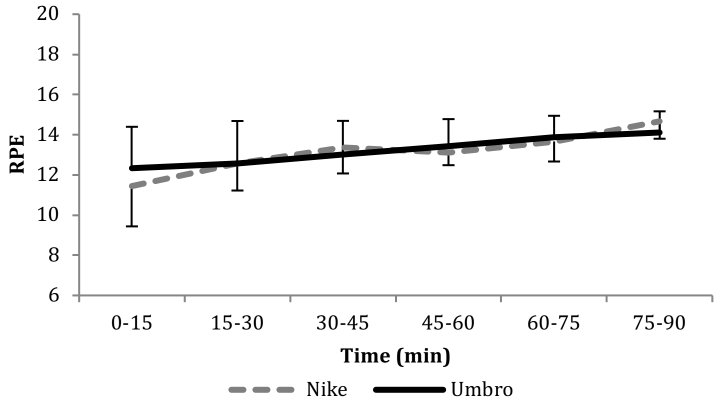


Figure 13.3. Rated perceived exertion (RPE) scores for each 15 min interval.

Change in performance was also measured directly by counter movement jump height and Illinois Agility Sprint completion times. Pre-session jump heights, acting as a baseline for individuals prior to match exposure in a set football boot, showed no difference (Nike 47.7 ± 7.3 cm, Umbro 48.1 ± 6.7, $P = 0.685$; Figure 13.4A), Change in sprint time between start and end demonstrated no significant difference between boots (Nike 0.1 ± 2.6%, Umbro 1.9 ± 2.8, $P = 0.602$; Figure 13.4A). Jump height significantly decreased in the Nike boot after 90 min (Nike pre 47.7 ± 7.3 cm, Nike post 45.2 ± 8.4 cm, P = 0.042; Figure 13.4B), whilst no significant decrease was seen in the Umbro boot (P = 0.563).

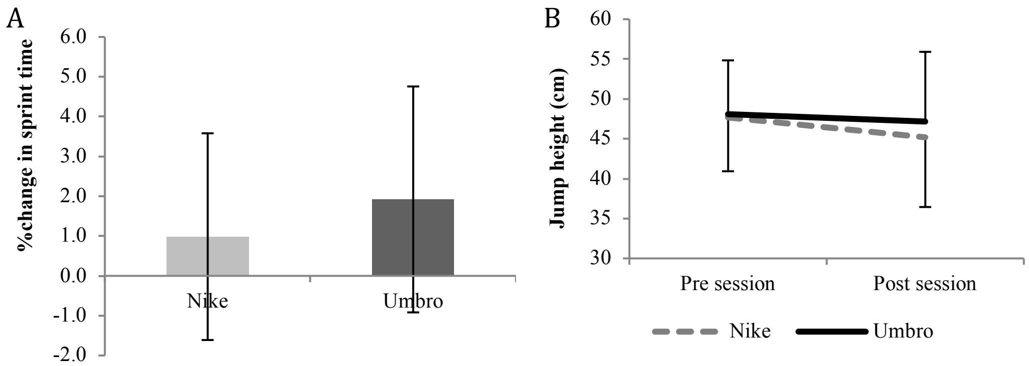


Figure 13.4A and B. Change in Illinois agility sprint times over session (A) and counter movement jump height obtained pre and post completion of 90 min SAFT90 (B).

Illinois Agility Sprint completion times demonstrated no significant decrease in sprint performance after completion of the 90 min match simulation drill in comparison to measures taken pre-session. Additionally, no significant difference in times pre-session (Nike 15.7 ± 0.8 s, Umbro 15.8 ± 0.5 s, P = 0.852; Figure 13.4B). The high similarities between boots were also evident for sprints performed post-session (Nike 15.8 ± 0.5 s, Umbro 16.0 ± 0.7 s, P = 0.397; Figure 13.4B). Additionally, change in performance was assessed and no difference was seen between boots (Nike 0.9 ± 2.5%, Umbro 1.8 ± 2.7%, P = 0.596).

Muscle soreness pre-session was assessed to ensure that players were not impacted by previous exercise. No difference was seen between boots for any muscle region of muscle soreness and all scored a mean <2, equivalent to no muscle soreness (Figure 13.5). Additionally, no significant difference was seen in soreness 1 h and 24 h post completion of the test session although a tendency towards higher soreness in the gluteal region 24 h post session in the Umbro boot was present (P = 0.084; Figure 13.5).

Muscle fatigue during the match simulation was also assessed. Good similarites were seen in the gluteal and anterior lower leg region (Figure 13.6). Hamstring, Quadriceps and calf regions showed a constant tendency of higher perception of muscle fatigue in the Nike boots, although not significant.

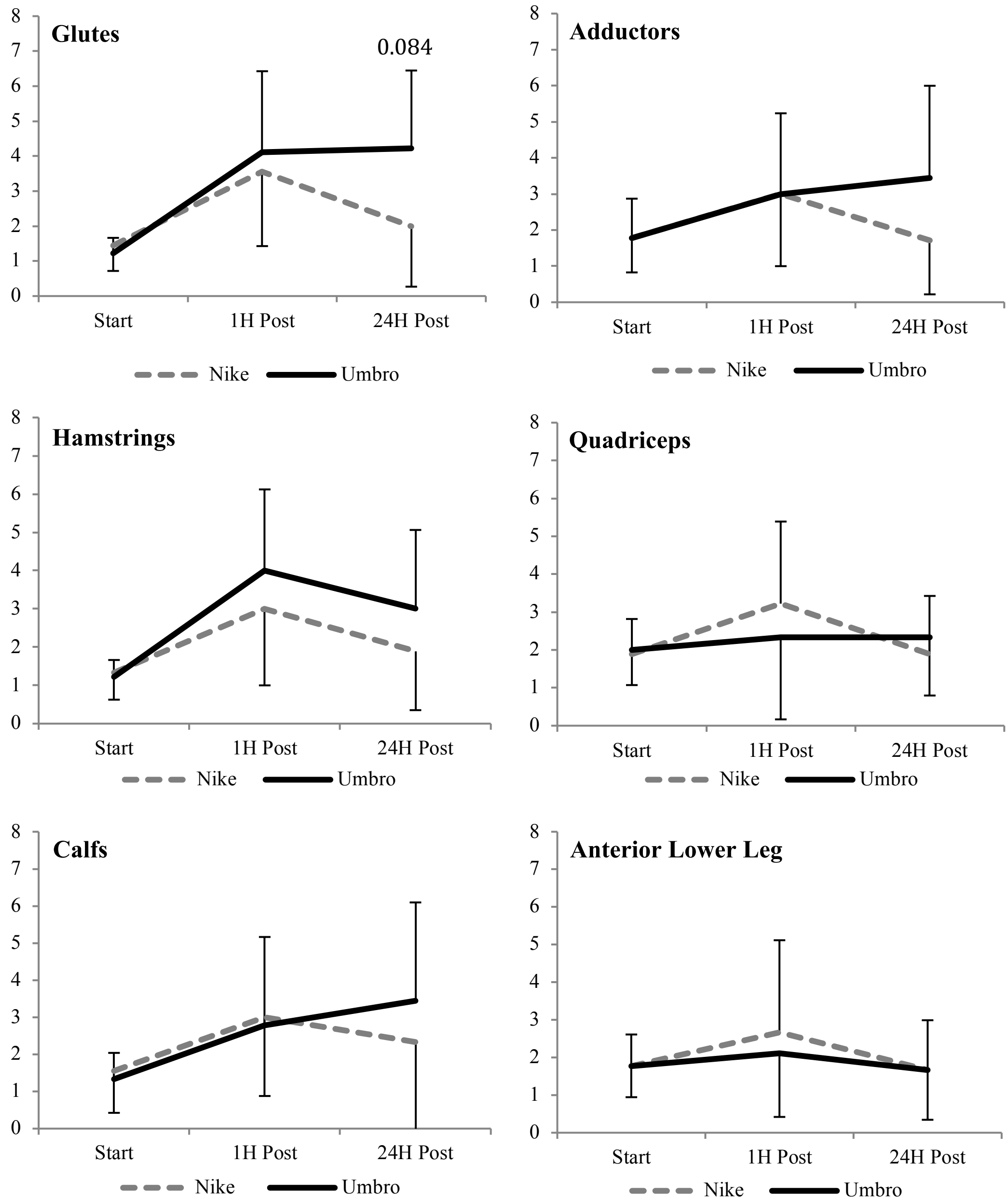


Figure 13.5. Muscle soreness score before, 1 h after and 24 h after completion of test session for the main muscle groups of the lower limb.

Start = Pre testing assessment; 1H Post = 1h post test session completion; 24H Post = 24 h post test session completion; Score of 1 = No muscle soreness; Score of 10 = Very, very sore.

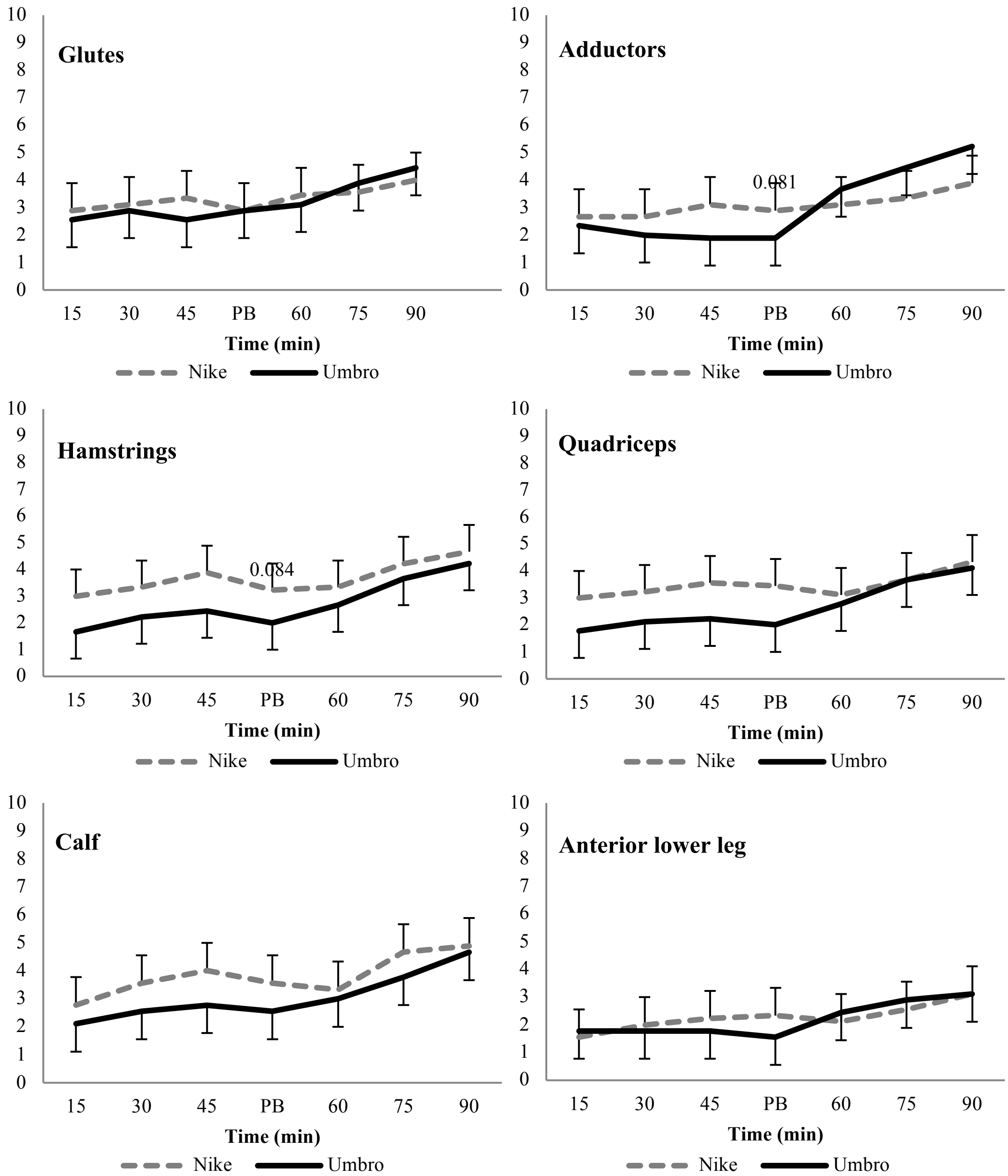


Figure 13.6 Muscle fatigue over the 90 min match simulation.

PB = Post half time break; Score of 1 = No muscle fatigue; Score of 10 = Very, very fatigue.

Measures of comfort

Overall foot comfort assessed using a 7-point Likert scale demonstrated high similarities and no significant difference between boots when first trying on and throughout the entire match simulation drill (Figure 13.7).

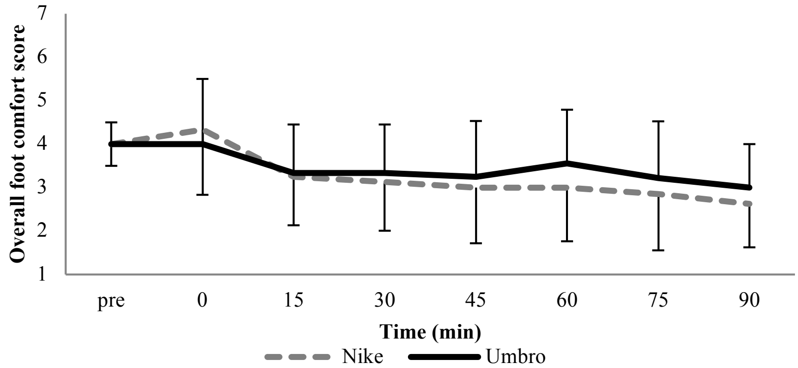
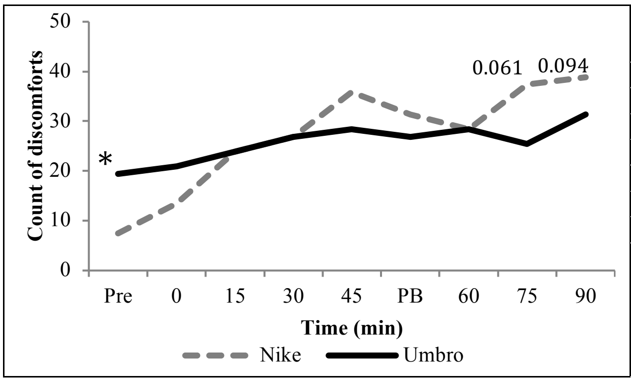


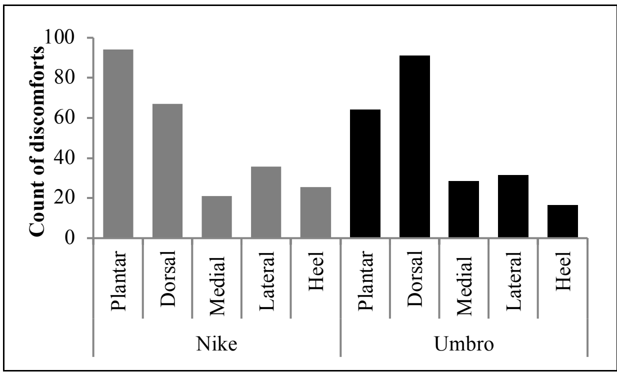
Figure 13.7. Change in overall foot comfort over time.
Pre = when trying on football boot prior to warm up; Score of 1 = Unbearable discomfort; Score of 7 = Extremely comfortable.

From the foot map, overall count of discomforts was assessed throughout the drill demonstrating a tendency towards higher count of discomforts marked when 'trying on' the Umbro boots (Nike = 7, Umbro = 19, P = 0.013; Figure 13.8). The count of discomforts however, only remains with a range of 19 to 31 for the Umbro boot throughout the test session, whilst the Nike boot demonstrates a steeper increase in discomfort count (7 to 39), which results in peaks at the end of each half demonstrating a tendency towards favouring the Umbro boot at the end of the match simulation drill (Figure 13.8). From Figure 13.9 it is evident that the majority of discomforts marked were on the dorsal side of the foot for the Umbro boot (count = 91) whilst Nike had more discomforts in the plantar region of the foot (count = 94). For both boots the heel, lateral and medial foot regions were least affected by discomfort.



Time	Nike	Umbro	P-value
Pre	7	19	0.013
0 min	13	21	0.213
15 min	24	24	1.000
30 min	27	27	1.000
45 min	36	28	0.125
PB	31	27	0.338
60 min	28	28	1.000
75 min	37	25	0.061
90 min	39	31	0.094

Figure 13.8. Count of discomforts marked on the foot map over the 90 min.
Pre = prior to start of test session when first trying on boot; PB = post break.



Time	Nike	Umbro	P-value
Plantar	94	64	0.092
Dorsal	67	91	0.049
Medial	21	28	0.371
Lateral	36	31	0.604
Heel	25	16	0.186

Figure 13.9. Count of discomforts on foot map grouped into foot regions.

Figure 13.10A and B subcategorises the count of discomforts for the plantar and dorsal foot regions throughout the match simulation drill. The plantar and dorsal regions demonstrate change in discomfort throughout the 90 min drill. The dorsal discomfort is constant throughout the entire session for Umbro, whilst no dorsal discomfort was initially felt in the Nike boot, making the Umbro boot significantly more discomforting at the 'trying on' phase (Nike = 0, Umbro = 10, P = 0.035; Figure 13.10B). For the plantar side little discomfort was felt in the 'trying on' phase (Figure 13.10A). Both boots showed an increase in count of discomforts but significantly more discomforts were felt in the last 30 min of the match simulation drill in the Nike boot (75th min: Nike = 15, Umbro = 9, P = 0.037; 90th min Nike = 13, Umbro = 9, P = 0.048; Figure 13.10A). The discomforts in the heel, medial and lateral regions remained low throughout the 90 min.

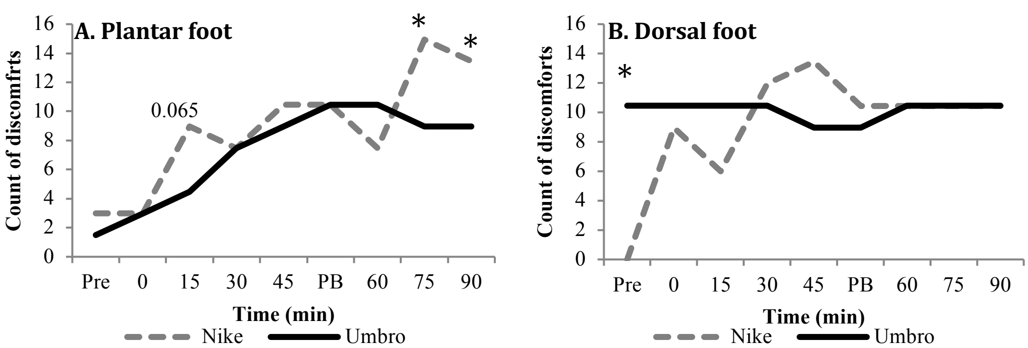


Figure 13.10A and B. Count of discomfort in the plantar and dorsal foot regions throughout the 90 min match simulation.

PB = post break; Pre = initial try on; * = P ≤ 0.05.

13.6 Discussion

The aim of this study was to assess changes in performance through speed and power generation, fatigue and foot comfort for two speed category football boot designs available on the market applying the protocol validated in Chapter 21.

The results firstly highlight the applicability of the protocol developed in Chapter 12 through the sensitivity to detect differences between boot designs as intended. Unlike the previously performed comparison studies (Chapter 6 and 10), where a controlled boot design component was assessed, this study did not evaluate the effect of a specific design components. In contrast, a comparison of boot designs offers a more generic understanding of whether differences are seen between boots currently available on the market. The results therefore highlighted significant differences in player's ability to maintain performance and foot comfort during match-play between currently available speed boots on the market.

Although a controlled match simulation drill was used, players experienced significantly higher mean heart rates in the last 30 minutes of the match simulation when wearing the Umbro boots. However, players did not, despite the difference in heart rate, perceive a harder exertion throughout the drill. This may indicate that players were able to work harder in the Umbro boot without feeling the exertion. Players also demonstrated no change in counter movement jump height ability after completion of the match simulation drill in the Umbro boot, whilst a significant decrease in jump height between pre and post-session was seen when wearing the Nike boot. This lead to tendencies towards a significant difference ($P = 0.066$) in jump height after completion of the match simulation favouring the Umbro boot. Players, therefore, appeared to be able to maintain their power generation better in the Umbro boot making them able to jump with the same height before and after the match simulation drill. The inability to maintain this performance in the Nike boot strengthens the assumption that players were able to work harder in the Umbro boot due to less fatigue throughout the match simulation drill.

A boot difference was also seen when assessing perceived discomfort through markings of discomfort on foot maps. The Umbro boot demonstrated a stable level of discomfort throughout the match simulation, whilst a steady increase, apart from a dip after half time, was seen for the Nike boot. The Umbro boot was, therefore, more uncomfortable in the 'trying on' phase prior to testing, which was primarily caused by discomfort experienced in the dorsal foot region. Player verbally reported that the thin synthetic upper of the Umbro boot was too tight and therefore rubbing against their dorsal forefoot and toes. The increase in discomforts seen when players wore the Nike boot was primarily due to plantar discomfort increasing throughout the match simulation drill.

Significantly higher plantar discomfort and lower mean heart rate during the last 30 min of the match simulation drill as well as decreased jump performance post-test completion in the Nike boot indicates a relationship between increased discomfort and decreased performance throughout the 90 min match simulation when wearing the Nike boot. This relationship was, however, not seen when players wore the Umbro boot. Assumptions on why football boot designs with multiple design variations should be made with caution. However, although the change in plantar pressure was not assessed throughout this study, the increase in plantar discomfort experienced in the Nike boot is likely to be associated with the significantly higher plantar pressures demonstrated for the Nike Mercurial Vapor X in the medial and lateral forefoot as well as the heel region during football specific movements (acceleration, sprint, deceleration, side cutting, cross cutting, landing and running; Okholm Kryger, 2014). Discomfort is a type of pain which can be described as a neural stimulus activated by the interaction of nociceptive stimulation and the cerebral cortex. A discomfort stimulus thereby provides information about the state of comfort via the neural networks of the body. A trigger for neural stimuli is needed to activate this pathway. One type mechanical stimuli, where nociceptors respond to pressure of mechanical deformation. Increased plantar pressure has been associated with football boots (Santos et al., 2001) and muscle fatigue (Weist et al., 2004). Past literature has, without assessing this relationship, the connection between improved ability to maintain performance and appropriate foot comfort and plantar pressures is widely assumed in football specifically (Sterzing et al., 2009; Sterzing and Hennig, 2008). Future research is suggested investigating the impact of local plantar pressure on foot comfort and ability to maintain performance during match-play in football.

The acknowledgement of additional parameters being likely to contribute to the variation in results must also be made (Miller et al., 2000). Based on previous literature on football boots no direct relationship can be confirmed between football boot parameters and ability to maintain performance or perception of comfort as no match-play or long-term exposure studies have previously assessed the impact of specific aspects of the boot design on foot comfort or ability to maintain performance. The 20 g mass difference (size UK8) is not believed to be a contributing factor based on Franz et al. (2012) who assessed the impact of boot mass on running economy whilst running in running shoes. Other contributing factors may include foot climate (temperature and sweat production inside the football boot), outsole stiffness and/or linear and rotational traction generated by the stud design (De Clercq et al., 2014).

Heart rate behaviour

The variation in heart rates between each 15-minute interval of the SAFT90 match simulation drill may appear as surprising due to its controlled distances covered and intensities. Past studies applying the SAFT90 protocol have, however, presented similar tendencies (Azidin et al., 2015; Nédélec et al., 2013). Likewise, other match simulation drills with controlled running distances per time interval have demonstrated similar results (e.g. Bendiksen et al., 2013; Funnell et al., 2017; Russell et al., 2011). Russell et al. (2011) presented a decreased variance in maximum and minimum heart rate throughout a match simulation drill, indicating players generated fewer high intensity movements towards the end of the simulation drill, which is believed to be the result of fatigue. The decrease in performance of high intensity movement towards the end of the game is also seen in during real match-play (Mohr et al., 2005). It is, therefore, still believed that players performed the match-simulation drill at the desired high level of effort and that players did, as also indicated by increase RPE scores, obtain a level of fatigue throughout the SAFT90 match simulation drill.

Difference between try on and performance in terms of comfort

This study also highlights the importance of splitting comfort between ‘trying on’ perception of comfort and ‘comfort throughout match-play’. Both measures are relevant to assess for the football boot industry. A ‘trying on’ perception of comfort is important when players buy they product in the store, whilst comfort assessing ‘comfort throughout match-play’ may, as indicated in this study and by Kinchington et al. (2010a, 2012) be an indicator of performance and injury risk. This was especially clear in the Nike boot demonstrating a large increase in discomfort experienced from ‘trying on’ to the 90th minute – most likely, although not assessed, a result of changes plantar pressure. Future research should assess the hypothesised relevance of plantar pressure. The results also demonstrated a constant change throughout the 90 minutes, indicating comfort assessments should be performed for a full 90 minutes to obtain an understanding of ‘comfort throughout match-play’.

Limitations
As mentioned previously, footwear comfort has been shown be individual, which may be related to natural variations in foot shape and size and hence variations in fit of the boot to the individual's foot. Additionally, the mass of the player may impact the plantar pressure level experienced and thereby comfort. Measures obtained in this study is therefore only transferable to the population tested, i.e. male, high level amateur football players with a normal mass. Future research would benefit for collecting images and measures of the participant's feet.

13.7 Conclusion
Differences between football boots were seen for measures of performance, power generation and comfort. These results indicate that the football boot design is important for obtaining optimal comfort, which is believed to impact performance and power generation throughout a 90-minute football match. More research is needed to understand what caused the changes in comfort and to assess the impact of comfort on performance in a more controlled setup.

Finally, this study highlights many potential impacting factors of the football boot design on maintenance of performance and comfort during match-play. The football boot spider diagram created in Chapter 3 demonstrated the many design features which impact on performance that are still to be understood. Additionally, the boot performance conceptual framework may now be used to develop novel hypotheses of how design may benefit performance, comfort or decrease injury risk. Links have been suggested in this study comfort and performance. The assessment of the relevance of increased localised plantar pressure would benefit the understanding of comfort and performance during match-play. Additionally, past literature suggests that boot mass my not alter performance, however, as this is still the key design feature of speed boot designs then the football boot industry would benefit from a clearer understanding of the impact of boot mass on comfort and performance during match-play

General Conclusion

CHAPTER 14

General conclusion – implications and future directions

14.1 Chapter Outline

This chapter assesses the outcome of the thesis purposes through the research questions in the introduction (Chapter 1), as well as identifying the novelty and implications of this research, the main limitations of the work and suggestions for future research.

14.2 Research Questions

The statement purpose posed in the general introduction (Chapter 1) will be addressed and summarised based on the outcomes of the individual studies performed within the thesis.

Q1. Which football boots does the current market contain and what are the claims and proofs for the benefits of these designs?

Changes to the football boot design have occurred for more than a century. Today the market is highly competitive which has led to multiple annual releases of new football boot designs with new design characteristics and a matching performance enhancing claim to distinguish the brand and boot design from others. Today, four main types of boots are available on the marks: (1) the power boot, claiming optimal shooting performance for the user, (2) the touch/control boot, claiming optimal ball control for the user, (3) the speed boot claiming optimal speed generation for the user, and (4) the heritage boot, which is a group of relaunched over boot generations and therefore no general claims are made for these boots (Chapter 2). The three design categories focusing on perform enhancement are marketed using bold claims. The review of publish literature, however, demonstrated minimal research performed on the impact of football boot design on these performance aspects of football.

For the power boot, limited research has been done on the impact of football boot design on shooting accuracy and ball velocity. A study comparing five masked football boots demonstrated 13% difference in shooting accuracy, indicating that boot design may impact shooting accuracy, however, more research is needed. For ball velocity optimisation during shooting, past literature indicates that stance foot traction, upper friction and toe box height may be impacting ball velocity, however, poor test setups were applied with high risks of allowing other impacting factors to alter results. No literature was therefore available to prove the marketing claims related to current design features of power boot designs.

For the touch/control boot, only a single study was published assessing the impact of football boot design on dribbling and passing performance. Different marketed boots were compared and differences in dribbling time, whilst no difference was seen for the passing accuracy assessment. Again, aspects of the test setup were found to potentially impact performance and, based on the setup quality and lack of published literature, no proof of the marketing claims related to current design features of touch/control boot designs was found in the past literature.

Finally, the speed boot claims have only been assessed in two studies, however, within pilot research of this thesis demonstrated poor test-retest reliability of the setup applied for these studies. Again, no literature was therefore available to prove the marketing claims related to current design features of power boot designs.

The review of literature performed in Chapter 2 therefore concluded that a current gap between marketing claims and evidence for the effect of the claimed performance benefits of specific boot designs is present for football boots.

Q2. How can a football player's demands from a football boot during match-play be logically presented?

A boot performance conceptual framework was developed in Chapter 3 to visualise the link between the player and the football boot in a match-play scenario. The framework highlights a bi-directional relationship between the player and the boot, which can be described as: '*A user of the boot tries to execute desired movements which involves boot-entity interactions achieving in-play boot behaviour influenced by boot characteristics determined by multiple boot components of the football boot'* or *'A football boot composed of multiple boot components giving certain boot characteristics affect the in-play boot behaviour at the different boot-entity interactions during the desired movement from the user of the boot'*. The framework was, however, not developed with links between each section due to the complexity and limited knowledge. The boot conceptual framework was instead developed and validated as a visual tool for researchers or manufacturers to aid discussions on how changes to the football boot design may benefit or worsen certain aspects of the player's game.

Q3. How does one reliably assess the impact of football boot design on the key performance aspects highlighted in the marketing of the main boots designs on the current market using human participants?

No validated test setups for human testing fitted the requirement for assessing the key performance claims for power boot, touch/control boot and speed boot designs. Reviews of methods applied in past literature, logical reasoning and pilot studies to content validate equipment and critically assess optimal test setups were performed to assess how optimal, ecologically valid and easily applied protocols for human testing of the key aspects of performance claimed by boot manufacturers for each boot style could be assessed. This was performed in Chapter 4, 7, 8, 11 and multiple smaller studies found in the appendix. The test protocols designed specifically for assessment of the impact of football boot design were consecutively validated using the test-retest reliability method and content validity assessment of equipment used (Chapter 5, 9 and 12). The setups primarily assessed shooting performance for the power boot, dribbling and passing for the touch/control boot and maintenance of football specific performance through perceived exertion and ability to maintain power and speed, as well as foot comfort during match-play simulation for speed boots. All setups obtained acceptable test-retest reliability scores and this thesis therefore offers future research to apply these validated protocols for performance assessment of power, touch/control or speed boots.

To demonstrate the applicability of the validated protocols a demonstration of the application was made. For the power boot and touch/control boot the impact of upper padding was assessed (Figure 14.1). No performance differences were seen for dribbling and passing performance when applying the touch/control boot protocol. A non-padded boot was, however, favoured for shooting as the padded boot increased vertical offset from target of shots significantly causing a significantly higher number of shots flying above goal and causing a decreased in chance of scoring goals.

To demonstrate the applicability of the validated protocol for speed boots, a comparison was made between two boot models available on the market. Assessed throughout a 90 min match simulation, differences were seen in performance, power generation and foot comfort. A link between decreased foot comfort during match-play and decreased ability to maintain performance was suggested but more research is needed to confirm this observation.

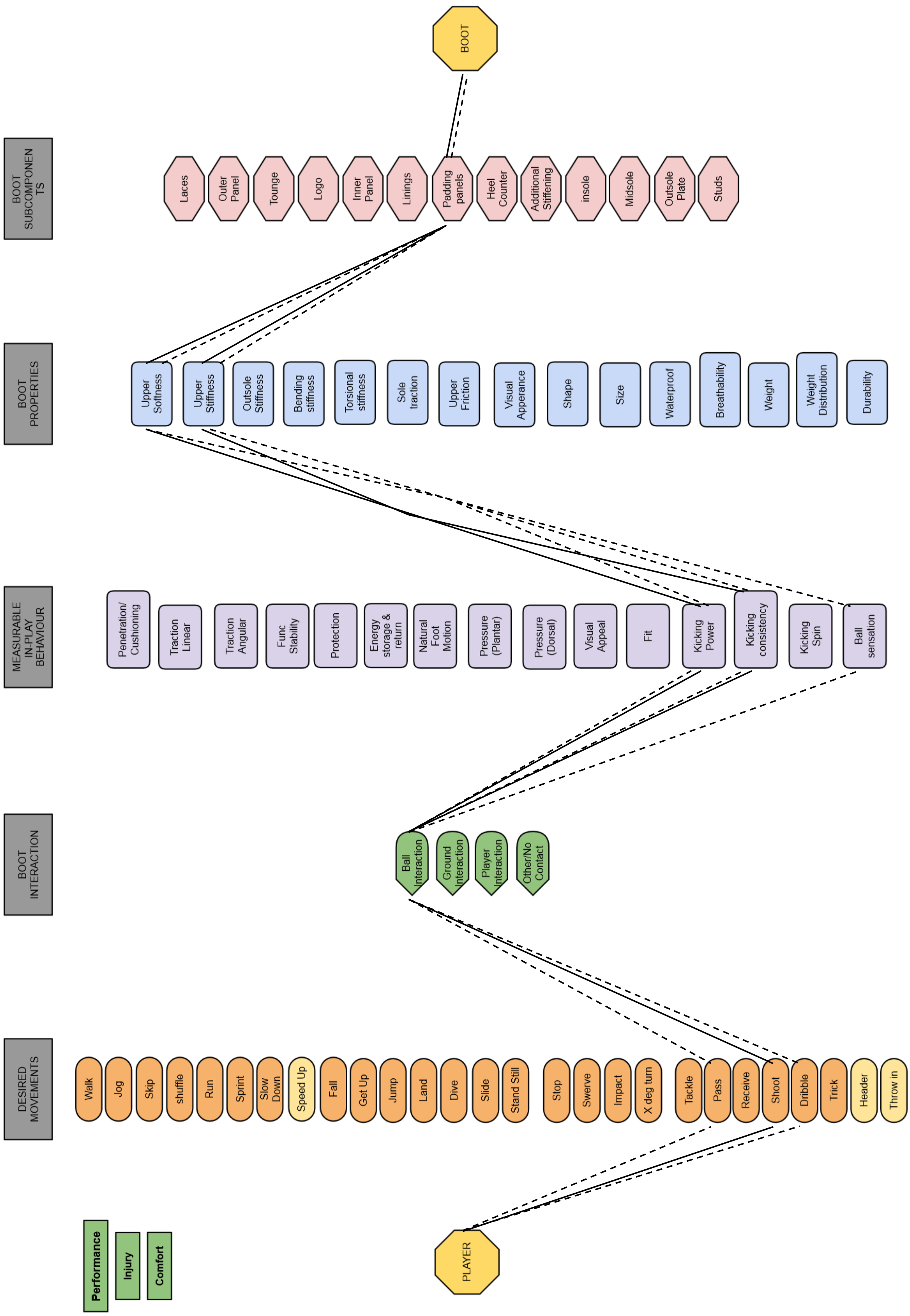


Figure 14.1. Visualisation of boot components assessed for power boots (solid line) and touch/control boots (dashed line) using the performance conceptual framework

In summary, human test protocols were designed, validated and applicability was demonstrated. The impact of this research is evident as the research has been handed over to industry to apply for future research and with publications of the different protocol validations, future research will also be able to apply the validated protocols.

14.3 Limitations

In this thesis, a consistent selection of players from the male university football/futsal teams was made. The choice of players used for both validation and comparison studies entail some limitations to transferability of outcome to other populations. Male and female players have previously shown to vary in performance as well as kinematic strategies (Barfield et al., 2001; Katis et al., 2015). In addition, applying the outcome of this thesis on players of a different playing level should be made with care. It can be assumed that larger levels of human error are experienced when assessing lower level players than the players used for testing. The smallest real difference bands obtained from test-retest reliability assessment can therefore be expected to increase in size when lower level players are assessed, which may consecutively minimise the importance of boot design on optimising performance in comparison to the player skill level and hence the likeliness of detecting significant difference between boot design designs will decrease. Finally, a small range of shoe sizes were assessed (size UK8 for power and touch control boots and UK8-12 for speed boots). The impact of boot size on performance has not previously been assessed but is can be hypothesised that measures such as plantar pressure, outsole and upper stiffness may vary between boot sizes.

Participants' foot shape were not assessed in this thesis. A general fit assessment through player feedback and palpation was performed. It should, however, be acknowledged that foot shape varies largely between individuals and in particular between sex, ethnical origin and maturation (Kouchi, 1998; Krauss et al., 2008; Wunderlich, 2001). Variations in foot shape are likely to alter measures of e.g. comfort perception as well as fit and plantar pressures. Inclusion of foot shape measures in future studies would enhance the assessment of these measures.

Finally, it must be mentioned that alterations of a single boot parameter are likely to alter multiple aspects of the football boot. This was previously highlighted for upper padding, which is likely to alter both upper stiffness and therefore perception or actual fit. This limitation should be appreciated when future research is conducted using any of the validated protocols designed in this thesis.

14.4 Novelty of Research and Implications

This research has provided the first validated assessment methods for assessment of the impact of football boot design on performance, which, if applied, offers future research improved reliability and ecological validity. By using the validated protocols novel information on the impact of padding on shooting, passing and dribbling performance as well as demonstration of links between decreased comfort and decreased performance by increased fatigue during match-play. Finally, the boot performance conceptual framework was developed, which improves the football boot researchers and producers' ability to visualise and thereby enhance the understanding of how boot components may impart performance, injury risk and comfort.

14.5 Future Directions

Over the course of this thesis a demonstration of the limited research available on the impact of football boot design has been made. Hence, many gaps in the understanding of 'optimal football boot design' exists based on the reviews performed in Chapter 2 and visualised in conceptual framework developed in Chapter 3. Future research to address these gaps using the validated protocols suggested in this thesis is recommended. Specific suggestions to specific boot parameters relevant to assess in future research has been highlighted in Section 6.7 for power boots, Section 10.7 for touch/control boots and Section 13.7 for speed boots. Additionally, the boot performance conceptual framework may now be used to develop novel hypotheses of how design may benefit performance, comfort or decrease injury risk.

APPENDICES

APPENDIX A

Potential Additional External Impacting Factors on Shooting Performance

Some basic and perhaps obvious factors need to be controlled when measuring ball velocity. These all need to be evaluated and defined when creating a test protocol to lower the chance of other factors influencing the results. These factors are defined in Table A.1, where a brief description explains how past literature has proven that these factors can affect the kicking velocity measured. Other more specific test settings to ball velocity testing are described in more details in the following sections.

Table A.1 Basic test settings to control when measuring ball velocity.

Sex	Large variation between sex has been found in maximum ball velocity obtained as well as in kicking kinematics (Barfield et al., 2002; Sakamoto et al., 2010, 2011, 2013, 2014). All studies including both male and female players found significantly lower kicking velocities for female players which is caused by significant variation from males in kicking technique and difference in muscle mass and thereby generated force (Barfield et al., 2002; Sakamoto et al., 2014, 2013, 2011, 2010). Results should therefore always be divided by gender, when analysing data. No study has analysed the effect of sex on the accuracy of kicking. Yet knowing that there is a significant difference in maximal kicking velocity ability (see previous section), then to target similar levels of the speed-accuracy trade-off then relative velocities should be targeted depending on the sex of the participants
Level of maturation	It has been found that maturation has an effect on kicking outcome, where more developed players obtain higher ball velocities (Figueiredo et al., 2011; Luhtanen, 1988; Vanderford et al., 2004). This should be taken into consideration if tests involve youth or not fully matured players. Previous literature has found that the level of maturation affects a player's kicking accuracy (Figueiredo et al., 2011; Rösch et al., 2000; Vanderford et al., 2004). Therefore researchers should keep this in mind when choosing and grouping test participants.
Skill level	Not surprisingly, more skilled players and players receiving special kicking training have been shown to perform higher kicking velocities and more consistent results (Anderson and Sidaway, 1994; Manolopoulos et al., 2006; Taïana et al., 1993; Trolle et al., 1993). It can only be suggested that skilled players should be used due to their higher consistency in kicking biomechanics. Logically, it has been proven in the literature that a player's skill level (often defined by level of competition the player compete at) is related to the player's ability to kick accurately (Haaland and Hoff, 2003; Rampinini et al., 2009; Rösch et al., 2000). It is therefore important to choose a homogenous group to limit a large variation in performance and to, ideally, use highly skilled players to lower the level of human error when evaluating another impacting factor.

Limb dominance	Maximum ball velocity and consistency are reduced when kicks are performed with the non-dominant leg for all skill levels (Barfield, 1995; Dörge et al., 2002; Nunome et al., 2006a). No studies were found with the focus on limb used. Yet based on logical thinking then it can only be concluded that accuracy will be higher when the dominant leg is used. Researchers should always define the test person's dominant side and ideally use this side to increase the level of accuracy.
Fatigue	Research has found that ball speed significantly decreases with fatigue (Apriantono et al., 2006; Kellis et al., 2006; Lees and Davies, 1988). The kicking biomechanics alter and the ability to generate force decreases. It is therefore important to prevent fatigue, if a consistent kicking velocity and a minimal alteration in kicking biomechanics is desired for a test. When exactly fatigue occurs varies depending on gender, fitness level and other physiological factor. It is therefore important to have a reasonable number of participants to take precaution by allowing appropriate restitution between trials and by lowering the number of repetitions per participant to an appropriate number. Research has shown that kicking accuracy is not impaired by intermittent treadmill exercise (Abt et al., 1998). Stone and Oliver, (2009) demonstrated that the mean total points used to score kicking accuracy was significantly reduced ($p = 0.012$) when fatigued after using a 90-minute fatigue protocol.
Support foot	No significant correlations between single-leg balance of the support foot and kicking velocity has been demonstrated (Chew-Bullock et al., 2012). But the stud length on the support foot has shown to be significantly correlated to kicking velocity (Sterzing and Hennig, 2007b). It was concluded that optimal stud length depends on the surface and can normally be found in the mid-zone between very long and very short stud length (Sterzing and Hennig, 2007b). None of the studies gathered for the literature review studied the effect of the support foot on kicking accuracy. It could be speculated that an optimal plant and an optimal traction may be beneficial. The exact definition of optimal is though yet to be understood.
Ball	The basic 'FIFA Inspected' ball standard FIFA specify that balls have to satisfy six criteria: weight, rebound, durability, pressure retention, circumference and sphericity (Fédération Internationale de Football Association, 2015b).It is important to use a FIFA standard ball and to use the same ball at every repetition. The football deforms during impact by as much as 68 mm (Shinkai et al., 2007). Robotic kicking leg testing has shown no effect of different ball pressures (0.6, 0.9, 1.2 bar) on ball velocity (Neilson and Jones, 2005). Still, the authors suggested that ball launch elevation was approximately 28° higher with lower ball pressure (0.6 vs. 1.2 bar). It was also seen that ball launch elevation was lower when placing the valve at the bottom versus the top. Research introducing a lighter ball (0.360 kg compared to a standard 0.445 kg) in women's football also found that ball maximum ball velocity could be increased by 4.1%. These data demonstrate the need to control ball characteristics for tests. It is therefore also important to include these values in any publication.
Surface	Sterzing and Hennig (2007b) found that optimal traction properties affect ball velocity. It is therefore ideal to control the surface conditions – ideally by using a single artificial surface under similar weather conditions for all tests - to allow optimal traction possibilities during run-up and for the stance foot during kicking. No studies have been found with the focus on the impact of the surface on kicking accuracy. The ideal is to use a standard pitch where measures of the

	surface can be done prior to testing to allow optimal traction possibilities during run-up and for the stance foot during kicking
Weather	Wetness alters the properties of the surface (Heidt et al., 1996; Torg et al., 1974, 1996). It is also logical that a wet upper shoe surface and ball will alter the friction properties and it can therefore, although not tested, be assumed to impact kicking velocity and consistency. Weather conditions should be controlled as much as possible by not testing under two different conditions when performing tests over different days.

APPENDIX B

Pilot Study - Validation of Equipment for Ball Velocity measurement

B.1 Chapter Outline

This pilot study aimed to validate equipment for measuring ball velocity. A range of tools previously used in the literature (Chapter 4) as well as an adidas MiCoach football (Adidas, Herzogenaurach, Germany) and TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) were compared to VICON MX motion analysis system cameras (400 Hz; Vicon Motion Systems Ltd, Oxford, UK). Previous studies assessing a similar Vicon system, to that used in this thesis reported a maximum error in angular measurements of 4.6º and distance between two markers of 0.062 cm (Richards, 1999).

B.2 Methods

Participants:

A single right-footed male university football player (age: 21 years, height: 1.97 m, mass: 88 kg) participated in the study. The player wore his own firm ground football boots (Nike Mercurial Vapor X FG).

Ethics

The study was covered under the ethical approval completed for the main study and was obtained from the Loughborough University ethics committee, and voluntary informed consent was obtained from all participants prior to the start of the test.

Equipment:

Baseline validated measuring tool: 10 × T20/40 VICON MX motion analysis system cameras (Vicon Motion Systems Ltd, Oxford, UK; 400 Hz, 1600 x 1280 resolution, 2-4 Megapixels (Souvr, 2008)) was compared with four other measuring tools: Adidas miCoach football (Adidas, Herzogenaurach, Germany; Diameter = 22 cm, mass = 0.43 kg, pressure = 0.9 bar), TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark; Doppler radar based launch monitor), Jugs Speed Radar Gun (Jugs Sport, Tualatin, OR; Range = 8-224 $km.h^{-1}$, accuracy index of ±0.80 $km.h^{-1}$ (0.5 mph)) and 2-D high-speed video FASTCAM ultima APX (Photron Inc, San Diego, CA; 1000 Hz, 1024x1024 resolution, 1.8000 s^{-1} shutter speed*).*

The equipment was placed as shown in Figure B.1. The 10 T20/40 VICON MX motion analysis system cameras were mounted on the wall approximately 3 m above ground and evenly distributed around the testing zone allowing a calibrated horizontal field of ball flight view of the first 3 m and 2 m vertical field of view from the ground and upwards. VICON MX was calibrated to a calibration factor <0.3 pixels, as recommended by VICON Motion Systems Ltd. The Adidas miCoach Smart Ball used was patterned with 8 hemispherical reflective markers used for tracking by the VICON MX motion analysis system.

The 2-D high-speed video camera FASTCAM ultima APX was placed perpendicular to the flight path 3.5 m back and 2.0 m in front of the starting ball position on a tripod 0.5 m above ground. High-speed video was aided with additional light in the form of two ARRI POCKET 400 lights (Arnold & Richter Cine Technik GmbH & Co, Munich, Germany).

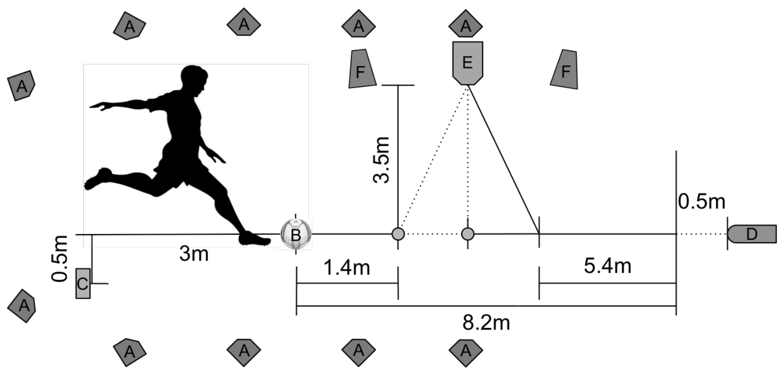


Figure B.1. Test setup for test validation performed in comparison to Vicon MX motion analysis. A: 10 × T20/40 VICON MX motion analysis system cameras (Oxford Metrics, UK); B: Adidas miCoach football (Adidas, Herzogenaurach, Germany); C: TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark); D: Jugs speed radar gun (Jugs Sport, Tualatin,OR); E: 2-D high-speed video FASTCAM ultima APX (Photron Inc, San Diego, CA), F = 2 × lights (ARRISUN 12 lights (Arnold & Richter Cine Technik GmbH & Co, Munich, Germany)

The Jugs speed radar gun (Jugs Sport, Tualatin, OR) was handled 0.5 m behind the target directly in line with the shot direction. TrackMan Football prototype (TrackMan Golf, Vedbaek, Denmark) was place 3 m behind with a 0.5 m displacement to the right of the ball. Since no official instructions are available for the prototype an initial pilot test was performed with 18 shots from seven different TrackMan positions to assess the best position for this device based on recording success rate (Table B.1). This was done to allow a better vision of the ball trajectory and in accordance with TrackMan Golf Pro’s (TrackMan Golf, Vedbaek, Denmark) instruction.

Table B.1. Analysis of appropriate position of TrackMan Football prototype by percentage of shots detected and measures assessed.

Position			
Setback (m)	Width (m)	Velocity (%)	Ball Flight Seen (%)
2	0	83	50
3	0	91	36
2	0.5	80	40
3	0.5	100	67
3	1	0	0
3.5	1	0	0
4	1	0	0

The Adidas miCoach football was placed with the manufacturer specified orientation for each shooting instance (valve facing shooter; middle arrow facing towards centre of target). Players were informed to shoot the ball in the valve zone as advised by the official guidelines. This was important to minimise any initial orientation angle error that can translate into larger errors in velocity estimates (Chrobotics, 2015).

Test Procedure:

Tests were performed in an indoor test laboratory over two day. The player was instructed to perform a wide variation of ball velocities to get a broad spectrum of the equipment performances. Shooting instructions varied from the participant being asked to perform 50% to maximum (100%) ball velocity intensity. A total of 70 shots were recorded. Shots were performed on an artificial turf run up path (1.5 m long) a target wall constructed of a safety net and pad 8.2 m in front of the starting point. Only shots >1 m above the floor were counted as successful. This criterion was included to follow the official guidelines for the usage on the Adidas miCoach football (Adidas, Herzogenaurach, Germany).

Analysis of data:

Data from the Adidas miCoach football, Football TrackMan and the radar gun were displayed as instant real-time feedback after each individual shot. Outcome was given in $km.h^{-1}$ and recalculated into $m.s^{-1}$. The 2-D high-speed video was post processed using Tracker (version 4.11; Open Source Physics), a video analysis and modelling software. Each individual shot was digitised using six reference points in each frame around the diameter of the ball (top, top right, bottom right, bottom, bottom left and top left). The ball was digitised between the same known distances for each individual shot using calibration markers as a reference in the field of view. An average of 50 ± 20 frames were digitised per shot depending on ball velocity. The x and y pixel coordinates of each frame were assessed using MATLAB (The MathWorks, Inc., Natick, MA). The MATLAB script worked by initially fitting any sized circle to any frame then filtered down by finding the mean radius size throughout the data in order to further interpret the differences between Tracker pixel coordinates from frame to frame and convert them into ball velocity units ($m.s^{-1}$). The MATLAB script worked under the principle of Pythagoras Theorem in order to calculate ball velocity from one frame to the next. VICON MX motion analysis system data was assessed using a custom written MATLAB script.

Statistical Analysis:
Statistical Package for the Social Sciences Software (SPSS), version 19 (SPSS Inc., Chicago, IL) was used for all statistical analyses performed with significance level was set at $P < 0.05$. Assumptions for parametric tests were validated. Pearson's Product Moment Correlation analyses of ball velocity between the measuring tools and GOM system results were performed to test for reliability. A paired samples two-tailed t-tests were performed to analyse the criterion validity as well as a Bland-Altman analysis of error following the method described by Bland and Altman (1999).

B.3 Results

A total of 70 shots were assessed. The shots varied in ball velocity as demonstrated in Figure B.2. Ball velocities ranged between 11.6 – 30.4 $m.s^{-1}$, which is representative of the ball velocity ranges seen in the literature (Table 4.6).

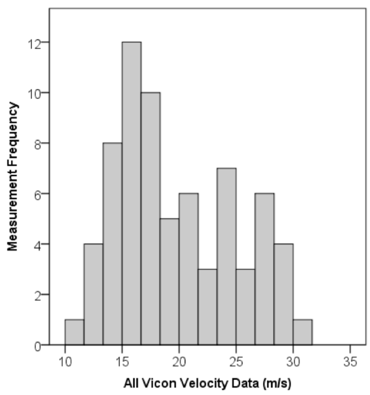


Figure B.2. Histogram of ball velocity from Vicon MX.

Equipment was also assessed in measuring success rate. Only 2-D high speed video succeeded in recoding all shot velocities for further assessment. The Radar Gun missed one reading, the TrackMan system missed five and miCoach missed 15 (Table B.2). Most of these were in relation to harder impact when stopped by the padded end wall.

Table B.2. Velocity outcome.

		Mean (m.s^{-1})	N	95% LL (m.s^{-1})	95% UL (m.s^{-1})	r	R^2 (%)
Velocity	Vicon	19.9	70				
	TrackMan	20.1	65	-2.34	+1.42	0.985***	97.0
	miCoach	21.4	55	-13.13	+4.35	0.763***	58.2
	Radar Gun	19.6	69	-1.15	+1.89	0.990***	98.1
	2-D HSV	18.2	70	-0.25	+0.59	0.999***	99.8

N = number of cases analysed; r = correlation; R^2 = coefficient of determination; SD = standard deviation; t-test results compare GOM results with each other measuring tool; 95% LL = 95 % confidence interval lower limit of agreement; 95% UL = 95 % confidence interval upper limit of agreement; *** = P < 0.001.

Reliability

The Vicon MX system ball velocity results demonstrated very strong correlations with TrackMan (r = 0.985, P < 0.001), Radar gun (r = 0.990, P < 0.001), and 2-D high speed video (r = 0.999, P < 0.001; Figure B.3). The coefficient of determination (R^2) demonstrated ≥97% of variability in the velocity measures for TrackMan, Radar Gun and 2-D high speed video is explained by the Vicon MX system. Hence, ≤3% is attributed to measuring error within the system.

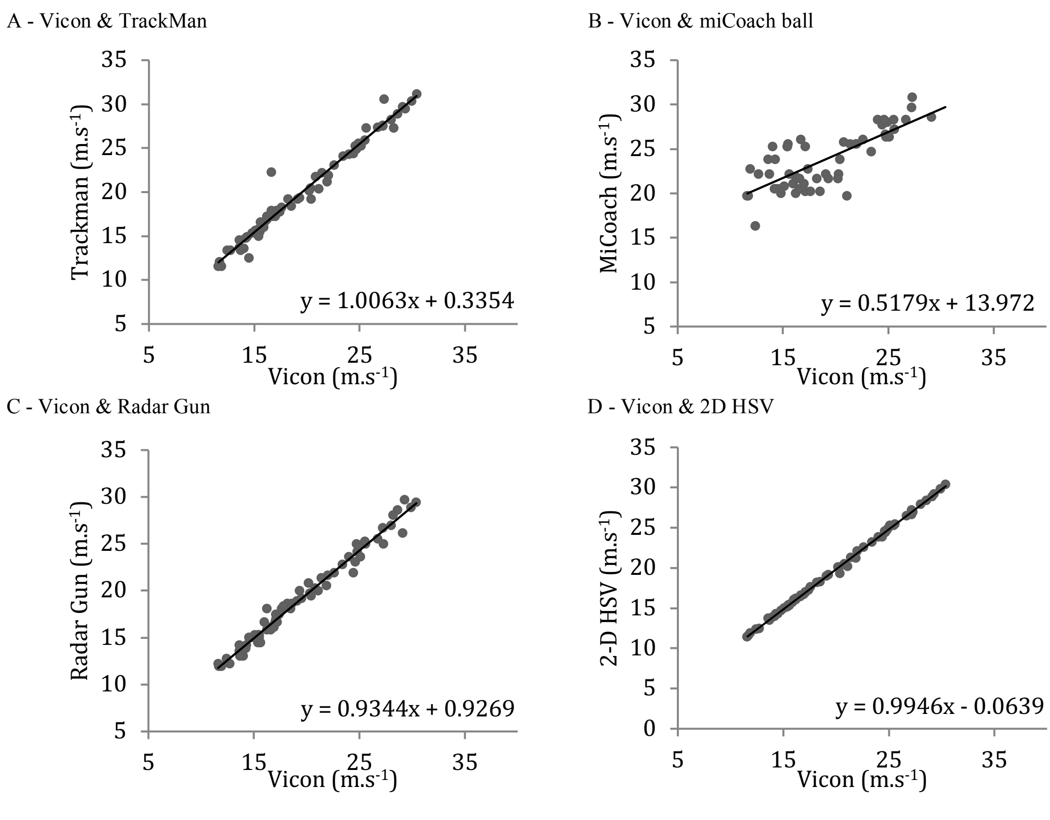


Figure B.3A-D. Pearson's correlation of ball velocity assessment tools in comparison to Vicon measures.

Criterion validity

An analysis of error was performed to further enhance the understanding of criterion validity. The Bland-Altman analyses of errors for each measurement system in comparison to Vicon MX measures are demonstrated in Figure B.4. The ideal relationship would be represented as a horizontal relationship along the x-axis with a difference score as close to zero. The results demonstrate a horizontal relationship for ball velocity data from 2-D HSV, TrackMan and the radar gun. Two outliers (mean difference >3 $m.s^{-1}$) were seen for TrackMan in relation to Vicon MX ball velocity measures (Figure B.4). The maximum mean difference was 2.99 $m.s^{-1}$ for the radar gun and 1.12 $m.s^{-1}$ for 2D HSV (Figure B.4). The miCoach did not demonstrate the same horizontal relationship with Vicon MX ball velocity measures and large mean differences were observed (maximum mean difference = 11.3 $m.s^{-1}$; Figure B.4).

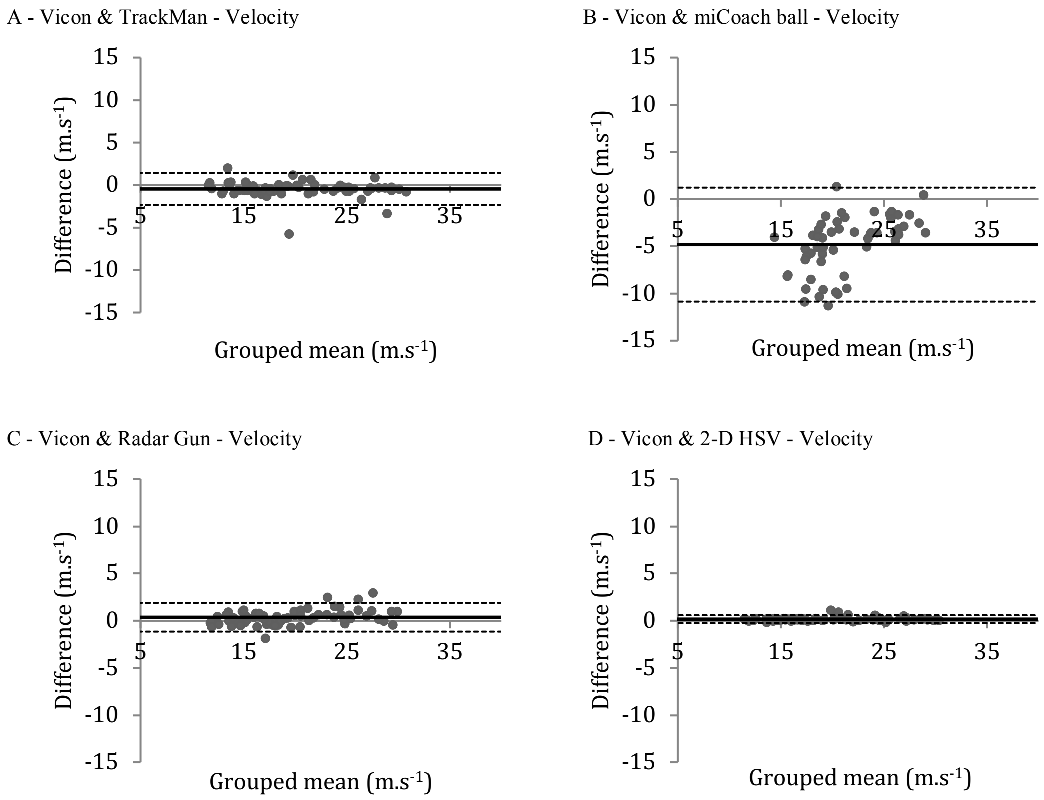


Figure B.4A-D. Bland-Altman analysis of error in measurement results.
Differences in outcome measure (Vicon – Comparison tool). Dashed lines = 95% upper and lower limits of agreement

B.4 Key Outcome

TrackMan, 2-D HSV and radar gun data all demonstrated good reliability and criterion validity. Research may therefore choose between these tools when assessing ball velocity. The benefit of using TrackMan as an assessment tool is that measures are done automatically; hence, no researcher is needed to control the tool whilst testing.

APPENDIX C

Pilot Study – Defining optimal placement of GoPro HERO4 Black Cameras for Measuring Offset Distance from Target

C.1 Chapter Outline

This pilot study is the second of two to assess the possibility of using two GoPro HERO4 Black cameras (GoPro Inc., San Mateo, CA) for assessment of ball accuracy. An appropriate placement should be close enough to capture ball offset from target with minimal pixel error but with a field of view large enough to cover typical offset distances from target. The (1) field of view size in relation to typical shooting offset and (2) pixel accuracy were assessed.

C.2 Methods

Participants:

Three right-footed male university team football players (age 19-22 years, height 1.77-1.87 m, mass 79-89 kg) participated in the study. Participants wore their own football boots.

Ethics

The study was covered under the ethical approval completed for the main study and was obtained from the Loughborough University ethics committee, and voluntary informed consent was obtained from all participants prior to the start of the test.

Experimental design

To assess typical offset a player was asked to perform simulation shots. The players each performed 20 shots from a stationary position 16 m in front of the centre of the goal. In the review of literature, a large variation in shooting distances applied in the past studies was discovered (Table 4.4) and no match-play data was gathered on typical shooting distances. A direct free kick scenario was therefore chosen on the edge of the box (16 m from goal directly in front of the centre of goal. All shots were performed following the setup of the main study (Chapter 5) The aiming target was explained to the player to be the top right corner of the goal.

Offset was recorded using two synchronised GoPro HERO4 Black camera (240 Hz, 1280 x 720 pixels; GoPro Inc., San Mateo, CA) following the setup instructions in Chapter 5 but with the camera facing goal placed 19 m in front of the right post (target side of goal) at the height of the target point 2.33 m (goal height 2.44 m – radius of the ball 0.11 m). Radial offset in pixels was calculated from the frame where the ball passes the goal line following the method described in Chapter 5. A calibration object (1.5 m length) was placed in the goal zone was used to obtain pixel-metre scaling factor to convert radial offsets into pixels. All GoPro HERO4 Black camera (GoPro Inc., San Mateo, CA) recordings videos were converted from .MP4 files to .AVI files in GoPro Studio (Version 2.5.7, GoPro Inc., San Mateo, CA) to be analysed in Image-Pro Analyzer (Version 7.0, Media Cybernetics, Inc., Rockville, MD).

To assess optimal distance, pixel accuracy and field of view were assessed placing the GoPro HERO4 Black camera (240 Hz, 1280 x 720 pixels) 11 m, 13 m, 15 m, 17 m, and 19 m from goal. The camera was at each distance placed facing goal in front of the right post (target side of goal) at the height of the target point 2.33 m (goal height 2.44 m – radius of the ball 0.11 m). A calibration object (1.5 m length) was placed in the goal zone was used to obtain pixel-metre scaling factor to convert radial offsets into pixels. All recordings were converted from .MP4 files to .AVI files in GoPro Studio (Version 2.5.7, GoPro Inc., San Mateo, CA) to be analysed in Image-Pro Analyzer (Version 7.0, Media Cybernetics, Inc., Rockville, MD). The length in pixels of the calibration object was assessed using a line dragging feature at each position. The pixel size was then converted into metre by conversion knowing the actual size of the calibration object.

C.3 Results

Common offset radius from target

The 60 shots were performed with a mean radial offset of 1.60 ± 0.72 m. The minimum radial offset was 0.59 m whilst the maximum offset was 3.08 m. Only six shots were performed with an accuracy radius from target >2.5 m (10% of the shots). These shots were observed above the goal.

Field of view size and pixel accuracy from different measuring distances

The field of view sizes, pixel accuracy for each camera placement are shown in Table C.1. Pixel accuracy was below 1 cm for camera placements within 15 m from the goal post. The area captured increased by >0.5 m in horizontal and vertical vision for every set back following a second order polynomial trend Figure C.1A and a linear relationship between horizontal and vertical frame size (R^2 = 1; Figure C.1B).

Table C.1. Accuracy assessed in metre per pixel and size of field of view for camera placement distances of 9 to 19 m.

Distance	Metre per pixel	Frame length (m)	Frame height (m)
9	0.0055	6.99	3.94
11	0.0061	7.85	4.41
13	0.0073	9.35	5.26
15	**0.0084**	**10.79**	**6.07**
17	0.0106	13.52	7.61
19	0.0138	17.62	9.91

With a maximum radial offset observed from shots of 3.08 m, minimum vertical capturing zone should be the sum of the target height (2.33 m) and the offset measure – giving a minimum capturing zone of 5.41 m, which with the smallest distance to target could be achieved with a 15 m placement of the camera (Table C.1). The pixel accuracy for 15 m placement was 0.8 cm (Table C.1).

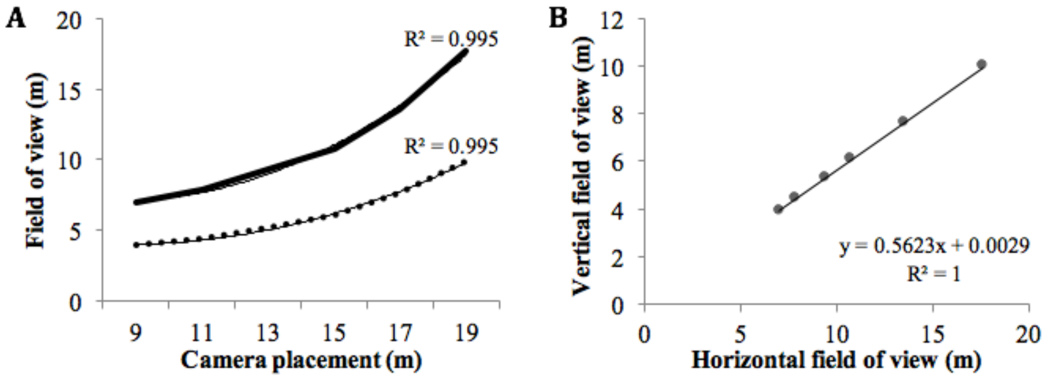


Figure C.1A and B. Visual demonstration of second order polynomial change in field of view size by camera distance (A) and linear relationship between horizontal and vertical field of view with change in camera placement (B).

C.4 Key Outcome

An assessment of mean and maximum radial offsets from pilot shots and the capturing outcome from different camera distances defined optimal offset distance of 15 m. This camera placement distance was therefore chosen for the main study setup.

APPENDIX D

Pilot Study – Validation of Synchronisation of High Speed Recordings using Two GoPro HERO4 Black Cameras

D.1 Chapter Outline

Based on the literature review (Chapter 4), no optimal method was found for measuring ball accuracy during shooting. This pilot study is the first of two to assess the possibility of using two GoPro HERO4 Black cameras (GoPro Inc., San Mateo, CA) for assessment of ball accuracy. One camera placed on the side-line to measure the point in time when the ball passes goal-line and one placed directly in front of target to assess the offset from target. This chapter assess the possibility of synchronising recordings of two GoPro HERO4 Black cameras using a GoPro Smart Remote (GoPro Inc., San Mateo, CA).

D.2 Aim

GoPro HERO4 Black cameras can be synchronised using a GoPro Smart Remote. Manufacturer claims synchronisation can be made between cameras within a distance of <180 m. Yet, it is unknown whether the synchronised recordings have any minor offset in its synchronisation. This pilot study therefore tested the synchronisation of the camera when controlled with the GoPro Smart Remote.

D.3 Methods

The two GoPro HERO4 Black cameras (240 Hz, 1280x720 pixels) were synchronised to GoPro Smart Remote following the official instructions. The two-faced synchronising test devise (Figure D.1) was placed in the visible field of both cameras for all recordings. The synchronising test devise was composed of four light channels with 10 lights in each channel. Each channel switched lights at different speeds: channel 1 every 1s, channel 2 every 1.10^{-1} s, channel 3 every 1.100^{-1} s and channel 4 every 1.1000^{-1} s. Recordings were made with the camera and remote distances shown in Table D.1.

Table D.1. Distances camera-cameras and camera-remote assessed for synchronisation ability.

	Distance between cameras (m)	Distance between camera 1 and remote (m)	Distance between camera 2 and remote (m)
Scenario 1	5	2.5	2.5
Scenario 2	5	2	5
Scenario 3	5	5	10

Figure D.1. Photos of synchronising test devise with two four-channel light faces.

D.4 Results

No difference was seen between results depending on camera or remote position. Mean offset was shown to be 3.3 ± 2.4 frames with a maximum difference of 9 frames, occurring once. The error occurred both at start and end of recording. The error was not systematic between cameras, meaning the recording length was not longer or did not start later for one specific camera. An error of 9 frames, which was the maximum seen in this pilot study, could cause a ball position error of 0.83 m when ball velocity is 22 $m.s^{-1}$ or 1.28 m for a high ball velocity of 34 $m.s^{-1}$.

D.5 Key Outcome

Based on the measuring error caused by synchronisation offset, all recordings with the synchronised GoPro HERO4 Black cameras (GoPro Inc., San Mateo, CA) will be controlled and corrected by including the synchronisation tool in the visual zone of both cameras during the tests.

APPENDIX E

Review of validation assessment methods

E.1 Chapter Outline

Based on the review of literature assessing shooting accuracy and velocity in football it is evident that a validated test protocol ideal for assessment of equipment, e.g. football boot design, using validated equipment for measurements has not yet been constructed. This section discusses statistical validation methods to find an appropriate method to validate an improved protocol for shooting performance.

E.2 Validation

A valid protocol is one that resembles the performance that is being simulated as closely as possible (Currell and Jeukendrup, 2008). Measurement error can strongly affect statistical analysis and interpretation of results. It is therefore important to assess the level of such errors in a study performed or base studies on previous literature assessing these errors (Grgantov et al., 2013). Measurement errors may be systematic or random. Systematic errors are predictable errors, occurring in one direction only, and are constant and biased. Random errors are due to chance and unpredictable, thus they are the basic concern of reliability (Bruton et al., 2000). To validate test protocols validity and reliability measures should be performed.

E.2 Test Reliability

Reliability has been defined as the reproducibility and consistency of values produced from repeated trials performed by the same individuals (Figure E.1) (Atkinson and Nevill, 1998; Hopkins, 2000). A reliable test or measuring equipment is consistent in its measure when no intervention has been made (Atkinson and Nevill, 1998; Baumgartner and Jackson, 1991) and therefore implies better precision of single measurements and better tracking of changes in measurements in research or practical settings (Hopkins, 2000).

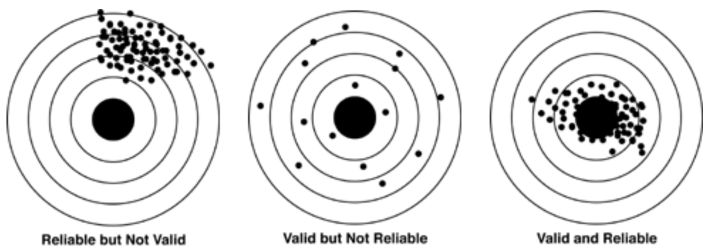


Figure E.1. Reliability and validity demonstrated on a shooting target.

Test-retest reliability

Test–retest reliability is a typical methods to validate test protocols (Currell and Jeukendrup, 2008; Lexell and Downham, 2005; Vaz et al., 2013). The method approximates the reliability of a protocol by administering it in the same way on two or more different occasions (Hopkins, 2000; Price, 2012). Perfect test–retest reliability scores are uncommon, as all instruments respond with some level of error (Vaz et al., 2013). Especially when assessing performance of human subjects as a level of human error is always present due to the inability to faultlessly repeat the performance.

Relative reliability

The test–retest reliability is commonly assessed using both relative and absolute methods (Atkinson and Nevill, 1998; Hopkins, 2000; Weir, 2005). Relative reliability assesses consistency or association of position of participants in a group, relative to others (Bruton et al., 2000; Vaz et al., 2013). This type of reliability has commonly been analysed by a correlation coefficient e.g. Pearson's correlation. High measures of correlation will be obtained when relative positions of each subject maintain the same from test to re-test (Bruton et al., 2000). Yet, a correlation coefficient will not detect any systematic errors (Bruton et al., 2000; Šerbetar, 2015; Vaz et al., 2013; Weir, 2005). It is therefore possible to have two sets of scores that are highly correlated, but not highly repeatable (see Weir (2005) for example). Research published solely basing their reliability outcome on correlation coefficients can therefore be misleading since correlation coefficients only express how sets of scores vary together and not the level of agreement between them (Bruton et al., 2000; Šerbetar, 2015; Vaz et al., 2013; Weir, 2005). In an attempt to overcome some of the limitations of the correlation coefficients the intra-class correlation coefficient (ICC) has been proposed as a more rigorous statistical tool (Bruton et al., 2000; Šerbetar, 2015; Vaz et al., 2013; Weir, 2005). The ICC offers an understanding of the ability of a test to distinguish between different individuals as it demonstrates a ratio of variance due to difference between subjects (the signal) to the total variability in the data (the noise) (Keating and Matyas, 1998; Weir, 2005). ICC therefore reflects both the degree of consistency and agreement among ratings. Numerous (case specific) versions of ICC exist and are calculated using variance estimates obtained through the dividing of total variance into between and within subject variance (known as ANOVA) and is given as a single index (Weir, 2005). The level will range from 0 to 1, where values closer to one represent the higher reliability.

Absolute reliability

Absolute reliability is assessing variability due to random error (Bruton et al., 2000; Vaz et al., 2013). Thus, an absolute reliability index is affected by the degree to which measurements vary, with the principle being the less the variability, the higher the reliability. This is today commonly done by the standard error of measurement (SEM) and smallest real difference (SRD) (also known as minimal detectable difference (MD), smallest detectable change (SDC) or repeatability coefficient (CR)), but is also seen assessed by coefficient of variance (CV), and Bland and Altman's 95% limits of agreement (Bland and Altman, 1999; Šerbetar, 2015; Weir, 2005). CV is calculated as the standard deviation of the data, divided by the mean and multiplied by 100 to give a percentage score (Bruton et al., 2000). This expresses the standard deviation as a proportion of the mean, making it unit independent. Though, as Bland (1987) remarks, the drawback with expressing the error as a percentage, is that x% of the smallest observation will differ markedly from x% of the largest observation. It has additionally been proposed that the above form of the CV should no longer be applied to estimate reliability, and that other more fitting methods should be employed based on analysis of variance of logarithmically transformed data (Atkinson and Nevill, 1998). The SEM is an index used to define the difference needed between separate measures on a subject for the difference in the measures to be considered real (Weir, 2005) and is therefore presented in the same unit as measurement of interest. It is displayed in the same unit as measurement and defines the ±68% limits of agreement (LOA) for the given measurement and offer researchers a 68% confidence that a score outside the SEM range around the mean is a true change (Lexell and Downham, 2005; Vaz et al., 2013). Since these limits of SEM are seen as rather wide then the SRD is usually calculated in relation to the SEM. The SRD of a tool is directly related to the 95% LOA proposed by Bland and Altman that contain 95% of differences between repeated measurements on same subjects (Bland and Altman, 2003; Lexell and Downham, 2005; Vaz et al., 2013; Weir, 2005).

5.4 Test Validity

Test validity is an assessment of the degree to which a tool measures what is it supposed to measure (Figure E.1) (Baumgartner and Jackson, 1991). So to determine the validity of a test the researcher seeks to answer the questions, ‘‘does the test tell the truth and does it measure what it sets out to measure?’’ (Ali, 2011). This sounds reasonable but it can be complex to know whether test setup and measuring equipment are measuring exactly what it is meant to measure. Test validity can be subdivided into three validity measures: content (also known as logical or face) validity, criterion (also known as concurrent or predictive) validity, and construct (also known as convergent or discriminant) validity (Currell and Jeukendrup, 2008; Thomas and Nelson, 1990).

Content validity

Content validity assesses whether the measuring tool is exact, meaning whether a measurement tool is measuring what it is supposed to. Comparing results from the chosen equipment with ‘golden standard’ equipment or under controlled conditions where the outcome measure is known are normally the ways to test for validity (Thomas and Nelson, 1990). Within the field of medicine and sports the commonly used guideline for assessing measuring tools by comparing with other measuring tools at defined by Bland and Altman (Bland and Altman, 1986, 1999, 2003).

Criterion validity

Criterion validity assesses whether measures are concurrent with real-world observations (Field, 2007). Concurrent criterion validity assesses whether the protocol is correlated with what is measured in real scenarios & predictive criterion validity assesses whether the outcome can predict future performance (Thomas and Nelson, 2001). Sports such as football are more difficult to simulate than other sports due to its complexity (Currell and Jeukendrup, 2008). This is especially difficult when attempting to measure only few components of the sport. Within criterion validity, it is important to acknowledge ecological validity, which relates to whether the intricacies of the test reflect what happens in the ‘‘real world’’ situation (Ali, 2011). Depending on the aim of a shooting test then the researcher must decide to what extent ecologically validity should be obtained. By this is meant that adding control parameters to a test will naturally restrict the player. This is beneficial as it may lower the risk of human error and other external factors to impact the results, but these may also lower the ecological validity and thereby the ability to transfer results from the test setup to a real match scenario. The array of technical movements involved in match-play complicates the practice of testing football skills in isolation (Shan and Westerhoff, 2005). Subsequently, attention should be given to various factors that influence isolated skill tests. Factors needed to optimise the ecological validity have been listed for a range of ball interactions in football by (Russell and Kingsley, 2011). In addition, a range of environmental factors (e.g. location, wind and playing surface) should also be considered (Shan and Westerhoff, 2005).

Construct validity

Also construct validity, which is the degree to which a protocol measures a hypothetical construct (practical tests developed from a theory), is difficult is assess for a test protocol. A way to measure this is by comparing groups that are known to be different (Thomas and Nelson, 2001). This involves two sub-categories: convergent and discriminant validity. Convergent validity refers to the degree to which a measure is correlated with other measures that it is theoretically predicted to correlate with. Whilst, discriminant validity tests whether concepts or measurements that are supposed to be unrelated are, in fact, unrelated. Assessing the content validity of the equipment used is feasible and important for the validation of the protocol. Criterion validity is not measurable for this test setup but based on knowledge obtained in the literature review, a critical evaluation of the setup had been made to ensure a controlled but ecological valid protocol setup. Lastly, construct validity is not fully possible as no known boot designs are sure to be significantly different in performance. Future research should re-assess this and indications from the levels of agreement can give information about the construct validity.

5.5 Main Outcome

Obtaining a valid and reliable setup for shooting performance will enhance the understanding the impact of boot design and optimise ability to compare future research results.

APPENDIX F

Potential Additional External Impacting Factors on Dribbling and Passing Performance

Key external factors are listed in Table F.1 and F.2 with a brief description of how these factors, according to past literature, affect dribbling performance measures.

Table F.1. Basic test settings to control when measuring dribbling ability.

Factor	Impact
Sex	Only a single study (Hoare and Warr, 2000) on dribbling ability has assessed female players. No study has compared sex and it can therefore only be suggested that a participant selection should not mix male and female players before the impact of sex has been determined.
Level of maturation	Level of maturation has shown to significantly impact a player's ability to complete a speed dribbling drill amongst youth players (Figueiredo et al., 2011; Vänttinen et al., 2010).
Skill level	Years of training has shown to significantly impact a player's ability to complete a speed dribbling drill (Figueiredo et al., 2011; Rösch et al., 2000). By using specific training then a player is capable of significantly ($p < 0.01$) improve their dribbling speed (Haaland and Hoff, 2003).
Fatigue	Two studies (McGregor et al., 1999; Stone and Oliver, 2009) performing a full match simulation test (Loughborough Intermittent Shuttle Test) found a significantly decrease in players' dribbling speed. It is therefore important to prevent fatigue by using adequate rest and limit the number of repetitions.
Ball	To qualify for the basic 'FIFA Inspected' ball standard FIFA specify that balls have to satisfy six criteria: mass, rebound, durability, pressure retention, circumference and sphericity (Fédération Internationale de Football Association, 2012). It is important to use a FIFA standard ball and to use the same ball pumped to the same pressure level at every repetition as variations in any of the criteria may alter ball behaviour (Asai and Seo, 2013; Neilson, 2003; Neilson and Jones, 2005). It is therefore also important to include these values in any publication.
Surface	No study has measured the actual effect of the pitch parameters on a player's dribbling ability. Yet a study players' perception on how certain parameters impact their dribbling performance. It was found that players do believe that the pitch type is believed to affect the player's ability to dribble (Zanetti, 2009). This seems logical, as the ball travels on the ground and any unevenness and the level of resistance from the grass condition will affect the ball motion.
Weather	No study has measured the actual effect of weather conditions on a player's dribbling ability. The study (Zanetti, 2009) on perception of surface impacting a player's ability to dribble also analysed how player's perceive that weather impact their dribbling ability. It was found that players do believe that weather conditions believed to affect the player's ability to dribble.

Table F.2. Basic test settings to control when measuring passing ability.

Factor	Impact
Sex	Only a single study (Hoare and Warr, 2000) on passing accuracy has assessed female players. No study has compared sex and it can therefore only be suggested that a participant selection should not mix male and female players before the effect of this factor has been determined.
Level of maturation	Research has shown that maturation affects the players passing accuracy (Vänttinen et al., 2010). Therefore, researchers should keep this in mind when selecting and grouping test participants.
Skill level	Logically, it has been proven in the literature that a player's skill level – often defined by level of competition – is related to the players ability to pass the ball accurately (Haaland and Hoff, 2003; Hoare and Warr, 2000; Rampinini et al., 2009; Rösch et al., 2000; Rostgaard et al., 2008).
Limb dominance	Not surprisingly, players perform more accurate passes with their dominant foot (Haaland and Hoff, 2003). It is therefore useful to only use the dominant foot for testing, when measuring the impact of an external factor.
Fatigue	A small improvement in passing accuracy and speed has been shown after moderate exercise (Bullock et al., 2012; Lyons et al., 2006), whilst fatigue has shown conflicting results in the literature. It has been found that fatigue decreases passing accuracy and speed (Lyons et al., 2006) whilst passing precision remained unchanged but the speed of passing was significantly reduced over 90 min of exercise in another study (Russell et al., 2011). Finally, Ali et al. (2011) showed that participation in 90 minutes fatigue protocol did not influence overall performance measures of passing performance. This is most likely due to the use of different participants used, fatigue protocols, and passing measure. What is known from real match scenarios is that the frequency and success of short passes were reduced during the second half when compared with the first half of match-play (Rampinini et al., 2008).
Support foot	No studies have yet analysed the impact of support foot parameters on passing. It can, however, be hypothesised that low traction due to unsatisfactory stud design can increase instability and potential slipping. Studs should therefore match the surface. Future research may assess what optimal traction is and the importance of traction for passing performance.
Ball	To qualify for the basic 'FIFA Inspected' ball standard FIFA specify that balls have to satisfy six criteria: mass, rebound, durability, pressure retention, circumference and sphericity (Fédération Internationale de Football Association, 2012). It is important to use a FIFA standard ball and to use the same ball pumped to the same pressure level at every repetition as variations in any of the criteria may alter ball behaviour (Asai and Seo, 2013; Neilson, 2003; Neilson and Jones, 2005). It is therefore also important to include these values in any publication.
Surface	No studies have analysed the effect of surface on passing ability. Yet an indirect suggestion to the impact has been shown in the literature. Match analysis data suggest players perform more short passes on artificial surfaces relative to playing on grass (Andersson et al., 2008). Players' perception of whether the surface affects the ball speed showed that players believe that the surface is a significant factor (Zanetti, 2009). No study has confirmed this but it appears logic that smooth surfaces with short grass

	will make the ball move faster and more accurately. It can only be suggested to use a natural and flat surface such as artificial turf.
Weather	Wetness alters the properties of the surface (Heidt et al., 1996; Torg et al., 1974, 1996). It is also logical that a wet upper shoe surface and ball will alter the friction properties and it can therefore, although not tested, be assumed to impact passing velocity and consistency. Weather conditions should be controlled as much as possible by not testing under two different conditions when performing tests over different days.

APPENDIX G

Validation of Appropriate Flat and Airborne Passing Distances

G.1 Chapter Outline

The literature review (Chapter 2) highlighted a large variation in passing distances applied with assessing passing performance in the literature. None of the studies argued why their passing distance was chosen. This chapter therefore assesses match analysis data obtained from the FA Premier League to understand what a match-typical passing length is for two types of passes: the flat over ground pass and the lover airborne pass. The results are later applied as passing distances in the novel test setup to assess the impact of football boot design on dribbling and passing performance in football.

G.2 Aim

To define match related passing distances for flat and airborne passes based on observational data from football matches.

G.3 Methods

Definitions of the flat and airborne passing times desired to replicate were developed:

- **Flat passing:** Flat over ground from one teammate to another without interference of an opponent or other obstacle. The pass is performed with the inside of the foot and is aimed to not bounce when moving over the ground. These passes are commonly used to maintain position in the middle third of the pitch by midfield players
- **Airborne passing:** Airborne passes from one teammate to another without interference of an opponent or other obstacle. The pass is performed with the instep of the foot and is aimed to not bounce on the ground before received by the teammate. These passes are commonly used by a midfield player to split a line of defender with a deep ball in behind the defence for the winger or forward to perform a deep run into space and create an attacking opportunity.

Search of literature

A search through the match analysis data published did not result in any data on typical passing distances in football.

Match data analysis
Data from two match data analysis sources were therefore gathered for the analysis. Firstly, Free Opta Sportsdata Ltd. (London, UK) match data from the FA Premier League match between Bolton Wanderers Football Club and Manchester City Football Club (21/08/2011) available online from http://www.mancity.com/mcfcanalytics was assessed. The match ended 3-2 for Manchester City Football Club. Passes were described by player, team, player position, time, whether the pass was complete or incomplete, pass length, zone on pitch where performed, zone on pitch where received. Secondly, Prozone Sports Ltd (Leeds, UK) supplied passing data from half a season from their data base of the season 2014/15 from the English Premier League. Passes were described by player, team and match code (masked), whether the pass was successful or unsuccessful, the pass length and direction of pass, the following event (e.g. touch, header, etc.). Passes were subcategorised by Prozone Sports Ltd (Leeds, UK) into short, medium and long passes. Their definitions of pass types are shown in Table G.1. The argumentation for these definitions is unknown.

Table G.1. Definitions of pass lengths applied by Prozone Sports Ltd (Leeds, UK).

Definition	Pass length range (m)
Short	≤ 9.99
Medium	10 – 24.99
Long	25 ≤

Histograms and descriptive statistics were performed in Statistical Package for the Social Sciences Software (Version 19, SPSS Inc., Chicago, IL).

G.4 Results

Passing distances from analysis of Bolton W.F.C.–Manchester City F.C. Opta Sportsdata Ltd. (London, UK) match data

A total of 748 successful passes were performed during the match. A successful pass was defined as a pass received by a team mate. Of these, 705 successful passes were flat passes delivered with the ball rolling over the ground (Figure G.1A) whilst 43 successful passes were airborne (Figure G.1B). The mean pass length for successful flat passes was 16.9 ± 14.4 m whilst the mean pass length for successful airborne passes was 28.3 ± 12.0 m. The low number of airborne passes prevented any further sub-categorisation.

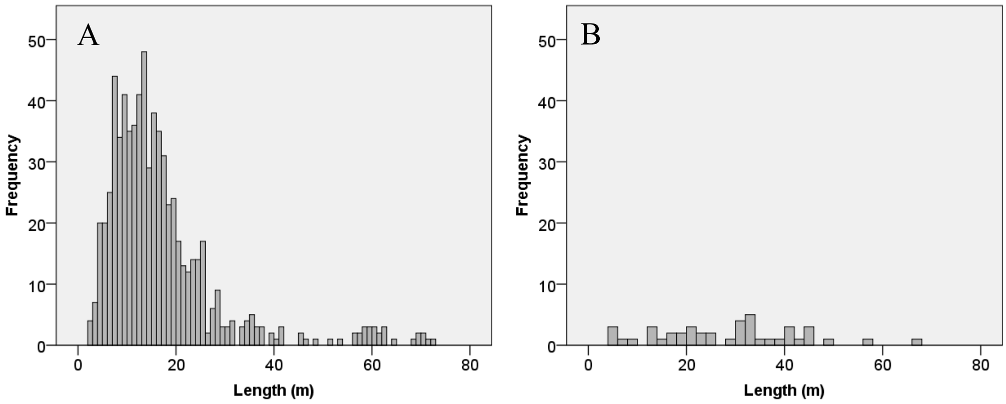


Figure G.1A and B. Histograms of pass length (m) for successful flat (A) and successful airborne (B) passes.

Flat passes data was, however, subcategorised. Because passing length depends on the area of the pitch where the pass is performed then a more detailed analysis of short passes was performed to better understand the passing length fitting the given scenario presented in the methods. Passes played and received on the middle third of the pitch were extracted (Figure G.2A) giving a total of 285 successful passes with a mean length of 13.8 ± 6.2 m. These passes were further divided into passes depending on the players performing them. Figure G.2B shows the 136 passes performed within the middle third zone by midfielders only. The figure shows a mean passing length of 14.1 ± 5.9 m. The last methods therefore demonstrated very similar results.

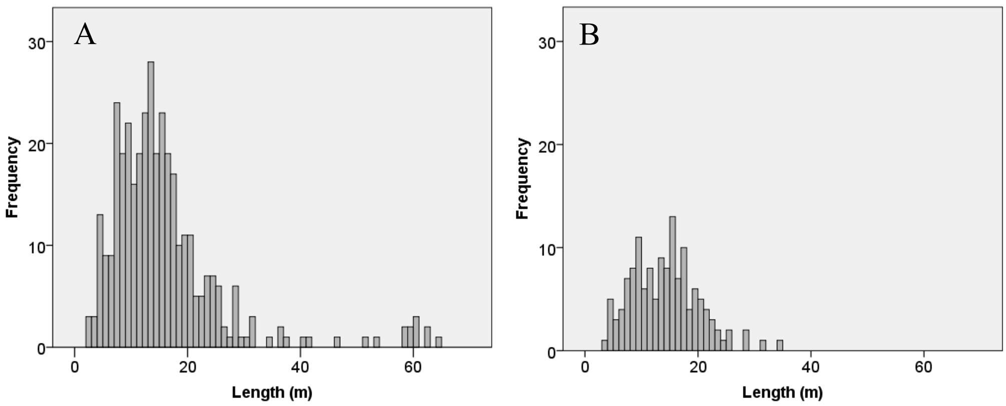


Figure G.2A and B. Histograms of pass length (m) for all successful passes performed from and to the middle 3rd of the pitch (A) and these passes performed by midfielders alone (B).

Passing distances from analyses of FA Premier league Prozone Sports Ltd (Leeds, UK) data

The data obtained from of Prozone Sports Ltd (Leeds, UK) included a total of 150,070 passes from the half 2014/15 FA Premier League season. Figure G.3 displays the frequencies of pass lengths for all successful passes summing a total of 125,367 passes with a mean length of 16.0 ± 9.1 m.

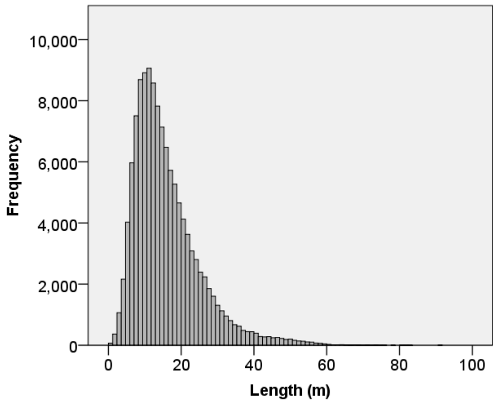


Figure G.3 Histogram of pass length (m) for all successful passes.

The data did not allow researchers to know whether the pass was flat or airborne. Data could, however, be split by method of receiving the ball. Any passes with the outcome of goalkeeper catch, goalkeeper catch drop, handball or header were excluded in Figure G.4A, to better represent flat passes as these were all assumed to be airborne due to the nature of receiving method. Additionally, for these assumed airborne passes ball pass distances are demonstrated in Figure G.4B. By performing this separation of data large variances in pass lengths were obtained. Successful passes with minimised number of airborne passes came to a total of 123,043 passes and demonstrated a mean length of 15.7 ± 8.6 m, a median of 13.7 m and a range of 0.2 m to 91.4 m. The wide range indicates that some airborne passes must be included despite the elimination of data depending on receiving method. Assumed airborne were less frequent and came to a total of 2,324 passes with a mean length of 34.8 ± 15.2 m, a median of 36.9 m and a range of 1.7 m to 71.0 m.

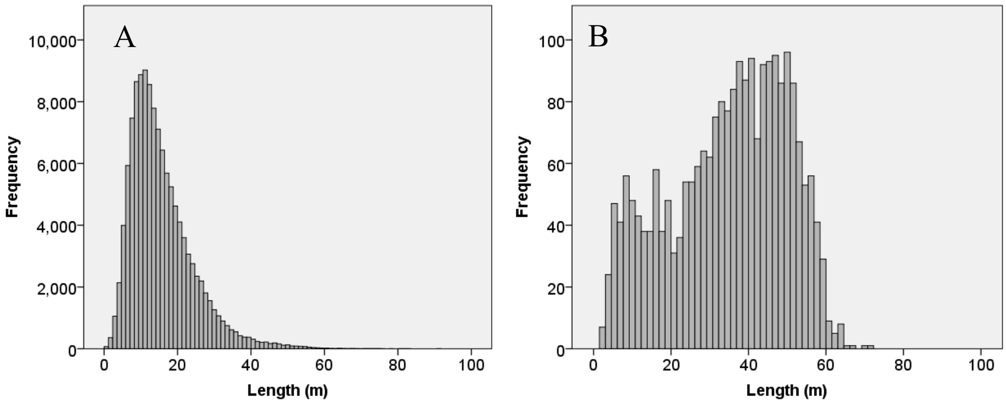


Figure G.4A and B. Histogram of pass length (m) for all successful assumed flat passes (A) and assumed airbone (B) passes.

G.5 Key Outcome

No match analysis data was found in the scientific literature. Free online match data from the Bolton Wanderers Football Club - Manchester City Football Club (August 21st 2011) and half a season from the Prozone Sports Ltd (Leeds, UK) data base of the season 2014/15 from the FA Premier League were therefore used to analyse appropriate passing lengths. Mean flat passing length was 14.1 ± 5.9 m for the single match data whilst data from half the FA Premier League season could not be directly split between flat and airborne passes and some level of error therefore exist within the results but a mean assumed flat pass was found to be 15.7 ± 8.6 m. Airborne passes were much rarer and were found to have a mean passing length of 28.3 ± 12.0 in the single match study. Yet this result includes all airborne passes due to the low number seen. Similarly, it was not possible to specify the airborne passing distance to the case specific scenario in the data from half the FA Premier League season and a mean passing length was found to be 34.8 ± 15.2 m.

A flat pass length of 14 m was therefore selected for the study and since airborne passes included many different types of passes – including defender clearances and passes from wingers into the 18 yard box, which are typically much longer pass types than the types attempted to assess in this study. A passing distance of 25 m was therefore selected. Match analysis data is increasingly applied by professional clubs and by the media. It is therefore expected that more data will be accessible in the upcoming years which will improve the analysis of appropriate passing distances to use for research.

APPENDIX H

Pilot Study - Validation of GoPro Hero4 Black for Radial Offset Measurements through Direct Linear Transformation of Data

H.1 Chapter Outline

The literature review (Chapter 7) highlighted the optimal approach to assess accuracy of dribbling performance is by direct measurement of offset from target. The literature review also underlined the importance of measuring multiple aspects of dribbling performance, including offset from cones when performing slalom dribbling. This chapter assessed the quality of measures of ball location using GoPro Hero4 Black cameras recordings analysed though the direct linear transformation (DLT) method.

H.2 Issue addressed

Video analysis pointing directly at the target for offset analysis (image plane) can be difficult to achieve. This issue was experienced when assessing attempting to assess offset from target for airborne passes and radial offset from cones when dribbling. Videos recorded from an angle and assessed applying direct linear transformation (DLT) methods could be an alternative solution.

H.3 Aim

To validate the use of GoPro HERO4 Black cameras (GoPro Inc., San Mateo, CA) (240 Hz, 1280x720) for assessment of offset from target with an angled recording analysed with DLT assessment.

H.4 Introduction to Direct linear transformation

When the plane of measurement (e.g. the ground) and the camera image plane (e.g. placed on tripod angled towards area of assessment) are not parallel, the outcome data cannot not be assessed in the same frame of reference as given on the camera image plane. A different method of converting pixels to meters therefore needed be employed. The DLT method (Abdel-Aziz and Karara, 1971; Kwon, 2008) is used to convert pixel data into real world co-ordinates. The foundation of the DLT method follows the assumption of collinearity. DLT states that the optical system of the camera maps a point of interest in the real world object space reference frame (O$[x, y, z]$) to a corresponding pixel in the camera screen image plane reference frame (I$[u, v]$) from the projection centre (Figure H.1). The projection centre point, pixel point and real world point are consequently collinear.

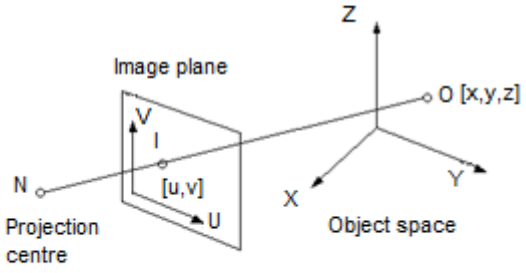


Figure H.1. Object Space and Image Plane in Direct Linear Transformation.
Object O is mapped directly to the projected image I. The projection plane is called image plane. Point N is the new projection centre. (Adapted from **http://kwon3d.com/theory/dlt/dlt.html**)

From the assumption that the projection centre is a point in the object space, a vector can be drawn to the point of interest and assessed in relation to a vector directed towards the central point of the image plane (principal point). This produces the rotation matrix required to realign the vectors. By multiplying the real world point and the transformation matrix achieved, the corresponding pixel co-ordinates are achieved. The DLT two-dimensional (2-D) method uses the same algorithms employed in tri-dimensional analysis, but considers the z-coordinates always equal to zero (Kwong, 1998). Following the principles described by Hatze (1988) then an eight coefficient (L1 to L8) DLT vector should be applied. The DLT vector reflects the relationship between the object space reference frame and the image plane reference frame as well as optical distortion corrections (Kwong, 1998). To complete 2-D DLT processing, these parameters need to be identified by calibrating the image. This is in the field of biomechanics commonly done by the methods described by Woltring and Huiskes's (1990).

H.5 Methods

Based on the setup details described in full details in Figure 9.2, the DLT method was applied and validated for the camera setups used for assessment of offset for long passing and radial offset from cones in dribbling.

DLT for long pass

Camera calibration requires a minimum of four points to obtain a DLT vector but more points reduce the level of error. In this study 156 points were taken around the target cone used for testing in a square grid of 10 x 10 m (Figure H.2A). The size of the calibration frame was chosen based on 20 pilot passes by a player equalling the level of players aimed to test (university team player). All passes were within a radius of 3.50 m and a square grid of 10 x 10 m was therefore selected. Points were defined by placing the ball used for testing on the allocated points. The centre point of the ball was chosen as point of reference. Ball centre coordinates at these points were determined in Pro Analyzer (Version 7.0, Media Cybernetics, Inc., Rockville, MD) using the 3-point best fit circle feature.

The International Society of Biomechanics supplies movement analysis software to standardise the assessment performed between researchers. MATLAB routines for 2-D camera with non-perpendicular camera angle calibration and point reconstruction using the DLT. The MATLAB code is based Woltring and Huiskes's (1990) mathematical application method for DLT for 2-D camera recordings. The codes are available online at http://isbweb.org/software/movanal.html. The MATLAB routines available consist of two codes. The first code delivers the calibration of a vector containing the eight DLT coefficients. These are obtained from the input of a matrix containing global coordinates and a matrix containing the coordinates of calibration points seen in camera following – both following the same sequence. The second code allow the user to reconstruct points from the camera coordinate points to the object plane position by inputting the previously obtained vector containing the eight DLT coefficients and the camera point coordinates for the points needed to be reconstructed. Both following the methods described in Woltring and Huiskes (1990).

To assess the quality of the DLT method, the object plane position outcome for the calibration points were compared with the direct linear transformed outcome when using the point of the image plane.

DLT for dribbling

Two different camera distances to the first cones were used. This was done to allow minimal distance to the field of assessment but without movement path for the players within the setup (See Figure 9.2 for setup details). For the dribbling drill 27 points were taken outside the turning cone used within the dribbling setup in a rectangular grid of 1.5 x 10.5 m (Figure H.4A and Figure H.4D). The size of the calibration frame was chosen based on 20 pilot dribbling trials by a player equalling the level of players aimed to test (university team player). All turns were within a radius of 0.80 m and a square grid with an offset distance of 1.5 m from the cone was therefore selected. Similar to the long passing drill, points were defined by placing the ball used for testing on the allocated points, which were then assessed in Pro Analyzer (Version 7.0, Media Cybernetics, Inc., Rockville, MD) using the 3-point best fit circle feature. Similar DLT methods were applied for the calibration data for dribbling as mentioned above for long passing.

H.6 Results

DLT accuracy for long passing

Figure H.2A and Figure H.2B demonstrate the calibration points used as seen in the object plane and the image plane. Mean error obtained when running the calibration data through the DLT was 0.045 ± 0.036 m along the x-axis and 0.041 ± 0.036 m along the y-axis.

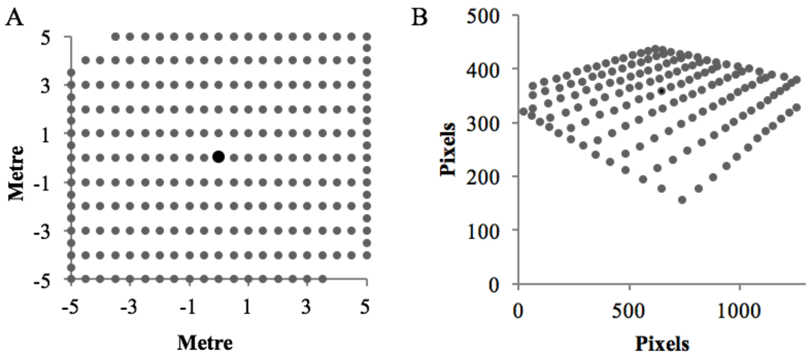


Figure H.2A and B. Calibration points from object plan (A) and image plane (B).

The range of error is demonstrated in the histogram Figure H.3A and Figure H.3B, where it is evident that the maximum error experienced was 0.162 m along the x-axis and 0.137 m along the y-axis. The positions with increased inaccuracy were located in the far top as shown in Figure H.2B, which is maximum distance from the camera but also from the target point and therefore not a frequently hit zone when passing

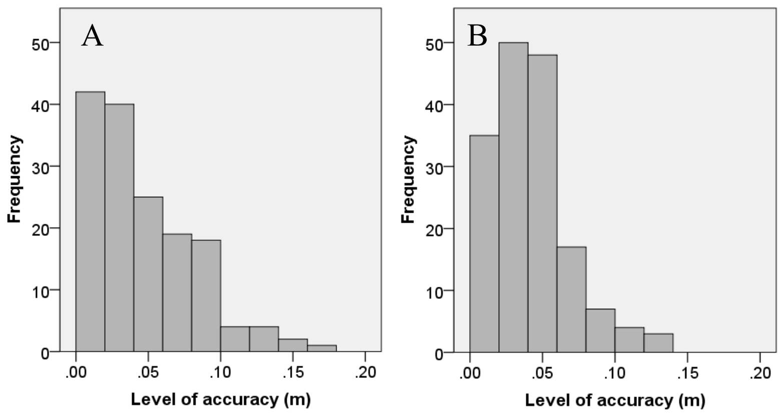


Figure H.3A and B. Histograms for accuracy for each point in the x- and y-axis for long passing recordings.

DLT accuracy for dribbling

Figure H.4A and Figure H.4D demonstrate the calibration points used as seen in the object plane and the image plane for both the camera positioned 3 m and the camera positioned 4.5 m from the first cone. Mean error obtained when running the calibration data through the DLT was 0.012 ± 0.009 m along the x-axis and 0.051 ± 0.038 m along the y-axis for the camera positioned 3 m from the first cone. For cameras positioned 4.5 m from the first cone the mean error obtained when running the calibration data through the DLT was 0.007 ± 0.004 m along the x-axis and 0.065 ± 0.049 m along the y-axis.

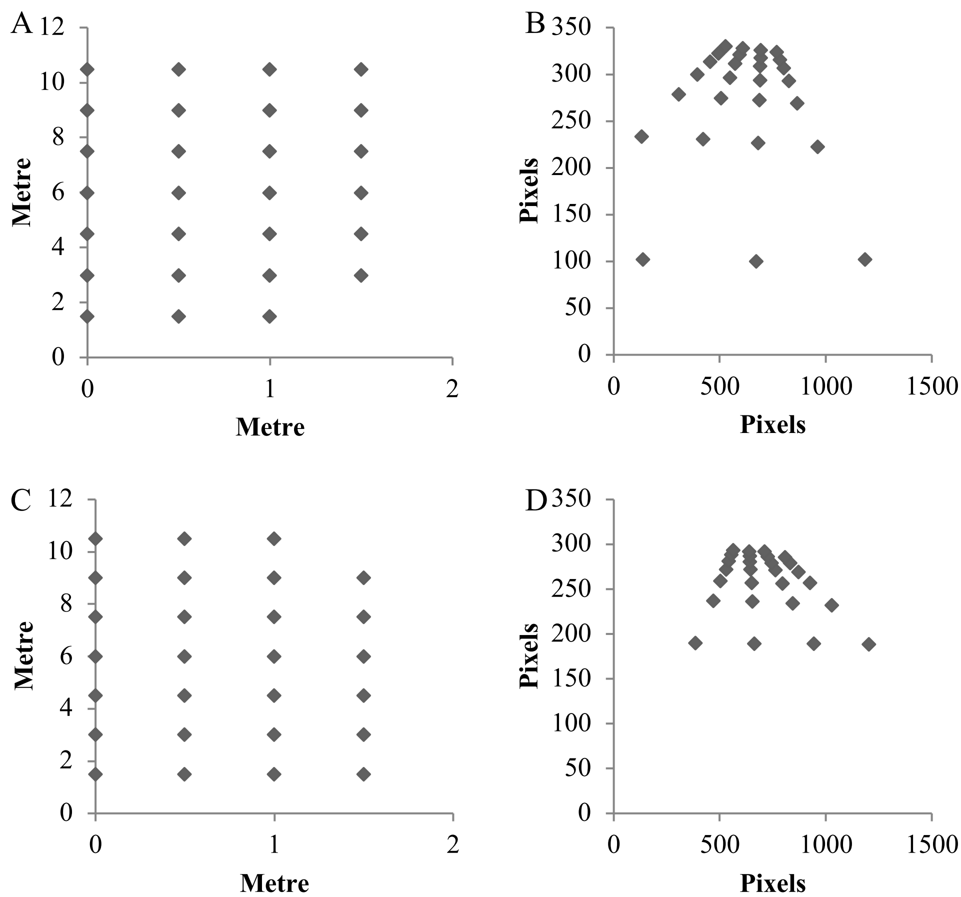


Figure H.4A-D. Calibration points from object plan (A) and image plane (B) for cameras positioned at 3 m distance and calibration points from object plan (C) and image plane (D) for cameras positioned at 4.5 m distance.

Maximum error experienced was 0.033 m along the x-axis and 0.142 m along the y-axis for the camera positioned 3 m from the first cone (Table H.1). For cameras positioned 4.5 m maximum error experienced was 0.015 m along the x-axis and 0.176 m along the y-axis (Table H.1). The positions with increased inaccuracy for y-axis data were located at the furthest distance and 1 m wide from the cone. The furthers cone was therefore excluded from the data, which optimised the critical scores of y-axis maximum inaccuracy measures by 0.063 m for the 3 m recordings and 0.099 m for the 4.5 m recordings (Table H.1).

Table H.1. Accuracy for recordings along the x- and y-axis for dribbling recordings.

		All Cones Included	Furthest Cone Excluded
3 m	x-axis mean (m)	0.012	0.011
	y-axis mean (m)	0.051	0.040
	x minimum (m)	0.001	0.001
	x maximum (m)	0.033	0.033
	y minimum (m)	0.003	0.009
	y maximum (m)	0.142	0.079
4.5 m	x-axis mean (m)	0.007	0.005
	y-axis mean (m)	0.065	0.041
	x minimum (m)	0.001	0.001
	x maximum (m)	0.015	0.014
	y minimum (m)	0.001	0.001
	y maximum (m)	0.176	0.0

H.7 Key Outcome

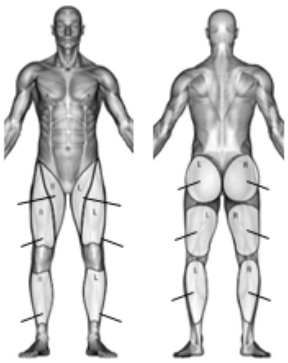
The accuracy level for long passing using DLT was found to be acceptable. It was also decided that data from the furthest cone would not be assessed for passing data due to the large error if radial offset from the cone would reach ~1 m. This alteration still allowed the researchers three cones to assess the mean offset per round from.

APPENDIX I

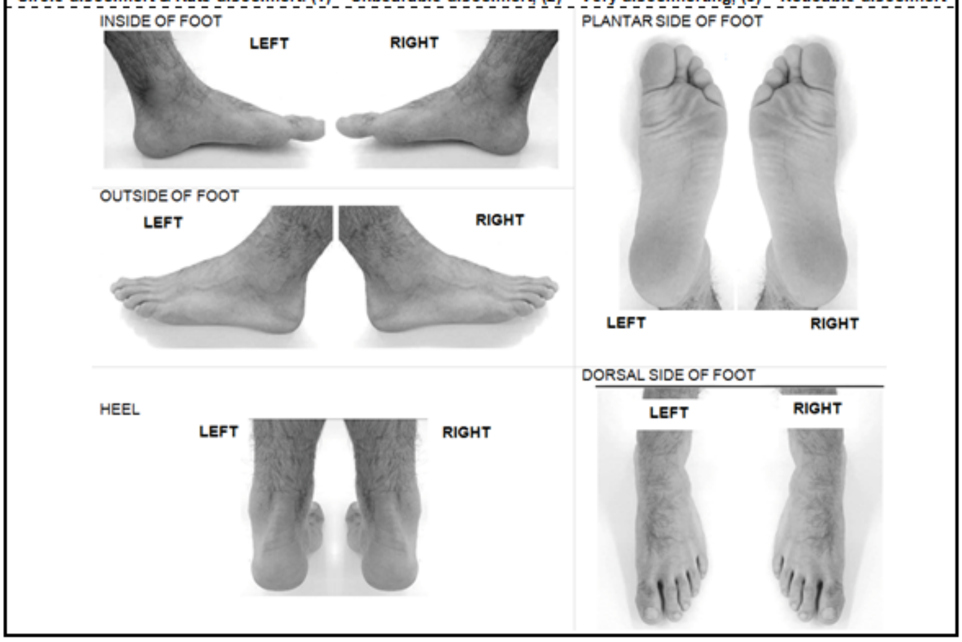
Questionnaire

Example page of pre- and post-session questionnaire

PRE

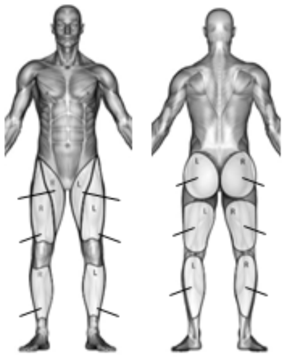
<u>Circle</u> the statement best describing your sleep currently:	<u>Circle</u> the statement best describing your level of stress currently:	<u>Circle</u> the statement best describing your current level of fatigue:	<u>Circle</u> the statement best describing your current level of muscle soreness:	<u>Rate</u> current level of <u>muscle soreness</u> in the highlighted regions:
SLEEP:	**STRESS:**	**FATIGUE:**	**MUSCLE SORENESS:**	
Very, very bad	Very, very low	Very, very low	Very, very low	
Very bad	Very low	Very low	Very low	
Bad	Low	Low	Low	
Neither good nor bad	Neither low nor high	Neither low nor high	Neither low nor high	
Good	High	High	High	
Very good	Very high	Very high	Very high	
Very, Very good	Very, Very high	Very, Very high	Very, Very high	1-2 = no muscle soreness 3-4 = a little muscle soreness 5-6 = quite sore 7-8 = Very sore 9-10 = Very, very sore

Circle discomfort & Rate discomfort: (1) = Unbearable discomfort, (2) = Very discomforting, (3) = Noticable discomfort

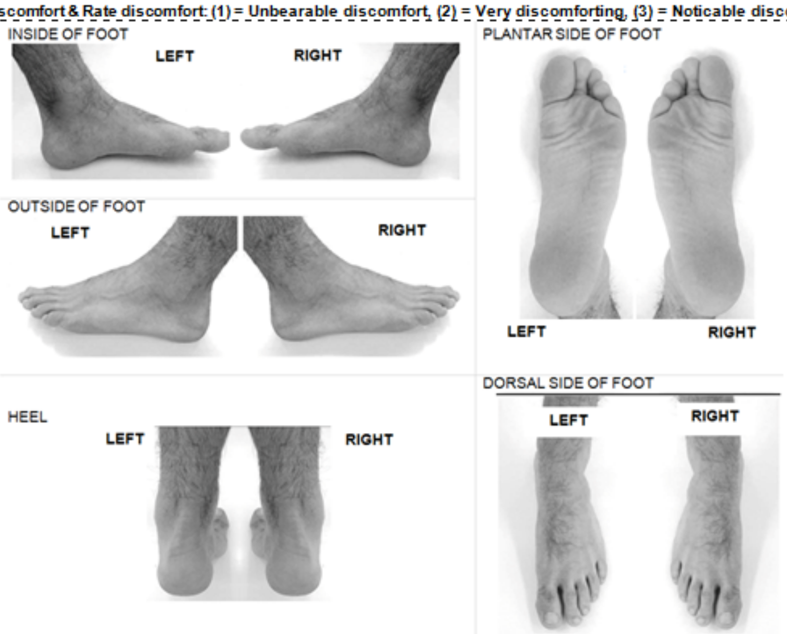


Example page of during session questionnaire

15 min

Circle the statement best describing your current foot comfort level	Circle the statement best describing your current level of fatigue:	Rate current level of muscle soreness in the highlighted regions:
FOOT COMFORT LEVEL: Unbearable discomfort Very discomforting Noticeable discomfort Neither comfortable nor uncomfortable Somewhat comfortable Very comfortable Extremely comfortable	**Borg Rating of Perceived Exertion** 6 No exertion at all 7 Extremely light 8 9 Very light 10 11 Light 12 13 Somewhat hard 14 15 Hard (heavy) 16 17 Very hard 18 19 Extremely hard 20 Maximal exertion	 1-2 = no muscle fatigue 3-4 = a little muscle fatigue 5-6 = quite fatigued 7-8 = Very fatigued 9-10 = Very, very fatigued

Circle discomfort & Rate discomfort: (1) = Unbearable discomfort, (2) = Very discomforting, (3) = Noticable discomfort



APPENDIX J

Pilot Study – Test-Retest Reliability of Football Specific Sprint Test

J.1 Chapter Outline

In the literature review of assessment methods to measure sprint ability in football several methods were suggested (Chapter 11). Sterzing et al. (2009) developed a football specific acceleration and agility sprint drill applied to assess the impact of boot design on football specific sprinting. The drills were, however, not been validated.

J.2 Aim

This pilot study therefore assessed the test-retest reliability of sprint times measured using the Sterzing et al. (2009) protocol.

J.3 Methods

Participants

Fourteen recreational football players (age 23.1 ± 2.8 years, stature 1.81 ± 0.05 m, mass 74.2 ± 6.6 kg) volunteered for this study. All subjects were UK size 8 to 10. During the test, subjects wore new similar Umbro football socks.

Ethics

Ethical approval was obtained from the Loughborough University ethics committee. Subjects provided written informed consent and completed a medical screening questionnaire.

Football boots

Umbro UX Accuro Pro With hard ground outsoles were used to validate the setup.

Experimental design

Subjects participated in two afternoon sessions separated by 7 days. Each session was initialised by a standardised warm up. Players completed two 45 min match simulation halves following the official instructions for the Soccer-Specific Aerobic Field Test (SAFT90; Lovell et al., 2008). Test setup followed the official instruction by Small et al. (2010).

Speed was assessed between warm up and start of the SAFT90 and directly after completion of the 90 min SAFT90 match simulation. Agility and linear acceleration setups followed the Functional Traction Course protocols developed by Sterzing et al. (2009). The Functional Traction Course agility course involved 12 multidirectional accelerations, 10 cutting movements and one complete (360˚) turn around a cone. Completion time was assessed by chest crossing start and finish like using high speed video (GoPro HERO4 Black, GoPro Inc., San Mateo, CA; 240 Hz, 1280 x 720 pixels). The Functional Traction Acceleration Course consisted of 6 m straight line acceleration and completion time was assessed using manufactured laser time gates (194-010 lasers, RS, Germany; photo transistor receiver, RS; Germany).

Statistical analysis

Statistical analysis was carried out using SPSS software (Version 23.0; SPSS Inc., Chicago, IL). Statistical significance was set at $P \leq 0.05$. Non-parametric tests were applied based on the violation of outliers in the differences between the two related groups for some variables. Systematic bias in the repeatability between sessions was analysed by Wilcoxon's matched-pair tests. The magnitude of relative reliability was determined by two-way random intraclass correlation coefficient ($ICC_{2,1}$) two-way random effect model (absolute agreement definition) analyses of the mean subject scores for each session following clinical significance levels suggested by Cicchetti (1994). Data was log-transformed due to heteroscedasticity as suggested by Vaz et al. (2013) and Weir (2005a). The $ICC_{2,1}$ is commonly suggested as the preferred assessment method to quantify relative reliability of test-retest validation setups (Beckerman et al., 2001; Hopkins, 2000; Lexell and Downham, 2005; Vaz et al., 2013; Weir, 2005). Absolute reliability was derived using standard error of measurement (SEM) and the smallest real difference (SRD) necessary to be considered real were derived from the intra-class correlation coefficients following the methods explain by (Weir, 2005). Both SEM and SRD were additionally presented at percentage of the mean (SEM% and SRD%) to allow results to be given without the constraints from the units of measurement following the methods expressed by (Lexell and Downham, 2005).

J.4 Results

The means and standard deviations (SD) as well as the median and range for all outcome measures are presented in Table J.1 for both sessions. Despite demonstrating small mean differences, then systematic bias was seen in three of four sprint assessments (Table J.1). The relative reliability between trials assessed by the intraclass correlation coefficients ($ICC_{2,1}$) are shown in Table J.1 and were shown to be poor ($ICC_{2,1} = 0.237$) for acceleration before the match simulation and fair ($ICC_{2,1} = 0.486$)

when completed after 90 min of match simulation. The agility sprint relative reliability was fair ($ICC_{2,1}$ = 0.571) before the match simulation and good ($ICC_{2,1}$ = 0.679) after completion of the 90 min of match simulation.

Table J.1. Systematic bias, relative reliability and absolute reliability for test-retest validation.

Variable	Session 1 Mean ± SD		Session 2 Mean ± SD		$ICC_{2,1}$	MD	Bias (P-value	Grouped mean	SEM	SRD
Acceleration time (s)										
0 min	1.276	±0.115	1.311	±0.065	0.237	-0.024	0.600	1.294	±0.103	±0.285
90 min	1.269	±0.103	1.320	±0.060	0.486	-0.065	0.005	1.292	±0.073	±0.203
Agility time (s)										
0 min	11.541	±0.641	11.061	±0.676	0.571	0.480	0.028	11.301	±0.420	±1.163
90 min	11.448	±0.874	10.956	±1.221	0.679	0.492	0.040	11.202	±0.495	±1.373

MD = mean difference; Significantly difference between sessions set to $P \leq 0.05$; $ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition); SEM = Standard error of measurement = SD × $\sqrt{1 - ICC}$; SRD = Smallest real difference at 95% confidence intervals = SEM × 1.96 × $\sqrt{2}$.

The 68% confidence interval represented by standard error of measurement (SEM) and 95% confidence interval represented by smallest real difference (SRD) expressed in both the measurement unit and as a percentage of the mean are demonstrated in Table J.1. For acceleration sprint times a 17% and 23% change in acceleration sprint performance would prove significant whilst significance for agility sprints would be detectable with a 12% change in time.

J.5 Key Outcome

The two sprint assessment methods developed by Sterzing et al. (2009) demonstrated violation of bias in three of the four assessments and poor test-retest reliability based on weak relative reliability scores and broad SRD bands, indicating large variation when repeated and therefore small chances in detecting actual differences in results when comparing two or more football boot models. The two sprint drills were, therefore, not applied in the main study setup and the generic and previously validated sprint drill Illinois agility test was preferred (Chapter 12). Additionally, the results presented by Sterzing et al. (2009) on difference in sprint performance based on different football boots designs must therefore be viewed with caution.

APPENDIX K

Pilot Study – Test-retest reliability and ecological validity of heart rate scores during SAFT90

K.1 Chapter Outline

To assess match related fatigue in football a controlled setup is needed. The soccer-specific aerobic field test (SAFT90) by Lovell et al. (2008) was identified as the most relevant, match simulation drill available to generate football specific fatigue in a simplistic and repeatable way. As the setup was developed based on semi-professional football players' match data on distance covered, count of changes of direction and heart rate then a pilot study to ensure that the SAFT90 is relevant to use for university level players was therefore relevant. Additionally, previous validation study by Lovell et al. (2008) has focused on a comparison between SAFT90 and real match data, whilst test-retest reliability not yet has been validated.

K.2 Aim

To validate test-retest reliability and ecological validity of match specific intensity of the SAFT90 simulated match-play through heart rate and perceived exertion measures.

K.3 Methods

Participants

Fourteen recreational football players (age 23.1 ± 2.8 years, stature 1.81 ± 0.05 m, mass 74.2 ± 6.6 kg) volunteered for this study. All subjects were UK size 8 to 10. During the test, subjects all wore new similar Umbro football socks to prevent the socks from altering the subjects' sensation of the boot and ball.

Ethics

Ethical approval was obtained from the Loughborough University ethics committee. Subjects provided written informed consent and completed a medical screening questionnaire.

Football boots

Umbro UX Accuro Pro with hard ground outsoles were used to validate the setup.

Experimental design

Subjects participated in two afternoon sessions separated by 7 days. Each session was initialised by a standardised warm up. Players completed two 45 min match simulation halves following the official instructions for the SAFT90 by Lovell et al. (2008) and Small et al. (2010).

Mean heart rate and players' rated perceived exertion (RPE) measures were assessed throughout the drill to evaluate the intensity players were working at throughout the drill. Every 15^{th} minute the recorded match simulation instructions stopped which allowed players to fill in the Borg's 15-point rated perceived exertion (RPE) questionnaire (Borg, 1970). Heart rate was recorded using heart rate belts (Polar Team Pro, Polar Electro, Kempele, Finland) continuously and averaged for each 15 min block of the SAFT90.

Statistical analysis

Statistical analysis was carried out using SPSS software (Version 23.0; SPSS Inc., Chicago, IL). Statistical significance was set at $P \leq 0.05$. Parametric tests were applied as no violations of assumptions were experienced. Systematic bias in the repeatability between sessions was analysed by dependent t-tests. The magnitude of relative reliability was determined by two-way random intraclass correlation coefficient ($ICC_{2,1}$) two-way random effect model (absolute agreement definition) analyses of the mean subject scores for each session following clinical significance levels suggested by Cicchetti (1994). The $ICC_{2,1}$ is commonly suggested as the preferred assessment method to quantify relative reliability of test-retest validation setups (Beckerman et al., 2001; Hopkins, 2000; Lexell and Downham, 2005; Vaz et al., 2013; Weir, 2005). Absolute reliability was derived using standard error of measurement (SEM) and the smallest real difference (SRD) necessary to be considered real were derived from the intra-class correlation coefficients following the methods explain by (Weir, 2005).

Heart rate and RPE values were also compared with data from real match-play studies and other studies applying the SAFT90 protocol as a match simulation drill to obtain an understanding of ecological validity.

K.4 Results

Mean heart rate did in both trials follow a tendency where the first 15 min of each half presented a lower value than the following 30 min of the halves (Table K.1). This was also evident from players' ratings of perceived exertion. Mean ratings started at 11.2 ± 1.2 in session 1 and 10.9 ± 1.1 in session 2, referred to as "light exertion", and gradually increasing to 13.7 ± 1.3 in session 1 and 13.1 ± 1.6 in session 2, referred to as "somewhat hard exertion". Mean heart rate showed a mean difference between trials of

< 6 bpm for each of the six 15 min intervals and between trial bias only proved to be just significant (P = 0.045) for the 30-45 min interval. For RPE mean difference was ≤ 0.5 and between trial bias showed non-significant difference at any time interval.

Relative Reliability

The degrees of consistency and agreement between trials as assessed by the intraclass correlation coefficients ($ICC_{2,1}$) are shown in Table K.1and was shown to be good to excellent (≥0.600) for mean heart rate from 30 min onwards and RPE for all time intervals.

Table K.1. Systematic bias and relative reliability for test-retest validation.

Variable	Trial 1 Mean ± SD		Trial 2 Mean ± SD		MD	Bias (P-value)	$ICC_{2,1}$
Mean HR (bpm)							
0-15 min	122	±14	124	±10	-2.1	0.724	0.169
15-30 min	140	±16	146	±10	-5.9	0.328	0.240
30-45 min	149	±10	144	±12	4.8	0.045	0.736
45-60 min	139	±8	136	±11	3.2	0.099	0.772
60-75 min	142	±10	140	±13	2.2	0.316	0.785
75-90 min	143	±10	141	±12	2.8	0.307	0.695
RPE							
15 min	11.2	±1.2	10.9	±1.1	0.2	0.387	0.704
30 min	11.7	±1.2	11.6	±1.4	0.1	0.794	0.763
45 min	12.2	±1.1	12.0	±1.3	0.2	0.578	0.884
60 min	12.5	±1.1	12.3	±1.4	0.0	1.000	0.818
75 min	13.2	±1.0	12.9	±1.4	0.3	0.366	0.603
90 min	13.7	±1.3	13.1	±1.6	0.5	0.190	0.645

MD = mean difference; $ICC_{2,1}$ = Intraclass correlation coefficient: two-way random effect model (absolute agreement definition).

Absolute Reliability

The 68% confidence interval represented by standard error of measurement (SEM) and 95% confidence interval represented by smallest real difference (SRD) expressed in both the measurement unit and as a percentage of the mean are demonstrated in Table K.2. Smallest detectable change for heart rate was 35-39 bpm for the first 30 min followed by a drop to 10-16 bpm for the following 60 min of the drill, which is a ≤11% change in heart rate. SRD interval for RPE scores were within a range from 1.1 to 2.1.

Ecological validity of heart rate

The mean heart rate per 15 min test interval ranged between 121.8 ± 14.1 bpm and 149.0 ± 10.0 bpm, which differs from heart rate measures in past literature on real match-play data and SAFT90 (Table K.3). The SAFT90 match simulation drill is designed to replicate movements, intensities and heart rates observed from mean performance of English Coca-Cola® Championship (2007/08 season).

Table K.2. Standard error of measurement (SEM) at 68% confidence intervals for and smallest real difference scores at 95% confidence intervals (SRD) for test-retest validation.

Variable	Grouped mean	SEM	SRD
Mean HR (bpm)			
15 min	123	±13	±36
30 min	143	±14	±39
45 min	147	±5	±14
60 min	138	±4	±10
75 min	141	±5	±13
90 min	142	±6	±16
RPE			
15 min	11.0	±0.7	±1.8
30 min	11.7	±0.6	±1.6
45 min	12.1	±0.4	±1.1
60 min	12.4	±0.5	±1.3
75 min	13.0	±0.6	±1.7
90 min	13.3	±0.8	±2.1

SEM = Standard error of measurement = SD × $\sqrt{1-\text{ICC}}$; SRD = Smallest real difference at 95% confidence intervals = SEM × 1.96 × $\sqrt{2}$.

Original validation of the protocol using semi-professional players demonstrated a mean heart rate of 165 and 167 bpm for first and second half respectively (Table K.3; Lovell et al., 2008). Heart rates have later been assessed during the SAFT90 drill on professional, semi-professional and recreational players (Table K.3). Nédélec et al. (2013) also assessed heart rate throughout SAFT90 testing of professional players and recorded heart rates of 151 ± 15 bpm on artificial grass and 145 ± 14 bpm on natural grass. Lovell et al. (2013) assessed semi-professional players again and recorded mean heart rate measures of 157 ± 10 to 161 ± 8 bmp (Table K.3). Azidin et al. (2015) assessed recreational players which, as a population, is closer related to the subjects tested in this study. The recreational players' heart rates varied from 160±16 to 166±13 bpm in the first 45 min, where measures were taken.

Table K.3. Heart rate data from match-play data in past literature (mean ± SD).

Study	Player level	Mean HR (bmp)					
		15	30	45	60	75	90
This study: Session 1	Recreational	122±14	140±16	149±10	139±8	142±10	143±10
This study: Session 2	Recreational	123±10	146±10	144±12	136±11	140±13	141±12
Azidin et al. (2015)	Recreational	160±16	164±13	166±13			
Lovell et al. (2008)	Semi-professional	165			167		
Lovell et al. (2013)	Semi-professional	161±8 157±10 157±10					
Nédélec et al. (2013)	Professional	151			145		

Note: SD = standard deviation; HR = heart rate; bpm = beats per minute.

Heart rate results from actual football games found in the past literature follow the heart rates seen in the past SAFT90 studies and are therefore higher than results obtained in this study (Table K.4). Heart rates obtained therefore do not follow the tendencies in past literature applying the SAFT90 protocol nor heart rate measures seen from real match-play assessments.

Table K.4. Heart rate data from 90 min match-play data in past literature.

Study	Level/Country	Mean Heart Rate (bpm)
Bangsbo (1994)	League/Denmark	159
Edwards and Clark (2006)	Semi-Professional/England	156
Mohr et al. (2004)	Division 4/ Denmark	162
Lovell et al. (2008)	Semi-Professional/England	162

Note: bpm = beats per minute.

Similar discrepancy trends to past literature were observed for mean RPE for each 15 min interval ranging from 10.9 ± 1.1 to 13.7 ± 1.3 referring to "fairly light" to "somewhat hard" on the scale. Only two studies have previously assessed players' RPE scores throughout the SAFT90 match simulation drill (Table K.5). Nédélec et al. (2013) applied the 10-grade scale and not 15-grade scale used in this study. The study found a change in RPE from 3.5 ± 1.0 to 4.4 ± 1.0 ($P < 0.01$) from start to 90th min SAFT90 drill for professional male players. A score of 3.5 is equivalent to 'fairly light' and 4.4 to 'somewhat strong/strong', which was similar scores to what was seen in this study. Azidin et al. (2015) , who assessed recreational players, found higher RPE scores in the 45 min assessed. These varied from 'somewhat hard'/'hard' to very hard. A strongly relationship has been proved between RPE and heart rate measures in the past literature (e.g. Crewe et al., 2008; Marcora et al., 2009; Presland et al., 2005), which was also shown in this study.

Table K.5. Borg scale RPE scores in current and past literature (mean ± SD).

Study	Player level	RPE 45 min					
		15	30	45	60	75	90
This study: Session 1	Recreational	11±1	12±1	12±1	13±1	13±1	14±1
This study: Session 2	Recreational	11±1	12±1	12±1	12±1	13±1	13±2
Azidin et al. (2015)	Recreational	14±2	16±1	17±1			
Nédélec et al. (2013)	Professional	3.5±1.0					4.4±1.0

Note: Nédélec et al. (2013) applied the 10-grade scale; all other studies applied the 15-point scale

In real match-play for professional players, RPE had been reported to increase throughout the game (Los Arcos et al., 2016; Rampinini et al., 2008; Table K.6). In all studies, the RPE finished with a perception of working hard (Table K.6).

Table K.6. Heart rate data from 90 min match-play data in past literature.

Study	Level/Country	Rated perceived exertion			
		< 20 min	20-45 min	45-70 min	>70 min
Los Arcos et al. (2016)	Professional/Spain	Easy to moderate	Moderate to hard	Hard	Hard
Rampinini et al. (2008)	Professional	Challenging		Hard	
Rampinini et al. (2011)	Professional/Italy	Hard			

K.5 Discussion

For the assessment of test-retest reliability heart rate measures demonstrated good to excellent ICC scores after 30 min of the drill, which matched players RPE scores demonstrating good to excellent ICC scores for any 15 min interval. This was also evident from the SRD detectable for heart rate, which dropped from 28-29% change in the first 30 min to 7-11% change in the remaining 60 min of the match simulation. Players' perceived exertion gave detectable SRD at changes in scores of 9.2-16.4% change over the entire 90 min match simulation. It therefore appears that with the intensity applied, a 30 min adaptation is needed to stabilise heart rate scores but scores obtained throughout the last 60 min are reliable.

Lower heart rate and RPE measures were obtained in comparison to match-play related scores and scores seen in previous studies applying the SAFT90 match simulation drill. The question arises why these discrepancies in heart rate and RPE scores from professional, semi-professional and recreational player scores from past literature and the recreational players testing appeared. The following section discusses potential causes to this issue. Setup error can impact work intensity but since four sessions were performed including a pilot test and no variance was seen between sessions then the setup error would have had to be constant. The leading test examiner had previously applied the SAFT90 protocol and was therefore familiar with the test setup. Players were tested in groups which resulted in a competitive environment where players put in the desired effort. Within the test, small breaks of 90-120 s were included for players to complete questionnaires. Past literature also included measures within these breaks, which eliminates these as the causative factor for the low heart rates (Azidin et al., 2015; Nédélec et al., 2013). Sessions were performed over winter in the UK with temperature (2-6˚ C). It was therefore questioned whether weather could impact results. Temperature has previously been shown to impact running performance (Haïda et al., 2013). But in controlled environment testing heart rate and time to exhaustion only shows to alter with extreme warm temperatures (31˚ in comparison to 4˚, 11˚ and 21˚; Galloway and Maughan, 1997). Validity of heart rate monitor data was not conducted but since heart rate scores, RPE scores and visual observations during the drill all indicated that players were not fatiguing or working hard then this is not believed to be the causative factor. It is, therefore, believed that heart rate measures and RPE scores represent the true fitness level of players. As fatigue is an expected component of the test setup then it can be argued that the protocol does not stress players to the desired level.

K.6 Key outcome

The SAFT90 demonstrated varying test-retest reliability of heart rate and RPE scores throughout the drill. Additionally, optimisation of the drill is needed to obtain desired heart rates to induce relevant player fatigue. Additional research has been performed (Appendix L) to assess the impact of stretching the SAFT90 drill length by 5% and 10% on heart rate and RPE.

APPENDIX L

Pilot Study – Adjustment of Intensity Induced by SAFT90 to Obtain Match Related Heart Rate Measures

L.1 Chapter Outline

As discussed in Appendix K, desired match-related intensity level as observed from heart rate (HR) data scores were not achieved when applying the traditional soccer-specific aerobic field test (SAFT90) setup. In this chapter modified SAFT90 protocols were therefore assessed to obtain match-related intensity measured as heart rate and player perceived exertion levels.

L.2 Aim

To validate a modified SAFT90 match simulation drill to match football specific HR scores and thereby ensure that match related intensity and thereby match related fatigue is achieved. A 15 min interval of the original 20 m long SAFT90 was assessed and compare with a 21 m and 22 m version. The chosen drill was then assessed for 45 min to ensure that appropriate and ecologically valid heart rates are achieved.

L.3 Methods

Five subjects were assessed. All subjects were therefore familiar with the drill. Three SAFT90 drills were prepared: one identical to the original setup ($SAFT90_{original}$; Lovell et al., 2008), one with the last cone place 21 m from the starting cones instead of 20 m ($SAFT90_{21\ m}$), and one with the last cone place 22 m from the starting cones ($SAFT90_{22\ m}$; Figure L.1). The subjects were randomly assigned the order of completion for the three drills. The drill was performed for 15 min during which HR recordings were performed (Polar Team Pro, Polar Electro, Kempele, Finland) and perceived exertion was rated by subjects on the Borg's rated perceived exertion (RPE) scale (Borg, 1970). A 20 min break was given to recover before performing the next SAFT90 intervention. For the chosen distance an additional 45 min case study assessment of HR was performed.

Analysis of data:

Raw heart rate data was extracted from the HR belts. Mean and maximum HRs were calculated for the total 15 min simulation and for 5 min sub-intervals and compared between $SAFT90_{original}$ and $SAFT90_{21\ m}$ and $SAFT90_{22\ m}$.

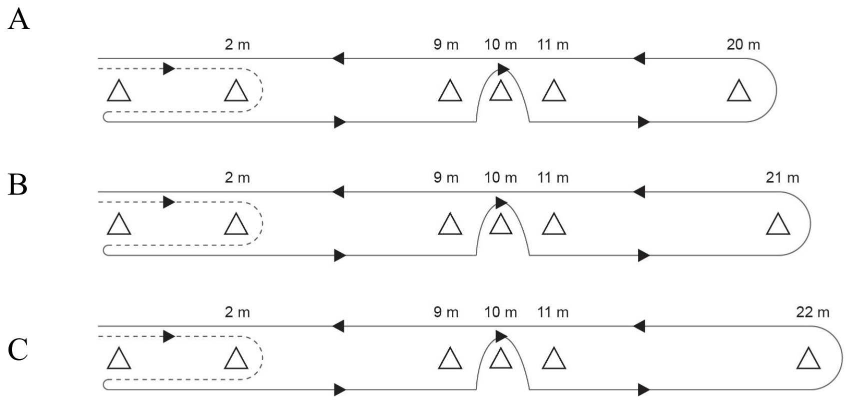


Figure L.1. Demonstration of alterations to the original SAFT90 setup based on Lovell et al., 2008. A: original SAFT90, B: modified 21 m SAFT90, C: modified 22 m SAFT90.

L.4 Results

Heart rate scores are shown in Figure L.2 for the total 15 min interval and split into 5 min intervals. Mean overall heart rate indicate similar scores for $SAFT90_{original}$ and $SAFT90_{21\ m}$ circuit ($SAFT90_{original}$ 136 ± 6 bpm; $SAFT90_{21\ m}$ 138 ± 8 bpm) whilst higher heart rates were seen for the $SAFT90_{22\ m}$ circuit ($SAFT90_{22\ m}$ 153 ± 16 bpm). Similar tendencies were seen for scores subdivided into 5 min time intervals (Figure L.2).

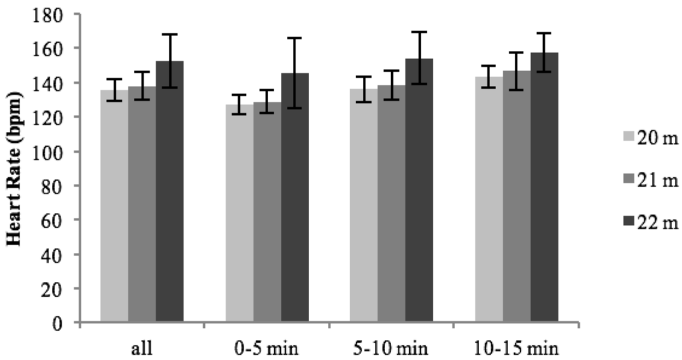


Figure L.2. Mean heart rate scores for 20, 21 and 22 m SAFT90 circuit.

RPE scores demonstrated no difference between sessions with mean scores of 11.5 ± 1.3 for $SAFT90_{original}$, 11.8 ± 1.5 for $SAFT90_{21\ m}$ and 11.5 ± 1.3 for $SAFT90_{22\ m}$.

For the extended 45 min $SAFT90_{22\ m}$ case study mean heart rates for each 15 min interval ranged between 162 and 168 bpm with maximum heart rates of 178-179 bpm and minimum heart rates of 112-151 bpm (Table L.1).

Table L.1. Mean, minimum and maximum heart rates for pilot subject completing 45 min of moderated SAFT90 22 m length.

	0-15 min	15-30 min	30-45 min
Mean (bpm)	162	168	167
Max (bpm)	178	179	179
Min (bpm)	112	139	151

bpm = beats per minute

LL.5 Key Outcome and Planned Changes

Data obtained at the conventional SAFT90$_{original}$ and SAFT90$_{21\ m}$ still demonstrated lower heart rate scores than seen in previous research. Extending the position of the last cone by 2 m gave a 17 bpm increased mean HR in comparison to the SAFT90$_{original}$. The mean score of 153 ± 16 bpm is more equivalent to data seen in the past literature (Table L.2) and is therefore preferred for future. Extending the assessment to 45 min offered slightly higher results for the SAFT90$_{22\ m}$ as showed by Lovell et al. (2008, 2013) and Azidin et al. (2015). Players were asked throughout the drill whether they felt that the intensity was similar to real match-play. All players agreed that the SAFT90$_{22\ m}$ felt more like match-play than the SAFT90$_{original}$ when asked after completion of the three SAFT90 length variations. The modified SAFT90$_{22\ m}$ was therefore selected for the main study to simulate intense match-play.

Table L.2. Heart rate data from match-play data in past literature.

Study	Player level	Mean HR (bmp)					
		15	30	45	60	75	90
New: SAFT90	***Recreational***	***136±6***					
New: SAFT90 21 m	***Recreational***	***138±8***					
New: SAFT90 22 m	***Recreational***	***153±16***					
New: SAFT90 22 m (case study)	***Recreational***	162	168	167			
Original Session 1	Recreational	122±14	140±16	149±10	139±8	142±10	143±10
Original Session 2	Recreational	123±10	146±10	144±12	136±11	140±13	141±12
Azidin et al. (2015)	Recreational	160±16	164±13	166±13			
Lovell et al. (2008)	Professional	165			167		
Lovell et al. (2013)	Professional	161±8 157±10 157±10					
Nédélec et al. (2013)	Professional	151			145		

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