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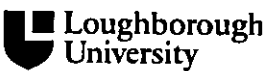
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MECHANICAL AND PERCEIVED BEHAVIOUR OF SYNTHETIC TURF FIELD HOCKEY PITCHES


By

COLIN YOUNG

A Doctoral Thesis Submitted in Partial Fulfilment of the Requirements for
the award of
Doctor of Philosophy of Loughborough University

1st January 2006

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ABSTRACT

This research has investigated the behaviour of synthetic turf pitches for field hockey. A combination of mechanical and perceived data collection methods were used to provide an increased understanding of pitch behaviour.

A methodology was developed to elicit perceptions from elite field hockey players. Part of the method was an inductive analysis of players responses during a participant led interview. This enabled the development of a 'structured relationship model' which illustrated five general dimensions. Each general dimension was part of a hierarchical structure formed from base themes via players responses.

Based on characteristics identified in the 'structured relationship model' a questionnaire was designed to quantify the importance and preferences of certain playing characteristics for elite field hockey players. It was found that players thought 'surface consistency' and 'the ability to demonstrate deft skills' as the most important surface characteristics. It was also identified that given a choice the majority of players would like to play on a fast, low bouncing surface conducive to deft stickwork with 'high' underfoot grip, no ball spin and with a moderate hardness.

Monitoring during the construction of a world class water-based synthetic turf hockey pitch has shown the influence each layer on the overall pitch system. Novel equipment to the sports industry was used to evaluate each layer during construction and a large amount of variability was identified across the pitch. It was identified that if the subgrade had a weak area of low stiffness then the subsequent layers above were also vulnerable to low measurements. This highlighted the importance of quality control during construction.

A laboratory investigation using a combination of shockpad and carpet samples identified the influence different systems had on the playing surface. During the investigation testing was conducted on the laboratory floor and in a prepared box constructed to simulate a 'typical' pitch. It was identified that the layers below the shockpad had little influence on the measurements. Conditions were monitored

and it was identified the importance water has on the behaviour of the surface. It was found to significantly reduce ball rebound height and rotational traction.

A series of site investigations using mechanical tests has shown the variability between pitches even at elite standard. Six pitches were evaluated and a range of results were obtained and compared with the requirements from the international governing body for field hockey. A correlation between the artificial athlete Berlin and 2.25 kg Clegg impact hammer demonstrated that the Clegg hammer could be a valuable tool for surface assessment.

A comparison of players' perceptions and the mechanical measurements of six pitches were evaluated. It was found that the perceived behaviour of ball rebound, underfoot traction and surface hardness correlated well with measured data. However, it was shown that players' perceptions of surface pace did not correspond to measurements of ball roll distance.

The three main sections of work comprising site data collection, laboratory testing and elicitation of players' perceptions have been used together to provide a much greater understanding of the behaviour of synthetic turf pitches for field hockey.

Keywords: *Synthetic turf pitch, Field hockey, Inductive analysis, Mechanical behaviour, Perceptions*

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INTRODUCTION

1.1 BACKGROUND

The majority of traditional sports were developed from participation on a natural outdoor environment using natural turf as a surface. The desire to make sports less dependent on external influences, shortage of space and the propensity to reduce operating and maintenance costs led to the development of man-made surfaces. However, these new surfaces had effects which were neither expected nor planned on both the participant and sport itself.

Field hockey was traditionally played on natural turf but since the inception of synthetic turf pitches the game has changed. The tactics of the game have altered significantly and ever since the first major international competition to use synthetic turf for field hockey, the 1976 Montreal Olympics, it has been used at international competitions.

The performance aspect of sports changed with the introduction of synthetic turf pitches including the magnitude and direction of forces acting on the human locomotor system. While these effects altered the way in which many sports are played some of the underlining scientific principles are still not fully understood. Although synthetic turf pitches have been around since the late 1960s and widespread since the early 1980s there is a real dearth in knowledge into how and what influence their behaviour. There are many manufactures of synthetic turf pitches all of whom make claims to the benefits of their particular surface. However, there is a lack of good quality public knowledge to support or refute these claims.

There is currently no systematic approach to elicit the perceptions of players to identify their requirements. Feedback provided by players could be a valuable tool in helping to improve design in the future.

Evaluation of pitches is restricted to a series of mechanical tests. The usefulness and efficacy of these tests is unclear. Factors including temperature, wind and rain can all have an influence on their measurements yet it is uncertain how much or even if the tests are appropriate.

1.2 AIMS AND OBJECTIVES OF THE RESEARCH

This research was run in conjunction with a steering group committee that aimed to enhance the playing quality and longevity of world-class pitches to provide the best facilities possible for English Hockey. Consultation within the steering group combined with a comprehensive review of literature identified the necessity to 'develop a more fundamental understanding of the mechanical and perceived behaviour of artificial turf pitches for field hockey'.

In order to achieve this overall aim a series of objectives were identified

- *Precisely define the performance requirements of the pitch and its constituent layers.*

To achieve an understanding of the requirements of the pitch and the role each layer has on the composite behaviour of the pitch a combination of laboratory and field based assessment was used. Monitoring each layer during the construction of a water-based pitch and the evaluation of a small scale pitch in the laboratory were used to improve understanding of the complex structure of synthetic turf pitches

- *Review the fundamental scientific principles of pitch behaviour and identify influences that control their measurement*

This objective was achieved primarily via an exhaustive review of the literature and a programme of controlled testing to supplement published knowledge. The multidisciplinary nature of this research project required information to be assembled from several fields of research including civil and sports engineering, biomechanics, sport science and sport medicine. Each discipline was comprehensively searched to discover the most current and relevant information. Controlled measurements were recorded on-site and in the laboratory to identify

factors that influenced pitch behaviour including construction specification and environmental effects

- *Devise and validate experimental methods to elicit perceptions from elite field hockey players and identify their performance requirements*

An extensive programme of qualitative and quantitative data collection techniques were used to fulfil this objective. Qualitative data was elicited via a series of interviews with elite field hockey players that identified pitch requirements and playing characteristics of importance. This was followed by two sets of questionnaires, the first to identify players preferences and the second to obtain specific feedback for six world class hockey pitches.

- *Evaluate pitch behaviour from a comprehensive programme of field and laboratory tests*

To achieve full understanding of pitch behaviour a comprehensive laboratory and field programme was developed. The laboratory investigation involved the construction of a 'typical' field hockey pitch and a parametric investigation was conducted to establish factors under controlled conditions. In the field work a series of pitches were evaluated using a combination of mechanical tests

- *Investigate the relationship between mechanical and perceived pitch behaviour.*

The evaluation of six world-class water-based field hockey pitches were assessed using mechanical test equipment and player feedback. Players perceptions were compared against results obtained from mechanical testing to establish a relationships.

Interaction between each section of work was required to enable the methodologies to be developed and provide a greater understanding of pitch behaviour. Figure 1.1 represents the transfer of data between each data collection method and how they relate to the overall influence of pitch behaviour.

1.3 THESIS STRUCTURE

Each chapter within the thesis is interlinked, and requires cross-referencing of data to enhance its full comprehension. A flow diagram was produced in Figure 1.2 to provide better understanding of how this was accomplished.

Chapter 1 provides an introduction to the thesis comprising an overview of the research topic and the importance of the findings. The aims and objectives are also included with a brief description of how each was achieved.

Chapter 2 contains a thorough review of the literature covering artificial sports surfaces this includes their history, design and construction. The interactions between the player and the surface and the ball and the surface are considered and methods used to evaluate synthetic turf pitches are reviewed.

Chapter 3 shows the development of the methodology used for the elicitation of players perceptions from a qualitative and quantitative approach. Furthermore, the methods used to obtain mechanical behaviour of artificial field hockey surfaces is presented.

Chapter 4 presents the findings from both the qualitative and quantitative analysis of player perceptions. Information on the inductive analysis of players responses is included.

Chapter 5 provides the results from the site and laboratory testing. Evaluation of pitch behaviour is made through the analysis of mechanical test equipment and factors that influence pitch behaviour are investigated.

Chapter 6 compares the results from perceived and mechanical pitch behaviour and discusses their significance.

Chapter 7 draws from the results of Chapters 4, 5 and 6 presenting conclusions on the research undertaken, and offers recommendations for future work.

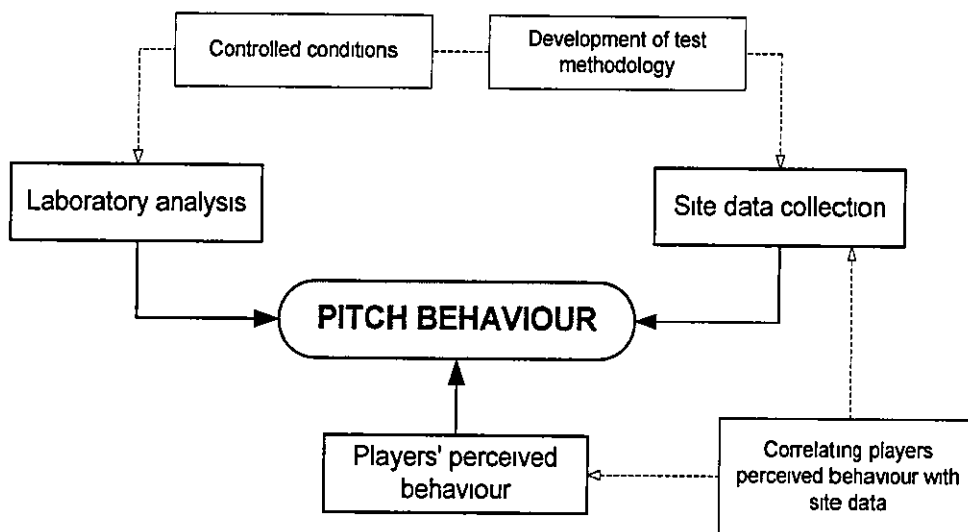


Figure 1.1 – Data transfer between site data, laboratory data collection and players perceived behaviour

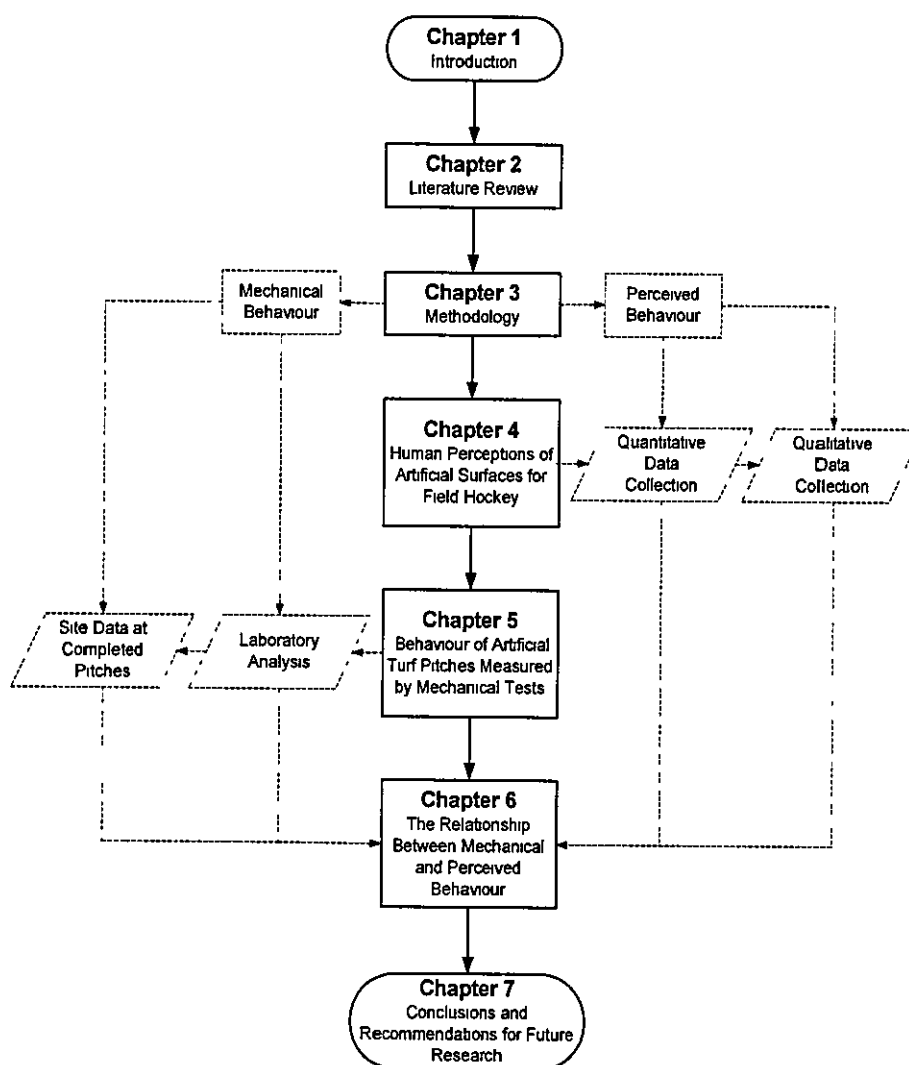


Figure 1 2 – A flow diagram to illustrate the interaction between thesis Chapters

CHAPTER 2

LITERATURE REVIEW

2.1 PREFACE

This Chapter presents a review of the literature covering outdoor synthetic turf pitches. The focus of this research is synthetic surfaces for field hockey. However, useful references have been derived from surfaces used for other sports due to a dearth of specific field hockey literature. Information determined from the other types of sports surface are considered appropriate as there are many similarities with their design, construction and usage.

The literature review has been arranged so that section 2.2 leads the reader through the history of artificial sports surfaces from their inception in the 1960s to the present day. This includes a discussion of their development, major innovations in design and for field hockey and how these surfaces have influenced the way the game is played.

The construction and constituent layers are outlined in section 2.3 and details of each layer are presented and discussed. Reference is made to the different types of materials, construction methods and how these influence the composite performance of the surface.

It is important to understand players' perceptions of sport surfaces. Methods used to elicit perceptions are discussed in section 2.4, several research approaches and data collection techniques are discussed and assessed for their suitability to elicit perceptions of field hockey players.

The interaction of the player and ball on the surface is presented in section 2.5. The response of the surface to these interactions has a significant influence on its performance and safety. An in-depth review of the literature is presented herein encompassing all factors that influence interactions with the surface. A critical evaluation of the current techniques used to assess sports surfaces is presented with a discussion of their suitability.

2.2 HISTORY OF SYNTHETIC TURF PITCHES

Outdoor sports surfaces can be split into two categories: natural and artificial. A natural surface is one formed by the suitable preparation of an area of land, which includes grass, ice, snow and loose mineral layers. An artificial surface is one constructed with materials which were prepared by human work, using synthetic or manufactured materials, which can include wooden boards, synthetic products or bituminous products (Nigg 1987). Within each of these groupings there are many sub-categories of surfaces which are used for a multitude of different sports.

The majority of outdoor sports evolved in environments using natural turf (Baker 1993) and this is certainly the case for field hockey. In recent times the desirability of using natural turf has been brought into question. Restrictions on available land, increasing participation in sport, the need to lessen external environmental influences and the desire to reduce operating and maintenance costs have led to alternatives becoming more widely used (Tipp and Watson, 1982). The most recent figures suggest that the UK has over 1000 outdoor synthetic turf pitches in use (Sport England, 2002).

As its name suggests 'field' hockey evolved on natural turf fields which in ideal conditions provides an excellent surface. Natural turf ensures an acceptable degree of player and ball interaction at the highest level of competition. Bartlett (1999) states that "natural turf is the ideal sports surface". Unfortunately playing sport on natural turf requires an intensive maintenance regime to ensure it retains its performance characteristics. If allowed enough recovery after each use, and if properly maintained, grass has a life-span that far exceeds any alternatives, as it is a living material with the ability to regenerate. However, the frequency of use is limited, otherwise wear damage can be considerable (Bartlett, 1999). Furthermore, when used in adverse weather conditions, such as heavy rain, grass is susceptible to damage and some conditions (freezing) can render it unplayable (Bell 1985; Baker 1989).

In the late 1970s there was a large demand for sports facilities which fuelled the growth in artificial alternatives (Tipp and Watson, 1982). Difficulties maintaining natural turf and a shortage of available space (especially for inner cities) further

amplified the demand for artificial surfaces. Many approaches were made in the search for an appropriate substitute for grass which could sustain a high level of use, required little maintenance, and yet still provided a suitable surface that offered desirable playing characteristics. The one development that has had the greatest impact was the use of plastics and rubber surfacing systems (Tipp and Watson, 1982).

Artificial alternatives have not been met with the same reaction in all sports e.g. soccer (Baker *et al.*, 1983) despite their practical and financial advantages (less maintenance). However, field hockey has completely adopted artificial surfaces to the extent that natural turf is no longer sanctioned for use at national or international competitions. Since the 1976 Montreal Olympics field hockey has used artificial surfaces for international competitions. This has filtered down to national and club level competitions to the extent that field hockey is rarely played on natural turf.

Today there are two main categories of synthetic turf used for field hockey, filled and unfilled. Filled surfaces, as their name suggests, are distinguished by a filling (normally sand) that is laced between the turf pile, these pitches are normally referred to as sand based (and more recently sand dressed). Unfilled surfaces have a denser pile and are irrigated with water before use, hence the name water based. Sand based pitches are more common and favoured by local governments and schools as they can be used for several sports and consequently are more cost effective. Water based pitches are less common as they are field hockey specific and not suitable for other sports. However, they are preferred by the international sports governing body for field hockey the Federation Internationale de Hockey (FIH) and specified as the only suitable surface for international competitions (FIH, 1999).

The first installation of an synthetic turf pitch (STP) is accredited to the Monsanto Company in the USA; it was designed and constructed with sponsorship from the Ford Foundation at Moses Brown School, Providence, Rhode Island in 1964 (Crawshaw, 1989; Tipp and Watson, 1982). The first mainstream installation was at the 'Astrodome' in Houston, Texas, in 1966. Artificial turf was considered because natural grass would not grow indoors under artificial lighting and survive heavy usage. With the success and versatility of this system it soon became prevalent in the USA for both indoor and outdoor use. The first artificial pitch was

installed in Britain in 1971 as a non-commercial football facility for Islington Borough Council, London. An STP was considered because of the durability/cost ratio and the limited availability of land (Crawshaw 1989). After this installation the introduction of STP's became widespread in the UK.

STP's have evolved over the past four decades since the first installation, which was a warp-knitted carpet with a polyamide pile and foam backing (Crawshaw 1989; Tipp and Watson, 1982). In the early 1980s sand was introduced into the pile (Knauf, 1995), followed by water in the mid 1990s and then a mix of sand and rubber granules at the turn of the century. Sand filled pitches quickly became popular in the late 1970s early 80s mainly due to lower costs (Tipp and Watson, 1982). Sand filled pitches, although popular, are often constructed as a compromise as they can be used for several sports (Crawshaw, 1989). While this is cost effective it can often lead to a trade off in surface performance as the requirements for different sports are often in conflict e.g. Tennis requires a resilient surface for ball rebound of between 40 – 60 %, whereas Field Hockey requires between 20 – 40 % rebound height (Bell *et al.*, 1985; Sports Council, 1978 and 1984). The compromise and conflict between performance requirements has led to the development of specific sports standards (e.g. ITF, 1997; FIH, 1999; FIFA, 2001; UEFA, 2002, IRB, 2004;) that a surface must achieve before it can be used for sanctioned competitions.

The most recent development in artificial turf is a long pile carpet. The carpet pile is longer than usual (in the region of 60 mm although there are many variations) and filled with rubber crumb (or sand and rubber crumb mix). This type of surface system is commonly known as 3rd generation or 3G (SAPCA, 2001) and is normally used for soccer and rugby. The FIH states that 3G pitches are not suited to field hockey (FIH, 2005). They claim the carpet pile is not as dense as traditional carpets and that the relatively small diameter of the ball (compared to soccer) makes it sink further down into the pile. Consequently, there is much more frictional drag on the ball which restricts its movement. Furthermore, they suggest the same principle applies to the hockey stick making deft stick work difficult and sometime resulting in 'lifting' (when the stick gets under the ball) which is a major safety concern in field hockey. It should be noted that the FIH have not (to date) supplied or published any experimental evidence to support these claims.

Since their introduction in the 1970s the number of artificial sports pitches have in the UK has increased rapidly. Current estimations suggest there are approximately 1000 STP's in the UK (Sport England, 2002), of which the majority are sand based and used for multi-sports. With regard to field hockey, it is believed that there exists 35 water-based pitches in the England.

2.3 CONSTITUENT LAYERS

The pitch system comprises many layers and Figure 2.1 shows a typical construction for a water-based hockey pitch. From the bottom-up the layers are consolidated soil (or compacted fill), often the natural soil found on site; a geosynthetic layer (to prevent the migration of particles between layers), two layers of crushed broken stone (normally a compacted graded aggregate), two layers of asphalt (a hot-rolled blend of aggregate and stiff bitumen binder); a shock absorbing layer often termed shockpad; and the carpet layer. Variations on this design are not uncommon. The dimensions illustrated in Figure 2.1 are taken from the design specifications of the Loughborough University water-based pitch

The synthetic turf and shockpad (occasionally) layers are the only prefabricated part of the system, the other layers being formed from their constituent parts insitu. The compacted fill (often the natural soils found at the site), the sub-base, and the asphalt layers form the pitch foundation. The foundation needs to provide a stable platform for construction vehicles, provide through pitch drainage, and remain very flat for its design life of 25 years or more. The shockpad and synthetic carpet form the surface system and together provide the player-surface and ball-surface characteristics. The shockpad can be formed from recycled shredded rubber particles bound together on site and laid with a similar method to the asphalt (termed an insitu shockpad), although it can be provided in the form of a foam layer as part of the carpet backing (termed an integral shockpad).

2.3.1 Subgrade

The pitch structure must reduce the stresses (and hence strain) transmitted to the subgrade to a level that ensures that there is only very limited deformation at the end of the design life. The magnitude of stresses transmitted to the subgrade at formation level is influenced by the elastic stiffness of the subgrade and the layers above. The stiffness controls the strains developed. The most common way to measure the strength and stiffness of subgrade in highway engineering is

by the California Bearing Ratio (CBR) (Barnes, 2000) From the CBR (in percentage) it is possible to estimate the elastic stiffness by using the following formula (Powell *et al* , 1984)

$$E = 17.6(CBR)^{0.64} \text{ MPa}$$

equation 2 1

Subgrade construction is typically achieved by removal of the topsoil. A cut and/or fill process occurs which uses earth taken from nearby embankments to reach the required pitch level which is monitored by a laser level. A minimum number of passes by a vibrating roller is required to compact the fill which improves the surface strength. Finally, drainage channels are dug diagonally across the pitch (often with a slight fall) and perforated pipes laid into them, which are then filled with gravel and compacted.

2.3.2 Sub-base

The sub-base is a structurally significant layer comprising of compacted high quality well-graded granular material. Once placed, it provides a working platform on which the surfacing materials can be transported, laid and compacted. It also acts as a regulating course and insulates the subgrade against the action of frost (Powell *et al.*, 1984). Compaction should create good particle packing and interlocking to give a high density, high strength and high stiffness layer. However, to allow rapid drainage the sub-base is often specified on the coarser side of the grading envelope (i.e. a particle distribution with a bias towards coarse stone), which affects the achievable density and hence strength/stiffness. The thickness of the sub-base required is usually derived from the subgrade CBR. A layer of coarse aggregate is placed above the subgrade, which is spread by an excavator whilst a process of grading and rolling occurs to achieve a level surface to the required thickness. A second layer of finer aggregates is then laid onto the coarse stone. This layer is often thinner than the first but more care is taken to achieve the required thickness and level tolerance of the pitch to then accept the asphalt.

2.3.3 Asphalt Layer

The asphalt layer provides a stiff and strong uniform layer consisting of aggregates bonded together with a (bitumen) binder. The aggregate grading, consistency of grading, binder type, binder content and mix temperature can all

influence its quality. The asphalt is usually installed in two layers: firstly the base course (typically 40 mm thick) which provides a stable, well-shaped flat platform on which to allow good compaction of the wearing course (typically 25 mm thick). The build quality and grading of the asphalt can improve the longevity of a pitch through improved compaction and drainage (SAPCA, 1999). The porosity of the layer is vital to ensure the rate of drainage specified by the FIH is achievable.

There is a strong similarity between the design and construction of an STP base structure and a thinly surfaced road. Thus, the principles of highway engineering and analysis can be applied to determine the influence of changes in design relatively simply. However, highway engineers have guidelines with respect to the 'failure' criteria for the road so that designs can be made safe and structural assessment data (e.g. for maintenance) can be benchmarked. The most important principle in highway engineering is that of limiting elastic strains in the materials to below acceptable limit(s) to avoid accumulation of damaging plastic strains from the repeated traffic loads. The strains caused by loading of the road surface are estimated from simple analytical models, and the layer thickness (and stiffness) adjusted to meet the limiting strain criteria. In addition, the deflection of the road structure as a whole, under a controlled load, can be used to identify its structural capacity to carry heavier and more frequent loads in the future. The strain and deflection criteria were developed partly from back-analysis of field measurements and many years of observation of long-term road trials.

2.3.4 Shock Absorbing Layer

A wide variety of cushion underlays or shockpads have been offered for use with synthetic turf systems. The three main types of shockpad currently available are cast in-situ, prefabricated and integral (to the carpet). The shockpad provides resilience, reduces injuries from falls, and helps provide the required playing characteristics (Tipp and Watson, 1982, Dixon, 1999, Brown, 1987). To be effective, the properties of the shockpad must not only be correctly chosen, but also be retained over the range of temperatures and other climatic extremes in which it is to be used and throughout its service life (Tipp and Watson, 1982). There is a significant dearth of recent information relating to shockpads; many manufacturers are unwilling to supply information on their products but freely make claims as to their performance which are impossible to substantiate.

In the UK the most common type of shock absorbing layer are insitu shockpads. These are made on site from a combination of elastomeric binder and rubber crumb (normally from recycled vehicle tyres). The mix design, thickness and compaction determine its characteristics. Advantages of insitu construction include the seamless layer, freedom of mix type and layer thickness. Problems with this type of shockpad are quality control which can include material inconsistencies, mix ratio and achieving the desired thickness.

Prefabricated and integral shockpads are expected to be more consistent than insitu pads as they are manufactured in a controlled factory environment. Prefabricated pads are rolled out on site and often adhesively bonded to the base foundation. However, over time, seams can part and create gaps or ridges on the surface. They are available from manufactures in a variety of profiles but they have limitations on thickness unlike insitu pads. Integral shockpads are generally made from a closed cell foam neoprene and like prefabricated pads should be less liable to inconsistencies. They are integral to the carpet which means they can't move and cause gaps or ridges under it like prefabricated pads but if a gap originates between carpet seams then that means a gap in the shockpad also. Furthermore, integral pads can become expensive, as they are required to be replaced at the same time as the carpet which generally has a shorter life span than the shockpad. However, without a whole life cost analysis the relative merits of each system is impossible to ascertain.

2.3.5 Synthetic Turf Layer

Synthetic fibres or ribbons are woven or knitted into a backing fabric (strands interweave) or tufted into previously made backing fabric. The pile strands are secured to the backing by a rubber latex binder to provide flexibility and dimensional stability and, for tufted products, structural integrity (Bartlett, 1999). Although used for a variety of sports there is no agreement on the size and shape of the pile for optimum playing characteristics nor on sand, rubber or water filling and other important aspects (Bartlett, 1999). Agreement will be unlikely due to the different performance requirements for each sport which has led to the development of sport specific surfaces i.e. water based for field hockey and 3G for soccer as two examples recent examples. Once more, published information about products is difficult to obtain, manufactures produce datasheets with information on pile weight, density, and several other empirical measurements. However, this information does not give any insight as to how the carpet will play.

or what influence it will have on certain playing requirements. Product approval schemes run by various sports governing bodies give a brief insight into carpet behaviour and is discussed later in section 2.5.

There are a number of fibre polymers used for synthetic turf, which can vary in structure depending on desired properties. The polymers used at present are all constructed from organic chemicals, with various combinations of carbon, hydrogen, oxygen and nitrogen (Tipp and Watson, 1988). Different combinations of these chemicals can influence polymer behaviour; at present the most commonly used polymers are Nylon, Polypropylene and Polyethylene. Polymer engineering can be used to manufacture many different specifications of each material. For example Nylon-6 and Nylon-6-6 have quite different properties, the melting point of Nylon-6 is 40°C less than Nylon-6-6, it has a lower tensile strength and glass transition temperature which makes it more compliant but less able to withstand heavy usage than Nylon-6-6.

Polymers are susceptible to damage from a variety of sources. It is therefore often necessary to introduce additives, plasticizers and stabilisers during the manufacturing process to reduce potential damage and/or degradation. Ultra-violet radiation from the sun, air pollution (e.g. acid rain), soilage from dirt and wear from user traffic can all contribute to the premature ageing of the turf (Brown 1987).

2.4 PERCEIVED BEHAVIOUR OF SYNTHETIC TURF PITCHES

Nigg and Yeadon (1987) suggest sports surfaces can be assessed with respect to technical specification, sport functional properties, safety consideration, and cost factors. However, players' requirements should be considered when developing and testing a playing surface, to ensure it meets their needs. In general, current sports surfaces are designed and built based on the experience of what has worked well in the past. However, new products are emerging in the market, and many make great claims for their improved playability properties. Players need to be comfortable and confident with the sport surface they play on i.e. it should be safe, consistent and allow them to perform and maximise their skills during a game. A better understanding of the surface's playing characteristics, and their importance to the players, will aid both design and

assessment of the sports surfaces in use and help develop surfaces for the future.

Currently in the UK each pitch is constructed on a site-specific basis and to the requirements of the user/operator, although all the pitches, when new, must pass a series of (mainly) mechanical playing performance related tests (see section 2.5.3). However, many of the pitches key components can vary in design and be further affected by construction techniques. Feedback from users and general anecdotal evidence suggests that hockey pitches differ in the way they play and 'feel' during play. There is little objectively measured information to substantiate these claims and no way of utilising player feedback in the design of further pitches in any systematic way. There is a lack of published peer reviewed data regarding the design and performance of artificial sport surfaces, and as a result a difficulty in validating designs, innovating materials, and determining the efficacy of claims made by the manufacturers about their products. Also, there is little to support mechanical tests as being suitable to what players perceive, and consequently their relevance.

To date no published literature exists that assesses perceptions objectively for the playing surface for any sport. Several approaches have been used to elicit users' perceptions of sports equipment for golf (Hocknell *et al.*, 1996, Roberts *et al.*, 2001). For field hockey the playing surface is considered a vital factor in the outcome of a game. Therefore, obtaining information to understand how players perceive it is crucial to understand if it meets their requirements. Social scientists have developed many methods to elicit perceptions depending on the type of information required, various different approaches are outlined below.

2.4.1 Quantitative and Qualitative Approaches

Quantitative methods use standardised measures that fit diverse opinions and experiences into predetermined response categories. The advantage of this approach is that it measures the reactions of a large number of people to a limited set of questions, thus facilitating comparison and statistical analysis of the data (Patton, 1987). On the other hand, qualitative methods permit investigation of selected issues in depth and detail; the fact that data collection is not restricted by predetermined categories of analysis contributes to the depth and detail of qualitative data (Patton, 1987). Consequently, qualitative data consists of

detailed descriptions and direct quotations, whilst quantitative data is represented in a form to allow statistical analysis. Obtaining each type of data requires different formats of questions and responses. Qualitative data is obtained via open-ended questions which allow the participant to respond in his/her own words and phrases, whilst quantitative data is acquired from fixed or scaled response questions (often via a questionnaire)

In order to understand the characteristics that contribute to a players' perception of a surface, a suitable research technique is required to analyse each component. Perceptions can be defined as 'our conscious interpretations of the external world created by the brain from a pattern of nerve impulses delivered to it from sensory receptors (Sherwood, 2001). However, the interpretation of sensory stimuli differs between individuals, who may not perceive the same sensory inputs in the same way (Roberts *et al.*, 2001). Therefore, to develop a meaningful understanding of the perceptions, feelings, thoughts and knowledge of a player, a suitable research methodology is essential. In the field of sports psychology, qualitative techniques have been used to elicit players' perceptions for evaluation and subsequent analysis. A number of previous studies employed qualitative techniques to obtain and analyse descriptive data. For example, Scanlan *et al.* (1989a, 1989b) designed a method which enabled the acquisition and structuring of qualitative data on sources of enjoyment and stress for elite figure skaters. Semi-structured in-depth interviews were used with open-ended questions to collect data from a sample of skating coaches. The data was structured using an inductive analysis to assist the emergence of significant components via a process known as clustering. Scanlan *et al.* (1989b, p 68) defined clustering as 'comparing and contrasting each quote with other quotes and emergent themes to unite quotes with similar meanings and to separate quotes with different meanings' This process is then repeated with the emergent themes grouped together generating higher-level themes until it is not possible to locate any further underlying data uniformities (Scanlan *et al.*, 1989b). Other studies have used similar methods to elicit information from Olympic wrestlers (Gould *et al.*, 1992), swimmers (Hanton and Jones, 1999) and golfers (Roberts *et al.*, 2001; Roberts 2002) However, none of these past studies elicited information regarding a playing surface or medium and all were individual sports as opposed to a team sport like field hockey

2.4.2 Data Collection Techniques

The two most common methods for eliciting data are the interview and the questionnaire. The relative advantages and disadvantages of the two techniques are summarised in Table 2.1.

An interview can provide greater opportunities for probing. the interview can use follow-up questions to seek clarification or elaboration (Roberts, 2002). This enables the interviewer to change the content and direction of the interview to explore an unexpected response, vary the sequence or rephrase questions that cause confusion. However, interviews vary in their level of structure and a fixed interview is merely a series of predetermined questions with less control.

Questionnaires generally do not provide the freedom of interviews but they are quick to perform, reduce the risk of interviewer effects and enable a large sample of people to be targeted for quantitative data analysis (Bryman, 2001) The disadvantages include potential errors in the design which can lead to respondents misinterpreting the questions, poor response rate and reduced freedom of expression

2.5 MECHANICAL BEHAVIOUR OF SYNTHETIC TURF PITCHES

Sports pitches are complex structures with several layers, all of which contribute to their composite behaviour (Bartlett, 1999) Therefore, the mechanical response of the surface to interactions from players, balls, maintenance and sports equipment are difficult to assess. Impacts involving sports objects, such as a ball or the player and the surface, can affect the technique and tactics of a sports performer and the way in which the game is played. Understanding interactions of this nature and identifying factors that can influence and control their performance is essential to comprehend the mechanical behaviour of the sports surface.

Many terms are used to describe sports surfaces. Below are examples of the most common terms with a brief definition and example of their meaning to help the reader clarify their use in the remainder of this chapter.

The 'compliance' of a sports surface relates to the deformation under load It is believed that some sports surfaces have an optimal value of compliance for

optimal performance (Bartlett, 1997; Nigg 1990 & 1993) Concrete and asphalt are examples of low compliance and a foam crash mat would be considered to be a highly compliant surface. It is important that a surface is not too compliant as this is tiring to run on (Bartlett, 1999).

Resilience is a measure of the energy absorbed by the surface that is then returned to the object. It is defined as the amount of mechanical energy after impact compared to the mechanical energy before impact (Nigg and Yeadon, 1987). It relates to the viscoelastic behaviour of most surfaces for sport, where the viscous stresses are dissipated, and not returned to the striking object (Bartlett, 1999). Resilience has no particular relationship with stiffness. Stiffness is defined as the ratio of applied force to deflection (Nm); usually it is not a constant, but varies with the rate of application of the force (Nigg and Yeadon, 1987). Compliance is often connected with resilience but the two qualities have no specific connection (Nigg and Yeadon, 1987). For example, a trampoline has a high compliance and high resilience, and concrete has a low compliance and high resilience.

Hardness is closely related to compliance, i.e. hard surfaces tend to be stiff and soft ones compliant. Bell *et al.*, (1985) stated that the terms are often interchangeable. In engineering terms, hardness (N/m^2) is a measure of the yield stress of a material and is related to plastic (or permanent) strain or deformation (Dixon *et al.*, 1998). However, stiffness (N/m) is a measure of the deformation under the application of load and primarily related to Young's modulus.

2.5.1 Player/Surface Interactions

For movement to occur, an athlete needs to produce a force against the ground. In reaction to this the ground exerts an equal and opposite force causing movement. This is Newton's third law of motion, the law of interaction, which states that for every action exerted by one object on a second, there is an equal and opposite reaction exerted by the second object on the first. There are many mechanisms that constitute player/surface interactions including footwear (Nigg, 1995), movement type (Dixon *et al.*, 1998), velocity (Munro *et al.*, 1987) and the ground itself (Frederick, 1986).

2.5.1.1 Impact Forces

In sport, more than one external force usually acts on the performer (Bartlett, 1997). In such a case, the effect produced by the combination of the forces will depend on their magnitude and relative directions. Figure 2.2 illustrates the effects of the surroundings on the runner, which are weight (G) and ground reaction force (F) which is a combination for the F_t (tangential or horizontal) and F_n (normal or vertical). The resultant of F and G will be the net force acting on the athlete. Newton's second law of linear motion states that the net force equals mass x acceleration (m a) or:

$$F + G = ma \quad \text{equation 2.2}$$

Figure 2.2 illustrates the resultant force acting on the athlete. This force does not act through the centre of mass, hence a translation moment of force causes the athlete to move (Bartlett, 1997).

Newton's second law of motion can be expressed mathematically as:

$$F = \frac{dp}{dt} = \frac{d(mv)}{dt} \quad \text{equation 2.3}$$

That is, F, the net external force acting on the body, equals the rate of change (d/dt) of the momentum (p or mv). Therefore, equation 2.3 can be rewritten for an object of constant mass as:

$$F = \frac{dp}{dt} = m \frac{dv}{dt} = ma \quad \text{equation 2.4}$$

This illustrates the relationship that force is mass (m) times acceleration (a). These two equations can be rearranged, by multiplying by dt, and integrated to give (Bartlett, 1997).

$$\int F dt = \int d(mv) (= m \int dv) \quad \text{equation 2.5}$$

The left side of this equation is the impulse of the force and is equal to the change of momentum of the object/athlete (Bartlett, 1997) The change in

horizontal velocity of a runner depends on the impulse of force exerted by the runner on the ground (from Newton's second law) and is inversely proportional to the mass of the runner. In turn, the impulse of the force exerted by the ground on the runner is equal in magnitude but opposite in direction to that exerted, in muscular action, by the runner on the ground (Newton's third law).

Using Newton's second law McMahon and Greene (1979) derived the following equation to determine average vertical force (\bar{F}) for a typical step of a runner:

$$\bar{F} = m_m g + 2m_m v / t_c \quad \text{equation 2.6}$$

Where,

m_m = mass of the runner (kg)

g = gravity (ms^{-2})

v = velocity (vertical) at moment of contact (ms^{-1})

t_c = foot contact time (seconds)

They found that this theoretical prediction agreed well with subject tests using a force platform. However, this equation predicted the average force applied during the entire contact.

2.5.1.2 Ground Reaction Force

The resultant force acting between an athlete and the ground during locomotion is known as the ground reaction force and can be measured using a force plate (Dixon *et al.*, 1998; Nigg, 1983). Figure 2.3 illustrates a typical ground reaction force time history for 'heel-toe running'. This first peak corresponds to the impact force (Fredrick, 1981) and is caused by the initial impact of the heel on the ground. Authors have used different terms for this force including high frequency force (Nigg, 1983), initial force (Cavanagh, 1980) and passive force (Clarke, 1983). Impact forces are defined as forces which reach their maximum magnitude earlier than 50ms after first contact with the ground (Nigg and Yeadon, 1987). They are characterised by high loading rates and have been associated with the occurrence of overuse injuries such as stress fractures, tendonitis and damage to articular cartilage (Cavanagh, 1990; Dixon *et al.*, 1998; Nigg and Bahlsen, 1988). The second peak, often termed active peak, occurs during

the push-off phase. It is defined by Nigg and Yeadon (1987) as the active forces which reach their maximum magnitude later than 50ms after first contact with the environment. Active forces are characterised by a lower rate of loading than impact forces and consequently have not been associated with the occurrence of injury (Dixon *et al.*, 1998).

Different patterns of running were identified using a force platform by Cavanagh and LaFortune (1980). They classified runners into rearfoot, midfoot or forefoot strikers, depending on which region of the foot experienced the initial contact. However, few attempts have been made to assess different movement patterns during sports activities (Adrian & Xu, 1990).

The level of cushioning provided by a surface has been described as the effectiveness of the surface to reduce the magnitude of the impact peak (Nigg *et al.*, 1995). It is generally assumed that a non-compliant material will provide less cushioning than a relatively compliant material (Dixon *et al.*, 1998). Figure 2.4 highlights the differences between a compliant and non-compliant surface and how they influence the vertical forces acting on a runner. Footwear worn by the athlete can significantly influence ground reaction force (Nigg, 1986; Shorten, 2000) and is discussed below.

It has been suggested that sports people can make kinematic adaptations to compensate for inadequate cushioning provided by the shoe and surface (Dixon *et al.*, 1998). Frederick (1986) found that the magnitude of impact ground reaction force is maintained at consistent levels when running on surfaces of different stiffness due to subjective kinematic adjustments. Herzog (1978, cited by Nigg and Yeadon, 1987) showed that for running barefoot on grass compared with asphalt that foot sole angle decreased at a faster rate and that changes in knee flexion angle and angular velocity changed for stiffer surfaces, and this was reinforced by Dixon *et al.*, (1999). Other studies have found similar influences on heel impact velocity (Wojcieszak *et al.*, 1997, Dixon *et al.*, 1999) and front foot pronation (Stergiou and Bates, 1997). It has been suggested that these minor kinematic modification over-stress the muscles as they are required to work harder and can lead to injury (Nigg, 1993).

Munro *et al.*, (1987), showed that for running velocities between 3 and 5ms⁻¹ the average vertical ground reaction force, loading rate and peak impact force all

increase with running velocity and that foot contact time decreased Nigg *et al.*, 1987 also found that an increase in running speed from 3 to 6ms⁻¹ magnified vertical ground reaction force from twice to three times body weight. Larger vertical impact forces have been recorded with force platforms for sport specific movements Nigg *et al.*, (1981) found athletes produced 8.3 times body weight on long jump take-off at an 8.0 ms⁻¹ approach velocity, 9.1 times body weight for foot strike in the delivery of a javelin throw (Deporte and Van Gheluwe, 1988) and up to 12.3 times body weight for front foot strike in the delivery stride for a cricket fast bowler (Mason *et al.*, 1989). High force impacts of this nature have the potential to cause injury, especially if repeated many times (Elliott *et al.*, 1992) These data are for vertical impacts only; what is currently unclear is the horizontal and lateral components and their respective magnitudes.

Adrian and Xu (1990) identified 10 movement patterns typical for field hockey including veering, cutting, dodging and lunging. They recorded the vertical and horizontal force components for each of the ten movements. The horizontal force component is considered by some researchers to be less significant in relation to injuries. However, during certain sport specific movements the horizontal component will have an increased magnitude and consequently, importance Adrian and Xu (1990) do not specify the velocity of the athlete during the various movement patterns but state that they were typical of a field hockey player. Furthermore, the force plate was located on a rigid surface very different from a typical field hockey surface. They found that the highest forces for medial/lateral and backward/ forward shearing to be approximately $\frac{2}{3}$ body weight ($\approx 500\text{N}$) compared with 3 times body weight ($\approx 2400\text{N}$) for the vertical component. It is clear that more research is required to approximate the forces for field hockey movements under typical playing conditions. The majority of ground reaction force data are for running not sport specific movements which will give different forces.

2.5.1.3 Frictional Forces

In hockey the player who is able to stop, accelerate, or change direction quicker than their opponent will have an advantage (Barry, 2000). The surface contact force acting on an athlete can be resolved into two components (Figure 2.5): one normal to (F_n) and one tangential to (F_t) the surface (Bartlett, 1997). F_t is the frictional (or traction) force. Traction is the term used when the force is generated by interlocking of the contacting objects (Bartlett, 1997), such as studded shoes

penetrating a grass surface and is known as form locking. In friction, the force is generated by force locking (Stucke *et al*, 1984 in Frederick) Acceleration in the horizontal direction is not possible without frictional resistant forces (Nigg and Yeadon, 1987)

If an object (shoe) was placed on an inclined plane, Figure 2.5 illustrates the forces that would act upon it. If the shoe is not moving, these forces are in equilibrium. Resolving the weight of the shoe (G) along and normal to the inclined plane the magnitudes of the components are equal to F_t and F_n .

$$F_t = G \sin \theta; F_n = G \cos \theta \quad \text{equation 2.7}$$

and, by dividing F_t by F_n :

$$F_t / F_n = \tan \theta \quad \text{equation 2.8}$$

Increasing the inclination angle of the plane (θ) will result in the frictional force becoming unable to resist movement of the shoe and it will begin to slide down the slope (Bartlett, 1997). The ratio of F_t/F_n when this occurs is known as the coefficient of static friction. If one of the two surfaces is moving relative to the other then the frictional forces acting between them is commonly known as the coefficient of kinetic friction.

The coefficient of friction is assumed to be independent of contact area and weight (Nigg and Yeadon, 1987; Dixon *et al.*, 1998; Bartlett, 1997). Conversely, it has been suggested that traction is influenced by contact area and load between the two surfaces (Dixon *et al.*, 1998) as can be expressed by the following equation.

$$\mu_r = \frac{3T}{2WR} \quad \text{equation 2.9}$$

where:

μ_r = coefficient of traction

T = applied torque

W = weight (applied load)

R = contact radius

Brown (1987) described how, for sports shoe/surface interactions, the classic laws of friction are not obeyed. Nigg (1990) supported this claim, by demonstrating that the translational friction coefficient can be significantly influenced by changes in the normal force. However, little is known of the fundamental mechanisms that effect friction in this field, particularly when considering the complex biomechanics of the athlete, their footwear and multi-layered pitch system. What is understood better are the effects of friction.

It is important to get a balance between ensuring friction is high enough to facilitate control for the athlete for optimal acceleration and changes in direction (Dixon *et al.*, 1999) and keeping friction low enough to prevent damage and injury to the athlete (Nigg and Yeadon, 1987) When artificial turf was first used there were few attempts to recommend upper and lower limits of friction (Canaway, 1986). However, with recent concerns over injuries and performance criteria many sports governing bodies (FIH, 1999; FIFA 2001; UEFA 2002; IRB 2002) have begun to recommend limits of acceptability, which will be discussed further in section 2.5.3 These limits depend on the movements required for the specific sports, for example, a large coefficient of friction is required to permit quick changes in velocity (large acceleration), essential for sprinting. However, sliding movements when turning are often desirable in games such as field hockey and soccer (Dixon *et al.*, 1999). The development of water based pitches in field hockey has added an additional factor that can influence friction, water. The lubrication of the carpet reduces friction between the pile fibres and the players footwear which can often result in slipping and sliding (Bartlett, 1997). There have been no studies however, that determine the precise influence of water on the surface and how this affect friction.

Mechanical tests have been developed to quantify both translational and rotational friction characteristics (BS 7044, 1990; Brown, 1987, Kolitzus, 1984). Resistance to sliding is a common method used for measuring translational friction, whilst quantifying the torque requirement is used to measure rotational friction. These methods and others will be discussed further in section 2.5.4

2.5.1.4 Footwear

An important contributing factor to athletic performance is the mechanical energy transferred between the athlete's foot, shoe and surface. Baround *et al.*, (1999b) found that certain combinations of shoes and surfaces produced significantly greater energy return (measured using a force platform) to the athlete's foot, which indicated that specific shoes may give an advantage on certain surfaces.

A great variety of shock absorbing materials have been incorporated into the cushioning systems of modern running shoes. These include foamed polymers, viscoelastic materials, air, gases, gels and molded springs (Shorten 2000). Materials are generally selected on the basis of their shock attenuation, energy absorption, weight and durability. Shorten (2000) suggested that although cushioning materials vary considerably, the principles of cushioning are common to all of them. The addition of a layer of compliant material between the foot and the ground distributes impact forces, both temporally (reducing peak forces) and spatially (reducing peak pressures).

Figure 2.6 compares the results of laboratory based impact testing of soft and firm cushioning systems (Shorten, 2000). The force-time curve of the two impacts illustrates the basic mechanics of cushioning. The more compliant shoe undergoes greater deformation when impacted, increasing the duration of the impact. The decelerating impulse is thus applied over a longer period of time. This redistribution of the impact force results in lower peak forces and the peak rate of force increase is also lower. Other literature (Clarke *et al.*, 1983a, 1983b, Dickinson *et al.*, 1985; Snel *et al.*, 1985) has shown that for running speeds between 4.0 and 4.5 ms⁻¹ that the relative degree of shoe hardness is related to increased loading rates (i.e. the harder the sole, the higher the loading rate). However, Nigg and Bahlisen (1988) found that shoes with the hardest midsoles showed the lowest maximal vertical loading rate whereas softer midsoles were associated with the highest rates. Nigg (1986) postulates that it is not only the nature of the shoe that determines the characteristics of impact forces but also the technique of running. He states as an example that impact forces will be reduced as the knee becomes more flexed at touchdown.

To ascertain the influence of footwear several studies have conducted research with participant running barefoot. However, it is difficult to collect comparable data on barefoot running while maintaining a heel-contact pattern, given the fact

that few individuals are accustomed to running barefoot (Miller, 1990). However, limited data have shown that impact peaks are higher when running barefoot than wearing shoes (Dickinson *et al.*, 1985; Snel *et al.*, 1985). It would therefore seem logical to assume that the magnitude of the impact peak for heel strikers would be in some way related to heel cushioning and shock-absorption properties of the shoe (Miller, 1990).

Segesser and Nigg (1993), identified two additional movements typical for most ball games: rotations and sideways movements. Shoes for these types of movements should not only provide attenuation of the impact forces but maintain foot stability, provide adequate friction-traction at the shoe-surface interface, provide foot stability and comfort for the wearer (Cavanaugh, 1980; Frederick, 1986; Nigg, 1986a). The outer sole material and tread configuration can affect shock attenuation, traction and friction. The degree of freedom for movement in the shoe-surface interface is a crucial factor in many sports. Abrupt changes in velocity, acceleration, deceleration, direction and twisting are common for many sports. Insufficient rotational freedom between the shoe and the surface is a common cause of injury as the foot remains fixed to the ground and the body rotates (Moore and Frank, 1994). Conversely, footwear with inadequate grip can cause loss of balance and a decline in the performer's ability to change direction.

Modern footwear is designed for the specific sport with field hockey no exception. Walker (1996) hypothesized that hockey players' footwear has the potential to reduce injury occurrence. He found special-purpose 'astro-shoes' lacked any cushioning system in favour of a close array of small studs and the lack of a shock absorbing mid-sole significantly increased impact forces. He suggested the rudimentary use of a cushioning system to reduce peak force to an acceptable level and highlighted the importance of choosing the correct footwear. Players who find the extra grip of a multi-stud sole essential to perform effectively should select a model with an in-built cushioning system (Walker, 1996).

2.5.1.5 Injury Incidence

The occurrence of injury during sports can be attributed to many factors. The combined effect of increased leisure time and health benefits of exercise have resulted in a rapid increase of sports participation over recent years (Dixon *et al.*, 1999). This trend has been accompanied by an increased incidence of sports injuries, costing the UK in excess of £500 million each year based on early 1990s

figures (Nicholl, 1993) Andreasson *et al.*, (1983); Clement *et al.*, (1984); James *et al.*, (1978) all claimed that both the type and frequency of sports injury occurrence have been influenced by the introduction of artificial sports surfaces. However, Dixon *et al.*, (1999) claim there is a lack of good science to demonstrate a clear relationship between surface characteristics and specific injuries. Several past studies conclude that there is an increased incidence in both overuse and accidental injuries when participating in sports on artificial surfaces (McCarthy, 1989; Torg, 1973). However, all of these studies are over 15 years old. There is a lack of good quality recent research to identify the effect of artificial surfaces and due to the rapid development of such surfaces this research is well overdue. A twenty year study by a leading manufacturer (Astro-turf, 1996) of artificial sports surfaces found that there were no significant injury differences between artificial and natural grass surfaces. However, this study was performed on American football players whose injury occurrence rate is influenced not only by the surface but through impacts between players.

Abraham (1990) claimed that although more injuries were caused on synthetic turf their severity was much less than typical natural turf injuries. Furthermore, artificial surfaces are believed to increase the speed at which games are played. This has been implicated as a possible cause for increased accidental injuries owing to player collisions (Dixon *et al.*, 1999; McCarthy, 1989; Borrie, 1992). There is a reported increase in the incidence of bruises and grazes for players participating on synthetic turf, which has been linked to the increased stiffness and friction coefficient often associated with synthetic surfaces (McCarthy, 1989; Nigg, 1988) This may be the case for sand based systems but has not been proven for water based pitches and research is required to determine their influence on injury.

Murtaugh (2001) published an epidemiological study on the injury patterns among female field hockey players. This research did not categorise injuries to surface effects but analysis of the data suggests that the incidence of lower limb injuries could be related to the playing surface. They found that 39.7 % of all injuries were sprains to ligaments in the knee and ankle. However, caution should be taken when relating these findings to surface influences to avoid misinterpretation of the data. However, it does highlight the need for clinical research in this area.

Head impacts with the surface carries the risk of severe injury (Shorten and Himmelsbach, 2002), consequently the shock attenuation properties are very important. An understanding of the impact conditions and material behaviour is required to recognise the shock attenuating properties of sports surfaces. For this reason several studies have developed models to predict surface behaviour.

2.5.1.6 Modelling Player-Surface Interactions

Modelling is defined as the attempt to represent reality (e.g. Nigg, 1999). When modelling the interaction of a player and the surface it is important to consider the influence of the elastic and viscous properties of the soft tissue heel pads, shoes and/or playing surface on the energy demands during locomotion (Anton and Nigg, 1990 & 1995). These three materials are used to cushion the landing of the heel during running.

McMahon and Greene (1979) showed how the use of a simple dynamic model (2 mass, 2 spring), see Figure 2.7, could be used to inform the design of running tracks (indoor). This paper demonstrated that muscles and reflexes (assuming they have an automatic, or reactive, component) can be represented as damped linear springs. Using their model they derived ground contact time, step length, foot force and running speed as a function of track compliance and found that it related well with subject tests. They discovered very compliant tracks resulted in a reduction of running speed by 0.70 times that of a hard surface. By comparison a track with intermediate compliance had a slight speed enhancement, due to a decrease in foot contact time and an increase in stride length in contrast with a hard surface.

Nigg and Anton (1995) proposed the use of a model to determine the effect of changes in stiffness and viscosity of the foot-ground interface on the work performed during locomotion. They developed a mathematical two-segment model (Figure 2.8), representing the foot and the rest of the body. They argued that the total mechanical energy content in a system composed exclusively of masses and springs remains constant over time (with only the relative amount of kinetic and potential energy altering), consequently the question of how much work is performed in such a system is meaningless, and therefore a spring-mass system was not suitable for their research. They claim their model shows a good comparison with experimentally determined ground reaction forces in shape as

well as in magnitude. However, limiting assumptions were made of the model such as landing and take-off speed being the same.

Baround *et al* (1999), used a finite element approach to provide an insight into the mechanical energy stored and returned for a sports surface during player interactions. It was found that the energy lost was very small in comparison to the energy input and approximately 98-99% energy was returned. Furthermore it was found that approximately 85% was returned in the vertical direction. This increased the centre of mass of the athlete and therefore stride length, thus, enabling the athlete to run at the same speed with less energy demand or increase speed when using the same energy expenditure. Nigg and Segesser, (1992) suggested that energy returned from a sports surface to an athlete can only be effective when returned at the right location at the right time and with the right frequency. Baround *et al.*, (1999) suggested it should be returned during the second half of ground contact and that energy return during the impact phase could be detrimental to performance by having an 'untimely' effect on the athlete's muscle activity. Nigg (1997) states that a muscle must be active to minimise vibrations due to such high frequency energy inputs. The advantages of Baround *et al*, (1999) finite element approach was that it enabled the use of actual loading conditions and could be adopted to measure complex movement patterns. Furthermore, consideration was given to the different layers of the sports surface rather than assuming it rigid.

Due to the complex nature of human locomotion many models focus only on one particular movement, the standard heel-toe-strike. While this identifies the key components involved in the interaction it is not typical of many sporting movements. More detailed models are required to investigate the influences of complex movement patterns and different foot striking patterns, which will in turn enable a greater understanding of the reaction of the ground (and sports performer) to different loads and rates of loading. Material models have used a simple linear vertical spring however future work needs to consider non-linear and horizontal components if these factors are to be better understood.

2.5.2 Ball/Surface Interactions

Interactions involving the ball and the surface influence how the sportsperson will perform. For example, if spin is imparted on a ball it will affect how it rolls across and rebounds from the surface, which both influence how the ball is next played

by the performer. The surface resilience can have a significant influence on the ball's behaviour during play. The behaviour of the ball after impact with the surface depends on a number of factors including the nature of the impact, the relative momentum of the ball before impact and the energy losses during impact (Bartlett, 1999).

2.5.2.1 Coefficient of Restitution and Direct Impacts

During the initial part of the impact, both the ball and surface will deform to some extent, although the amount of deformation may differ considerably between the two, and the greater the deformation the longer the impact lasts. The energy returned, stored in the surface and returned to the ball is reliant on the type of deformation. If perfectly elastic, all of the energy will be returned to the ball or if totally plastic, none is regained and the energy is lost as heat e.g. a ball embedding itself into the ground (Bartlett, 1999). Deformation can occur in the ball and/or the surface and is related to their stiffness.

The restoration of a deformed ball and surface to their original shape is a result of elasticity (Hay, 1993). Elasticity differs from one object to another. Some return quickly to their original shape while others do so much less quickly. There is no direct method to measure the elasticity of an object, therefore it is necessary to rely on experiments to help predict the outcome of impacts (Hay, 1993), or the use of an indirect method such as high speed video analysis. Newton investigated the properties of elastic bodies and formulated the following empirical law (Newton's law of impact)

"If two bodies move towards each other along the same straight line, the difference between their velocities immediately after impact bears a constant relationship to the difference between their velocities at the moment of impact".

In algebraic terms,

$$v_1 - v_2 = -e(u_1 - u_2) \text{ or } \frac{v_1 - v_2}{u_1 - u_2} = -e \quad \text{equation 2.10}$$

where:

e = coefficient of restitution (COR)

v_1 & v_2 = velocities immediately after impact of objects 1 and 2, respectively

u_1 & u_2 = velocities immediately before impact.

This law indicates that how two bodies move after impact depends on how they were moving prior to impact and on the coefficient e . If we assume object 2 is the ground and therefore has a velocity of zero (for practical purposes) both before and after impact then the equation for e.g. a ball bounce is reduced to (Hay, 1993):

$$e = \frac{v_1}{u_1} \quad \text{equation 2.11}$$

The coefficient of restitution depends on the materials and construction of the colliding objects. Daish (1972) showed that resilience, or rebound resilience, is the square of the coefficient of restitution between the ball and surface ($R = e^2$). The FIH specify a value of between 0.1m and 0.25m from a vertical drop height of 1.5m for 'global' standard pitches (discussed in section 2.5.3). This equates to a rebound resilience of approximately 0.07 and 0.17. Resilience is sometimes represented as a percentage (Bell *et al*, 1985) i.e. a ball drop from 1.5m that rebound 0.5m would be expressed as 33%. However, in most sports it is very unusual for a ball to drop vertically onto the ground (Bartlett, 1997).

2.5.2.2 Oblique Impacts

Oblique impacts are far more common in sports than direct impacts. They involve an object (the ball) striking the ground at an angle other than 90°. The velocity and angle prior to impact affects the velocity and angle after impact (see figure 2.9a). However, there are several other factors which can influence the velocity and angle after impact. These include the compliance of, and friction between, the ball and surface and the spin/rotation of the ball (Daish, 1972; Hay, 1993, Bartlett, 1999).

Illustrated in Figure 2.9b are the velocity changes of a ball during an oblique impact. The velocity of the ball during contact with the ground is represented by the vector u and its horizontal and vertical components by u_H and u_V . To simplify the impact it is assumed the ball and surface are perfectly smooth i.e. there are no forces that can alter the horizontal forces acting on the ball,

therefore, $u_H = v_H$. However, the vertical velocity alters for both its direction and magnitude as a result of the impact (Hay, 1993). Firstly, the ground causes the ball to reverse its direction of vertical motion. Then the elasticity of the ball and surface modify the magnitude of the vertical velocity, as in equation 2.11, which can be adapted to:

$$v_V = -e u_V \quad \text{equation 2.12}$$

The composite effect of the horizontal and vertical velocities can be determined and its direction compared with that of the resultant velocity before impact. Normally the angle before and after impact is specified from the perpendicular line at the point of contact (Bartlett, 1999), as shown in Figure 2.9b. The angle before impact is known as the incidence and after contact is called the reflection (Hay, 1993). Daish (1972) demonstrated the influence of rotation on the angle of reflection. Simply, forward rotation (top spin) will lower the angle of reflection and increase velocity, while backwards rotation (back spin) will increase the angle of reflection and decrease velocity. The angular velocity (rad/s) and amount of friction between the ball and surface alters the magnitude of this effect.

Carre and co-workers (1999) suggested that pitch deformation had a major effect on the rebound angle after impact. They found that the angle of reflection when measured using an angled ball cannon was higher than existing models predicted (on a natural turf cricket wicket), which they suggested was a result of the ball making a depression (permanent deformation) on the surface during impact. It is unclear how the deformation of the surface and ball will influence the rebound behaviour in field hockey, or indeed the influence of the carpet pile, sand and water infill. Furthermore, it is unclear if the ball slides during impact and how much influence friction has on rebound behaviour.

2.5.2.3 Frictional Resistance

Frictional resistance occurs not only for sliding and impacts but also when one object rolls along another, this 'rolling resistance' is considerably less than the resistance to sliding. It is, however, important in ball sports and ideally will be consistent across the surface. Roll resistance is defined as the force acting at the point of contact between the ball and surface whose direction is opposite to that of the motion and thus causes deceleration of the ball as it moves across the

surface (Bell 1993). Friction between the ball and the surface is responsible for variations in speed, direction and rate of rotation (Bell *et al.*, 1985). The type of surface can dramatically influence friction. Differences in carpet pile height, density and stiffness all contribute to the ball's behaviour (Bartlett, 1997). Baker (1989), states that if the friction between a ball and the surface is too great, then the ball will not roll the required distance, however, if it is too low then the ball will continue to roll for an undesirable amount of time/distance. In field hockey the role water has on the carpet pile will significantly influence friction between the ball and surface.

Consider a ball of mass M is at rest on a horizontal surface. This ball is dealt a horizontal blow at its central point A . This initiates rolling across the surface with a velocity of V , see Figure 2 9c. A frictional force F acts at point O . If the coefficient of friction between ball and surface is μ , the value of this frictional force will be given by (Daish, 1974):

$$F = \mu Mg \quad \text{equation 2.13}$$

This frictional force will have two consequences; it will produce a linear deceleration of the ball, and a moment about C will produce an angular acceleration and by Newton's laws,

$$\text{Linear deceleration} = \frac{F}{M} = \mu g \quad \text{equation 2.14}$$

$$\text{Angular acceleration} = \frac{\text{torque}}{\text{inertia}} = \frac{Fr}{I} \quad \text{equation 2 15}$$

Where r is the radius of the ball

The ball will continue to slide across the surface until the linear velocity has been reduced and the angular velocity has increased to the point where rolling occurs. For smooth rolling there can be no skidding between the ball and surface, therefore, a balance between the forward velocity and rate of rotation at the point of contact with the surface is required for pure rolling (Daish, 1974).

2.5.3 Hockey Pitch Performance Standards

In order to implement an international standard of STPs for field hockey the FIH produced a list of requirements to which all pitches must conform if they are to be used at a certain level of competition. These are summarised in Table 2.2. The standards are presented in the 'handbook of performance requirements and test procedures for synthetic hockey pitches – outdoor' (1999). The objectives of the standards are to ensure that all field hockey competitions are played on pitches which:

- Provide a proper reflection of relative team merit
- Allow all players to display and develop their hockey skills
- Offer comfort and limit risk to players
- Extend playability in adverse weather conditions

The handbook has three tiers of standards for different levels of ability/competition: global, standard and starter. Global standard is the most stringent and is compulsory for international competitions, for which only unfilled water-based systems are approved. The lower standards allow pitches to be built with wider limits of acceptability for the development of the game and for cost efficiency reasons especially in schools and developing countries.

Several other sports have adopted the use of performance guidelines including Soccer, Tennis and Rugby. Furthermore, many countries have their own performance criteria for multi-sport surfaces including the UK (BS 7044), Germany (DIN 18035), USA (ASTM F355-86) and several others. In Europe there is a move towards normalisation of these standards to comply with EN and ISO requirements (currently in draft format). Many of the sports governing body standards are related to performance within each specific sport and often have a product certification or registration programme for approval. Laboratory and field based tests are required to satisfy the requirements of the FIH involving product approval in the laboratory and build quality in the field. The FIH enforce their licensing scheme for sanctioned events to ensure field hockey is played on surfaces that behave similar worldwide.

Many of the tests are similar from sport to sport with only slight differences in requirements based on the nature of the game. Table 2.2 summarises the

requirements of the surface standards for field hockey, rugby and various soccer governing bodies. Due to the nature of each sport they have different levels of acceptability for the various tests. In particular, the requirement for impact response for hockey (30 – 65 %) is less than rugby (60 – 75 %) and soccer (>55 %). The tests are discussed in the following section (2.5.4). To complement the playing performance standards, the FIH stipulates surface tests for slope, smoothness, watering, drainage/porosity, colour, lighting and many others that help categorise a pitch but are not directly related to playing performance.

FIH accreditation tests have a large degree of acceptability between the range of requirements. This facilitates many pitches to pass, even at the more stringent 'global' standard. There is a lack of any good quality peer reviewed research on pitch accreditation. The majority of testing is performed by in-house test laboratories and the acquired data remains unpublished.

The following section provides a critical review of the numerous tests used for the assessment of artificial sports surface. Specific attention is given to tests used for the accreditation of synthetic field hockey surfaces.

2.5.4 Mechanical Test Methods

Various methods have been developed to test sports surfaces (for example see: Bell *et al.*, 1985, Kolitzus, 1984; Tipp and Watson, 1982). A review of the biomechanical methods is provided by Nigg and Yeadon (1987) and Dixon *et al.*, (1999). Test methods can be classified either subject led or material based. Subject led tests usually include measuring ground reaction forces (Nigg and Yeadon, 1987), and they have the advantage of taking into account possible interactions between surface and subject (i.e. accurate and realistic representation of in-game movements) but have the disadvantage of not being very reliable (Nigg and Yeadon, 1987) or repeatable. Consequently, material tests, which are deemed to be highly reliable and repeatable (Nigg and Yeadon, 1987; Dixon *et al.*, 1998) are commonly used by many sports governing bodies to assess the suitability of artificial surfaces (including the FIH). Many types of material tests have been developed to 'simulate' in-game situations. The following section provides a discourse of the leading test methods.

2.5.4.1 Vertical Player/Surface Assessment

Player/surface assessment can be split into two main categories: vertical and horizontal behaviour. Vertical behaviour involves measuring the surface for its ability to reduce loads on the human locomotion system and horizontal behaviour to determine the frictional forces imparted by the surface on the participant. The most commonly used tool for assessing vertical behaviour are drop tests and of these the most widely used are the 'artificial athletes' (Kolitzus, 1984). The artificial athlete Stuttgart consists of a 50 kg mass which falls onto a soft spring (50 kNm^{-1}) from a height of 30mm. It has two measuring devices which are located above the test sample, consisting of a load cell (0 – 2000 N) and a displacement cell ($\pm 10 \text{ mm}$). Typically, it has a contact of around 100 – 200 ms (refer to Figure 2.3) which corresponds to the contact time of a foot with the ground in many sports activities (Nigg and Yeadon, 1987). The 'Artificial Athlete Berlin' (see Figure 2.10) is a modified version of the Stuttgart and was developed to simulate forces with a shorter contact time (in the impact force range approximately 50 ms). The Berlin is currently used by the FIH as a measure of impact response and consists of a much stiffer spring (2000 kNm^{-1}). Table 2.2 summarises the two artificial athletes (from Kolitzus, 1972 and 1984).

The peak impact force is measured, and surface cushioning (force reduction) is presented as the percentage reduction compared with a rigid (normally concrete) surface

$$\text{Force Reduction} = (F_c - F_i) / F_c \quad \text{equation 2.16}$$

Where:

F_c = maximum force measured on concrete

F_i = maximum force measured on surface i

A typical force on concrete is 6700 N (Harrison, 1999) and the FIH specify an expectable range for field hockey of between 40 – 65 % (approximately 2700 - 4400 N). A comparison of the requirements for other sports are discussed in section 2.5.3. Although the artificial athlete Berlin reproduces a characteristic force/time history for initial ground impacts in heel-toe running, it has been indicated that this procedure may not be appropriate for simulating athlete interaction with a surface (Dixon *et al.*, 1998a). It has been shown in subject led

studies that ground reaction force does not correlate well to surface stiffness (force reduction) (Dixon *et al.*, 1998b, Feehery, 1986; Kaelin *et al.*, 1985; Nigg and Yeadon, 1987). In addition to these two standardised drop tests there are several other similar instruments that vary in drop height, spring system and drop weight.

Another method frequently used to assess mechanical properties of sports surfaces and which simulates the possible load on an athlete's body, is a drop test (Nigg and Yeadon, 1987). A cylindrical missile or sphere of a known mass is dropped onto the surface with a mounted accelerometer that records the force/time history of the contact. However, there efficacy has been identified by some researches. Nigg (1990) showed that with two different drop weights, the ranking of sports surfaces was not consistent, showing the inherent inconsistencies in drop weight testing. This highlighted the non-linear nature of the material load-deflection characteristics and finite thickness of sports surfaces (Walker, 1996). A sports surface with high shock absorbing characteristics may, at high levels of loading 'bottom out'. That is, the impact will deform the shock absorbing material to its limit resulting in large forces being transmitted to the athlete (Walker, 1998).

Drop tests differ from the artificial athlete tests in that they are free-falling direct impacts with the surface and not dampened via a buffer. They have been used to assess the potential of a surface to return energy (Bowers *et al.*, 1974; Nigg *et al.*, 1978; Frederick *et al.*, 1980). The typical results from these drop tests give values of energy return between 40% and 70% (Baround, 1999) However, the drop tests used to determine mechanical energy return of sports surface have several limitations; firstly, the peak impact force from material tests showed little correlation with the impact force peaks during running with test subjects (Nigg *et al.*, 1987); secondly, contact times during drop tests are much shorter than contact times during locomotion (Kolitzus, 1984; Nigg *et al.*, 1984). Energy loss is dependent on time. Thus, tests with substantially different contact times should be expected to deliver inappropriate results (Baround *et al.*, 1999).

The assessment of energy loss is a useful tool to understand the affect of viscoelastic surfaces that tend to give different results for single and repeated impacts. Figure 2.11 illustrates the energy loss as the area enclosed by the hysteresis loop for a force-deformation curve. The area under the curve signifies

energy and is calculated via integration. The difference in total energy between load and unload represents the energy lost during impact. The viscoelastic properties of sports surfaces are not clearly understood but typical field hockey surfaces are known to be both load and rate dependent

Nigg and Yeadon (1987) illustrated how impact forces, deceleration and surface deformation measured using a mechanical drop test can be influenced by the mass and shape of the impacting device. Furthermore, Junqua *et al.*, (1983) showed that the spring in the artificial athlete tests makes it impossible to separate the effect of the spring and surface on the measured peak force. In summary, results from drop tests don't accurately reflect the interaction between a human and the surface (Dixon *et al.*, 1999). There is a distinct difference between material tests and subject tests. Results from material tests often cannot be related to results in situations where actual movements are performed by subjects (Nigg and Yeadon, 1987). Past subject tests have indicated that changes in playing surfaces can produce changes in movement patterns of athletes. Nigg and Yeadon (1987) suggest that to understand the performance aspects of a surface material tests need to be complemented with subject tests. However, mechanical tests are a useful tool to standardise surface categorisation and with an absence of any suitable alternatives. Simple mechanical tests afford control and can rank/index surfaces although they may not be linked to performance, although arguably they could be validated with players' perception.

The compliance of the sports surface materials are typically quantified by the measurement of surface deformation under the controlled application of a constant load (Dixon *et al.*, 1999). The artificial athlete Stuttgart, previously outlined, measures the deformation of the surface but other methods include the Shore A, which provides a measure of the resistance to permanent deformation and is a commonly used measure of material hardness. However, Denoth (1983) concluded that as large reaction forces may occur, which deform the material substantially, do not provide meaningful information.

2.5.4.2 Horizontal Player/Surface Assessment

Horizontal behaviour of sports surfaces can be split into two types: translational and rotational friction. Mechanical test methods have been developed to quantify both (Kolitzus, 1984; Bell *et al.*, 1985; Brown, 1987). Translational friction is typically assessed by measuring the resistance to sliding, whilst rotational friction

is calculated by quantifying the torque required for rotational movement on the surface (Dixon *et al.*, 1999). As highlighted earlier in this section an appropriate horizontal reaction force between the surface and subject is essential for efficient locomotion.

The most common method used to determine translational friction is the swinging pendulum (Bell *et al.*, 1985). The British transport and road research laboratory developed a portable skid resistance tester (BS 7044 part 2.2). This test is comprised of a small rubber 'foot' attached to the end of a pendulum, which is released from a horizontal position to slide over the sports surface. The mechanical energy lost during contact with the surface relates to the frictional coefficient and is determined using the maximum height attained by the foot after contact with the surface. A modified version of this tester has been developed for field hockey, known as the modified Leroux, (which uses a slightly different configuration and studded foot specimen, see Figure 2.12 a and b). A second method exists to determine translation friction. It consists of a weighted shoe being placed on and then dragged across a surface (Schlaepfer *et al.*, 1983, Denoth, 1978; Nigg and Denoth, 1980). This test has the advantage of using a 'real' shoe (i.e. a representative shape/contact area) rather than a very small rubber foot. Neither test is considered suitable to represent 'real' human locomotion as the normal forces and strain rates involved are much lower than players generate. However, they are deemed useful to index pitches (Dixon *et al.*, 1999).

Rotational friction is derived by applying a torque on a weighted test foot from a stationary position, with the maximum resistance to rotational movement measured. The contacting test foot is covered with a specific material (or studded) which is typical for the sporting application of the surface. Bell (1981) and Canaway (1983, 1985) used a studded test foot for natural turf soccer pitches.

The force required to initiate disc movement is the static coefficient and to sustain movement, the dynamic coefficient. Previous studies (Schlaepfer *et al.*, 1983; van Gheluwe *et al.*, 1983; Valiant, 1987 & 1990) have shown that rotational friction is influenced by the surface materials, normal force, speed of movement, contact area and structural nature of the two materials. Therefore, when designing a test for frictional characteristics, it is important to consider all of the above in the

context of the range of situations that will be experienced during sporting movements (Cole *et al.*, 2003). Needless to say, the rotational disc system and pendulum testers do not meet all of these requirements.

In the early 1970s during the widespread inception of STPs several studies took place to determine/identify a relationship between the frictional properties of artificial turf, injuries and performance. (Garrick & La Vigne, 1972; Torg *et al.*, 1973, 1974; Stanitski *et al.*, 1974; Bowers & Martin, 1975; Bonstingl *et al.*, 1975). The age of these studies limit their usefulness in today's climate as the development of both surfaces and footwear has been considerable. However, in general they found water reduced the frictional and traction coefficients, the stud configuration had a significant influence on both also, and natural grass gave lower coefficients than most artificial equivalents.

Cole and co-workers (2003) have developed a method using a Stewart Platform (a six-legged parallel robot) that is capable of developing forces in directions and speeds similar to human locomotion. Load cells are used to record the force acting on the shoe/surface interface. Entire shoes can be used by fixing them onto a prosthetic foot and synthetic surfaces can be fixed to the platform to give a large variation of shoe/surface interfaces. Initial findings have shown the test to be repeatable and to overcome the traditional problems associated with mechanical testing (i.e. test the range of actual sports movements). It also overcomes the main disadvantages of subject testing, i.e. that subject testing can only show the frictional requirements for a specific movement and not the maximum friction of the surface, which is important because excessive friction has been related to injury (Nigg and Segesser, 1988). While this equipment appears to overcome the conventional problems of subject and mechanical testing, it is the only one in the world and can only be used in the lab not onsite.

2.5.4.3 Ball/Surface Assessment

Interactions between the ball and the surface are typically measured in three ways: ball rebound resilience, rolling resistance and friction/spin characteristics. The way in which the ball interacts with the surface is of utmost importance for ball sports including field hockey (Borrie, 1992). The playing surface should be non-directional (i.e. have the same properties in all directions) and behave predictably. Differences between field hockey surfaces including, pile height, pile

density, shockpad specifications and environmental conditions can all influence the behaviour of the ball on the surface,

Vertical rebound resilience is measured using a simple technique. A ball is released from a known height and the maximum rebound height is measured. For example, a ball dropped from a height of 1 m which rebounds 0.4 m has a rebound resilience of 0.4 (sometimes expressed as a percentage). This is a very simple measure of surface resilience that can be influenced by several factors including but not exclusive to: pitch construction, pile height, pile material, pile density, surface moisture, fill material, ball properties and environmental conditions such as wind and temperature. The test is not representative of what happens in game situations as the height, velocity, angle of impact and ball rotation do not correspond to typical values during a game. To combat this, tennis, cricket and, more recently, soccer and rugby have developed tests to measure oblique impacts at high velocities which improve simulation of game conditions. These tests use a angled firing cannon to fire a ball against the surface that can closely simulate typical ball velocities, spin and angle of impact. Measurements are taken before and after impact. Carre *et al*, (2002) identified large differences for natural grass courts, and that clay courts gave the slowest and steepest rebounds of all commonly used tennis court systems. Carre *et al*, (1998) also found that the moisture content and bulk density of natural cricket pitches had a significant effect on their rebound behaviour. To the author's knowledge there is no published data for field hockey pitches.

Rolling resistance is measured for sports where ball roll is important, e.g. golf, bowls, soccer and field hockey (Bell *et al*, 1985). The test consists of measuring the distance a ball rolls from an inclined plane or the velocity change once the ball is rolling (Baker, 1990). The rolling resistance is often referred to as the 'speed' of the surface. There is no published data for field hockey, which makes it difficult to ascertain the carpet's influence on ball roll distance. However, Bartlett (1997) states that moisture has more of an effect than pile height. This is reinforced by Langvad (1968) who found that on a natural turf soccer pitch grass height reduced ball roll from 13 m (20 mm mow height) to 11 m (40 mm mow height) while a wet pitch reduced roll distance from 13 m (dry) to 10 m (wet). Dury & Dury (1983) also found that on a cricket pitch outfield a cricket ball rolled 14 m dry and 10 m when damp. There is no recent published values of ball roll and none at all for field hockey

The ball behaviour during games remains unclear for field hockey. There is no published data of in game analysis of ball velocities, roll distances, rebound heights or angles. Consequently, the FIH uses the simplified tests which afford control and can rank/index surfaces but are maybe not linked to performance.

2.5.4.4 Test Methods During Construction

The quality and longevity of STPs is significantly influenced by the design specification, material type, build quality, usage and maintenance. When designing a pitch it is important to consider its 'buildability' and operational life span. Construction may involve a few high magnitude loads during compaction and laying of the bound and unbound layers. Construction and maintenance vehicles are often overlooked when designing a pitch but the rate and magnitude of their loads may be significant factors regarding its structural integrity. The common base construction of a pitch can be expected to last more than 25 years (resurfacing approximately every 7-10 years for the carpet and/or shockpad). There are strong similarities between the design and construction of an STP base and a thinly surfaced road.

Besides the performance tests outlined in the previous section new pitches are assessed during construction primarily by flatness and permeability/drainage testing. However, these observations may not establish if the asphalt is of sufficient stiffness, the correct thickness or if the sub-base is still competent in terms of the thickness or stiffness/strength. It is considered that the stiffness of the asphalt layer(s) is likely to influence the overall stiffness behaviour of the finished pitch, the degree depending upon the type of surface system. It is thus important that the combined effect of the upper layers of the pitch are carefully designed to provide the right playing quality and safety performance (Fleming *et al* , 2002).

There appears to be little previous published research into the design and playing quality of different sport surfaces, and importantly the structural competence of the constituent layers, the influences on their behaviour and changes over their life (Fleming *et al* , 2002). Testing on the finished carpet surface is common, but there is a need for simple quality assurance tests on all the constructed layers to better demonstrate good build quality and consistent performance. Fleming and colleagues (2002) suggested that strength and stiffness measurements of the

layers during construction has the potential to improve both the means of monitoring uniformity and overall quality of the insitu behaviour.

In highway engineering there are several devices that are used for field assessment, known as portable dynamic plate tests (Fleming and Rogers, 1995). These devices deliver a transient load pulse through a bearing plate, effected by a manually lifted weight falling onto a rubber buffer. The deflection of the ground under the plate is measured using a velocity transducer. An example is shown in Figure 2.13 of the Prima from Denmark. The drop height and bearing plate diameter are adjustable to deliver a controllable contact pressure. The depth of stress pulse is a function of the plate diameter, with a relationship of approximately depth = 1.5 × diameter (Fleming *et al.*, 2002b). The load pulse duration is controlled by the rubber buffer arrangement, which damps the impact to produce a transient load pulse of typically 25 milliseconds duration. Many tests can be completed in a few hours, and the data are recorded automatically for each drop including values of load, pressure, pulse time and deflection. The test is interpreted as an elastic modulus (often termed the 'stiffness' as it may not be truly elastic), using the principles of elastic theory by the equation:

$$E = \frac{A.P.r.(1-\nu^2)}{d} \quad \text{equation 2.17}$$

where,

A = plate rigidity factor ($\pi/2$ for a rigid plate)

P = applied pressure (kPa)

r = plate radius (m)

ν = Poisson's ratio

d = deflection (mm)

Dynamic plate devices have been extensively used for assessing unbound granular materials, stabilised materials and asphaltic materials. The large trailer-mounted Falling Weight Deflectometer (FWD) test device has been utilised for the structural assessment of roads. It has the advantage of recording the transient deflection in several locations and thus defines a 'deflection bowl' for the structure under test. These data can then be back-analysed to determine the

contribution of individual layers to the structure as a whole. However, the smaller plate test devices are increasingly being used due to their simplicity, accessibility and lower cost. The most useful aspect of these devices is their ability to control the load/stress and obtain a meaningful engineering value.

The Clegg Hammer impact soil tester was developed to assist with the evaluation of low-volume unsurfaced roads in Western Australia (Clegg, 1976). It is a lightweight portable impact tester (Fleming, 2000). Unlike the Prima and FWD its impact on the surface is undampened. It measures the maximum deceleration upon impact, termed the Clegg Impact Value (CIV), from a drop height of 0.45m. Originally it only had a mass of 4.5 kg but recent models have been developed with a mass of 2.25 kg and 0.5 kg. It has a much smaller diameter in comparison with the dynamic plate testers which results in very large inferred stresses (Fleming, 2000). The Clegg is only suitable for the assessment of relatively soft materials i.e. soils. Consequently, rigid layers, like asphalt, can cause damage to the transducer.

Prior to pitch construction, it is often necessary to perform a ground investigation to confirm the risk of frost heave, clay shrinkage and swelling, presence of soft ground and groundwater level. Tests for these properties involve laboratory and field based research to determine moisture content, plasticity index, particle size distribution, strength and density. All of these tests can help towards designing a pitch since any weaknesses discovered in ground conditions can be rectified by adopting appropriate measures. These ground investigation tests are common in civil engineering but Bull (2000) suggests that the ground is seldom examined before construction and suggests that many failures of artificial surfaces could have been avoided if the ground conditions had been examined in advance.

In summary, assessment prior and during construction is essential to ensure each of the constituent layers are built appropriately. It is vital to understand how each layer affects the composite pitch system. Current standards do not require a pitch to be monitored during construction but anecdotal evidence from Bull (2000) illustrates that poor quality subgrade and sub-base can lead to problems with structural integrity. This may not cause a problem in the short-term but over time weakness of the foundation layers can result in unwanted movement of the pitch and damage to the playing surface.

2.6 SUMMARY

This Chapter has reviewed literature for synthetic turf pitches for field hockey. Clear similarities between other sports pitches are evident in respect to their construction and usage and have also been included in this review. Methods used to evaluate the performance criteria were discussed from a perceived and mechanical perspective.

A clear understanding of the performance requirements of field hockey players is currently not available. No past research exists that identifies what players require from the surface and indeed how they perceive existing pitches match their requirements. To date no suitable method to elicit perceptions of field hockey players has been developed. Therefore, an appropriate method is required to elicit perceptions to identify how they perceive current synthetic pitches behave and what performance criteria they desire.

While the construction of each layer of the surface is important to its overall playing characteristics, there is little research into how different design specifications, material selection and construction techniques affect performance of the composite system; and how these will change and influence playing characteristics over time. More research is required to understand the influence of each layer to improve understanding of the complete system.

It has become apparent from the literature review that, at present, mechanical testing of sports surfaces cannot accurately simulate or reproduce what a player or the ball experiences during impact with a surface. Mechanical tests used by sports governing bodies for the accreditation of sports pitches are empirical and don't accurately represent in-game situations. These tests are useful for classification as they need to be simple, repeatable and quick. Surface classification or accreditation is essential for safety and performance. In that respect, detailed biomechanical understanding of human locomotion and complex consideration of material properties, while important for research are not necessary for everyday sports surface analysis. If a simplified test can be used that closely matches what players' feel or perceive then it can be considered appropriate for surface classification. Consequently, eliciting players' opinions of pitches and comparing perceived properties with results from mechanical tests will help to establish the validity and therefore usefulness of these tests.

The purpose of this study is to address the lack of understanding in the mechanical and perceived behaviour of synthetic turf pitches for field hockey. This will involve monitoring a pitch during construction and the evaluation of existing pitches to FIH standards. To compliment this work a methodology is required to elicit perceptions from elite field hockey plays to improve understanding of their performance requirements and obtain feedback on existing pitches to compare with measured mechanical data.

Table 2 1 - Comparison of the strengths and weaknesses of two data collection techniques (from Cohen and Manion, 1989)

| | <i>Interview</i> | <i>Questionnaire</i> |
|--|--|-----------------------|
| Flexibility to vary content, sequence and wording of questions | Limited to extensive (depending on structure) | Limited |
| Opportunities for probing | Possible | Difficult |
| Number of respondents | Limited | Extensive |
| Rate of return | Generally good | Generally poor |
| Sources of error | Interviewer effects, instrument, sample | Instrument, sample |

Table 2 2 - Comparison of the sport specific standards for synthetic turf pitches

| | Field Hockey | | | Rugby | | Soccer | |
|------------------------------------|--|-----------------------------|------------------------------|--|--|---|---|
| | FIH: Handbook of Performance Requirements | | | IRB: Performance Specifications for Artificial Surface | FIFA: Guide to Artificial Surface | UEFA: Artificial Turf Requirements and Recommendations | FA: Guideline Performance Standards for Artificial Grass Pitches |
| | Starter | Standard | Global | | | | |
| Player Interaction | | | | | | | |
| Impact Response | 30 % - 65 % | 40 % - 65 % | 40 % - 65 % | 60 % - 75 % | 55 % - 70 % | > 60 % | ≥55 % (or ≥ 45 % when frozen) |
| Gmax | n/a | n/a | n/a | Max 125G | n/a | n/a | n/a |
| Vertical Deformation | < 2 % difference | < 2 % difference | < 2 % difference | 4 mm – 10 mm | 4 mm – 9 mm | < 10 mm | 4 mm – 12 mm |
| Slip Resistance | 0.6 – 1.0 μ | 0.6 – 1.0 μ | 0.6 – 1.0 μ | 0.6 – 1.0 μ | 0.6 – 1.0 μ | n/a | n/a |
| Rotational Friction | n/a | n/a | n/a | 30 Nm – 50 Nm | 25 Nm – 50 Nm | 30 Nm – 45 Nm | 30 Nm – 50 Nm |
| Sliding Distance | n/a | n/a | n/a | n/a | 0.25 m – 0.55 m | | 0.25 m – 0.75 m |
| Ball Interaction | | | | | | | |
| Ball Rebound | 0.1 m – 0.4 m from 1.5 m | 0.1 m – 0.3 m from 1.5 m | 0.1 m – 0.25 m from 1.5 m | 30 % - 50 % | 30 % - 50 % | 0.6 m – 0.85 m from 2.0 m | 0.6 m – 1.0 m from 2.0 m |
| Ball Roll | 5 m – 20 m | 5 m – 15 m | 9 m – 15 m | n/a | 4 m – 10 m | 4 m – 8 m | 4 m – 10 m |
| Angled ball behaviour (or Pace) | n/a | n/a | n/a | 50 % - 70 % at 50 km/h with an impact angle of 250 | 50 % - 70 % at 50 km/h with an impact angle of 250 | 45 % - 60% | 45 % - 60 % dry, 45 % - 80 % wet |
| General Information | | | | | | | |
| Test Locations | 5 | 5 | 5 | 3 | 3 | 3 | 3 |
| Approval System | yes | yes | yes | yes | yes | yes | yes |

Table 2 3 - Characteristic data for the two Artificial Athletes (Kolitzus, 1972 and 1984)

| <i>Comment</i> | <i>Unit</i> | <i>Stuttgart</i> | <i>Berlin</i> |
|-----------------------|--------------------|-------------------------|----------------------|
| Dropping mass | kg | 50.0 | 20.0 |
| Mass of test foot | kg | 9 0 | 1 8 |
| Spring constant | kN m ⁻¹ | 50 | 2000 |
| Drop height | mm | 30.0 | 55 0 |
| Test foot diameter | mm | 49 5 | 70.0 |
| Contact velocity | ms ⁻¹ | ≈ 0.7 | ≈ 1 0 |
| Time of peak force | ms | ≈ 150 | ≈ 10 |

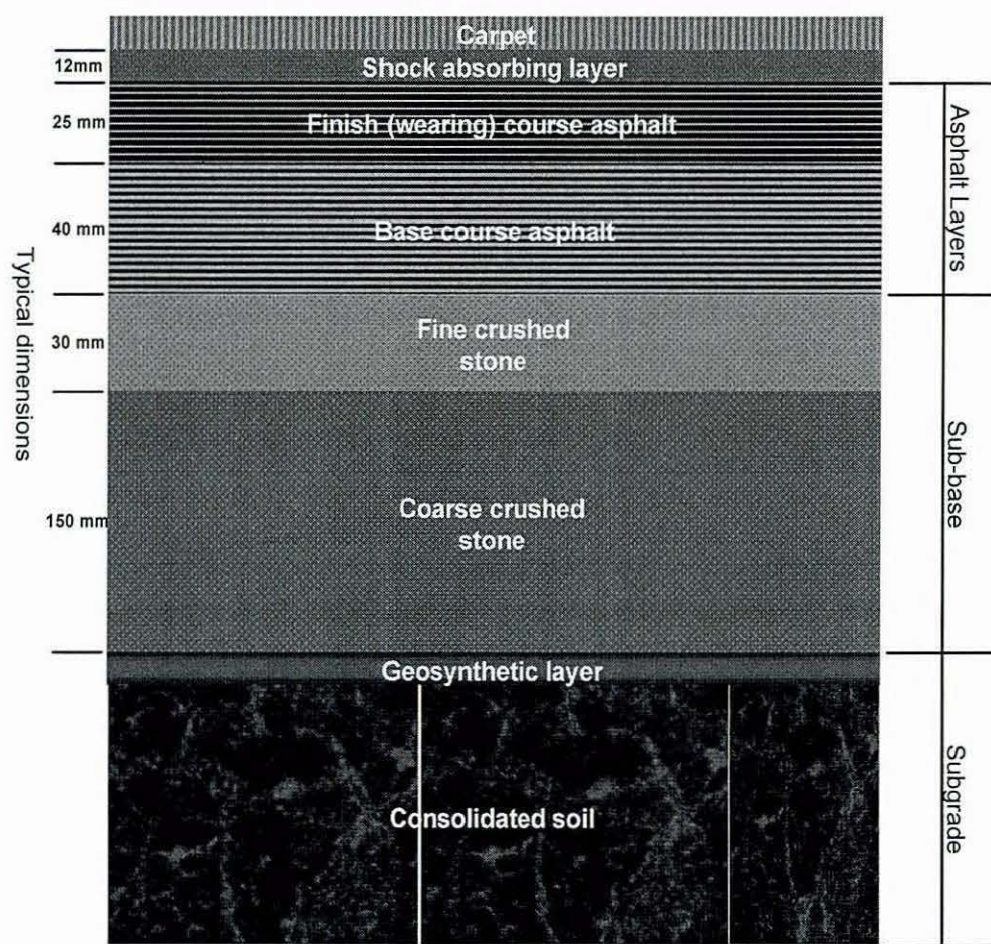


Figure 2.1 - Typical construction of a synthetic turf pitch for field hockey

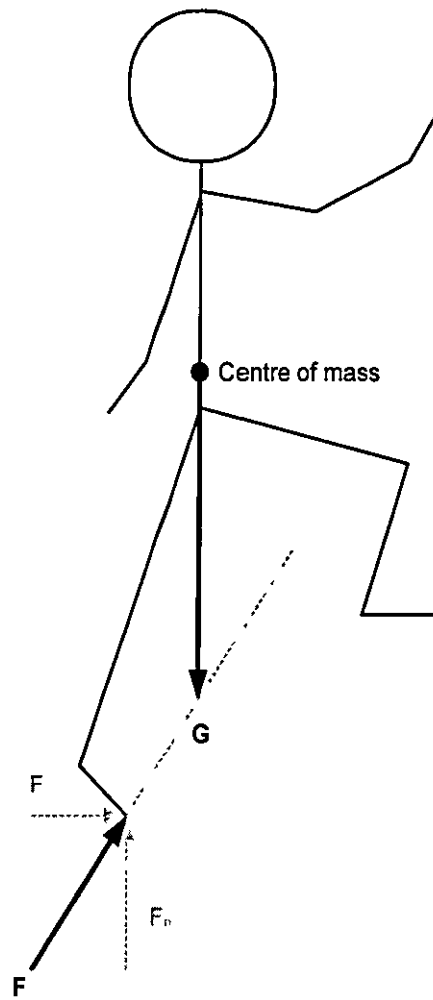


Figure 2 2 – The forces acting on a runner

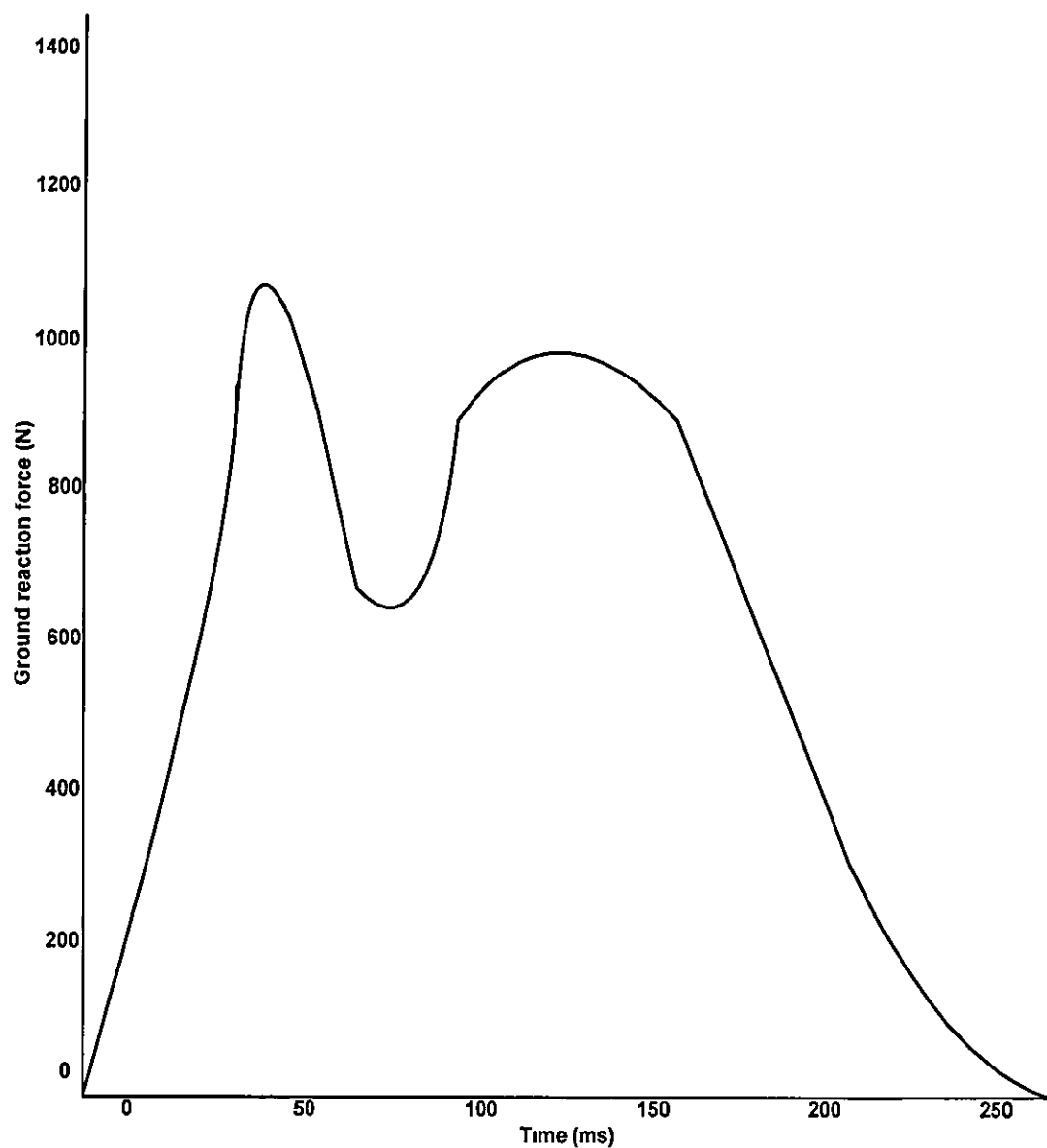


Figure 2.3 – Ground reaction force/time history curve for 'typical' heel-toe running

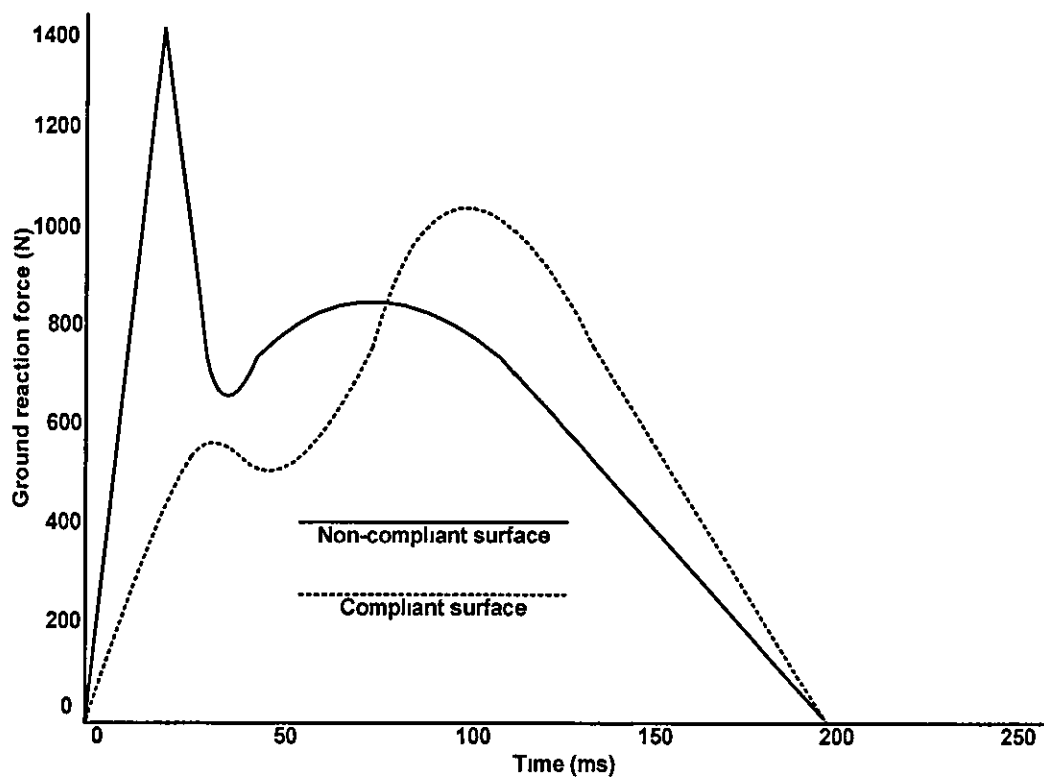


Figure 2.4 - Ground reaction force for a compliant and non-compliant surface
(after Nigg, 1986)

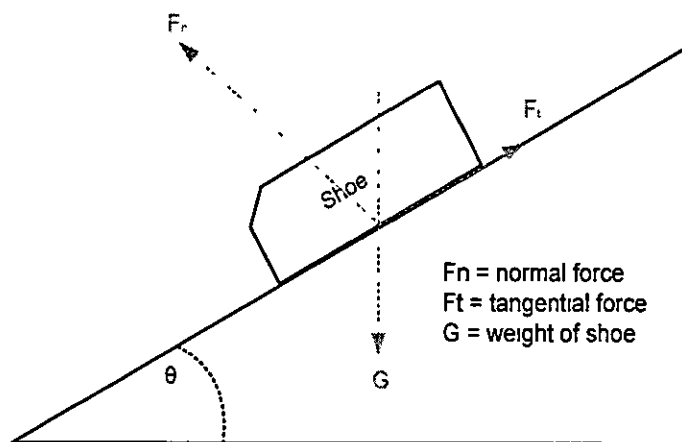


Figure 2.5 - Forces acting on a shoe on an inclined plane

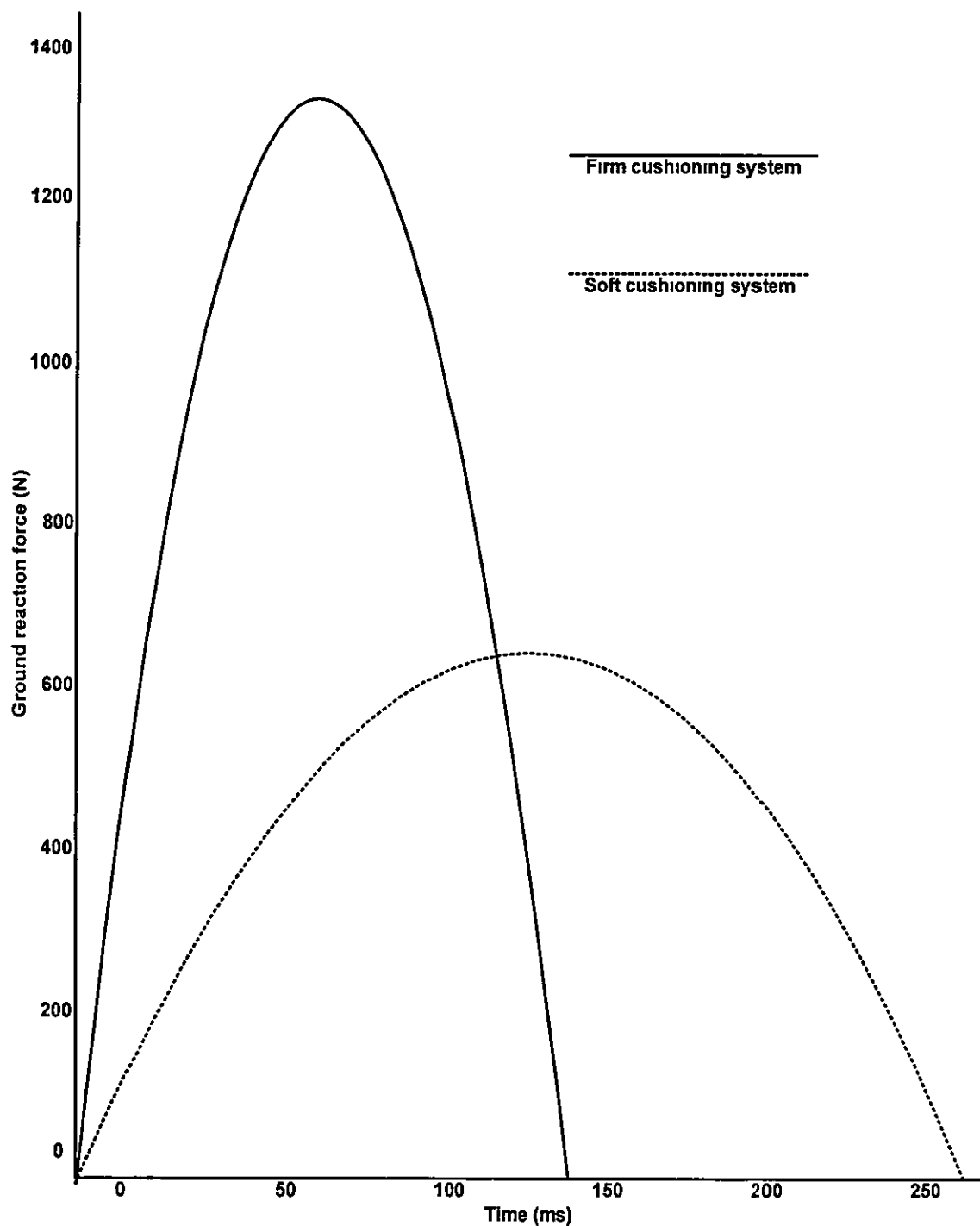
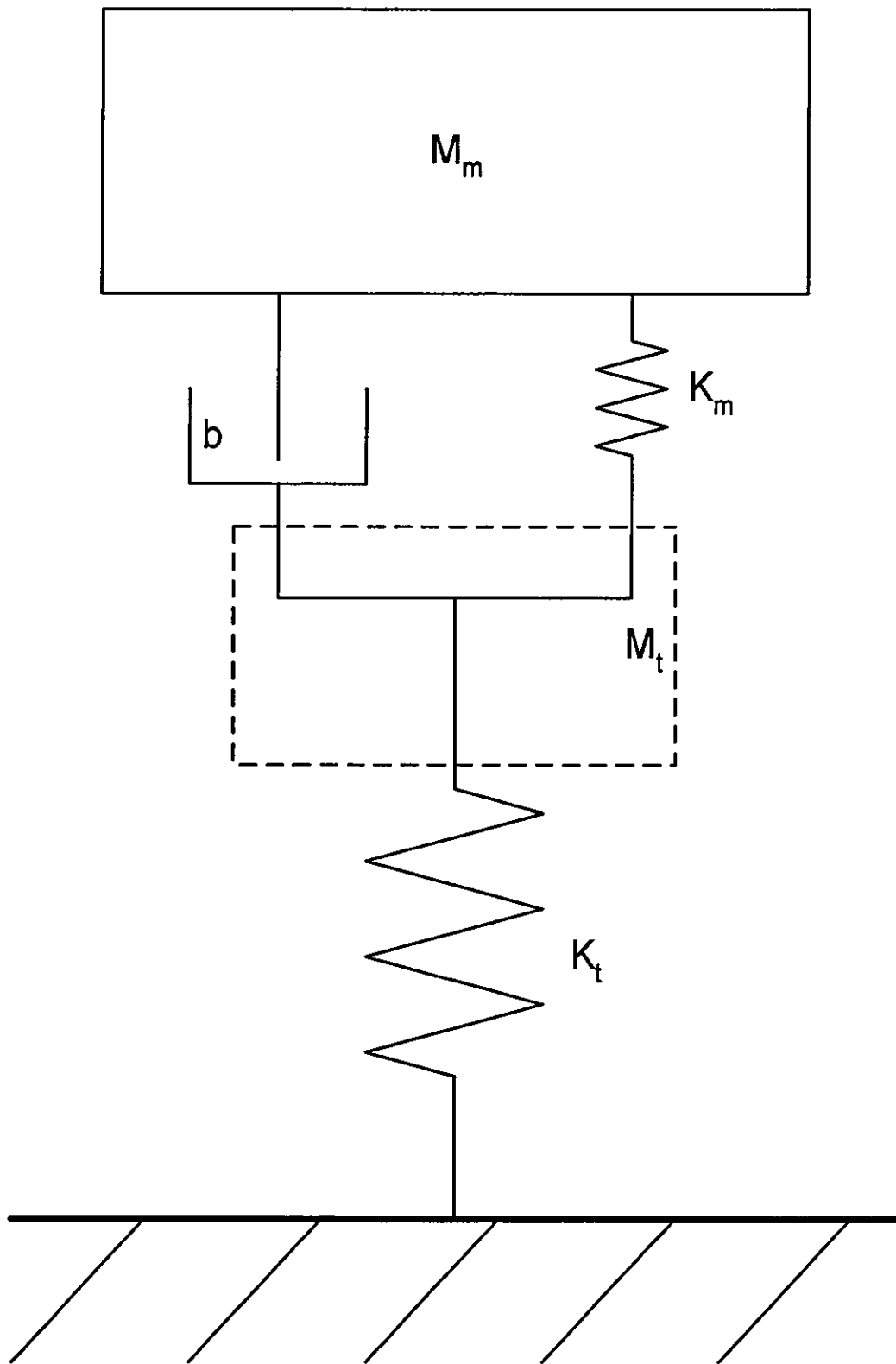


Figure 2.6 - Effects of different cushioning systems on ground reaction force
(after Shorten, 2000)



Where:

M_m = mass of subject (kg)

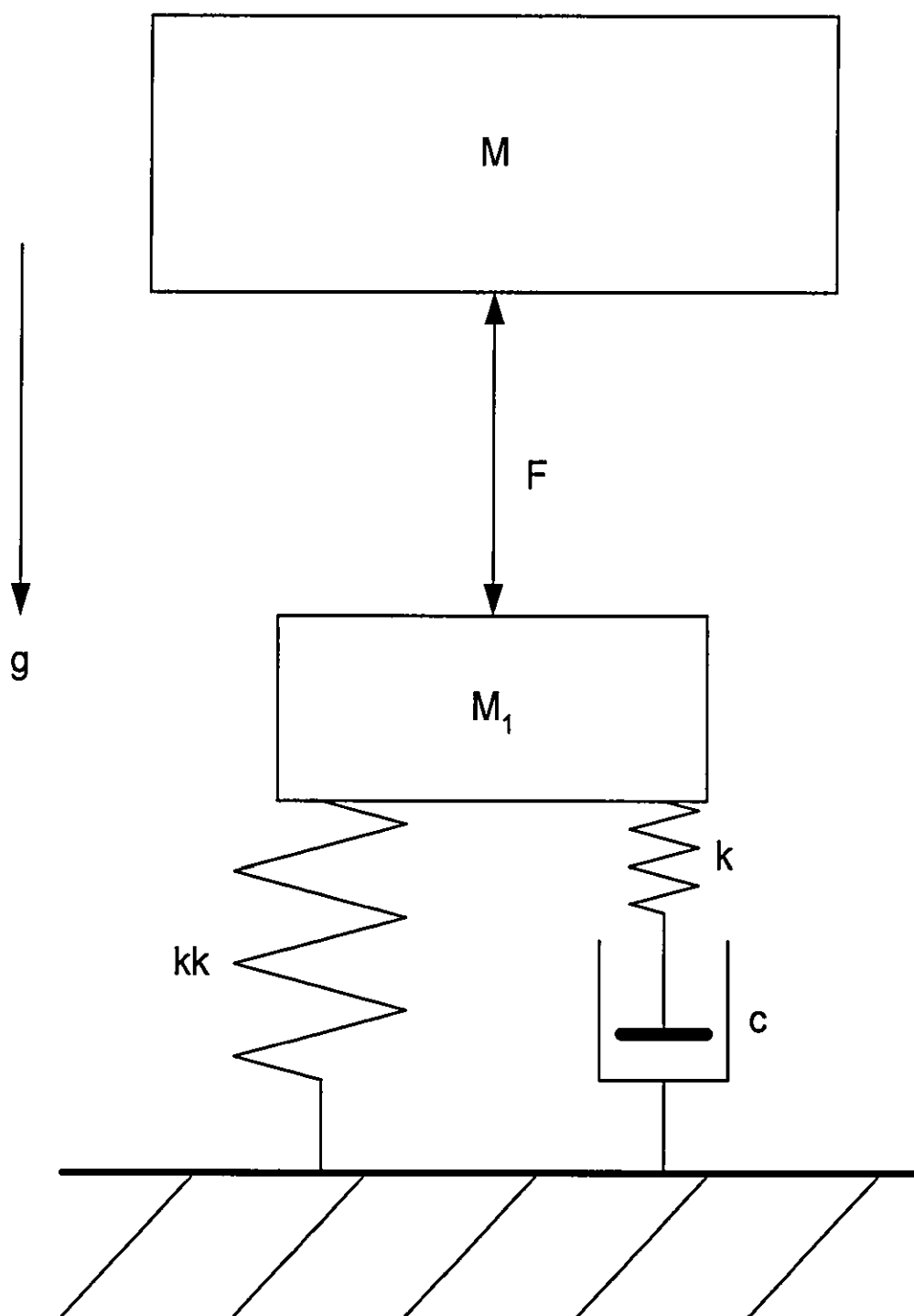
K_m = subject stiffness (N/m)

M_t = effective mass of the track

K_t = track stiffness (N/m)

b = linear dashpot damping constant of subject (N/ms^{-1})

Figure 2 7 - The McMahon and Greene (1979) 2 mass, 2 spring dynamic model for running



Where:

M = mass of subject

F = force between upper body and foot

kk = material properties of the surface

k = material properties of the shoe midsole

M_1 = mass of foot

g = acceleration due to gravity

c = human heel

Figure 2.8 - Two-segment model (after Nigg and Anton, 1995) of a runner

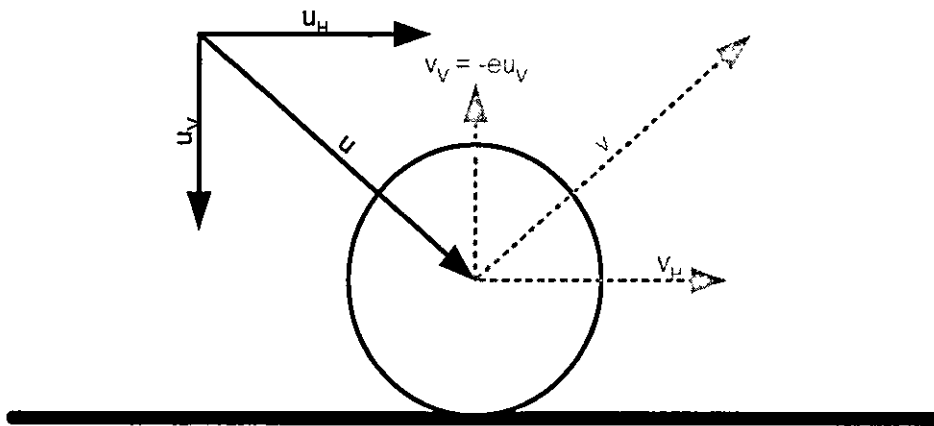


Figure 2.9a - Velocity changes during an oblique impact (after Hay, 1993)

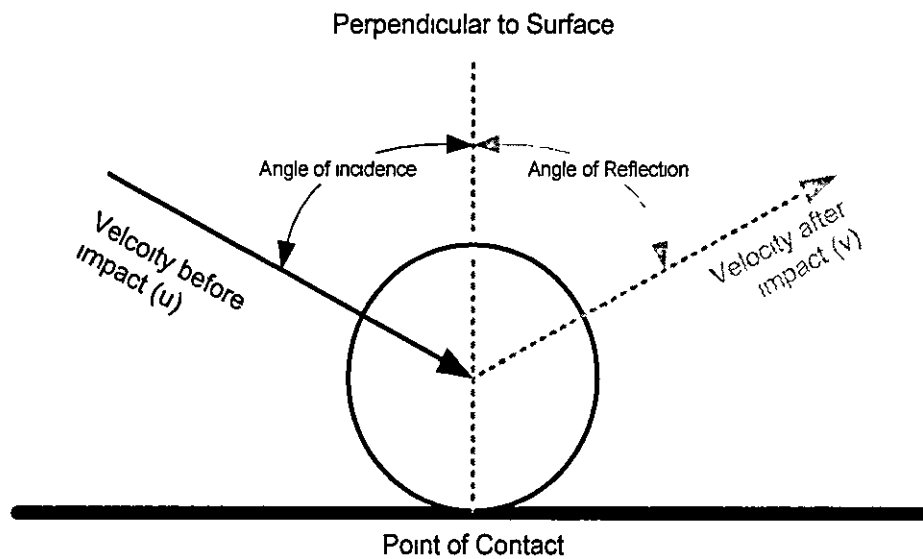


Figure 2.9b - The angles of incidence and reflection in an oblique impact (after Hay, 1993)

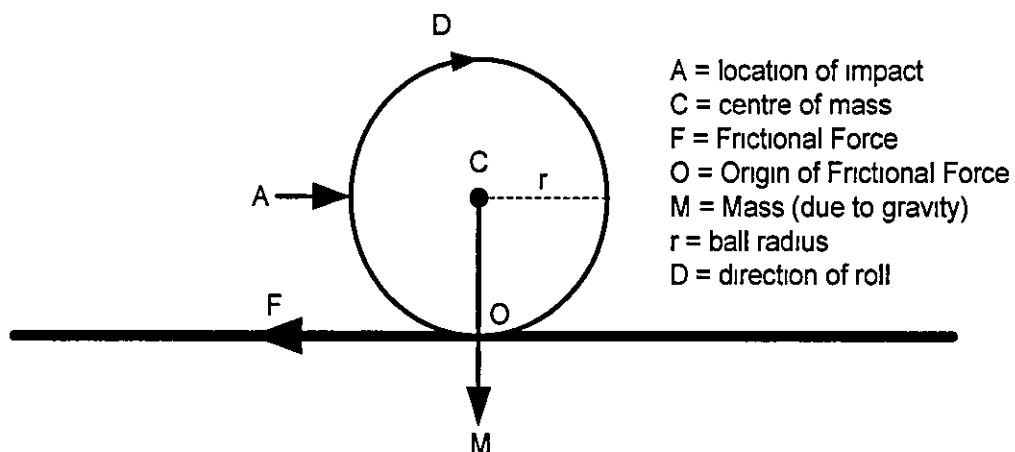


Figure 2.9c - The movement of a ball over a plane surface (after Daish, 1974)

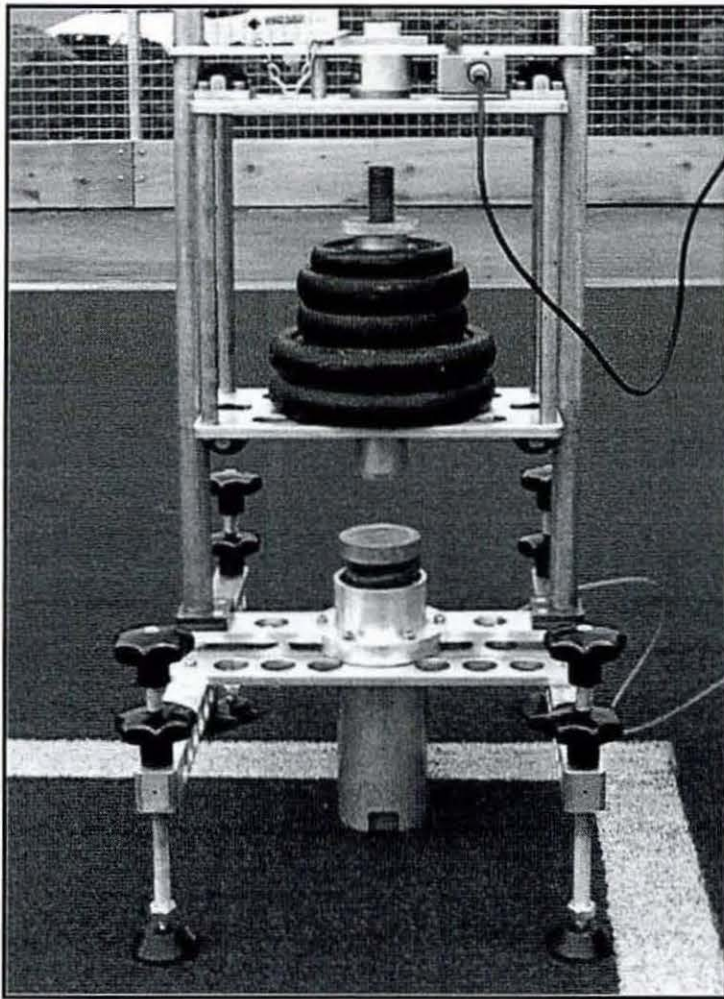


Figure 2.10 – The artificial athlete Berlin (AAB) in use on a water-base synthetic turf pitch

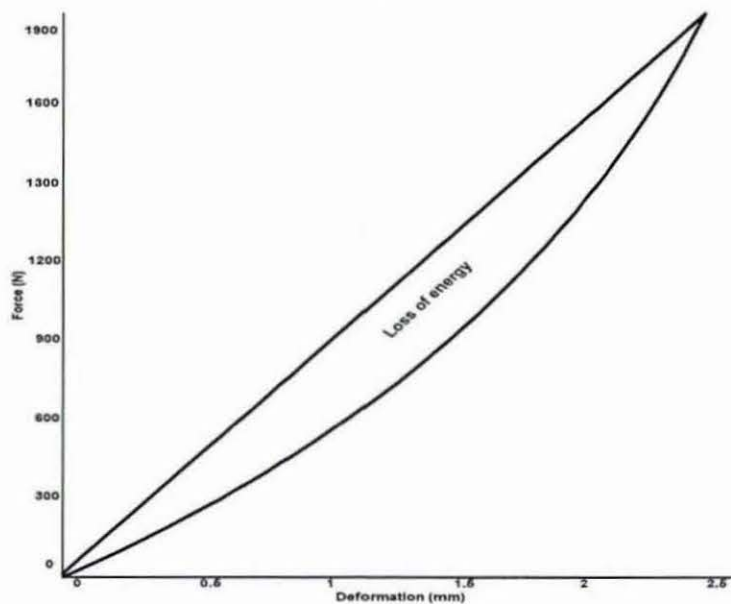


Figure 2.11 - Representation of energy loss at the area enclosed by the hysteresis loop for a force-deformation curve (after Nigg and Yeadon, 1987)

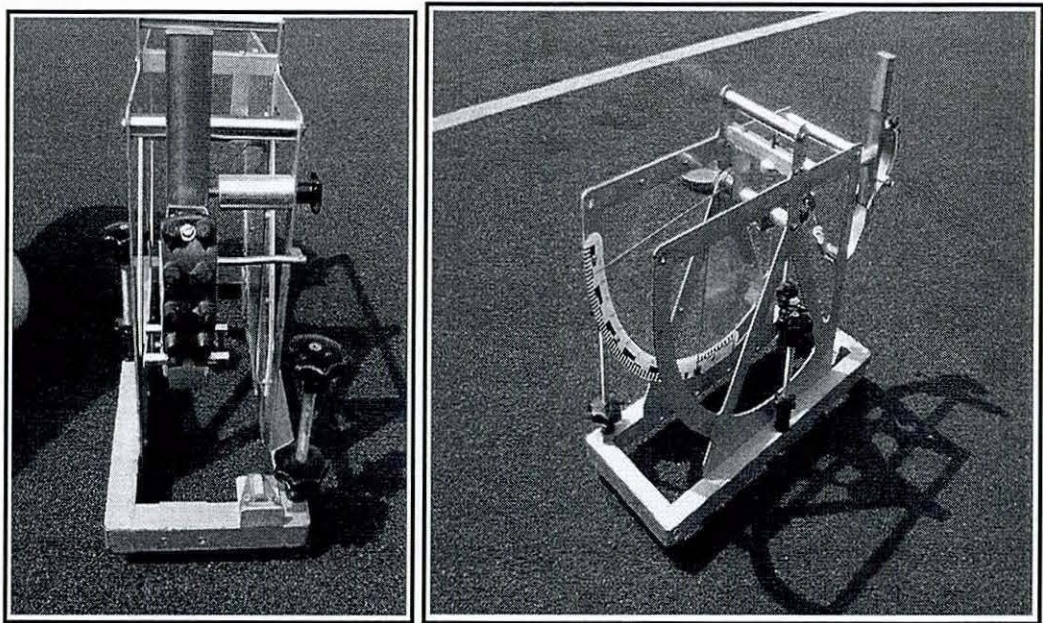


Figure 2.12 - The modified Leroux friction tester in use on a water-based synthetic turf pitch

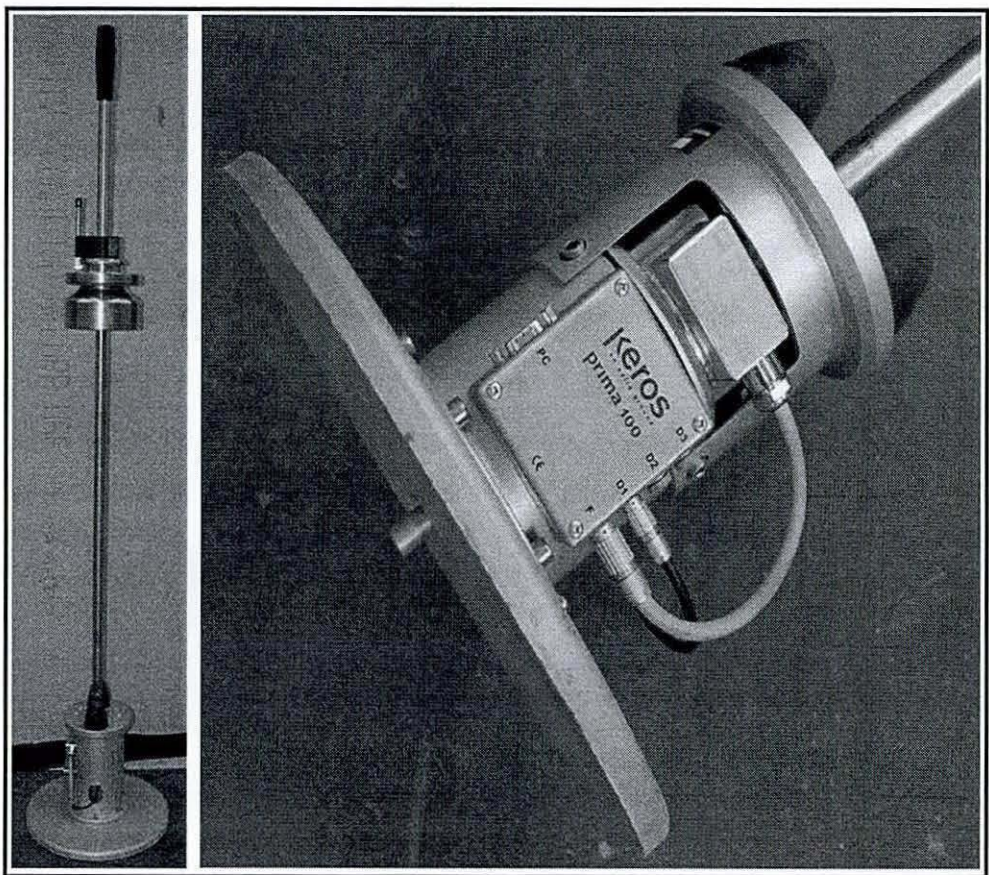


Figure 2.13 – The Prima dynamic plate test with a 300 mm diameter plate installed

METHODOLOGY

3.1 INTRODUCTION

Chapter 2 describes previous research studies that have been conducted to investigate the behaviour of synthetic turf pitches. The review of literature highlighted, in particular, that few studies have been undertaken to measure the mechanical behaviour or indeed investigate player's perceptions. The aim of the research programme was to develop a more fundamental understanding of the mechanical and perceived behaviour of synthetic turf pitches for field hockey. To achieve the aim it was necessary to develop and assess the following. a new measurement technique to elicit and analyse human perceptions, review existing test methods to evaluate the mechanical behaviour of synthetic turf pitches, review novel tests for the assessment of STPs, and develop a suitable method to assess the relationship between mechanical and perceived pitch behaviour.

This Chapter outlines the design process and methodology of the research. The description of the experimental work is in two sections: perceived and mechanical behaviour of STP's. The perceived behaviour was elicited through player interviews and questionnaires whilst mechanical behaviour was measured via a combination of laboratory and field based experiments. Finally a section linking the two together was developed and is discussed in Chapter 6. Considerations of the experimental techniques and the decisions made to arrive at them are presented herein.

3.2 PERCEIVED BEHAVIOUR

A suitable previous study exploring players' perceptions of artificial sports surfaces from which a successful methodology could be drawn was not identified from the literature. Furthermore, only a few studies of note were found on human perceptions of sports equipment (Roberts *et al.*, 2001 & 2002; Scanlan *et al.*, 1989; Gould *et al.*, 1992; Hanton and Jones, 1999). Previous methodologies used to investigate perceptions have shown a propensity towards the use of

surveys or interviews within a qualitative analytical framework as the primary data collection method. The literature review identified that a subject led semi structured interview was suitable for eliciting players perceptions, in that it permitted investigation of selected issues in depth and detail (Patton, 1987). However, it also showed that this qualitative method had several limitations including the lack of a facility for comparison and statistical analysis (Bryman, 2001). This could be overcome with a quantitative approach but at the cost of losing details, as perceptions would be forced into predetermined categories. Consequently, it was decided to use a combination of qualitative and quantitative techniques to overcome the disadvantages of each.

Firstly, interviews were used to elicit subject led responses and minimise investigator expectations and/or bias. These were followed by the production of two postal questionnaires developed from the responses in the interviews. The combination of these two data collection methods is shown in Figure 3.1 and the specific components of each method are discussed below.

The objectives of the interview phase was to elicit undiluted information that was rich in depth and detail from which selected themes could be chosen for further investigation. Allowing the participants to lead the interview ensured accuracy of matters significant to him/herself and reduced the risk of investigator bias. The objectives of the first postal questionnaire were to quantify the themes obtained from the interviews and rate their relative importance to the players. The second postal questionnaire derived the player's rating for specific pitches by ranking pitches against each other for the characteristics of importance.

3.2.1 Qualitative Data Collection

Qualitative designs are naturalistic to the extent that the investigator does not attempt to manipulate the participants' responses for the purpose of the evaluation. They allow the participant to express matters of central significance to him/her rather than those presumed to be important by the investigator, i.e. it uncovers what is on the subject's mind rather than his/her opinion of what is on the interviewer's mind (Merton and Kendall, 1946)

Qualitative data require particular analytical techniques which avoid the problems of research bias, data overload or unsubstantiated or erroneous conclusions being drawn (Miles and Huberman, 1994). The main types of data collection for

qualitative methods consist of: in-depth open-ended interviews; direct observations and written documents (including such sources as open-ended written items on questionnaires); personal diaries and programme records (Patten, 1987). Open-ended interviews were considered ideal for this study as they place minimal restraints on the replies and enable a vocabulary of terms to be built up from the responses of hockey players.

Pawson (1996) provided an a good insight into the theoretical implications of interview strategy, and the debate between structured and unstructured approaches. He warns that without steering from the researcher, there is a danger that extracts will be selected from the massive flow of data which will be re-fitted in an unrepresentative framework. However, too much structuring leaves the subject's response entirely defined by the researcher's conceptual system. Hence, semi-structured interviews were used.

By using a semi-structured approach, the participants were encouraged to talk in their own terms, but around subjects defined by the researcher. Where a subject was covered, the researcher noted and, if required, probed their responses. Probing involved the interviewer asking questions to enable the player to expand on their responses. For example, if a player stated that the ball bounce was 'high' the interviewer would asked the player 'what do you mean by high?' or 'high compared to what?'. This process allowed the interviewer to elicit further information from the players without leading their responses. A topic was only probed once it had been introduced by the player and topics were never introduced by the investigator.

The semi-structured format was continually developed and adapted as different findings emerged from the interviews. As a result, the questions asked were specific to each respondent, and related to their individual experiences within a broad framework of emerging themes. Questions were not set in a specific order, but were structured in a way which developed the conversation (Burgess, 1984). The length of the interviews was not restricted, with the respondents being allowed to talk until the interview reached its natural conclusion. The average interview time was around twenty-five minutes and all were carried out after a competitive game. An interview guide was produced as it was found to provided a good balance between structured and unstructured approaches.

3.2.1.1 Inductive Analysis

Qualitative methods are particularly oriented toward exploration, discovery, and inductive logic (Patton, 1987). The process begins with specific observation and builds towards general patterns. In contrast, the deductive approach requires the specification of the main variables prior to data collection. Previous studies in sports psychology (Scanlan et al., 1989a, 1989b, Gould et al., 1992a, 1992b; Harwood, 1997, Hanton and Jones, 1999, Roberts et al., 2001) have argued that they followed an inductive process for structuring qualitative data. In order to allow characteristics important to the hockey player to emerge and minimise restrictions imposed by the investigator, an inductive approach was considered the most suitable for this research

An inductive analysis attempts to understand the responses without imposing pre-existing ideas or expectations on the collected data. Using this process of inductive analysis, the 'themes' emerge from the quotes rather than being pre-determined, which enables the issues of importance to the players to be identified and reduces the risk of investigator bias. Thus, the use of an individual interview with open-ended questions allows the participants freedom to express their opinions and the semi-structured format gives the investigator the opportunity to probe the players' responses. The themes developed from the data are then grouped together to form 'dimensions' which represent the highest level of this hierarchical system, illustrated in Figure 3.2. Roberts *et al.*, (2001) showed that the emergent dimensions may not be exclusive and that there can be a level of interactivity between dimensions. Consequently, an additional stage of analysis was used to aid investigation of inter-dimensional relationships known as structured relationship modelling.

3.2.1.2 Pilot Study

In qualitative research, a workable research design is essential to ensure coherence and rigor during the project (Mason, 1996). Therefore, having established a suitable research design which allowed the collection and analysis of data in a manner appropriate to the issues under investigation, it was necessary to test its design.

Six players from the Loughborough University (LU) second team were interviewed following the research design. These were conducted prior to the main interview programme and helped to refine techniques and familiarise the

interview team with player terminology. From these interviews, several changes were made to the interview guide including the introduction of non-leading prompts and a vocabulary of 'typical' phases.

3.2.1.3 Data Collection and Analysis

Data were collected through one-on-one interviews post game. Investigators used the interview guide to optimise the amount of data obtained from the players and the provision of a selection of unambiguous questions ensured that a consistent approach was followed even with different interviewers. The use of different investigators has been shown to reduce the risk of misinterpretation by a single researcher (Roberts, 2002). To understand the participants' subjective responses, it was first necessary to understand the way in which they perceived their own playing environment. Therefore, the interview was structured in a way to compare their home pitch to the pitch they had just played on. It was decided to use the LU water-based hockey pitch as a benchmark for comparison with other pitches nationally in the English Hockey League. When the LU men's and women's first teams travelled away, several individuals were interviewed one-on-one about the pitch they had just played on in relation to their (LU) home pitch. When away teams travelled to Loughborough, several of their team's perceptions of the LU pitch were obtained in relation to their home pitch. This methodology allowed a direct comparison between two pitches, enabling the identification of desirable or undesirable qualities of each pitch. In addition, it aimed to help the process of selecting pitches for engineering assessment at a later date (i.e. those pitches that elicited strong views or concerns regarding playing performance). The pitches visited represented a diverse range of the carpet types, age and usage levels; in total feedback was obtained for 24 locations. Team, position, shoe type, shoe age, stick manufacturer and ball preference were recorded from each player. In addition, the outcome of the game, the weather conditions, and how well the player believed they had played were also recorded in order to identify how, or if, any of these extraneous factors could have influenced their perceptions.

Patton (2002) raises the issues of sampling for qualitative methods. The quality of data can be influenced by the sample of people from which the data is collected. An approach known as 'purposeful sampling' was used to select the participants for this study. Purposeful sampling targets participants from which one can learn a great deal about issues of central importance to the purpose of the study.

(Patton, 2002) It was envisaged that elite players would give relatively high quality responses due to their higher level of skill and better understanding of their playing environment compared to lower standard players. Therefore, elite (national standard) hockey players were selected. Furthermore, elite players were considered the most appropriate because they would have more experience on water-based hockey surfaces. It was decided that players from Premier and 1st division clubs in the English Hockey League be selected and a range of playing positions covered.

Patton (1990) recommends specifying a minimum sample size with a flexible design that could be increased if required. Initially it was thought that a minimum sample size of fifteen was required for this study in line with the experiences of a number of past similar research studies involving interviews with elite performers (Scanlan *et al.*, 1989a, 1989b; Gould *et al.*, 1992a, 1992b; Harwood, 1997, Hanton and Jones, 1999; Roberts *et al.*, 2001). However, this research involved team players who might have different perceptions based on their playing position, so a sample size of twenty was chosen. This number of interviewees was deemed appropriate as it was evident that saturation point had been reached with no new information emerging from the ongoing data processing after approximately 16 interviews. However, in the interest of completeness 8 additional interviews were undertaken to ensure no new data emerged.

A total of twenty-two players (eight from LU), with an age range of 18 – 32 years were interviewed within one hour of the end of play to ensure they retained detailed memory of their experiences. Of the twenty-two players, twelve were male. Players from six teams (three men's) were interviewed. Full verbal consent was obtained prior to the interviews (from the players and team coach/manager). A range of playing positions were covered including three goal keepers/minders, six defenders, seven midfield players and six forwards.

3.2.1.4 Interview Guide

The interview guide was produced (Appendix A) with the help of two senior hockey coaches (International standard ex-Olympic representatives, 1 male and 1 female). It contained three sections that were consistent for all interviews. Topics within the guide were only discussed if the players themselves had introduced them into the conversation. The initial lead question, which was

designed to focus the player's response but allow free expression, was structured:

"Having just finished a full match I would like you to describe your feelings/perceptions of the pitch you have just played on, drawing specific comparisons with your home pitch."

The interviewer then had complete freedom to probe the response of the hockey player to this initial question. It was important that the interviewer did not lead the responses of the player, so the interview guide contained several questions designed to elicit perceptions without suggesting characteristics of importance:

"What were the main/major differences between the pitch you have just played on and your home pitch?"

"Was there anything in particular that you liked/disliked about this pitch, or was different from your home pitch?"

Open-ended questions were used to obtain qualitative data in the form of detailed descriptions. To ensure the validity of the interview technique, six pilot interviews were carried out, from which several minor modifications were made, to reduce the possibility of ambiguous and leading questions.

3.2.1.5 Interview Recording

The recording equipment needed to be robust, portable and able to accurately reproduce each spoken word such that verbatim transcriptions could be produced. Two wireless lapel microphones were transmitted to a recordable mini-disc player. The mini-disc system enabled the player and interviewers responses to be captured on separate tracks (left and right stereo), which greatly eased transcription, particularly when both parties spoke at the same time. The recordings were transcribed verbatim into (Microsoft Word) text documents for subsequent analysis. Interviews typically lasted twenty-five minutes and resulted in a fifteen page long transcribed document.

3.2.1.6 Quality of Data

During interviews there were several data quality issues of concern, including the player misunderstanding what was being asked, the interviewer misinterpreting

the responses and the preconceived attitudes and opinions of the interviewer influencing the player's responses (Cohen and Manion, 1980). For example, players' terminology could differ from the investigators' causing misunderstanding. Throughout these interviews a number of methods were employed to reduce the potential for bias. Prior to the interview phase, the pilot interviews helped define player terminology to construct a usable interview guide. The pilot study also allowed the interviewers a chance to practice their interview technique and be consistent and clear in their questioning and probing. The result of the game and how the interviewee perceived they had played were recorded to evaluate any potential bias caused by this. Furthermore, two investigators were used throughout the interview process to reduce the risk of misinterpretation by a single researcher. Dialogue between the investigators and familiarisation with each others transcripts ensured continuity and consistency between interviews

3.2.1.7 Data Analysis

Data analysis involved the organisation of raw data (quotes) into a set of meaningful structured themes by means of inductive analysis. An inductive analysis involved obtaining categories and themes from the quotes rather than forcing them into pre-determined groups. The analysis followed the procedure developed by Scanlan *et al.*, (1989) which began with each interview recording being listened to, transcribed and then re-read. This increased familiarity with the interview data and helped identify the emerging themes. To aid analysis the software package QSR-N6 NUD*IST (QSR International Pty Ltd, 2000) was used to identify and group each emergent theme

Once emergent themes had been identified, the next phase was to group them together into a hierarchical structure to develop the dimensions. Discussion of the emergent dimensions by the two interviewers, plus a third person (who aided in the research design) experienced in qualitative analysis, was conducted to remove any possible effects of misinterpretation or individual opinions. This process is known as 'triangular consensus validation' (Scanlan *et al.*, 1989; Patton, 1990) and was done until the final emergent dimensions were realised.

The template of semi-structured interview followed by an inductive content analysis highlighted the significant components of a players subjective perception but it did not facilitate exploration of the possible inter-dimensional relationships.

The structured relationship model was produced to address this. The process involves finding links between dimensions via player responses. Initially players' quotes were coded into individual themes. However, to preserve the quote's meaning they were kept whole. This often resulted in quotes with several themes, which then had to be coded into numerous categories. This process was illustrated graphically to highlight the inter-dimensional links between themes and is known as structured relationship modelling (Roberts *et al.*, 2001)

To validate the procedure, a reversal of this process was used. The players' quotes were coded using NUD*IST into the arranged structure using a deductive approach. This procedure provided a more organised format with more subtle themes emerging which allowed the creation of refined themes (Roberts *et al.*, 2001).

3.2.1.8 Computer aided analysis

Computer aided methods enhance qualitative research in two ways: by assisting the management of data; and by offering the facility to code and retrieve all data on a particular topic (Kelle, 1995). They free the researcher of mundane organisational and mechanical tasks, and allow more time for interpretative work.

The decision to use NUDIST (Non-numerical unstructured data indexing, searching and theorising) was primarily taken because it was specifically designed for inductive analysis (Bryman and Burgess, 1994), and because it allowed the combination of the different data sets, including the facility to include references to data unsuitable for inputting into a computer (QSR, 1999). NUDIST is a 'conceptual network builder', in that it aids the researcher in formulating and representing conceptual schemes through networks of nodes and links (QSR, 1997). The package incorporates advanced searching operations for detailed investigation of links between conceptual labels in the system.

NUDIST provides a wide range of tools which can be applied to analyse data including: code and retrieval; theory development and exploration; text searching and content analysis; and the incorporation of non-textual data into the analysis. These tools are organised within two distinct but interrelated sub-systems: the documents system, which contains the actual document being analysed and the index system, which contains the coded conceptual categories created by the researcher which develop as the data are analysed. This hierarchical 'tree'

structure graphically represents the developing findings and concepts emerging from the data

NUDIST facilitates the attachments of codes to sections of data and their retrieval and display (Weitzman and Miles, 1995). Additionally, it allows connections between the codes to be found, and aids the creation of a hierarchical 'tree'. Breaking down complex issues into a hierarchical format reduces them into manageable elements at lower levels, thereby facilitating their analysis (Muya *et al.*, 1997).

The nodes formed the storage areas for the conceptually labelled issues emerging from the raw data. They were subdivided through the hierarchy from base themes to general dimension. Each node was given a code known as the 'node address', according to its position within the analytical hierarchy. The in-built indexing system is completely flexible and can be manipulated by cutting, pasting, deleting and merging nodes (and the data that they contain) together. The 'tree' within the indexing system can be adjusted as the issues emerging from the data being to define the shape of the hierarchical structure.

More than one code can be applied to each piece of text, and codes may overlap each other. To code a document, the appropriate selection of text is highlighted. The user is then asked for a node under which to code the text within the indexing system. If no suitable conceptual label exists then a new one can be created and added to the system. No matter how many different codes are assigned to each document, the original text can be returned to at any time within the document system.

Inductive analysis uses the nodes for emerging ideas during the coding process (QSR). Thus, the coding process is part of the analysis, as the interpretation of emerging issues by the researcher, and the placing of these concepts within the index system, represent a conceptualisation and re-working of the emerging findings of the study.

As theories emerged from the data, they were recorded so that they could be subsequently analysed, validated and grounded within the data. NUDIST allowed memos to be attached to the data and to the nodes within the indexing system, and for them to be operationally linked with the data. Thus, the researcher could

move around the ideas derived from the text without having to laboriously go through all of the text to find the memos. This allowed ideas to be continually built upon within the index system.

Searching and testing the data was done in two ways: firstly, through text searching using either simple 'string-searing' or sophisticated 'patter-searching' which look for test matches of patterns of characters; and secondly through 'index system searching', where links between the conceptual labels created in the index system are investigated by the use of Boolean (and, or, not) and other more complex search operators. NUDIST facilitated the exploration of overlaps and text contained within codes, and produced a report of where it found the text and logs of all the searches made for future reference. A schematic representation of the data collection is illustrated in Figure 3.2.

3.2.2 Quantitative Data Collection

In order to quantify the players' responses from the inductive analysis, a suitable method was required that would facilitate comparison and statistical analysis. From findings in the literature review, a questionnaire was considered the most appropriate instrument to elicit quantitative data. Patton (1987) states that quantitative measures are succinct, parsimonious, and easily aggregated for statistical analysis. Due to the systematic and standardised method, they simplify analysis by assigning diverse opinions and experiences into predetermined response categories thus facilitating comparison and statistical analysis. However, a poor design can lead to misinterpretation without the capacity to clarify uncertainties (Bryman, 2001). In view of these disadvantages, the questionnaire was developed based on the responses from the interviews. This not only ensured that player terminology was used, but also allowed questions to be derived from the players' own responses, reducing any potential errors, investigator bias or misunderstanding.

Questionnaire Development

The qualitative study identified features of importance to the players, but a technique was required that could reach a larger sample of people so that the results could be considered statistically significant. A postal questionnaire was considered suitable for this purpose as it could target a large sample of players.

The important playing surface features were understood from the qualitative study. However, the relative importance of the emergent themes was unclear from this type of analysis. Consequently a questionnaire was used that could quantify the relative importance of each theme to the players and facilitate contrast between the themes Roberts (2002) highlighted the advantages of using a questionnaire to elicit and quantify the relative importance of each dimension Furthermore, a second questionnaire was used to target responses directly relating to pitches chosen for further investigation for subsequent comparison with mechanical data.

Questionnaire Distribution

The first questionnaire was distributed to the same population of players that were interviewed. However, to obtain a statistically significant number of responses 10 questionnaires were sent to each team in the top two divisions of the English Hockey league for both male and female teams This equated to 400 questionnaires and represented the total population of elite field hockey players in England at that time. Each questionnaire was accompanied with a letter explaining the purpose of the study and a consent form.

The second questionnaire was similarly distributed to the same population of players but rather than sample the entire two divisions it was specifically targeted at teams that regularly played on the six pitches chosen for further investigations This reduced the total number of players but ensured focused responses and familiarity with each pitch under investigation Some teams use the same pitch for their home games which gave a total sample size of 14 teams and hence 140 participants

Questionnaire Design

Both questionnaires are included in Appendix B and C respectively, the design for each is discussed below. The first section of the first questionnaire was used to obtain general information about the participant, including their age, playing position and shoe type. The player was also asked to complete a description of their home pitch to build up an accurate and specific database of the types of pitches in use. The second section was designed to elicit the players' pitch preferences for each characteristic being investigated and their relative importance to each other The chosen characteristics were measured on a scale of 1 to 7 to quantify the players' preferences A scale of 1 to 7 was selected as it

provided a good balance between having enough points for the subjects to accurately rate their preferences without the need to force their responses into the most relevant category. The question below shows an example of the method used to measure the preference rating of 'ball rebound'.

What height do you prefer the ball to bounce from the surface?

| | | | | | | | | |
|-----------------|---|---|---|---|---|---|---|------------------|
| Low, ball stays | | | | | | | | High, ball |
| low to the | 1 | 2 | 3 | 4 | 5 | 6 | 7 | rebounds high |
| surface | | | | | | | | from the surface |

To measure the relative importance of each characteristic a similar style was used, employing a 1 to 7 scale but instead of using descriptors to orient the scale, the phrases 'not important', 'moderately important' and 'extremely important' were used as in Roberts (2002) For instance, the importance of 'ball rebound' was obtained using the question below

How important is the bounce height of the ball?

| | | | | | | |
|-------------------|----------|----------|-------------------|----------|----------|------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| <i>Not at all</i> | | | <i>Moderately</i> | | | <i>Extremely</i> |
| <i>important</i> | | | <i>important</i> | | | <i>important</i> |

The third section of the questionnaire was used to build up a database of existing pitches and comment on their playability. The participants were asked to give details of their three favourite and least favourite playing surfaces. This information not only helped to build a database, it gave an indication of which surfaces the players preferred and why, thereby helping in the selection of pitches for site investigation.

The second questionnaire was split into three main sections. The first section asked the players to state the last time they had played on each specific pitch. A longer time frame would indicate less confidence with the participants rating. The second section asked the participants to rate 'in their own opinion' how each of the six pitches played for the following characteristics; height of ball bounce, underfoot grip, speed of ball roll, coverage of watering system, surface hardness and overall surface consistency. Like the first questionnaire players rated each pitch on a scale of 1 to 7 with descriptors to aid their decision (all descriptors were based on qualitative feedback). In the final section players were required to

rank each pitch, for the previous playing characteristics, thereby giving an indication of each pitch in relation to one another. This was specifically included to help facilitate relationships between mechanical and perceived behaviour and is discussed in Chapter 6.

3.3 MECHANICAL BEHAVIOUR

To investigate the mechanical behaviour of selected sports surfaces a combination of site and laboratory methods were used. Fieldwork was split into two sections, monitoring during construction and examination subsequent to completion. Pitch measurements were classified in two groups quality control and performance. Quality control looked at the construction specification (including adherence to them), layer thickness and flatness. Conversely, performance measures were related to pitch behaviour such as strength, stiffness and resilience. Quality control has a significant influence on pitch performance and to understand the mechanisms of pitch behaviour it was essential to understand the influence quality control (and construction specifications) had on performance. Furthermore, environmental factors were assessed in relation to pitch behaviour. The literature review (Chapter 2) identified a lack of published information relating to synthetic turf pitches. However, guidance on pitch behaviour were found in the FIH handbook of performance requirements (1999). This publication outlined performance standards (and test procedures) that a pitch must achieve to obtain accreditation and hence be used for specific levels of competitions. The handbook is reviewed in section 2.5.3. The information provided within this publication gave a source of data to benchmark against but only for completed pitches.

Loughborough University's water-based field hockey pitch was selected for monitoring during construction. Its construction coincided with the start of this research project and its locality made comprehensive testing possible. Many resources were devoted throughout the construction phase ensuring ample data could be collected for each layer. A variety of methods were used to assess the pitch, many of which were novel to the sports surface industry as no current test methods existed. Post construction testing took place at six hockey pitches which were chosen based on the player feedback and their construction specifications. The pitches represented a diverse array of construction types and perceived performance characteristics. All pitches conformed to the FIH 'global' standard

(international competitions) and were used regularly in the English Hockey League. To complement the fieldwork a sensitivity analysis was conducted in the laboratory under stringently controlled conditions to identify parametric differences between surfacing systems. The laboratory testing involved the construction of a small scale pitch (including full sub-base) in a rigid container

The following section provides information on the field and laboratory data collection, this is followed by a description of the test devices. The equipment that was used for measurement in the laboratory and on-site followed the same methodology, hence, direct comparison between the result from the two could be assessed

3.3.1 Monitoring During Construction

In order to understand the constituent influences of each layer, a comprehensive programme of field testing was undertaken during the construction of a 'global' standard water-based field hockey surface at Loughborough University. Extensive testing took place on each layer as it was formed, including the formation (subgrade), sub-base, asphalt and shock-absorbing shockpad layer. Prior to testing, construction specifications were obtained and analysed, to determine what tests would be most suitable for each layer.

A series of tests were performed on the formation and sub-base layers to determine the material strength. A probing penetration test was used to determine the bearing strength through the ground by depth. The apparatus comprises a sectional rod with a cone fitted at the base of a slightly greater diameter than the rod. It is driven into the ground by a constant mass that is dropped from a constant height with the distance penetrated into the ground each drop recorded and expressed as CBR. The Dynamic Cone Penetrometer (DCP) was used and is described in BS 5930:1999, 26.2, it was used on both the formation and sub-base layers. A hand vane device was used to determine the shear strength of the formation material. A cruciform vane on the end of a solid rod was forced into the soil below the bottom of a borehole and then rotated. The torque required to rotate the vane was then related to the shear strength of the soil and is described in BS 1377-9:1990, 4.4.

A grid system consisting of a 10 m x 10 m matrix was used to measure the pitch during construction and was labelled with rows (numbers) and columns (letters),

as illustrated in Figure 3 3, to cover the entire pitch area the last row was only 5m distance from the previous row. To evaluate the layer properties, understand the changes as construction proceeded and for repeat tests it was essential to test at the same location layer-upon-layer. Therefore, this grid system was used throughout the construction and was set out in relation to the pitches outer kerbs/fencing prior to testing. The grid provided a good global coverage of the pitch, an area of just over 7000 m². In order to identify local variability, repeat tests were often performed on the same spot and at a 1 m radius offset from the grid to evaluate global and spatial variability. Test devices were compared against one another to identify correlations and thus determine if they were measuring similar properties.

A number of geotechnical road foundation testing methods were chosen for the assessment of the different layers during construction. They were chosen based on their relevance to the materials used to construct the STP. Different apparatus were required to measure across the material properties and for varying depths below the surface. Due to constraints on equipment availability, construction speed, site accessibility and device suitability, it was not always possible to test at all locations with every piece of test equipment Table 3 1 illustrates which test methods were performed on each layer Due to a dearth of information to benchmark results against, test data was compared between and across layers to assess quality control and performance for consistence and repeatability.

Further to site investigation, numerous samples were taken during construction and classified in the laboratory. Bulk bag samples of between 10 – 20 kg were removed from site, as that amount of material was required to perform sufficient testing Moisture content (the ratio of the mass of water to the mass of solids) was used to classify the material characteristics following BS 1377-2:1990, 3. The Atterberg limits were used to determine the plasticity index following BS 1377- 2: 1990, 5. Particle size distribution was obtained following BS 1377-2.1990,9 to ensure distribution limits were met. Finally, compaction tests were performed on the materials to determine the maximum dry density and optimum moisture content of the soil. Testing consisted of a 2.5 kg and 4.5 kg rammer following BS 1377-4· 1990.

A site diary was kept throughout the testing programme The diary contained information on site conditions, construction practices and test locations of

interest, e.g. positions which gave surprising results that could be re-tested for further analysis. Photographic and video evidence was collected during pitch construction for later analysis of typical pitch construction practices.

3.3.2 Laboratory Analysis

For laboratory testing to be representative of in-situ conditions, it is crucial to ensure that testing circumstances are comparable. Sports surface laboratory testing for accreditation may be uncharacteristic of the situation on site because of the differences between the sub-surface layers, in particular the asphalt on-site compared with a rigid concrete in a laboratory. Typical pitch construction consists of a synthetic carpet laid on top of a polymeric shockpad over bound macadam and unbound granular soil. However, laboratory testing is used to assess the carpet and shockpad system directly on the laboratory floor, often rigid concrete, as outlined in the FIH handbook of performance specification (1999). This approach will be different to on-site conditions but does afford greater control and hence the compromise may be acceptable. However, the structural differences between a laboratory floor and typical pitch structure are significant. This disparity will almost certainly lead to different laboratory and insitu results. Therefore, a steel box was produced with a typical bound base (same dimensions and grading to the Loughborough University build) to achieve a base foundation with similar properties to an outdoor pitch. Prior to the construction of the box a grid system was produced, see Figure 3.4, to ensure testing at each layer was performed at the same location within the box. The grid consisted of sixteen test locations evenly spaced at 200 mm intervals and consideration was given to possible boundary effects at the box edges.

Box and Sample Preparation

A large rigid steel box was utilised for testing, 1 m by 1 m in plan and 0.5 m deep. The box rested on a heavily reinforced concrete floor and to ensure sufficient permeability, drainage holes were drilled into the base of the box. A well graded crushed limestone, conforming to a Type 1 sub-base grading (MCHW 1), was placed in the box and compacted in two 150 mm layers and one 100 mm layer, for a total thickness of 400 mm. Each layer received a light hand tamping, to level it uniformly across its surface, and was then compacted with a vibrating Wacker plate with a foot size of 250 mm by 330 mm. Four passes from the centre outwards were performed for each layer of the sub-base. Moisture content was measured during installation for each layer. All levels were tested for evenness.

with a straight edge and special attention was given to the last layer to ensure the best degree of evenness was achieved. Material classification and elastic stiffness properties of the subbase were obtained.

A bound macadam layer was formed on top of the sub-base. This was a cold lay mix with open texture to allow rapid drainage, cold lay was used as it afforded more time to work into place and hence more practical than a hot mix. A thickness of 6.5 mm was chosen, as this closely represents what is typically found on-site and was the same as Loughborough University's build. The asphalt was laid in one layer and compacted in the same manner as the sub-base. However, significant time was spent to ensure evenness of the surface. The macadam layer was tested for elastic stiffness properties with the Prima and four DCP tests were performed to measure the bearing strength of the materials.

Three 1 m² in-situ shockpads of different thickness were produced in the laboratory of 6 mm, 12 mm and 20 mm. A range of 6 – 20 mm encompassed typical constructions limits. A mixture of binder (Conipur 326) and rubber crumb (2 – 6 mm grading) was combined to produce the shockpad samples. Prior to mixing, a particle size distribution of the rubber crumb was undertaken to ensure all particles fell within the grading envelope. A binder content of 10 % was chosen, as this corresponded to typical design specification of recently installed in-situ shockpads. A rotary mixer was used to blend the binder and rubber together, and mixing was undertaken for six minutes to ensure a satisfactory consistency. The mix was then laid and compacted into a 1 m² frame of the required thickness (6, 12 and 20 mm) and left for 7 days to cure. Finally, measurements of the shockpads' physical properties were recorded to ensure mixing was performed correctly and consistently. Additionally, two shockpad samples were taken from site visits; one cast in-situ (11 mm thick) obtained during the construction of the Loughborough University water-based pitch, and one dimpled (approximately 11 mm thick) pre-fabricated from a pitch re-installation scheme with an age of seven years. These two samples combined with the self-made products and integral pads with carpet samples gave a good range of shockpad types.

Two carpet samples were obtained, one from Loughborough University with a 3 mm integral shockpad and one from Belle Vue hockey pitch with a 6 mm integral shockpad. Table 3.2 shows the differences between the two carpet samples.

Both carpets were very similar, the main difference being the thicker integral pad from the Belle Vue sample which increased the overall system weight.

Parametric Testing

A parametric study of the combinations of shockpad and synthetic carpet was undertaken. Table 3 3 illustrates the methods and devices used on each layer of the box and Table 3 4 shows a testing matrix of the carpet/shockpad systems evaluated during the sensitivity analysis. The matrix shows that both carpet samples were tested directly on ground (laboratory floor and in box asphalt) and with each shockpad sample. Further to this each carpet combination was tested at different moisture levels. On the shockpad and carpet layer the FIH test methods were followed for ball rebound and impact response but additional tests namely the Clegg Impact hammers (0.5 & 2.25 kg) and rotational traction devices were used. These tests method are discussed in detail in section 3.3.4. The sub base and asphalt layers were tested with the Prima and DCP to measure the layer properties and for comparison with on-site measurements to ensure the sub-surface layers could be compared to the values measured on-site. Additionally, the shockpad and carpet layers were tested on the laboratory floor to establish if there was a difference between it and the prepared box surface.

The laboratory provided an opportunity to test the different surface configurations under simulated conditions. The main issue was the influence water/moisture had on the various equipment and performance characteristics of the pitch system, therefore the following method was employed to identify the influence of water. Firstly the samples were tested dry, then fully saturated (i.e. the carpet sample fully submerged in water ($23^{\circ}\text{C} \pm 2^{\circ}\text{C}$) for 30 minutes (as specified in the FIH handbook of performance requirements, 1999). Testing of the carpet was conducted immediately after it was removed from the water, and repeated after 20 and 40 minutes. This gave a contrast between dry, fully saturated and two degrees of partial saturation. All test methods could be completed at 16 locations within a five minute period, apart from the AAB for which only 8 locations could be recorded within a satisfactory time period, therefore every second test location was measured. In field hockey, a game half lasts 35 minutes, so the longest time between irrigations will be in the region of 40 minutes, therefore a period of 40 minutes was considered ample to test the carpet with all realistic moisture contents.

3.3.3 Fieldwork at Completed Pitches

Six pitches were evaluated on two occasions (a year apart) for mechanical behaviour, the test equipment and procedures used are described below. Pitch construction specifications and FIH accreditation results were acquired from the relevant organisations and evaluated prior to testing and then again in relation to the measured data. Pitch age, maintenance regime and usage level were all obtained from pitch owners/operators to facilitate understanding of how these factors could influence this pitches behaviour. Furthermore, environmental conditions were monitored throughout testing to be consistent and supplement the data from the laboratory study.

Pitch selection was based on several criteria. Firstly, feedback given by players during interviews and questionnaires were analysed and a shortlist of suitable pitches were identified based on perceived playing characteristics and regular use in the English Hockey League. The rationale behind player familiarity was to ensure relationships could be established between perceived and mechanical behaviour. The shortlist was then reduced to pitches that conformed to FIH 'global' standard accreditation. From the remaining list priority was given to the pitches with available construction specifications to facilitate understanding of the effects of different constructions. Derived from the criteria above the pitches chosen for field testing were Loughborough University, Highfields, Cannock, Bowdon, Belle Vue and Old Loughtonians.

Due to constraints on equipment availability and site accessibility/time it was not always possible to complete the desired amount of testing. In April 2003 access to the AAB was restricted to one week. Therefore, a method had to be employed to ensure all sites were visited and adequate testing performed. Consequently, the same procedure as the FIH handbook (1999) recommendation was used. Spot tests were made at five locations (see Figure 3.5) and repeated three times radially at each position to test for local variability. The FIH sport tests are specifically based on pitch usage, with central locations considered high usage and wing locations low usage. For the second series of site visits in March 2004 equipment availability was not so restricted, therefore it was decided to evaluate the pitches with an improved global coverage and obtain a larger set of data over the entire pitch. Therefore, a grid system was produced (see Figure 3.6) with 25 test locations evenly spread across the entire pitch. This provided comprehensive

coverage of the pitches and at each location three repeat tests were performed to monitor device repeatability and local pitch variance.

The FIH handbook of performance requirements (1999) states that a pitch must be thoroughly watered as it would be for a competition match, and then re-watered every 45 minutes, if necessary, to maintain competition playing conditions. The efficacy of the irrigation system, wind, draining speed and evaporation rate can all influence the quantity of water on a pitch during testing. The six pitches tested had similar irrigation systems which consisted of six watering cannons (see Figure 3 7). The range and spray dispersion of each cannon can lead to non-uniform irrigation which could be amplified significantly by environmental conditions including wind. An alternative to using the irrigation system would have been to manually irrigate each location with a known quantity of water prior to testing. However, this method would not have corresponded to 'typical' match conditions, would still be liable to evaporation and drainage differences between pitches and could have given unrepresentative data which may be unsuitable to link with players' perceptions of the pitch. Consequently it was decided to test each pitch under typical match conditions rather than to try to force a known quantity of water into each test area. Prior to testing each pitch was subjected to one full cycle and left for 5 minutes to allow the excess surface water to drain (as it would be before a game). This was followed by 40 minutes of testing (approximately half a game of field hockey) before the irrigation cycle was repeated to ensure the pitch remained watered to a similar level as would be expected during a game. This procedure was followed until the entire pitch had been evaluated with all test equipment.

3.3.3.1 FIH Performance Standards

Where appropriate each test was compared to the FIH performance specifications. Furthermore, accreditation data was acquired for each pitch (except Old Loughtonians) which enabled direct comparison. This was combined with analysis of the construction specification.

3.3.4 Test Equipment Details

The sections provide details of the test equipment and methods used throughout the testing during construction, in the laboratory and on completed pitches. The same procedure was used in the laboratory and on site to ensure comparison between the devices was appropriate.

The Prima is a relatively recent development, and is very similar in specification to the TFT (Fleming *et al* , 2002b) It consists of a falling mass of either 10 or 20 kg that impacts the bearing plate via an arrangement of buffers, which can be altered to control the pulse duration (typically 15 – 25 milliseconds). The standard plate size is 300 mm, but two alternatives are available to manage the contact pressure and depth of influence. It has a load range of 1 – 15 kN, i.e. up to 200 kPa with the 300 mm diameter bearing plate The Prima measures both the force and deflection, utilising a velocity transducer calibrated to a maximum deflection of 2.2 mm. The velocity transducer is mounted on the ground through a hole in the plate. The versatility of the Prima ensures its efficacy on all layers of the pitch. Currently there is no published data on the effectiveness of the Prima, therefore throughout testing several methodologies were employed for each layer and after initial analysis the most appropriate method was selected. Due to material differences of the constituent layers, several approaches were used including different drop heights and plate sizes. For the formation and sub-base layers, the standard procedure was to perform 3 unrecorded pre-compacts followed by three recorded drops (low, medium and high) thus allowing for interpolation of the results (Fleming *et al* , 2002b). On the asphalt layer the weight was dropped from two drop heights twice, medium and high. As asphalt is a bound material a pre-compaction was not deemed necessary. For the shockpad, a low drop height was required as a higher drop height resulted in overload of the velocity transducer due to a large deflection. Thus a height of approximately 1/3 the shaft length (to give a contact pressure of 40 kPa) was used and repeated six times at each location.

The GDP comprises a total mass of 25kg, and a falling mass of 10kg that loads through a rubber buffer onto a bearing plate of 300mm diameter. Within the plate is an accelerometer. The drop height of the falling mass is fixed, which provides a peak of 7.07 kN (i.e. 100 kPa contact stress) when calibrated on a standard (manufacture's) foundation (Fleming *et al.*, 2002b) The load pulse duration is stated as 18 ± 2 milliseconds, and can reputedly measure a stiffness modulus in the range of 10-225 MN/m². The recommended operational procedure for the GDP is six drops on the same spot to provide a single value of stiffness. The initial three drops are termed pre-compaction, to remove any bedding errors, and are not recorded. The deflection of the subsequent three drops are recorded and

an average stiffness is computed. The GDP has an electronic hand-held device to record and store data, which allows for rapid assessment

The Clegg hammer, shown in Figure 3.8, is a lightweight portable impact tester (Clegg, 1976). It records the maximum deceleration upon impact, termed the Clegg Impact Value (CIV), of a 4.5 kg, 2.25 kg or 0.5 kg mass from a drop height of 0.45 m. It has a very small (50 mm) diameter impact area which results in substantial maximum stresses, especially the 4.5 kg model. The load applied by the Clegg is not buffered, thus it has a relatively short contact time in the region of 2 milliseconds (Fleming, 2000) dependent on the surface under investigation. The standard procedure for the Clegg hammer involves 5 manually recorded drops on the same spot, each drop returns a CIV (Clegg impact value). The 4.5 kg hammer was used on the formation and sub-base and the 0.5 kg and 2.25 kg hammer were used on the shockpad and carpet layers. Due to potential damage of the transducer the Clegg hammers were not suitable for testing the asphalt layer. No data exists for comparison on synthetic turf pitches and the Clegg hammer is not currently used by the FIH. Therefore, analysis of the findings were compared between pitches, laboratory set-ups and other devices (mainly the AAB).

The artificial athlete Berlin (AAB), illustrated in Figure 2.10 and discussed in section 2.5.4, consists of a falling mass of 20 kg that is electronically released from a height of 55 mm onto a spring with a stiffness of 2000 kN/m^{-1} that is connected to a test foot of 70 mm. The AAB is widely used in the sports surface industry and was developed in Germany in the early 1970s. The premise is that it reproduces the general force time history found to occur during impact in heel-toe locomotion. However, the validity of its accuracy has been brought into question (Dixon *et al.*, 1999). The peak impact force is measured three times, and surface cushioning is presented as the average percentage reduction of the second and third drops compared with a rigid (normally concrete) surface, as described in DIN 18032 part 2, section 5.2 and the FIH handbook (1999). The size of the AAB and power source makes repeat testing difficult as the battery life of the equipment is approximately 2 hours which enables in the region of 10 – 20 locations to be assessed before recharging is required.

Translation friction was determined by the TRL portable road tester. The equipment was set out and tests performed as specified in the BS 7044-

2.2.1990, 3. The FIH stipulate that the coefficient of friction should be between 0.6 and 1.0 with, at maximum ± 0.1 deviation from the mean. The testing was carried out on a fully irrigated surface and assessed in each reciprocal direction. The modified Leroux which is specified by the FIH was not available for testing, hence the TRL portable road tester was used.

The FIH don't specify a test for rotational traction hence there are no limits of acceptability. However, there is no suitable alternative available to investigate traction and as other sports governing bodies (FIFA, UEFA & IRB) have adopted this procedure it was decided to evaluate its suitability for evaluating field hockey surfaces. BS 7044-2.2:1990, 2 outlines a method to quantify the rotational traction of a sports surface. The test gives a measure of the resistance to movement of the player's foot on the surface. The apparatus consists of a rigid disc, centrally weighted with a total mass of 46 ± 2 kg and having a central shaft to which a torque wrench can be attached, see Figure 3.9. A sports shoe sole, in this case a specific water-based outsole, of 150 ± 2 mm was bonded to the disc bottom. The standard procedure consists of the weighted disc being placed on the test surface. Gradually an increasing force is applied to the torque wrench until the disc begins to slip, ensuring that the disc remains parallel to the surface. The torque is recorded at the point of slippage and the test is repeated for a total of five readings, using a new area of surface for each measurement.

Ball roll distance, or pace, was identified by rolling a ball down a standard inclined plane or ramp. The ball (approved FIH) should roll a prescribed distance within a maximum deviation from the straight line of 3° . The test is repeated in the opposite direction and results are averaged, thus reducing the possible effects of wind, slope, wear, pile bias and smoothness. The test follows the procedure outlined in BS 7044-2.1:1989, 2 and the FIH handbook (1999). The playing surface should be 'wet' prior to testing. The requirement for global standard pitches is between 9 m – 15 m $\pm 10\%$ of the mean.

To determine the ball rebound resilience a vertical drop test was used. The test followed the procedure of the FIH standard (1999) and BS 7044-2.1:1989, 1. It consisted of releasing a ball from a height of 1.5 m (surface to underside of ball) on to the synthetic surface. The height of rebound for global standard pitches should be between 100 mm and 250 mm with a maximum deviation of 20 % from

the mean The FIH specify that the test should be 'wet' and an approved hockey ball be used

3.4 SUMMARY

The primary aim of the research programme was to investigate the perceived and mechanical behaviour of synthetic turf pitches for field hockey The techniques used to achieve these were outlined in this Chapter and were developed and selected based on the findings from the literature review.

It was decided that players perceived pitch behaviour would be obtained via a selection of quantitative and qualitative methods to help understand players requirements and improve awareness of their perceptions. The combination of in-depth participant led interviews followed by two questionnaires were designed to elicit perceptions in a manner suitable to evaluate player perceptions of existing synthetic turf pitches and provide a better understand of their playing requirements. Following on from this, perceptions were elicited for specific pitches and compared with mechanical test data to identify relationships between them

A combination of laboratory and field based methods were chosen to investigate the factors that influence pitch performance. A combination of existing and novel (to the sports surface industry) test devices were chosen as evaluation tools Pitches were assessed for quality control (mainly during construction) and performance. Where possible the results were compared to past data (using the FIH performance criteria) and construction specifications. Furthermore, comparisons were made between laboratory and field data.

The results from the two data collection types are presented in Chapter 4 (player perceptions) and Chapter 5 (mechanical data) respectively. In Chapter 6 a discussion of the results is presented with focus on the relationship between the perceived and mechanical pitch behaviour.

Table 3.1 -Test methods/equipment used on each layer of the Loughborough University pitch during construction

| | | Layer | | | |
|-----------------------|------------------------------|-----------|----------|---------------|----------|
| | | Formation | Sub-base | Asphalt Layer | Shockpad |
| Test Method/Equipment | Prima (300 mm plate) | | | | |
| | Prima (100 mm plate) | | | | |
| | German Dynamic Plate | | | | |
| | Falling weight deflectometer | | | | |
| | Clegg 4.5 kg | | | | |
| | Clegg 2.25 kg | | | | |
| | Artificial athlete Berlin | | | | |
| | DCP | | | | |
| | Hand Vane | | | | |

Table 3.2 - Properties of the synthetic carpets used for laboratory analysis

| | Loughborough University | Belle Vue |
|-----------------------------------|-----------------------------------|-----------------------------------|
| Pile Material | Nylon 6, 6 | Nylon 6, 6 |
| Pile Length | 12 mm | 11 mm |
| Weight (dry) | 3.95 kg/m ² (inc. pad) | 5.10 kg/m ² (inc. pad) |
| Fabrication Method | Knitted and Curled | Knitted and Curled |
| Integral Pad Material & thickness | Polyurethane foam, 3 mm | Polyurethane foam, 6 mm |

Table 3 3 - Test methods/equipment used on each layer of the box during the laboratory analysis

| | | Layer | | | | | |
|-----------------------|---------------------------|-----------|------------|----------|---------|----------------|-------------------------|
| | | Lab Floor | Box Bottom | Sub-base | Asphalt | Shockpad (all) | Synthetic Carpet (both) |
| Test Method/Equipment | Prima (300 mm plate) | | | | | | |
| | Clegg 4.5 kg | | | | | | |
| | Clegg 2.25 kg | | | | | | |
| | Clegg 0.5 kg | | | | | | |
| | Berlin Artificial Athlete | | | | | | |
| | Ball Rebound Resilience | | | | | | |
| | Rotational Traction | | | | | | |
| | DCP | | | | | | |

Table 3.4 - Laboratory testing matrix illustrating the combinations of shockpad and carpet systems measured

| Layer | Asphalt (box) | 6mm S/P | 12 mm S/P | 20 mm S/P | 11 mm LU S/P | PEC Pre-fab S/P | LU Carpet | Belle Vue Carpet |
|----------------------|----------------------|---------|-----------|-----------|--------------|-----------------|-----------|------------------|
| Asphalt (box) | | | | | | | | |
| 6mm S/P | | | | | | | | |
| 12 mm S/P | | | | | | | | |
| 20 mm S/P | | | | | | | | |
| 11 mm LU S/P | | | | | | | | |
| PEC Pre-fab S/P | | | | | | | | |
| LU Carpet | | | | | | | | |
| Belle Vue Carpet | | | | | | | | |
| Layer | Concrete (lab floor) | 6mm S/P | 12 mm S/P | 20 mm S/P | 11 mm LU S/P | PEC Pre-fab S/P | LU Carpet | Belle Vue Carpet |
| Concrete (lab floor) | | | | | | | | |
| 6mm S/P | | | | | | | | |
| 12 mm S/P | | | | | | | | |
| 20 mm S/P | | | | | | | | |
| 11 mm LU S/P | | | | | | | | |
| PEC Pre-fab S/P | | | | | | | | |
| LU Carpet | | | | | | | | |
| Belle Vue Carpet | | | | | | | | |

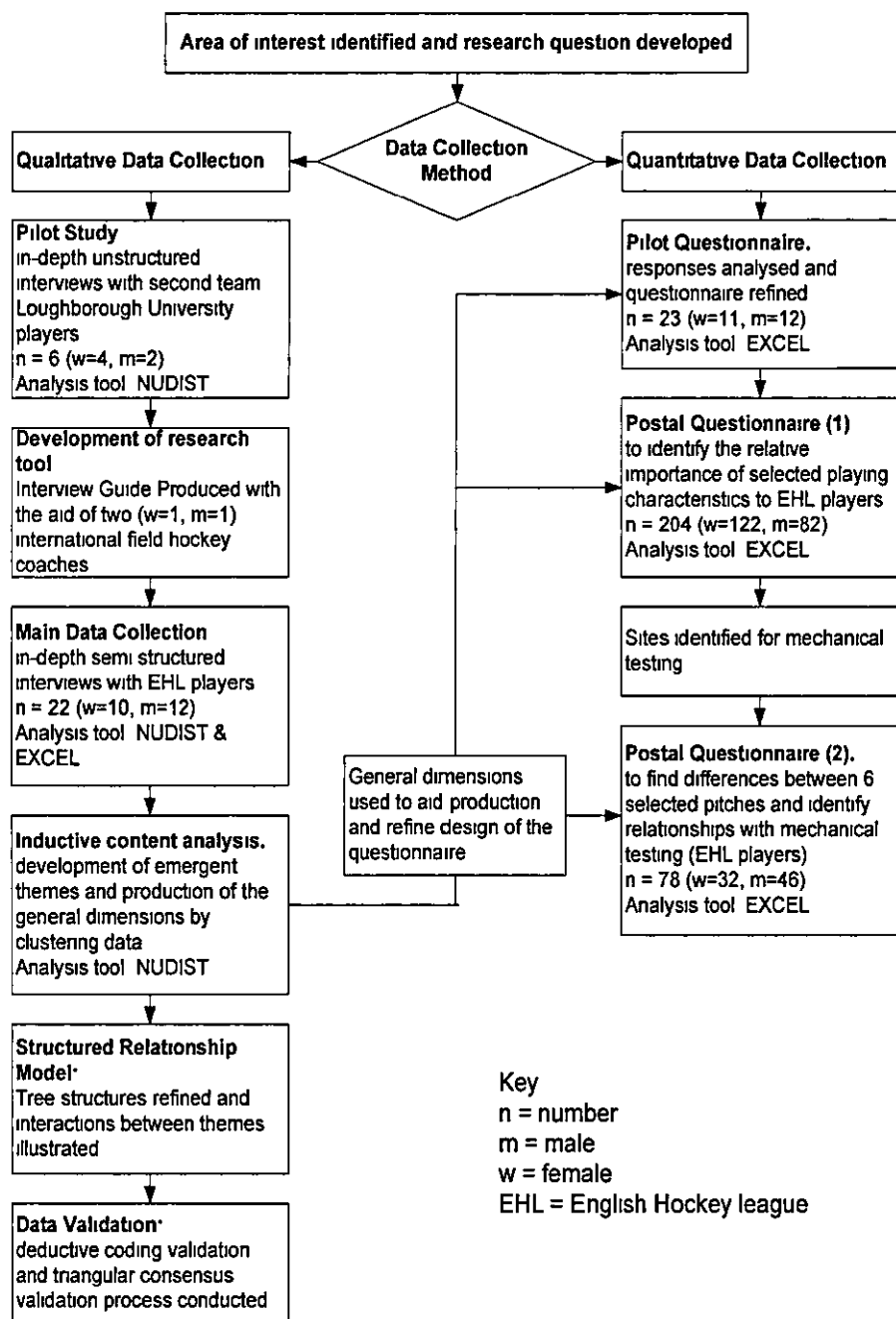


Figure 3.1 - Diagrammatic methodology model for eliciting perceived behaviour of synthetic turf pitches

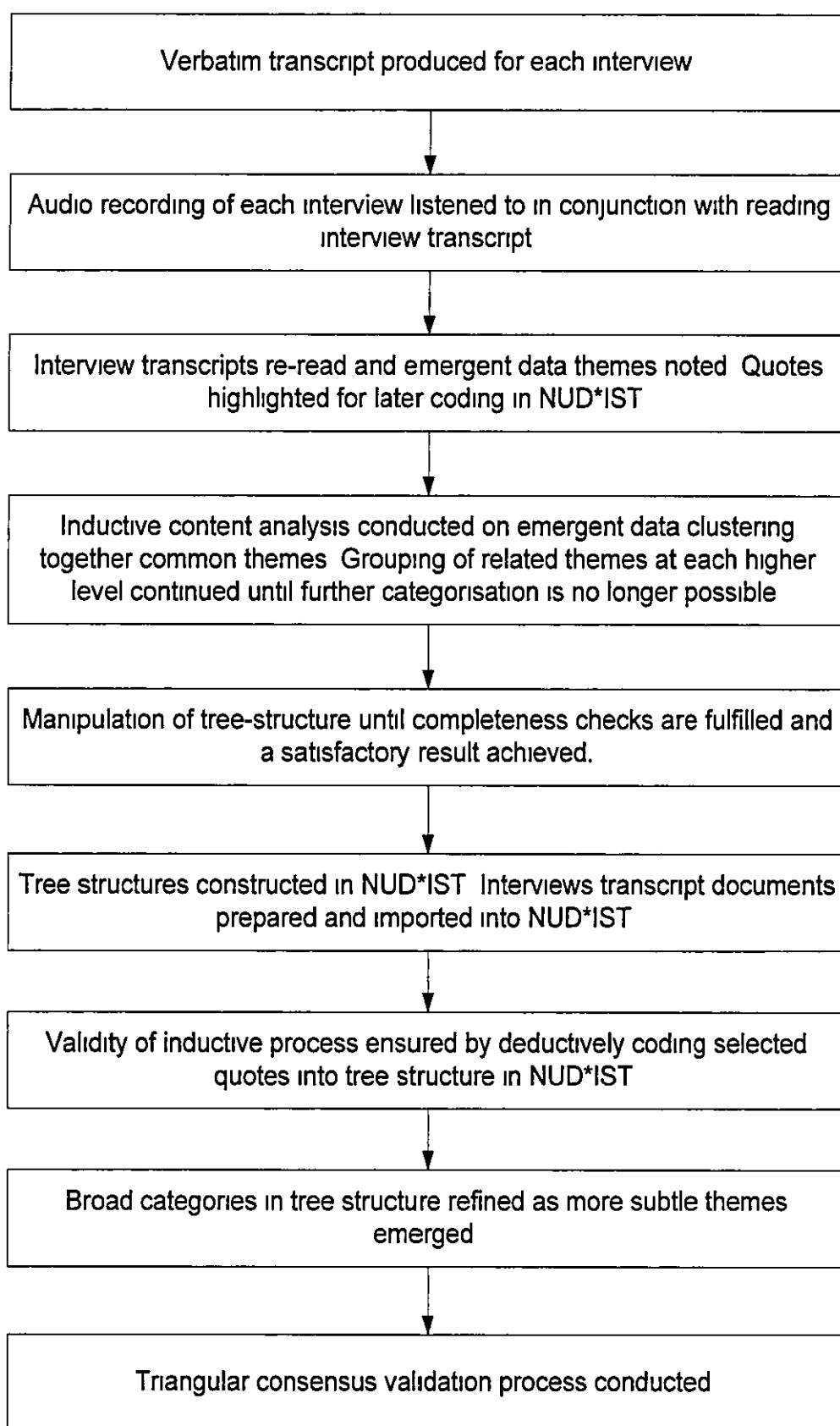


Figure 3.2 - Schematic representation of the interview transcript data analysis procedure

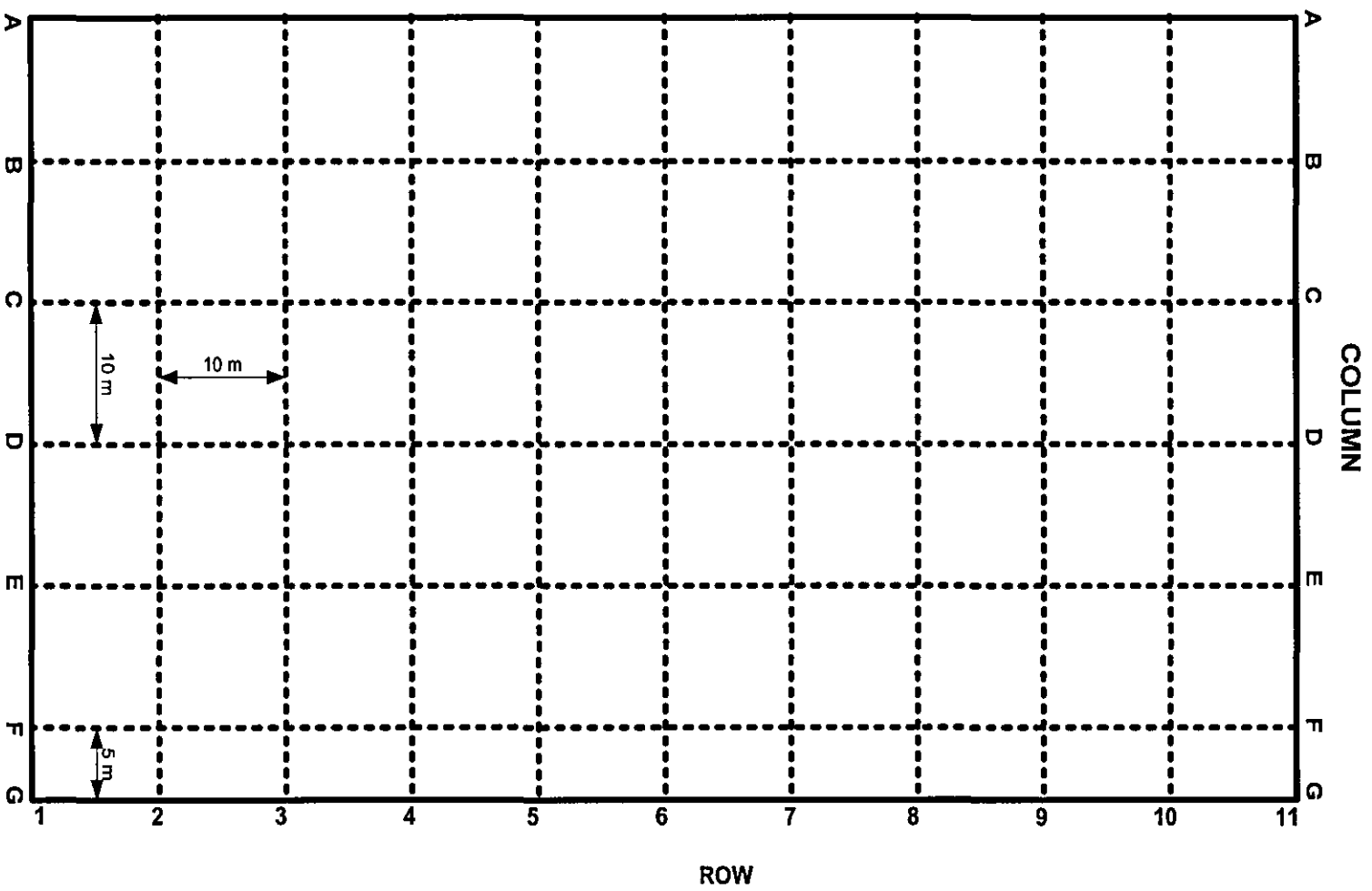


Figure 3.3 – A Grid illustrating each test location for monitoring during construction

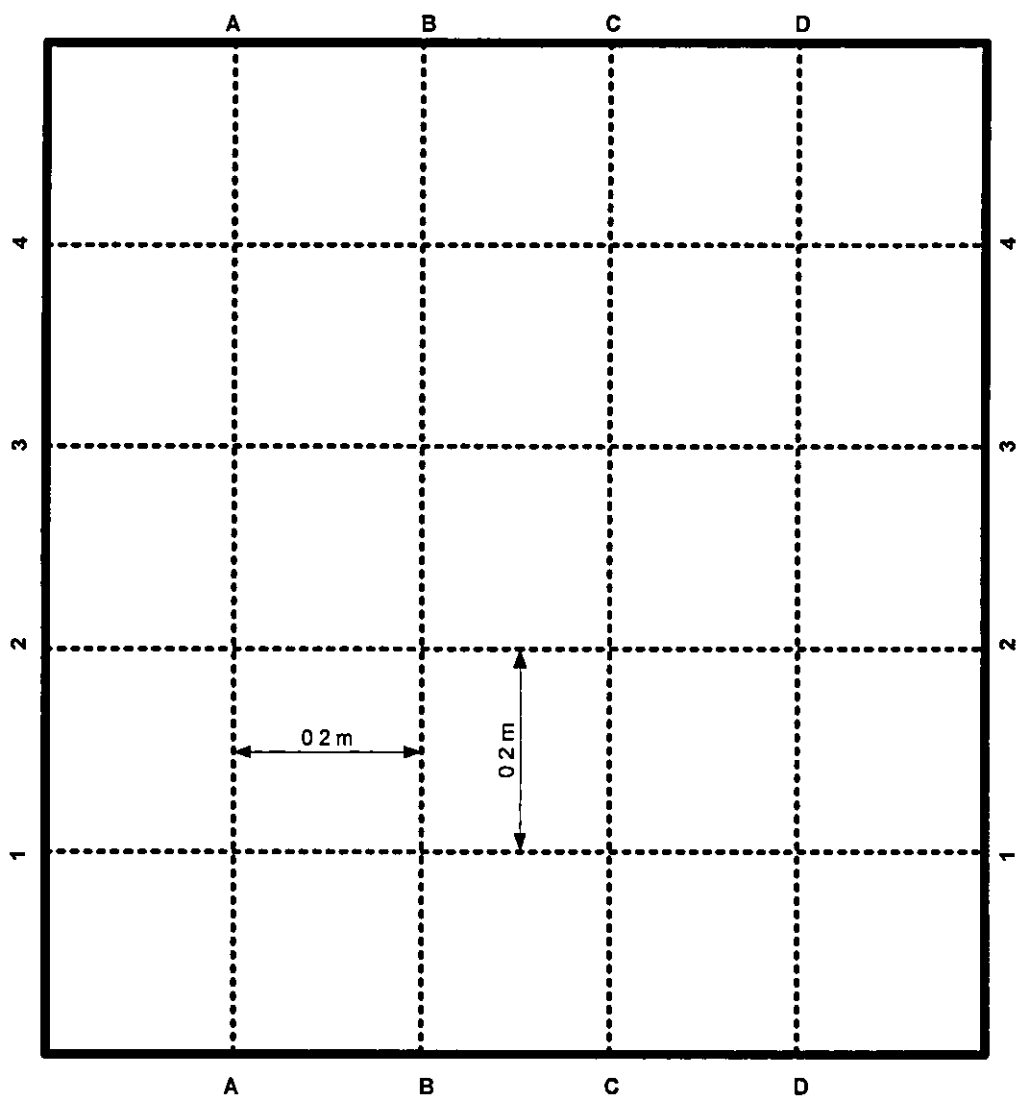
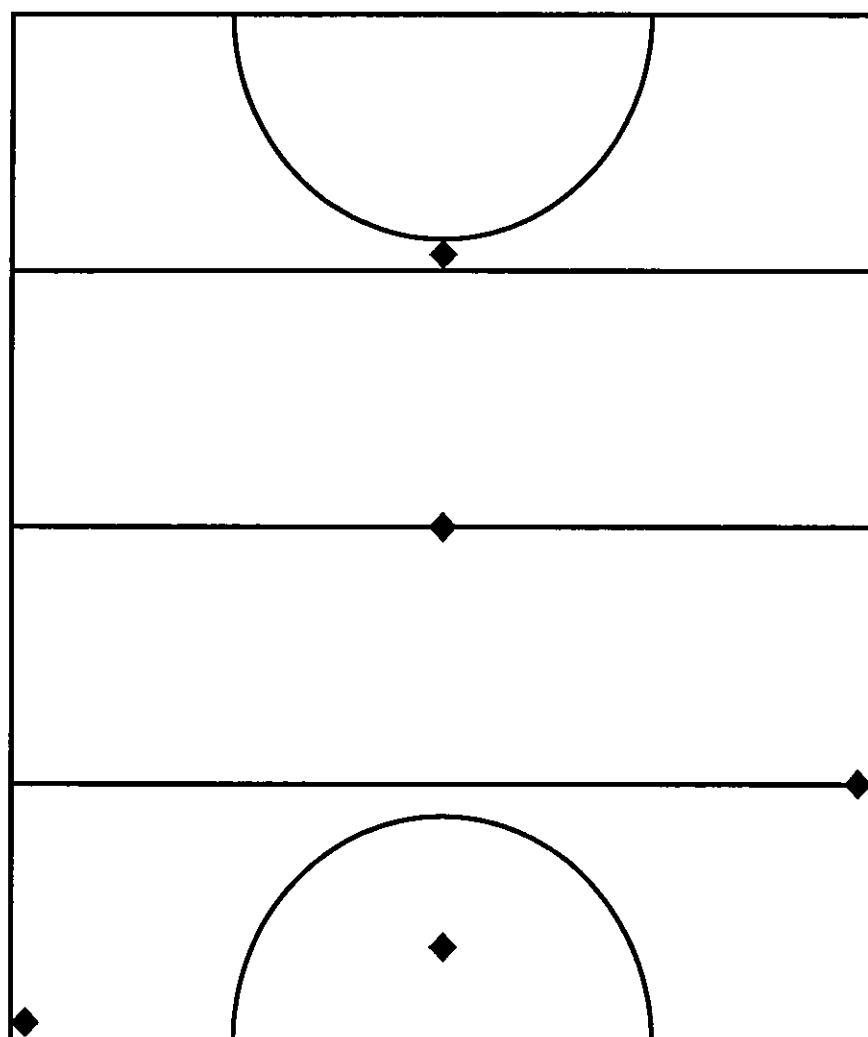


Figure 3.4 - Test grid illustrating each test location for laboratory analysis



◆ FIH Spot test location

Figure 3 5 – Location of the FIH spot tests, FIH Handbook of Performance Requirements (1999)

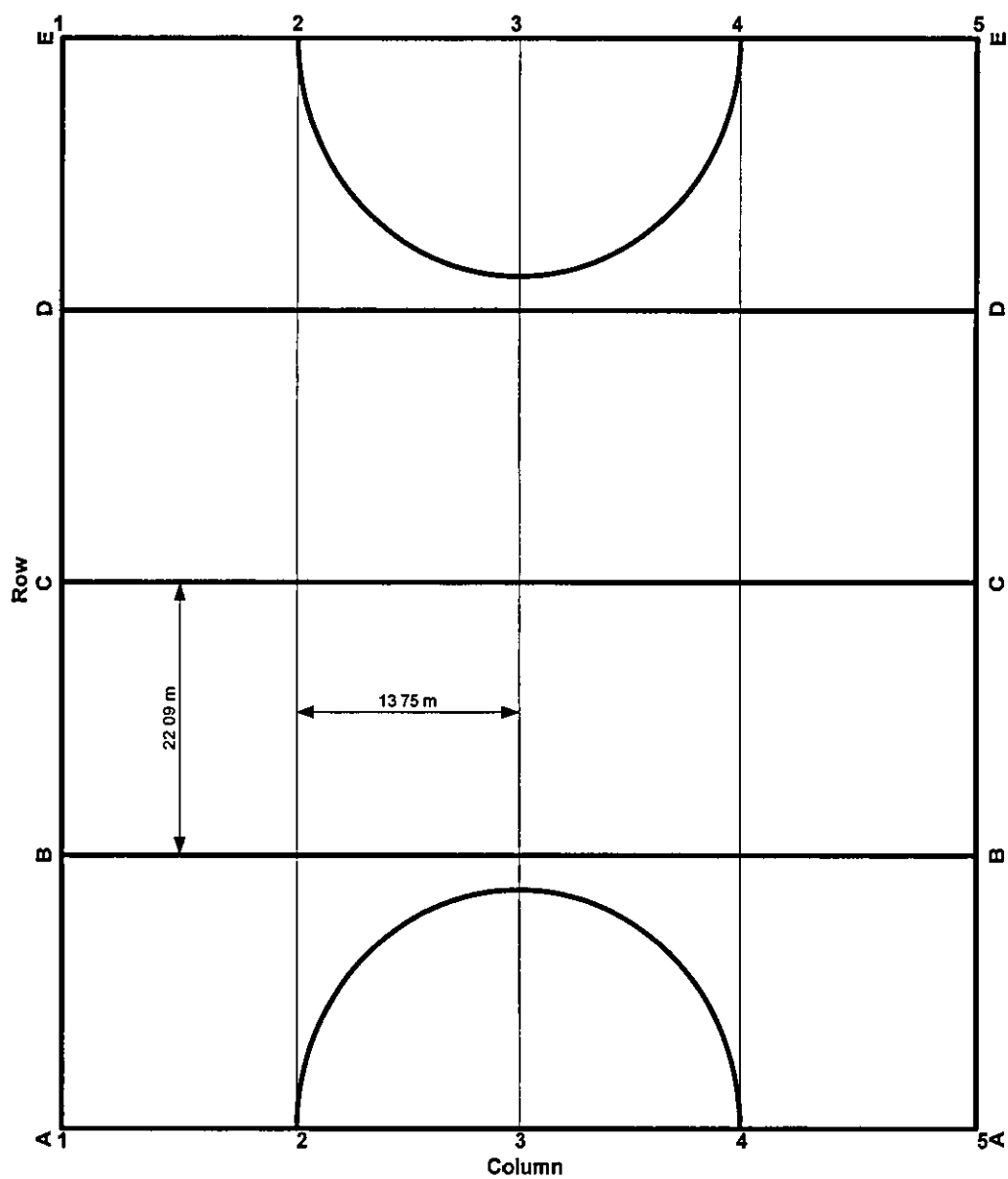


Figure 3 6 - Test grid illustrating each test location for field analysis in March 2004

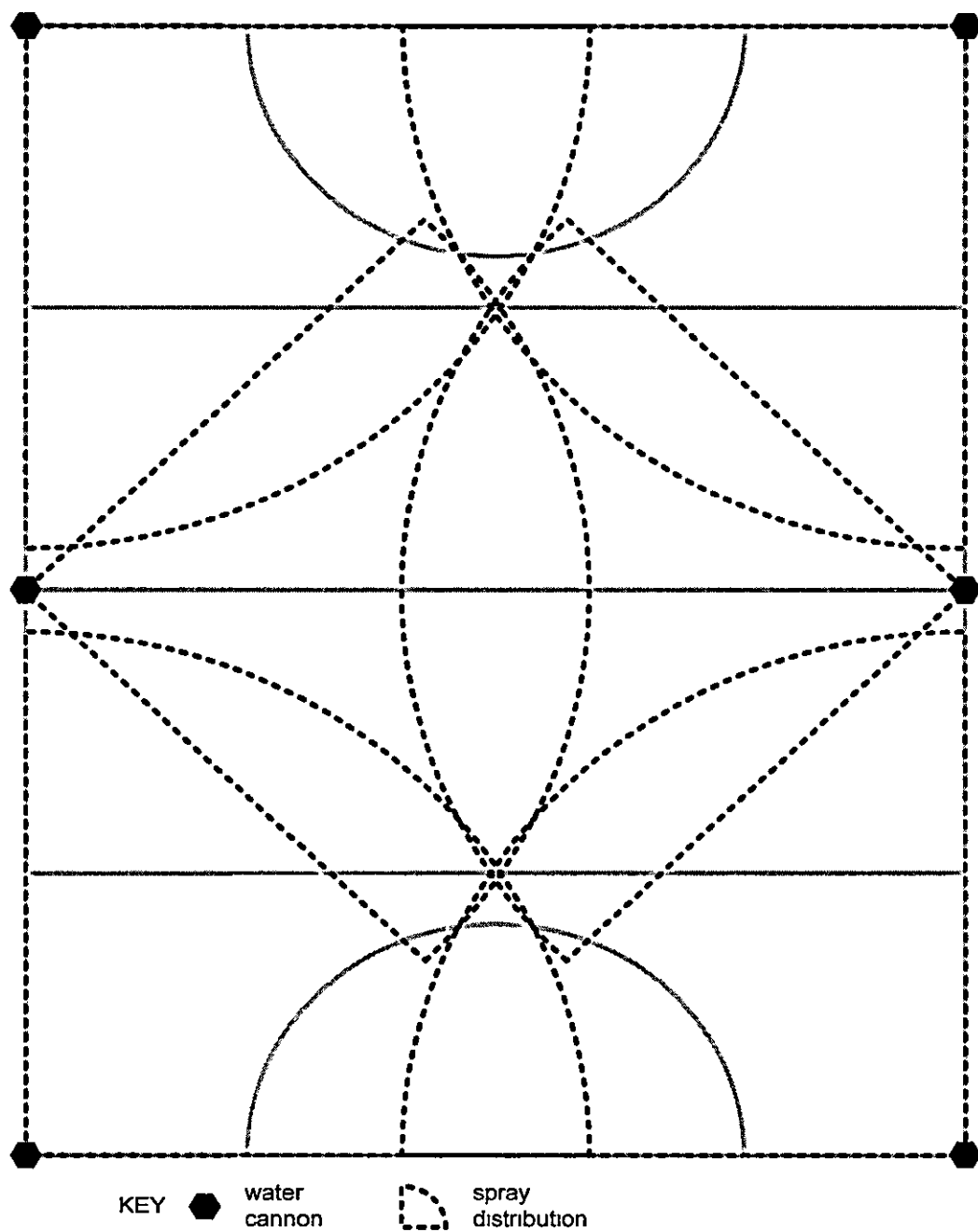


Figure 3 7 - Typical water distribution for a six cannon irrigation system

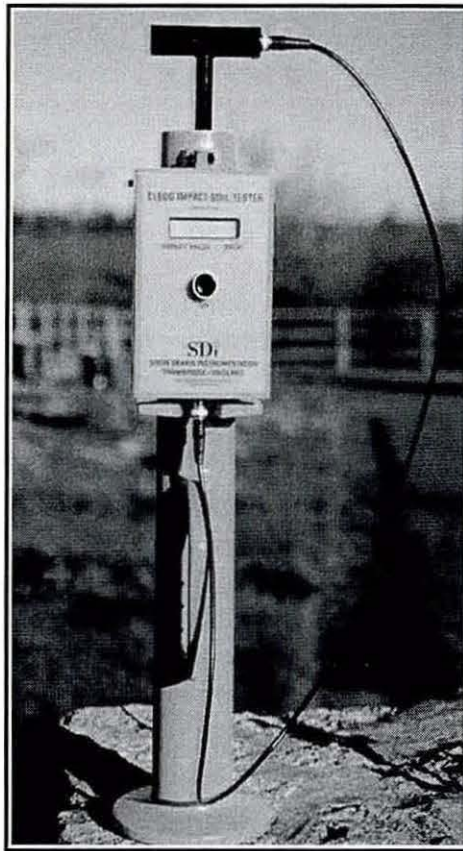


Figure 3.8 – The 2.25 kg Clegg impact hammer

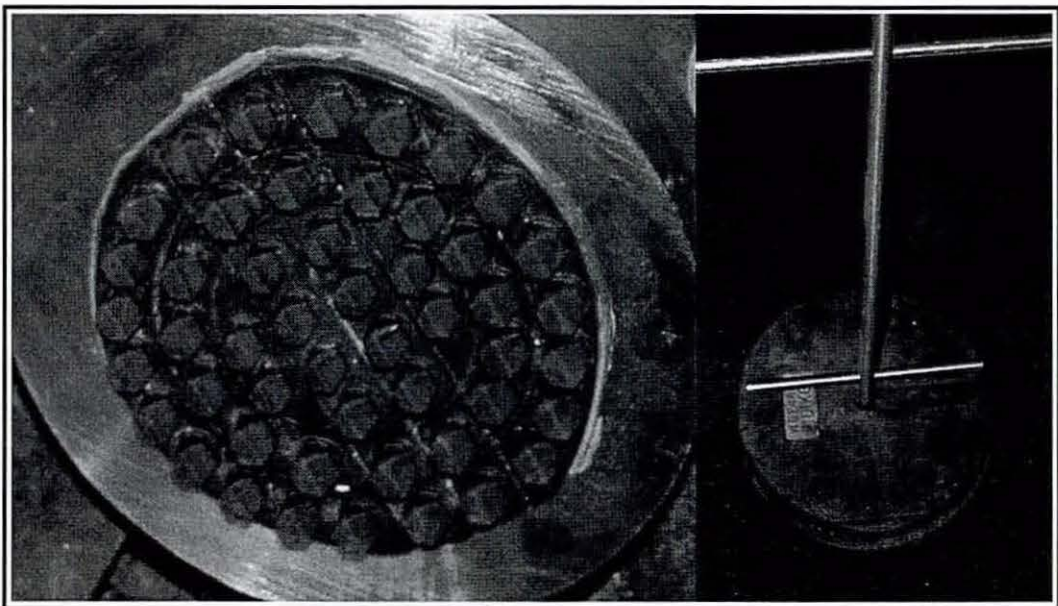


Figure 3.9 - The rotational traction device, bottom and side view

HUMAN PERCEPTIONS OF ARTIFICIAL SURFACE FOR FIELD HOCKEY

4.1 INTRODUCTION

This Chapter is composed of two main sections, comprising the result from the qualitative and quantitative data collection. These methods of data collection were used to obtain players' perceptions of the synthetic turf pitches they use and thus improve understanding of their performance requirements. In Chapter 3 a methodology for eliciting the players' perceptions of field hockey pitches was developed, the results from which are presented herein.

To elicit meaningful unbiased perceptions of a playing surface, an individual subjective analysis was carried out, using interviews and inductive analysis of the recorded player statements. A qualitative analysis of elite hockey players ($n = 22$) was performed to obtain their perceptions after a competitive match. The significant pitch surface characteristics that emerged as part of an inductive analysis of their responses were grouped together and formed five general themes or dimensions. Each dimension was formed from a hierarchy of sub-themes. Throughout the process, relationships between the dimensions were identified and a structured relationship model was produced to highlight each relationship.

During validation of the emergent themes seven playing characteristics were identified for further investigation and the relative importance of each was measured via a questionnaire. The questionnaire was designed to elicit quantitative feedback from field hockey players and enabled a larger sample of participants to be investigated ($n = 204$) and hence provide greater statistical significance.

A second questionnaire was designed to elicit perceptions directly related to the behaviour of specific synthetic turf pitches. The findings from this questionnaire

are presented in Chapter 6 and are related to the measurements of mechanical behaviour which are discussed in Chapter 5, Figure 4.1 illustrates the flow of data between Chapters and how they interact. Following this section Chapter 5 presents the results from measurements of mechanical behaviour for a selection of synthetic turf pitches on site and in the laboratory. This leads to Chapter 6 which discusses the relationship between player feedback and measured mechanical behaviour.

4.2 QUALITATIVE DATA FINDINGS

A total of twenty-two players were interviewed, at most one hour after play to ensure they retained detailed memory of their experiences. The age range of participants was 18 to 32 years and twelve were male. All subjects were from the top two divisions of the English hockey league and they represented an equal range of playing positions. Full verbal consent was given prior to the interview taking place. Twenty-two was considered enough participants as it was evident saturation point had been reached with no new information emerging from the ongoing inductive analysis.

Players responses covered a large range of pitches in the English hockey league including twelve water based and six sand-based. The outcome of each game was recorded, interviewed players were found to have won twelve games, lost six and drawn four. However, no evidence was found within the transcripts to suggest players responded negatively to a pitch they had lost on, or positively to a pitch they had won on.

Five general dimensions emerged from the inductive analysis of the elite hockey players' responses. These were identified as: player-surface interaction, ball-surface interaction, pitch properties, player performance and playing environment. Tree-structures for each dimension were produced and are discussed below in each section. Each tree-structure illustrates how the analysis progressed from player quotes, through levels of clustering, to form the base themes, sub themes and into the eventual general dimensions. Responses regarding 'player-surface' and 'ball-surface' interactions were much more common than the other three dimensions and hence are given more discussion in the text. It was found that some quotes could be placed into more than one base

theme. Hence a structured relationship model was produced to illustrate these links, and is discussed in section 4.2.6.

The terminology used in this Chapter is a direct outcome of the language used by the players. Verbatim transcriptions of the interviews were used during the inductive analysis and consequently the dimensions, sub-themes and base themes are all derived from player quotations; hence, unfamiliar terminology may be presented. However, clarification of some words is given to help the reader understand their meaning when it is not clear within the context of the statement. Quotations are used throughout this sections to illustrate and reinforce points made within the text, similarly example quotations are used in the tree-diagrams. Where possible different quotations have been used within the text from in the tree diagrams to give the reader a broader indication of players' responses. Quotations are presented indented within the text and used to help illustrate observations made during the inductive analysis.

4.2.1 Player-Surface Interactions

Player interaction with a surface has been extensively studied in human biomechanics research, and is discussed in Chapter 2. It comprises human interactions with the surface including running, falling and sliding. Perceptions of the players' interaction with the surface are clustered into three sub-themes: 'surface grip', 'hardness of the surface' and 'abrasiveness of the surface'. Figure 4.2, illustrates the tree-structure for player-surface interaction.

There were large differences between the perceived abrasive qualities of pitches. There was a consensus that low-abrasive pitches allowed players to make more aggressive movements without the risk of abrasion injuries and that pitch wetness had a large influence on abrasiveness. Furthermore, some players identified that during the course of a game the pitch begins to dry and becomes more abrasive. Example quotes are.

"When a pitch begins to dry out towards the end of a game I tend to be more conservative with my movements. There is much more chance of getting an abrasion injury at the end of a game than the beginning."

"Some pitches are much more abrasive than others. Today's pitch was very abrasive, my home pitch is much less abrasive."

The surface grip was identified by players to be influential on playing performance. Three categories were created based on the their responses: 'weather conditions', 'pitch age' and 'type of footwear'. Players highlighted the importance of wearing the correct footwear for the type of pitch and stated that in certain environmental conditions the playing surface grip behaves differently.

"Shoe type is very important for grip I have specific shoes for artificial pitches and don't have as many problems as my team mates who don't have the correct footwear."

"Some pitches have much more grip than others but the amount of rain and water can alter how slippery a pitch is. When a pitch is too dry it can become very sticky [high underfoot grip]."

Surface hardness was described as either a soft/compliant surface or hard/stiff surface. Players' responses relating to 'surface hardness' were diverse and it appeared that many had different opinions as to their favoured degree of 'hardness'. Several players identified 'hard' pitches as a cause of injury. However, soft pitches were perceived to require additional energy expenditure and have undesirable effects on ball behaviour.

"The pitch we just played on was far too hard I can feel my back, its going to be very stiff tomorrow."

"That pitch was very soft, I was exhausted at half time, it felt like it was draining all of my energy."

4.2.2 Ball-Surface Interactions

Perceptions associated with ball interactions with the surface are grouped into three sub-themes 'ball roll', 'ball bounce' and 'ball spin' Figure 4.3 shows the tree-structure for ball-surface interaction. It was found that players perceived large variation between ball interactions from pitch to pitch and also across the same pitch. The theme 'ball roll' embodied all the players' comments about how the ball 'rolled' across the surface including speed, consistency and distance

"The roll on this pitch was much faster than my home pitch The ball rolled across the surface very fast "

"The ball roll on this surface was very consistent and easy to predict. All across the pitch the ball played [behaved] the same."

The 'ball bounce' behaviour was also reported to show a large difference from pitch to pitch. Players responses suggested that there was a significant difference between sand and water based pitches and that a true (consistent) bounce was important for deft stickwork Players' comments encompassed the 'height', 'angle' and 'consistency' of ball bounce

"The ball didn't come up from the surface very much, it stayed low."

"The pitch was not very consistent, the bounce was very unpredictable which made control very difficult."

Two different types of spin were identified, one produced by the player hitting the ball and the other caused by the ball's interaction with the surface. Player generated spin was regarded by most players as unintentional and occurred only if the ball was hit incorrectly or if the ball was stopped suddenly from game action such as a short corner. The majority of players believed that spin could not be imparted on the ball intentionally in order to gain a playing advantage It was perceived that different pitch types considerably affected the amount the ball spun. Players stated that some pitches had more tendency to cause the ball to spin and they suggested that this could be a result of the carpet pile type.

"The ball spins more on some pitches than others due to the carpet type."

"I don't know of anyone who intentionally puts spin on the ball, its just something that happens if you miss-hit it [the ball]."

"When I stop a ball that is rolling fast it sometimes spins, this happens a lot on penalty corners especially on these types of pitch [water based]."

4.2.3 Pitch Properties

This dimension comprises perceptions associated with 'pitch properties', and is shown in Figure 4.4. It is split into five sub-themes, pitch colour, pitch consistency, carpet properties, pitch type and shockpad thickness. The main characteristics players described were attributable to the differences between sand and water based pitches, although many quotes were related to surface consistency and carpet properties.

"The pitch was inconsistent [Wimbledon sand based], it was different at each end. It was like playing on two different pitches."

"Water based pitches are much better than sand based, the game is completely different... faster, more skilful and better quality [on water based pitches] "

The majority of players interviewed played the majority of their games on water based pitches and it was clear from their responses that many believed sand based to be inferior.

"If I had the choice I would always play on them [water based], they are 100 percent better. I can really use my stickwork and the ball bounce and roll is true [consistent]... all new pitches should be water "

4.2.4 Player Performance

The dimension 'player performance' brings together the contrasting themes of the players' feelings towards ability, playing position and past experiences. It is illustrated in Figure 4.5. Players responses were made as to how different playing positions altered opinions of the pitch and how ability and past experiences transformed perceptions.

"I'm a defender so this pitch suited me, our forwards had loads of problems but as a defender I enjoyed playing on it... the ball was very true [consistent] and I could predict everything which made defending easy."

"I'm used to playing on this type of pitch [sand based]. I trained on a similar pitch to this for years when I was younger so I found it very easy to play on."

"I found it easy to play on this pitch [LU water based] but I consider myself a skilful player. Some of my team found it difficult to adapt because it was different from our pitch [Old Loughtonians water based]."

4.2.5 Playing Environment

The players description of environmental issues relating to the pitch are grouped together in the general dimension 'playing environment' which is illustrated in Figure 4.6. Players identified the following factors within the theme playing environment; floodlights, drainage and irrigation

"The water cannons [irrigation system] didn't cover the entire pitch, places were dry The goal mouths and the edge of the 'D's' were especially bad [dry]."

"It was raining when we played and the pitch became very wet, too wet. The water just sat on the carpet, I don't think the drainage could handle that amount of water."

"Some pitches have floodlight that make it difficult to see the ball... the water sometimes reflects [the floodlights] and you can get dazzled."

4.2.6 Structured Relationship Model

The template of semi-structured interview followed by an inductive content analysis highlighted the significant components of a player's subjective perception. However, it did not facilitate exploration (by the investigator) of any possible inter-dimensional relationships. Roberts *et al.*, (2001) proposed the use of a structured relationship model to investigate common themes. This process involved finding links between dimensions the via players' responses. Initially players' quotes were coded into individual themes. However, to preserve the quote's meaning they were kept whole This often resulted in quotes with several themes, which then had to be coded into numerous categories. Take, for example, the following quotation:

“The ball bounced very high, it was probably the thick shockpad... it felt very soft to run on.”

The above quote describes three different perceptions; the ball bounce height, the shockpad thickness and the player/surface impact. Initially, the quote was coded into the base level themes ‘bounce height’, ‘shockpad thickness’ and ‘impact’. However, the quote also suggests the player believes there is a relationship between ball bounce height and shockpad thickness. After further analysis of the data, ten similar inter-dimensional relationships emerged, these are shown in Figure 4.7. These relationships showed an extra dimension to the analysis that could not be achieved by simple tree-structures. Each dimension is illustrated with their sub themes and base themes along with each inter-dimensional relationship to highlight what themes players perceived influenced others. The software NUD*IST facilitated in the formation of each relationship and it provided a search resource to identify links amongst the coded data between each dimension. Several of these relationships are discussed below.

4.2.6.1 The Effect of Shockpad Thickness

Players perceived that the thickness of shockpad affects both the bounce height of the ball and the impact feel for the player. This was perceived by the players by a high ball bounce and soft underfoot impact.

“The pitch was very soft the ball bounced very high it must have been a thick shockpad.”

“It was nice to run on because it was very soft but the ball bounce was very difficult to judge because it was so high.”

Likewise, it was found that players perceived a ‘hard’ pitch to have a low ball rebound height which was perceived to be influenced by shockpad thickness.

“The ball stayed low to the ground, it had very little bounce. The pitch was also quite hard, the shockpad must have been quite thin.”

4.2.6.2 The Effect of Pitch Type

The type of pitch was found to have a large effect on the players perception of surface abrasiveness and grip. Many players suggested that water based pitches

were less abrasive than sand based pitches, but that sand based pitches provide better grip.

“Sand-based pitches are very abrasive, if you fall you are likely to get a friction burn whereas water-based pitches you can dive around without getting any burns.”

“Our home pitch is sand, you get much more grip there than you do here [LU]. The water makes the pitch much more slippery, but then again, it's much less abrasive too.”

4.2.6.3 Factors Affecting Ball Roll

Players responses indicated that there are two main factors that influence ball roll, pitch consistency and carpet pile. Several players made reference to the effects carpet pile has on the roll of the ball, suggesting that a dense pile reduces the roll distance/speed of the ball.

“The pile was very thick and dense, it really slowed the ball down.”

“. the ball played very slow today, the pile was quite thick and the ball kept slowing down when it ran over it ”

Players described the effect of pitch consistency on ball roll. A consistent pitch was deemed to provide the ball with a ‘true’ ball roll.

“The pitch was true [consistent], the roll of the ball was predictable and easy to judge.”

4.2.6.4 Factors Affecting Ball Bounce

The characteristic ball bounce was identified by players to have an influence on game speed. Players identified a reduction in game speed as the result of a high ball bounce. A high bounce took longer to get the ball under control and hence increased the time between passing or shooting. Conversely, a low bounce was perceived to increase game speed as it was quicker to bring the ball under control.

"The bounce was low, it made the game fast... I could control the ball much quicker than on my normal pitch [Bowdon] and get a shot in much quicker."

4.3 QUANTITATIVE DATA FINDINGS

The next phase of the study was to identify the relative importance of selected themes that emerged from the inductive analysis of interview, to quantify the players responses using an approach that would facilitate direct comparison and statistical analysis. Consequently a questionnaire was designed that could quantify the relative importance of each theme to the players and facilitate contrast between them. Furthermore, the requirements for playing characteristics were obtained by eliciting preferences for each theme. From the inductive analysis seven characteristics were identified for further investigation; 'height of ball bounce', 'underfoot grip', 'surface pace', 'amount of ball spin', 'surface hardness', 'ability to perform skills' and 'surface uniformity'. The terminology used to describe each playing characteristic was derived from player quotations, hence the risk of players misinterpreting the questions was reduced as the language used was familiar to them. A copy of the questionnaire is included in Appendix B

In total 400 questionnaires were distributed to players in the top two division of the English hockey league (the same population of players that were interviewed) 204 questionnaires were returned (122 female and 82 male respondents) from 14 clubs, this represented a response rate of 51 %. It was found that they had a mean age of 23.8 ± 5.2 (SD) years. On average they trained 6 times per week with a range between 4 and 12. The vast majority of participants used surface specific footwear (92.6 %) and the remaining players wore either 'fell' running shoes or cross trainers. 19.8 % of the participants reported at least one surface related injury resulting in more than 7 days rehabilitation. The most common injuries included serious abrasions (4.5 %), knee and ankle ligament damage (7.9 %), periostitis (shin splints) (3.0 %) and lower back problems (3.5 %) Murtaugh (2001) published an epidemiological study on the injury patterns among North American high school field hockey players (N = 158), and also identified the most common type of injuries (39.7 %) were ligament sprains to the knee and ankle.

Participants were asked to complete information on their home playing surface and to give details of other synthetic turf pitches, 3 which they perceived good

surfaces and 3 poor. From this information 6 pitches were identified for further investigation of their mechanical and perceived behaviour, which is discussed in Chapters 5 and 6.

A comparison between male and female responses to each characteristic was conducted to identify any significant differences between the genders. Using an ANOVA and selecting a P-value of less than 0.05 for rejecting the null hypothesis, no significant differences were found between their responses. Similarly, it was found after statistical analysis of playing positions (between goal keepers, defenders, midfield and attack) that again there was no significant ($P > 0.05$) differences between their responses.

The two main sections of the questionnaire were split into obtaining the relative importance and player preference for each characteristic. Table 4.1 shows a summary of the findings for both, each section is presented and discussed below in more detail. For each theme, players were asked to rate their perception on a scale of 1 – 7, therefore for importance, 1 would indicate that characteristic as 'not important' and 7 'extremely important'. Likewise for player preferences a similar scale was used but the ranking was oriented towards ideal behaviour, e.g. for ball bounce 1 would indicate a preference for a 'very low' bounce height and 7 would denote a preference for a 'very high' bounce height. To ensure players understood the orientation of the scale descriptors were used. Each descriptor was obtained from the inductive analysis to reduce the risk of player misinterpretation.

4.3.1 Relative Importance

The theme considered most important was 'ability to perform skills' with a mean and standard deviation of 5.80 and 1.06 respectively. Figure 4.8 illustrates the distribution of opinions by a histogram of the results from all 204 respondents. 'Ability to perform skills' is one of the more descriptive characteristics described by the players in that it encompasses a multitude of in-game situations. They expressed that a 'good' surface will facilitate deft stick work and enable them to gain an advantage over their opponents by manipulating the path of the ball. Poor surfaces were considered difficult to demonstrate these skills and were not judged conducive to 'skilful' play.

Following a similar rationale the theme 'surface uniformity' was considered by players to be favourable for high standards of play, it recorded the second highest importance score of 5.71 ± 1.16 . Players indicated that a 'true' or uniform pitch improved their ability to predict the behaviour of the ball and enhanced feel during locomotion. Conversely, non-uniform pitches were perceived by players to be detrimental to performance, often resulting in a 'slower' game (as they required more time to bring the ball under control). Qualitative findings suggested attacking players could gain an advantage over defenders on an inconsistent pitch as the surface was more difficult to 'read' or predict and often led to defensive indecision from which an attacker could benefit. Subsequently, an inconsistent pitch could be preferred by attacking players. However, no statistical difference was found between the responses from attacking and defending players.

With a mean rating of 5.61 ± 0.86 , the characteristic 'surface pace' was regarded as the next most important with over 90% of player responses over 5. A standard deviation of 0.86 shows the majority of players were in agreement, illustrated by the small spread in Figure 4.9.

'Height of ball bounce' was also considered important with a mean rating of 4.57 ± 1.34 . However, a standard deviation of 1.34 suggests that some players were not in agreement hence this characteristic can be considered more specific to the individual, this is highlighted in Figure 4.10, which illustrates a large spread of responses that appear more normally distributed. It was considered that a large disparity in responses was due to different requirements for each player. Inductive analysis suggested that some players did not consider the rebound height as important as the consistency of the surface which reinforces why players rated 'surface uniformity' more important than 'height of ball bounce'.

Figure 4.11 illustrates the theme 'surface hardness' which has a mean rating of 4.82 ± 1.16 . The shock attenuation properties of the surface are considered vital for its biomechanical influence on the player (Nigg, 1987). However, the player may not be aware of this or attribute the influence of hardness to footwear rather than the surface. Alternatively, they may consider 'surface hardness' a comfort factor and not directly related to performance and consequently not as important as other factors such as 'surface pace' or 'surface uniformity'.

'Underfoot grip' was given a mean value of 5.23 ± 1.01 and its spread is shown in the histogram Figure 4.12. Like 'surface hardness' it was considered very important by the participants but not as important as 'surface pace', 'surface uniformity' or 'ability to perform skills'. Players may have also considered the influence different footwear has on 'underfoot grip' which could have reduced its relative importance.

'Ball spin' was considered the least important theme by the majority of players, with a mean value of 3.72, it also had the largest variance of responses with a standard deviation of 1.39, the spread is shown in Figure 4.13. 70.8 % of players rated surface spin as 'moderately important or lower' indicating that it was not important to the majority of players.

4.3.2 Player Preferences

Players' preferences for 5 surface characteristics were elicited using the questionnaire, including 'height of ball bounce', 'underfoot grip', 'surface pace', 'surface hardness' and 'ball spin'. Table 4.1 shows the mean and standard deviation for each characteristic and is illustrated in Figure 4.14.

The preferred 'height of ball bounce' was very low with a mean of 1.88 ± 0.86 . Figure 4.15 highlights the small spread of opinions which indicates that the majority of players were in agreement. Low bounce was considered by players to increase game speed, as they could bring the ball under control quicker than on a pitch with a high bounce height. 94.1 % of the players sampled described their preferred 'height of ball rebound' to be either low, very low or extremely low.

With a mean of 6.08 ± 0.88 the preference for 'surface pace' was 'very fast'. The small standard deviation indicates players' opinions were similar which is shown graphically in Figure 4.16. 97.6 % of players indicated a preference for fast, very fast or extremely fast. This clearly demonstrates a strong preference towards fast 'surface pace'.

In field hockey it is important to optimise the balance between ensuring friction/traction is high enough to facilitate efficient movement but low enough to prevent excessive resistance and hence injury to the athlete. The players' responses reinforced this with only 7.3 % stating a preference for 'extremely' low or high. The majority of players' preferences for 'underfoot grip' were spread

between 'average' to 'very high' (illustrated in Figure 4 17) A mean of 4.98 ± 1.00 indicates that a 'high' amount of 'underfoot grip' was deemed preferable by the majority of players.

'Surface hardness' (Figure 4.18) had a mean of 3.51 ± 1.08 which indicated that the majority of players neither preferred a hard or soft surface but a compromise with 83.9 % of the players selecting a mid-range category (soft, average or hard) and only the remaining 16.1 % selecting the other options (extremely soft, very soft, very hard and extremely hard). It has been shown that a hard surface can result in impact injuries (Nigg & Yeadon, 1987; Shorten, 2000) and a soft/compliant surface can increase energy expenditure (Bartlett, 1998; Nigg, 1990). Therefore, players preference for a mid-range surface is understandable.

The preference for 'ball spin' is very low with a mean of 2.56 ± 1.26 , this indicates that players prefer 'extremely low' to 'low' ball spin with 72.2 % of players selection these options. There was a larger variation of responses indicated by a standard deviation of 1.26 and illustrated in Figure 4 19.

4.4 DISCUSSION OF PERCEIVED FINDINGS

This section provides a summary of the perceived findings from the qualitative and quantitative data collection. The combination of the two data collection methods allowed an in-depth examination of players perceptions. The interviews made it possible for the players to express what they felt was important in their own words and facilitated the appropriate design of a questionnaire able to identify the relative importance and preference characteristics for each theme that had emerged from the players own perceptions.

Overall the majority of players considered a 'hard' pitch with a 'low' ball bounce facilitating 'fast' game speed with a high degree of 'underfoot grip', little or no ball spin and a moderate 'hardness' as their preference. Furthermore, the players identified 'surface uniformity' the most important playing characteristic and a surface conducive to skilful play was also very important.

Comparing the players' perceptions of their own performance and the game outcome with their opinion of the surface they had just played on led to the conclusion that they did not necessarily attribute the quality of the surface to the

result of the game or their own performance. It was often stated that the reasons for poor performance or result were related to the player 'not being used to' playing on the surface rather than a 'poor surface'. Conversely, players often criticised a pitch they had won on and praised a pitch they had lost on. Attribution theory suggests that it is in human nature for the players' 'causes' given for losing a game are more likely to blame pitch problems than the players' own personal shortcomings. However, from the acquired data it is difficult to either support or reject this assumption

It became evident that most players had strong opinions regarding the two generic pitch types, water-based and sand-based, and that most preferred the water-based surface system. However, players also identified large differences between the variety of water-based pitches they had encountered. Water-based pitches are more common at elite level and became the sole surface type used for premier league games in 2004. Players commented on the difference between some aspects of water-based carpets such as pile height, pile density and the pile material. In general they perceived that greater pile density and length caused more ball bounce but also that more watering was required. Too much ball bounce was often perceived as a negative aspect, making it harder to control the ball during play. Players used the terms 'cheap', 'copy' and 'like a normal carpet' to communicate a dislike of how the carpet looked as well as played. Perceived effects of a 'poor' quality carpet included undesirable ball behaviour and an uncomfortable feeling during movement. However, several attacking players identified inconsistency of bounce as a positive feature as it could lead to uncertainty between defenders facilitating an attacking advantage

The irrigation and drainage of a water-based pitch was seen as very important, and was mentioned by most players. Consistency of water coverage was a clear issue, especially in windy conditions (when it can be blown away) and also as to how well the water was retained on the surface during play (i.e. rate of drainage). Most of the water applied drains relatively quickly. Differential drying across the pitch and 'becoming too dry' was mentioned by many as a potential source for injuries. Furthermore, any inconsistencies with the irrigation system can lead to poor surface uniformity that may give the impression to a player of surface inconsistencies.

The colour contrast of the pitch, the line markings and the ball contrast (relative to the sand) were highlighted by many players as important to them. The main concern was for contrast between the ball and the sand for sand-based pitches, with lighter colour sands causing more problems with white balls as opposed to orange balls. In addition, the white line pitch markings were deemed more difficult to define against lighter coloured sand infill. Few players mentioned floodlighting as affecting the visual pitch qualities, and the comments received were restricted to floodlight height i.e. players suggested low floodlights often 'dazzled' them, making it harder identify the ball and other players. However, it should be noted that the interviews were conducted during day light without the need for floodlights and comments relating to them were from past experiences.

Only a few players made reference to their preference for footwear on the different surfaces. Although this does not diminish the importance of choosing the proper footwear for different playing surfaces, it does bring into question how different footwear may shape perceptions of the playing surface. Footwear has been shown to improve shock attenuation Nigg and Segesser (1992) demonstrated that footwear can significantly reduce the impact to the lower extremities. A few players highlighted a link between injury and surface hardness but none related this to their choice of shoe. However, players often wore the same footwear on each pitch type and thus the only difference to player/surface interaction was the surface; hence the responses are more focused on the surface rather than the footwear. However, it was noted that many players did use different footwear for sand-based and water-based pitches.

The game speed on water-based pitches was perceived to be faster; consequently, many players stated that the skill level needs to be higher to exploit the pitch to its full potential. In addition many skills could be performed that were not applicable to a sand-based pitch, such as advanced stick work and diving or sliding, due to the higher abrasiveness of the sand-based. The few (2 of the 22) players who preferred sand-based pitches have this system as their home pitch. Some players have the ability to adapt better than others to different surfaces (Ferris *et al.*, 1999). The skill level aspect of play was mentioned by many, and it is possible that players with more experience of many surfaces will have learnt to adapt more than those with less experience of different playing surfaces.

The players gave feedback on pitches in the English Hockey League and from these six were chosen for further investigation. These pitches represented a range of perceived playing characteristics. A second questionnaire was designed to elicit specific feedback on the playing characteristics established in this section. The findings from this questionnaire is presented in Chapter 6 and compared with a section of the mechanical behaviour presented in Chapter 5.

Table 4.1 - Summary of questionnaire responses for relative importance and player preference with regard to the key playing characteristics

| Characteristic | Relative Importance | | | Player Preference | | |
|-----------------------|----------------------------|------|------|--------------------------|------|------|
| | Mean | SD | Mode | Mean | SD | Mode |
| Ball Rebound | 4.57 | 1.34 | 5 | 1.88 | 0.86 | 1 |
| Surface Pace | 5.61 | 0.86 | 6 | 6.08 | 0.88 | 6 |
| Underfoot Grip | 4.29 | 1.04 | 4 | 4.98 | 1.00 | 5 |
| Surface Hardness | 4.21 | 1.21 | 4 | 3.51 | 1.08 | 4 |
| Ball Spin | 3.72 | 1.39 | 4 | 2.56 | 1.26 | 2 |
| Surface Uniformity | 5.71 | 1.16 | 6 | - | - | - |
| Skill* | 5.80 | 1.06 | 6 | - | - | - |

* = 'ability to perform skills'

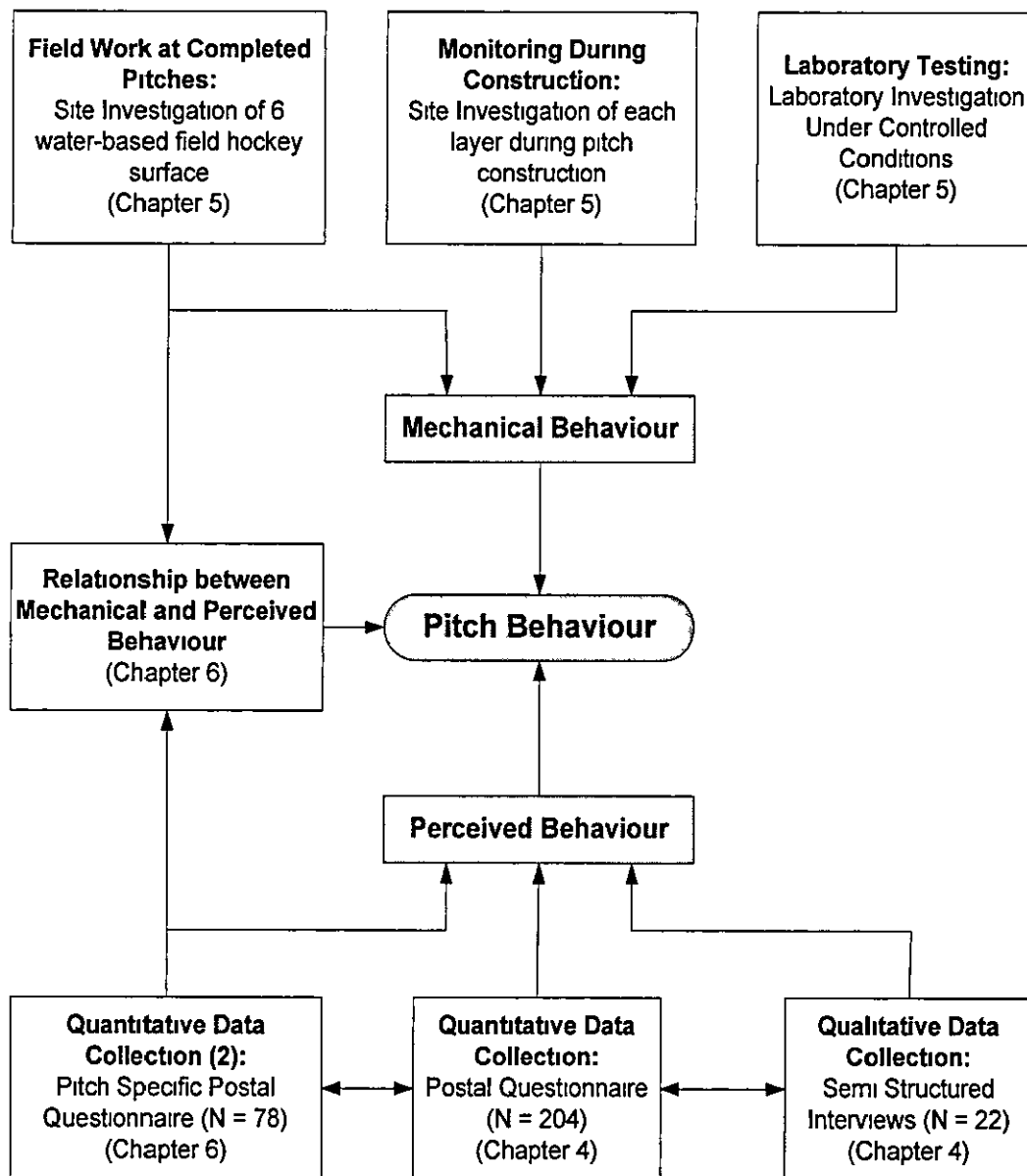


Figure 4 1 - Data flow between perceived and mechanical behaviour of synthetic turf pitches

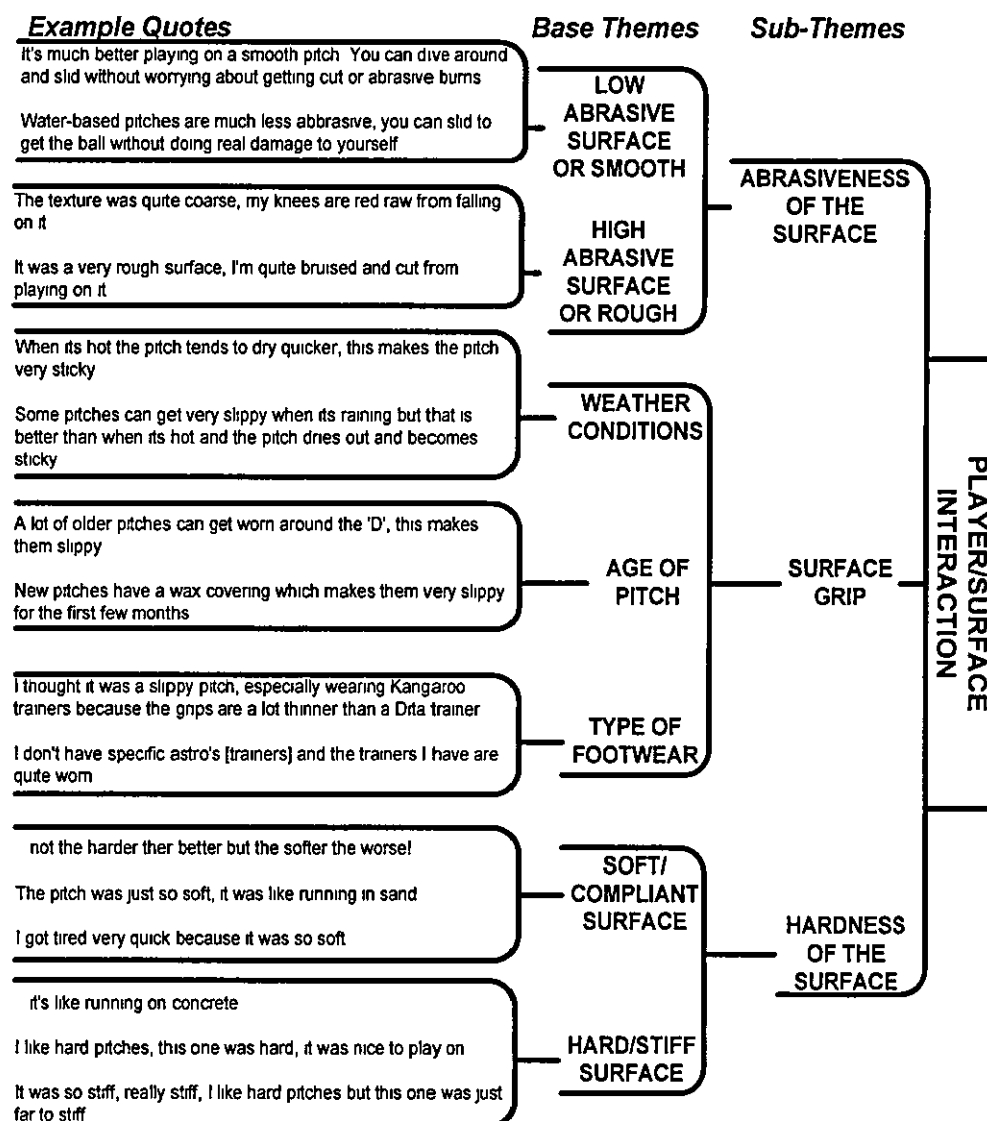


Figure 4.2 - A Tree Diagram to Illustrate the General Dimension Player-Surface Interaction

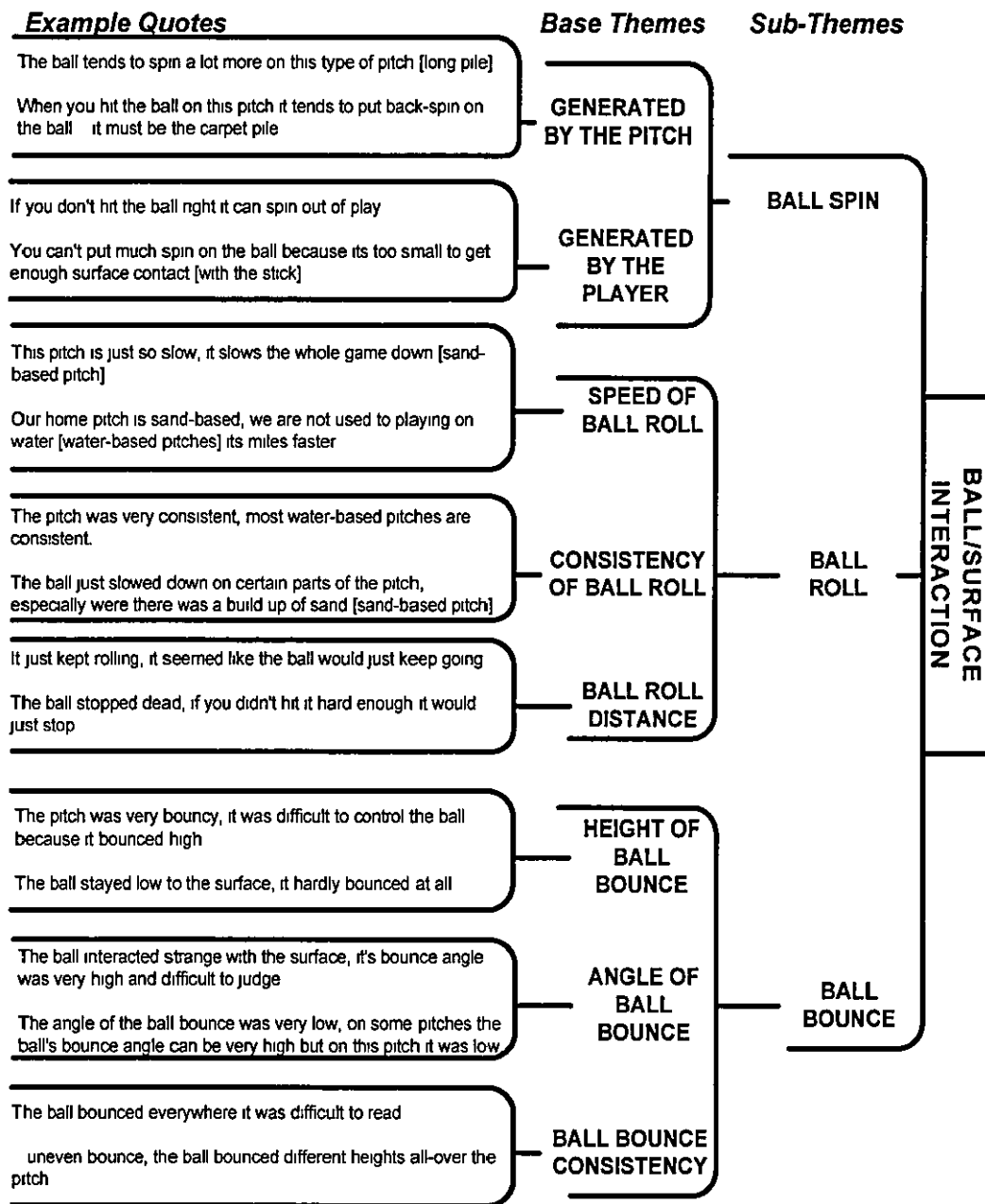


Figure 4.3 - A Tree Diagram to Illustrate the General Dimension Ball-Surface Interaction

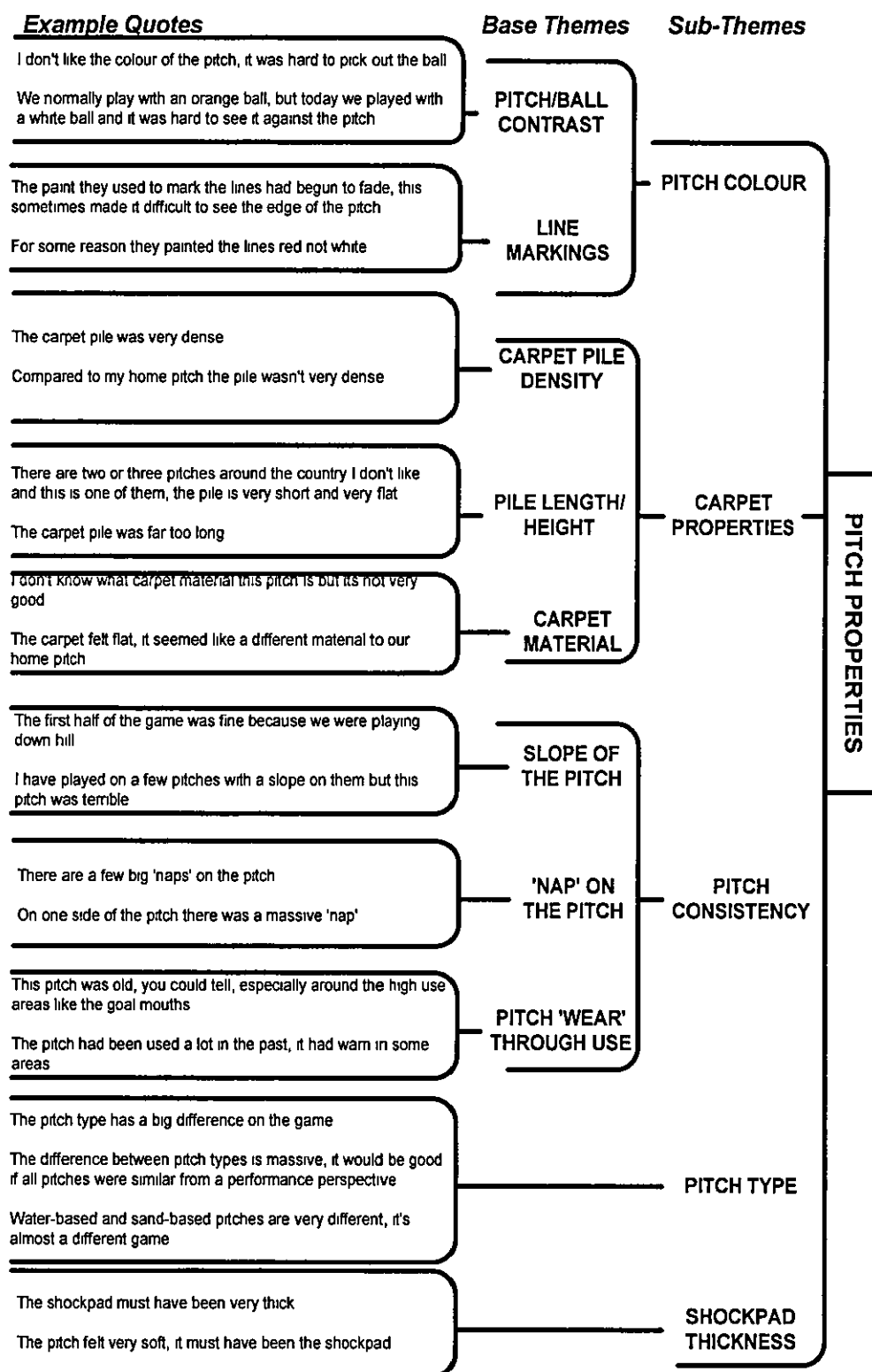


Figure 4 4 - A Tree Diagram to Illustrate the General Dimension Pitch Properties.

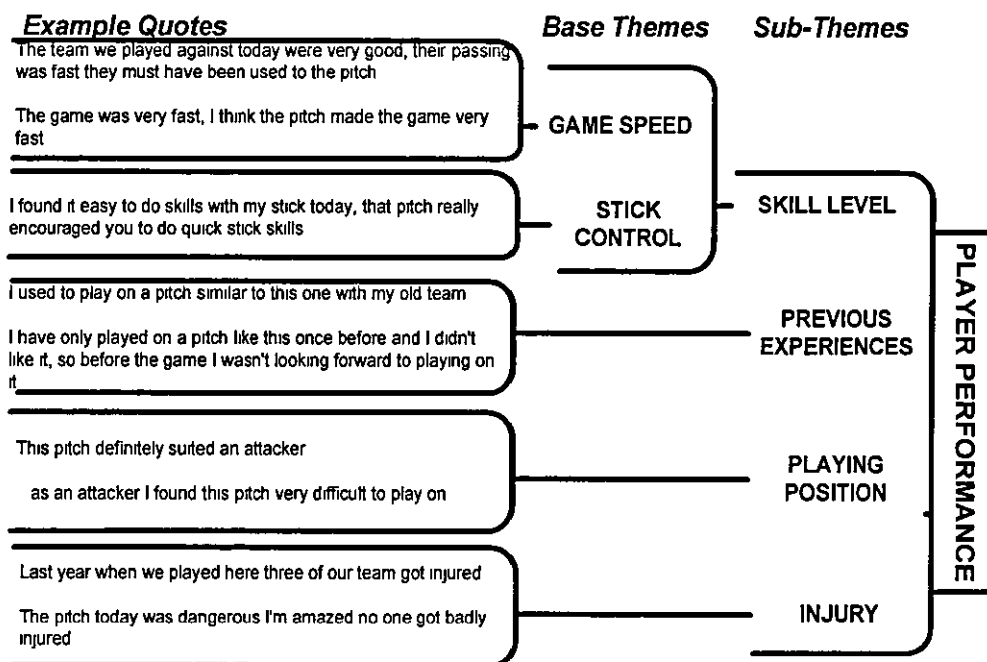


Figure 4.5 - A Tree Diagram to Illustrate the General Dimension Player Performance

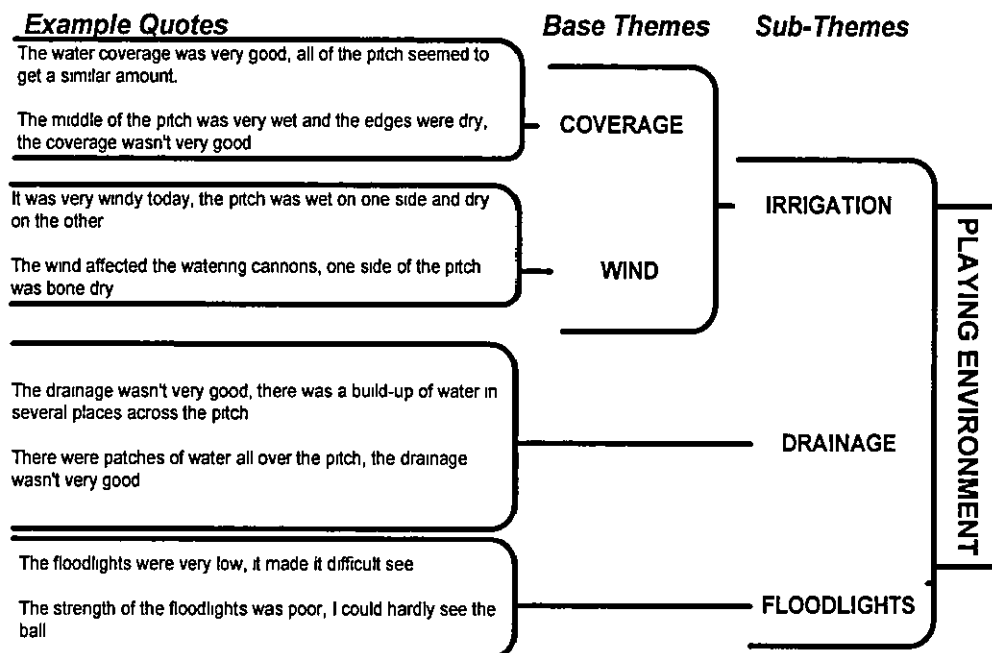


Figure 4.6 - A Tree Diagram to Illustrate the General Dimension Playing Environment

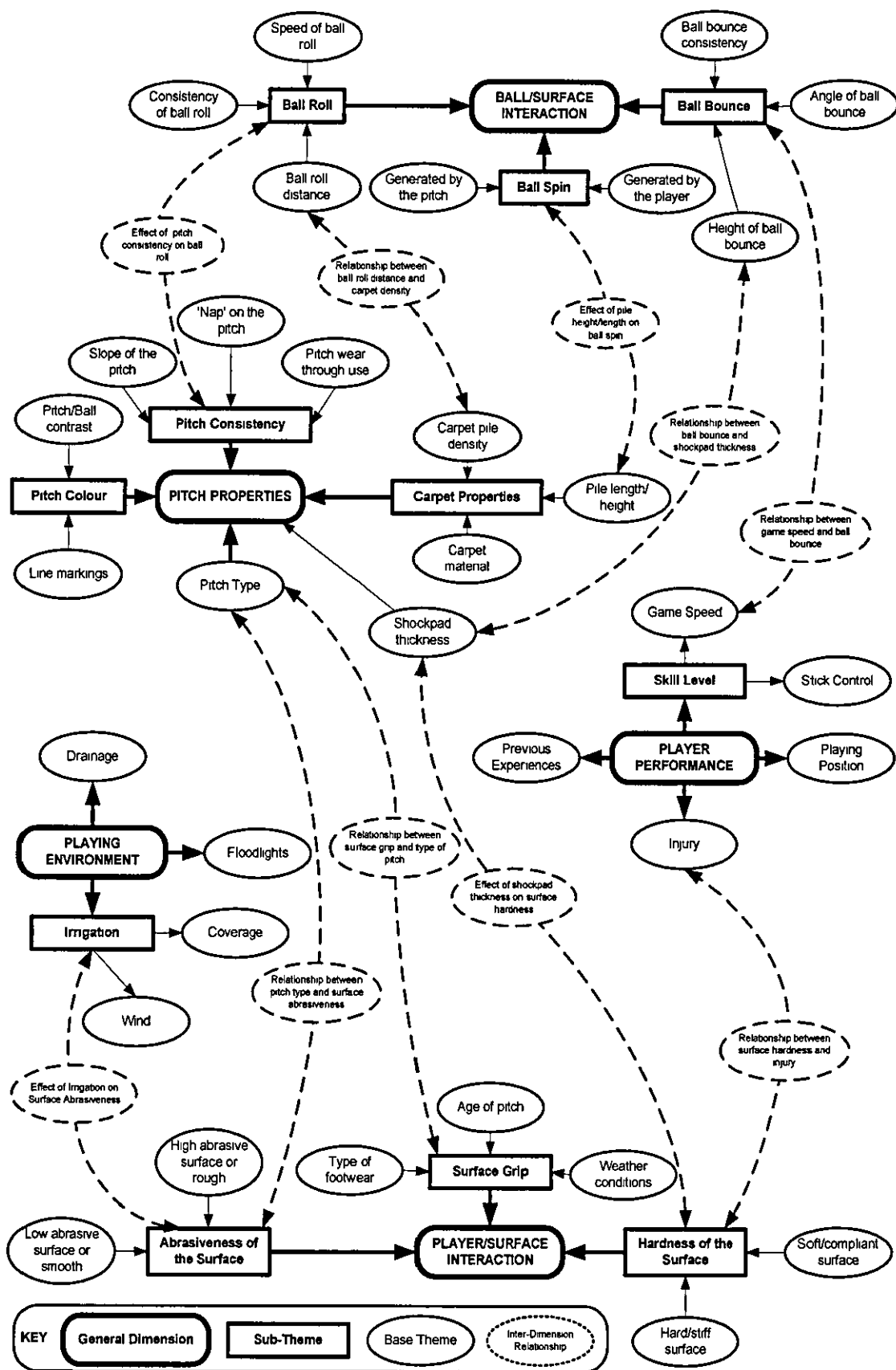


Figure 4 7 - The Structured Relationship Model of Elite Field Hockey Players Perceptions of Synthetic Turf Pitches

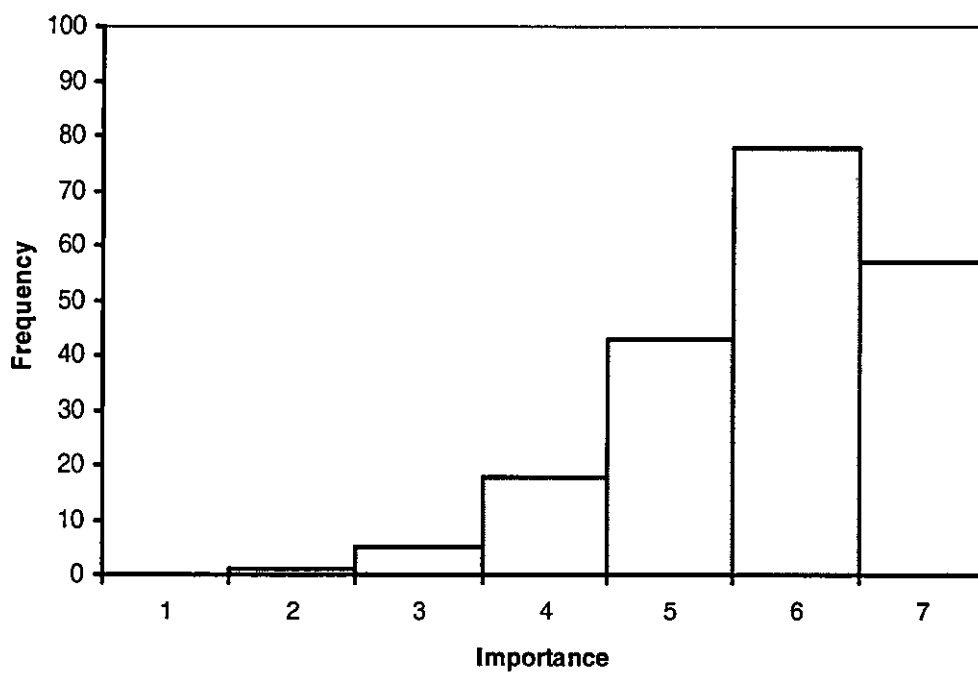


Figure 4.8 - A histogram of the perceived relative importance of a players 'ability to perform skills'

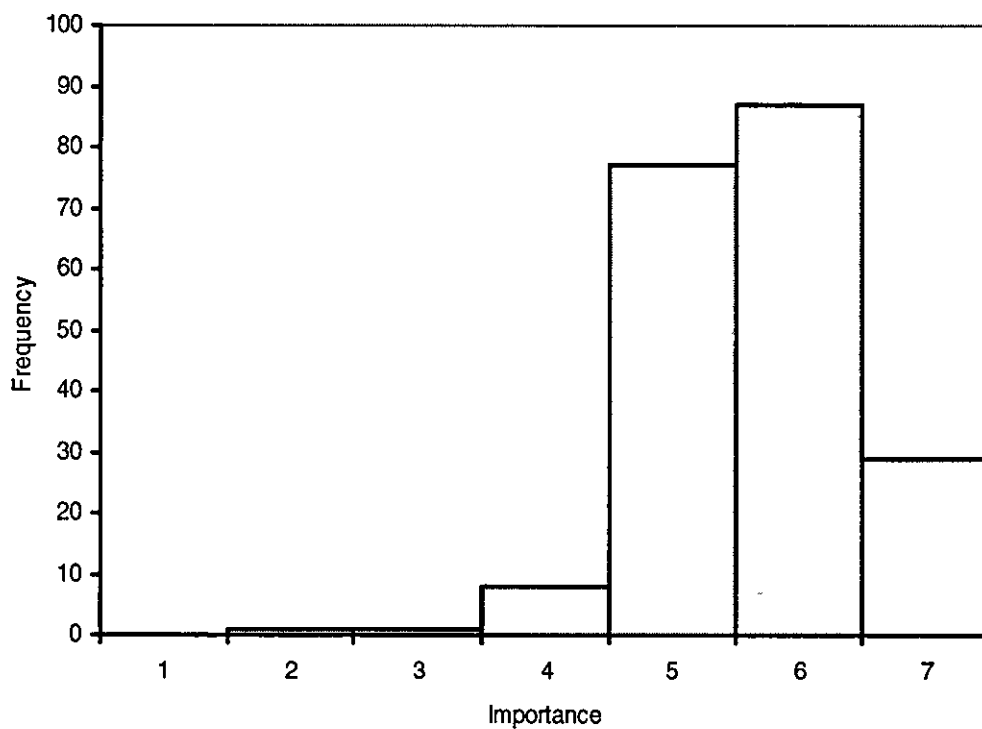


Figure 4 9 - A histogram of the perceived relative importance for 'surface pace'.

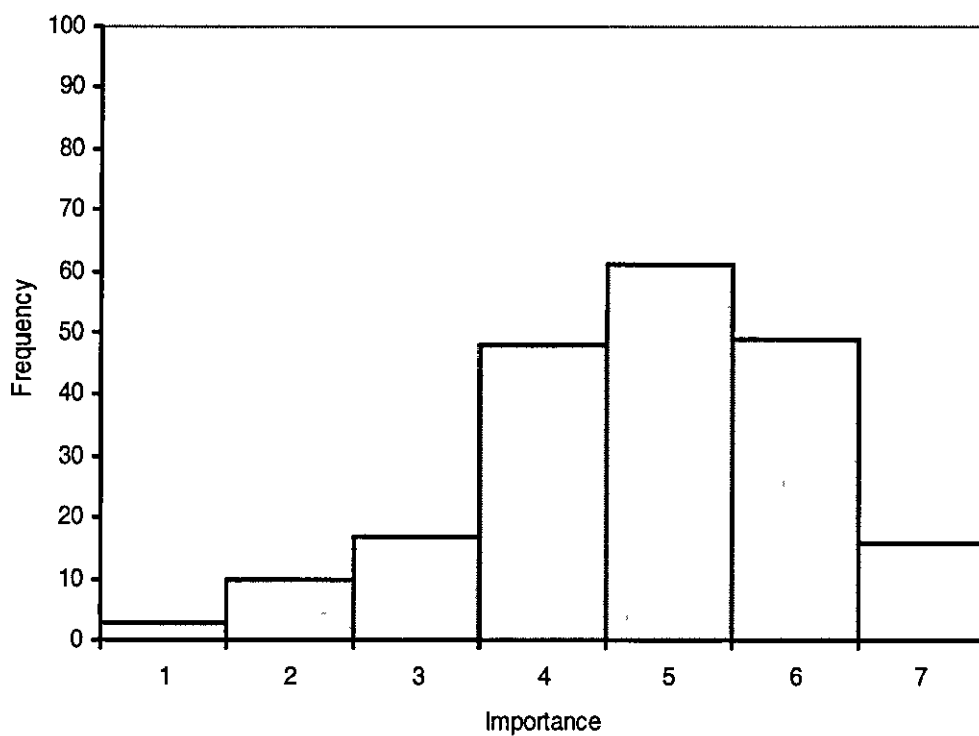


Figure 4.10 - A histogram of the perceived relative importance for 'height of ball bounce'

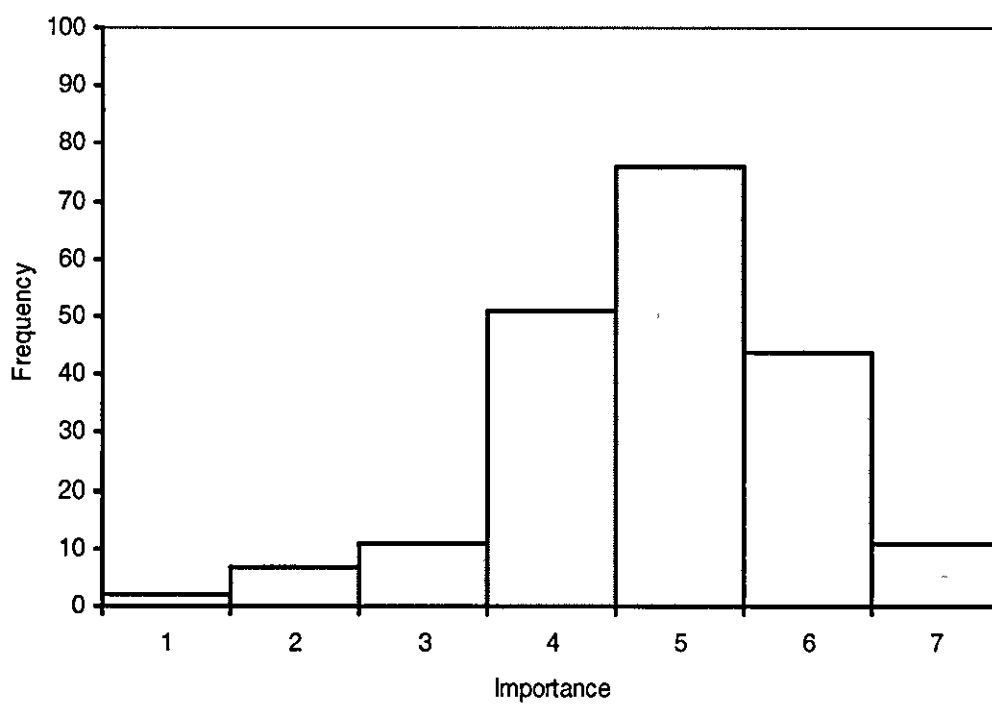


Figure 4.11 - A histogram of the perceived relative importance for 'surface hardness'

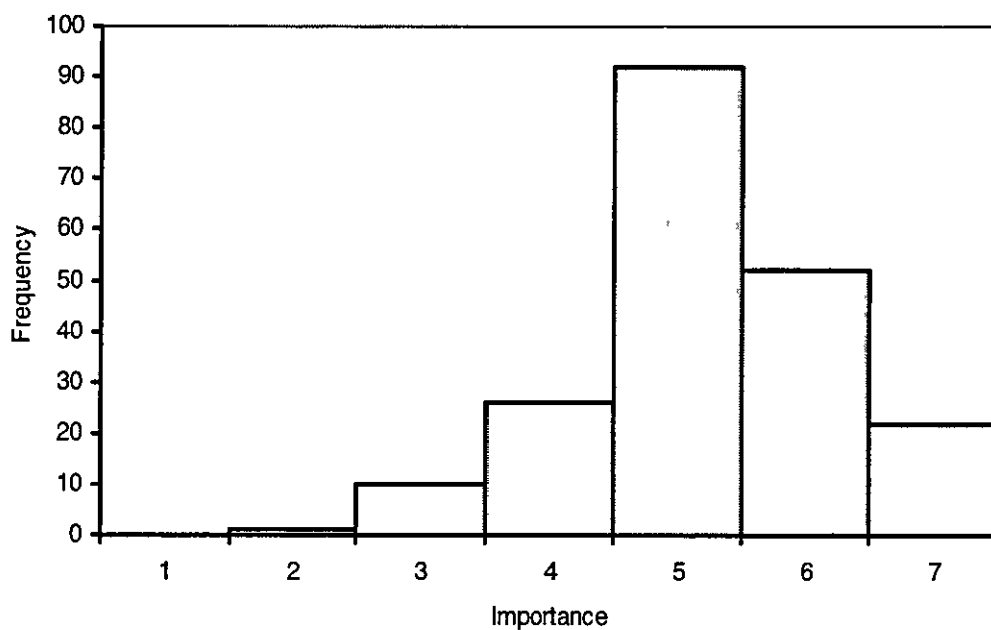


Figure 4.12 - A histogram of the perceived relative importance of 'underfoot grip'

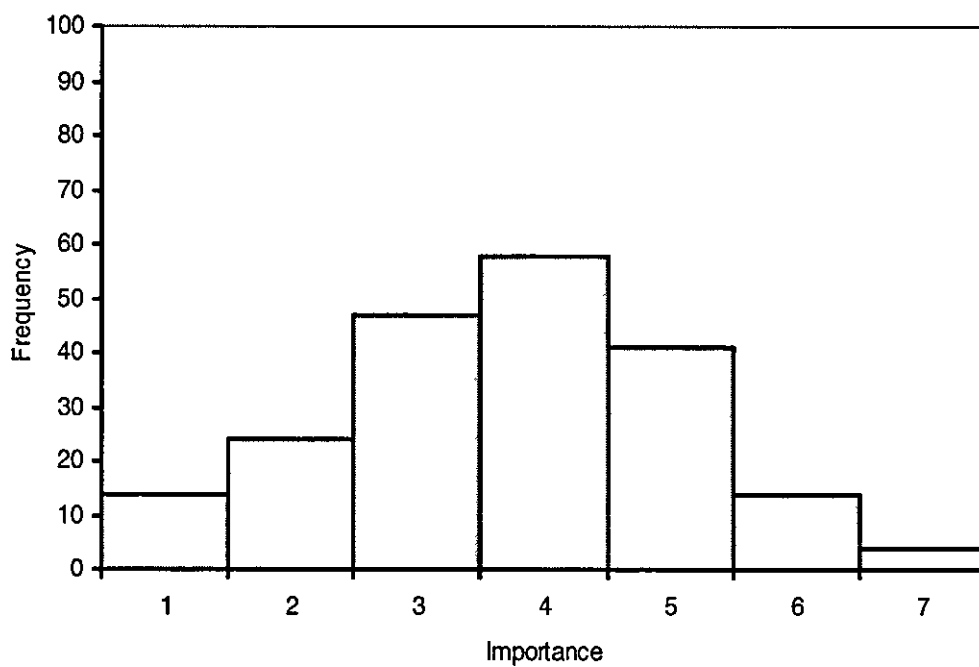


Figure 4.13 - A histogram of the perceived relative importance of 'ball spin'

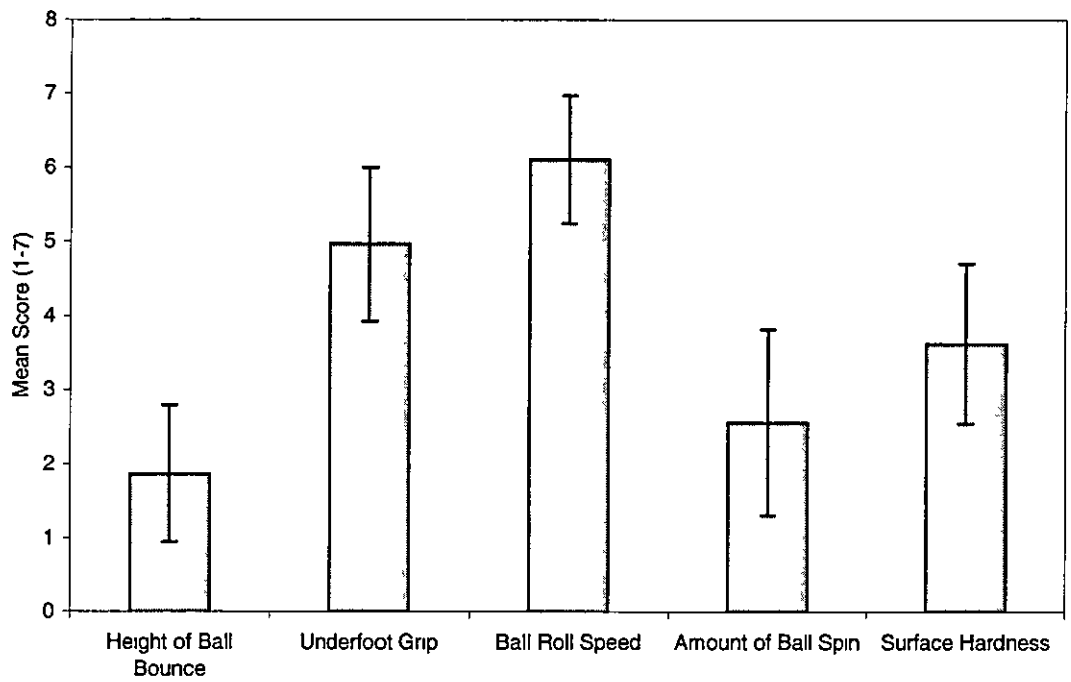


Figure 4 14 – The mean preference for each playing characteristic with standard deviation error bars.

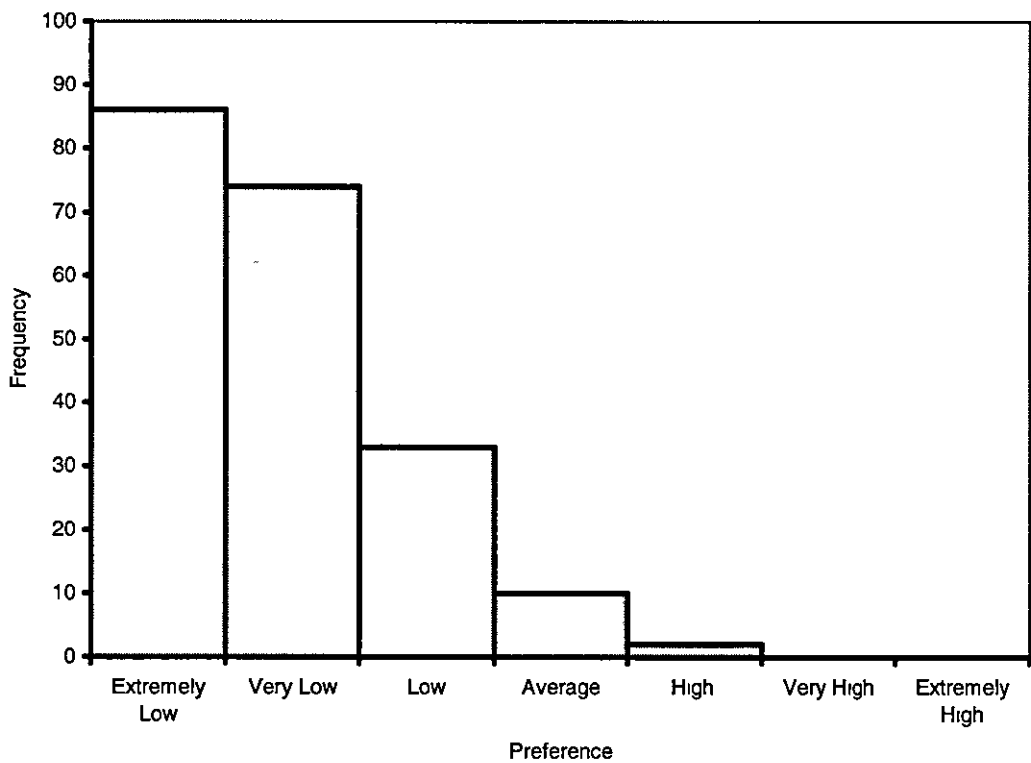


Figure 4.15 - A histogram showing the spread of preferences for 'ball rebound height'

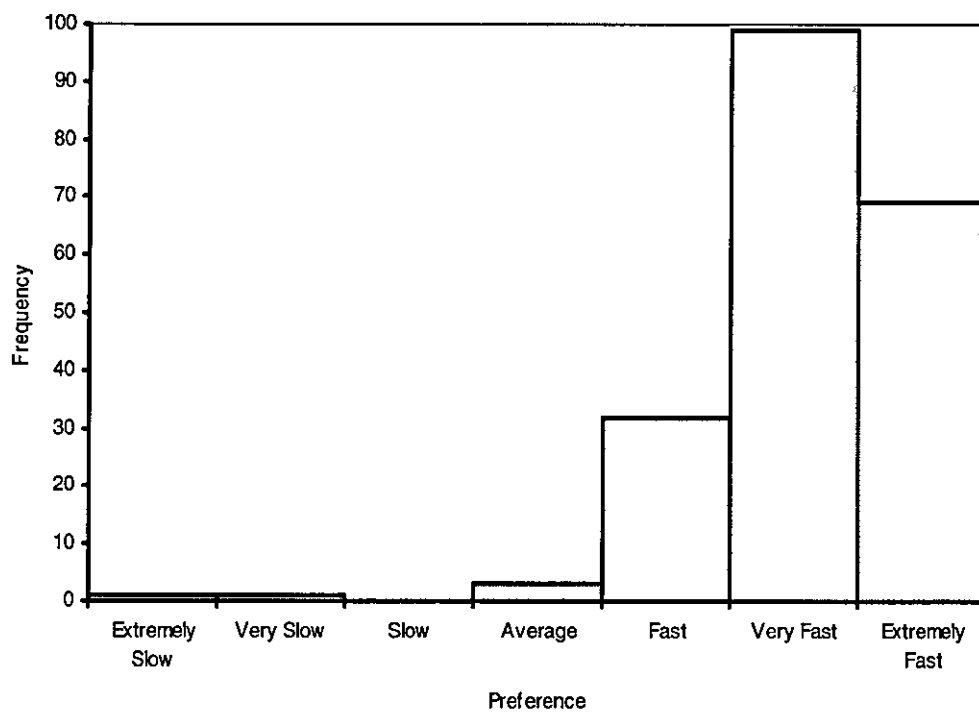


Figure 4.16 - A histogram showing the spread of preferences for 'surface pace'

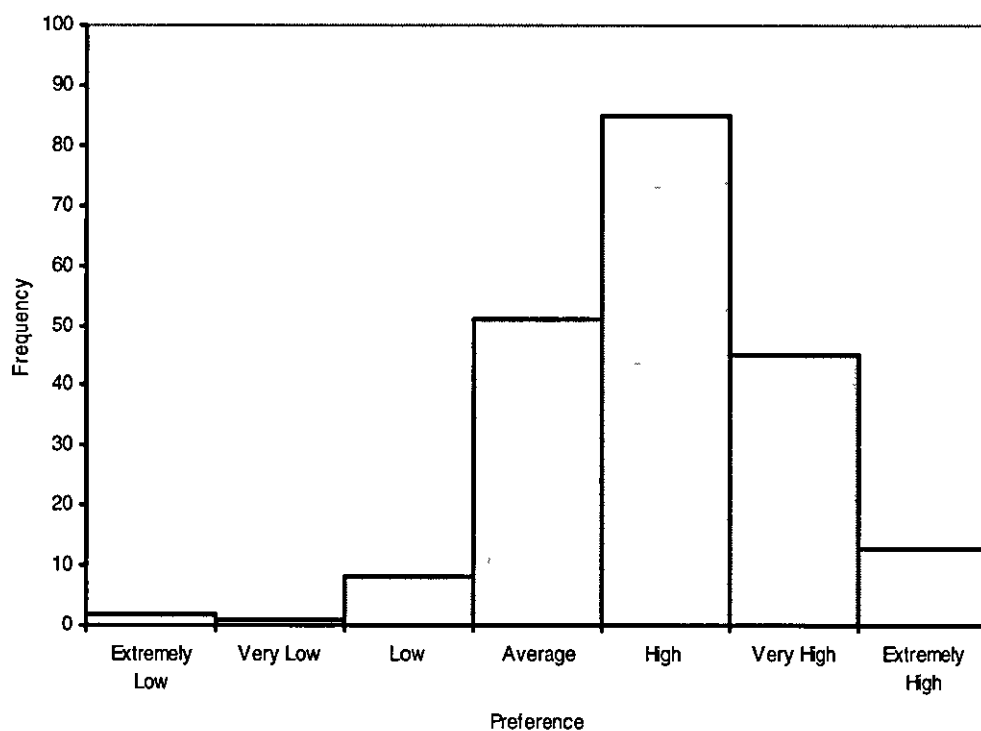


Figure 4.17 - A histogram showing the spread of preferences for 'underfoot grip'

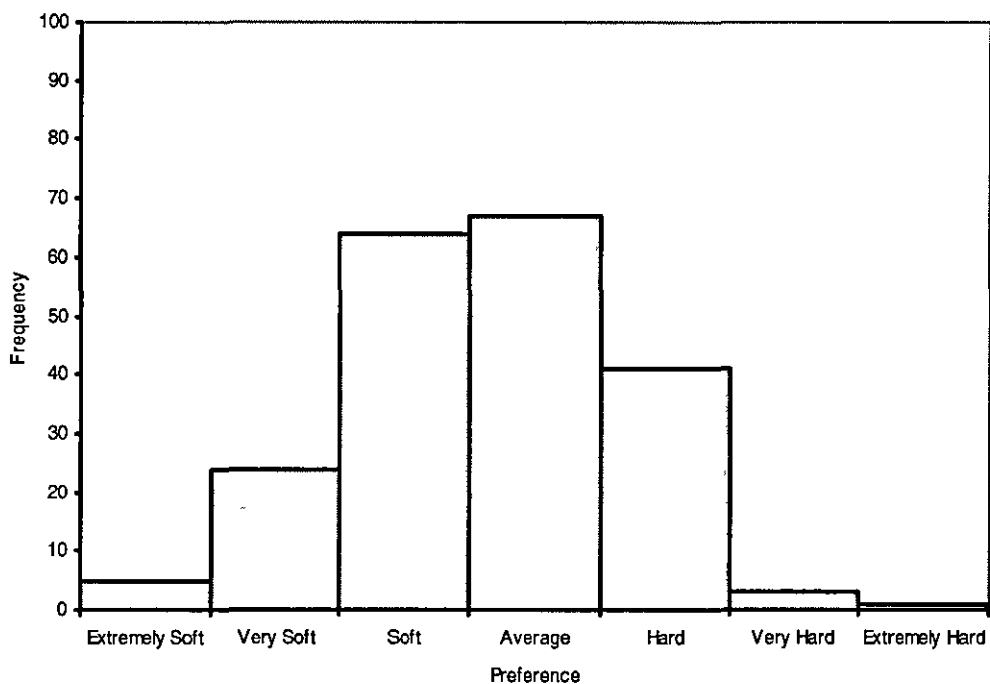


Figure 4.18 - A histogram showing the spread of preferences for 'surface hardness'

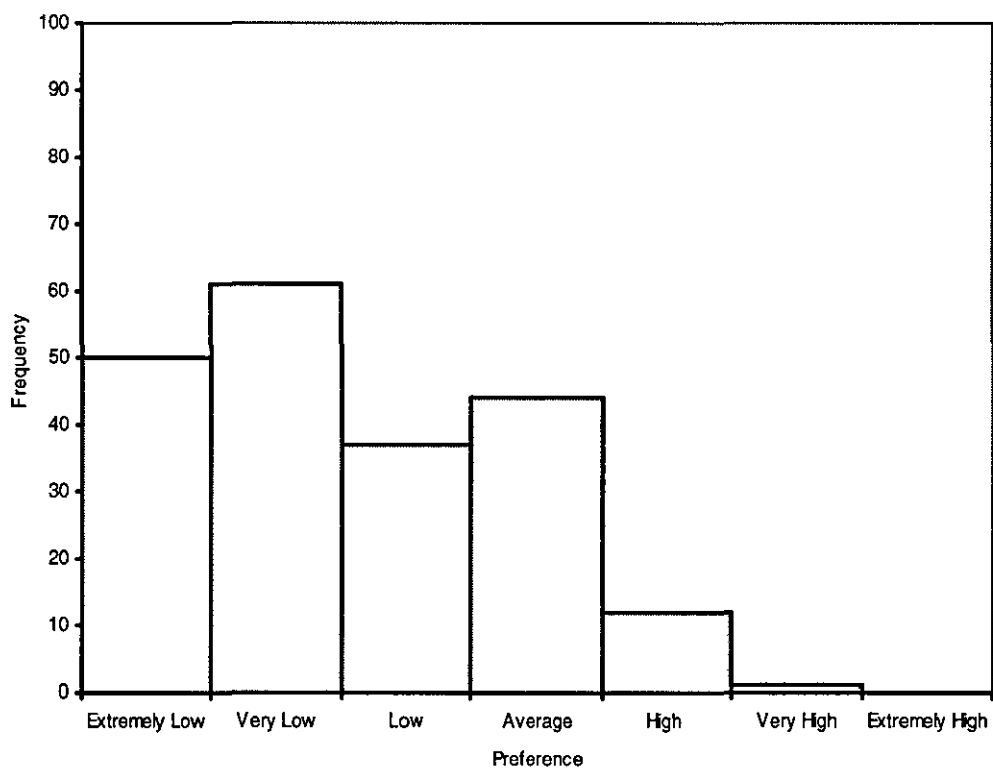


Figure 4 19 - A histogram showing the spread of preferences for 'ball spin'

BEHAVIOUR OF ARTIFICIAL TURF PITCHES MEASURED BY MECHANICAL TESTS

5.1 INTRODUCTION

This Chapter is composed of the findings from three data sources, namely, monitoring during construction, laboratory analysis and site investigation of completed pitches. Although the work was split to examine each area individually, the data are cross-referenced where appropriate to produce a more detailed and clearer understanding of mechanical pitch behaviour. Figure 5.1 illustrates the flow of data between the three collection methods illustrating how they interact with one another.

An initial laboratory and field programme was used to develop the methodology but is not presented herein (in Chapter 3). The main laboratory programme provided an environment that afforded more control than it was possible to achieve on-site and hence control of extraneous variables. Further to the laboratory data collection six existing installations were selected for site investigation. To ensure the measured data would be comparable to players' perceptions they were chosen based on the responses during quantitative and qualitative data collection (Chapter 4). Each pitch was regularly used in the English Hockey League and hence the players had recent experience of playing on them. This ensured that adequate feedback could be obtained from the players to ensure links with the mechanical testing would be valid. All six pitches conformed to 'global' standard in the FIH performance handbook (1999) and the accreditation results for five of them were able to be obtained along with their construction specifications. To complement the main data collection methods an additional investigation was undertaken during the construction of a field hockey pitch, this gave an insight into the build quality of a 'typical' sports pitch and provided an opportunity to evaluate the constituent layers of a pitch during construction.

5.2 MONITORING DURING CONSTRUCTION

A comprehensive programme of monitoring and testing took place during the construction of a 'global' standard water-based pitch at Loughborough University. This section presents the results from the evaluation of each layer, from the formation through to shockpad. Table 5.1 summarises the findings for the test devices on each layer, with the results presented below. This table highlights the difference between and the variability across each layer. Unfortunately, no existing data was found to benchmark against, therefore comparison between the layers and the influence they have upon one another was evaluated.

The testing was carried out to coincide with the construction of a 'global' standard field hockey pitch at Loughborough University. Testing was performed during pitch installation, and consequently, access and time on site were limited to the contractors work schedule. Daily consultation with the contractors and significant resources (3 full-time staff, a research student, research associate and laboratory technician) were used to plan and collect data. However, due to changeable weather and the nature of pitch construction the research team needed to be flexible with their data collection. On several occasions testing had to be cut short and the targeted number of locations were not measured. However, over the course of the 3 months of monitoring a significant amount of testing was conducted with the most relevant data presented herein. Not all the data are presented as it was outside the scope of this thesis but the key elements are included and discussed.

The role of each layer is discussed in section 2.3 and Figure 2.1 illustrates their dimensions and design. The formation (or subgrade) consists of natural ground, which is levelled and compacted often with drainage channels added. The sub-base provides a working platform on which the surfacing materials can be transported, laid and compacted. It also protects the formation from damage via frost. The asphalt layer provides a strong uniform layer which should improve the longevity of the pitch by limiting the strain on the layers below. The shock absorbing layer (shockpad) cushions the surface to make it safer for the users and helps to provide suitable playing characteristics. Finally the carpet is laid onto the shockpad in roll and either stitched or glued in place.

A testing grid was used (Figure 3.3) for each layer during construction to ensure each test was performed at the same location layer on layer. The grid is described in section 3.3.1 and consists of 77 locations.

5.2.1 Formation

The formation consisted of natural ground which was levelled by a cut and fill process and then compacted. A total of 24 locations were assessed by the Prima 300mm plate at evenly spaced locations around the testing grid. The formation was found to have a global mean elastic stiffness of 28.1 MPa with a standard deviation of 18.2 MPa and hence a coefficient of variance (COV) of 64.7 %. The Clegg 4.5 Kg impact hammer was used to assess 23 positions across the grid. A mean of 12 IV was recorded with a SD of 4.5 IV, and a COV of 38.8 %. The Clegg was found to produce large permanent indentations in the formation of between 5 mm and 30 mm which was due to the large inferred stresses produced by its small contact area (Fleming, 2000) and illustrates the shear failure of the soil.

The strength of the formation was measured using the hand vane, Mexicone and DCP. Large differences were obtained with each piece of equipment. 42 locations were measured with the hand vane and of these 16 were out of its range (greater than could be measured or could not penetrate the surface) of the remaining positions a mean of $116 \text{ kPa} \pm 30 \text{ kPa}$ was found. The Mexicone was used at 28 locations with a mean of 11.7 % CBR and range between 2 – 14 %. The DCP was used to measure from the surface to a depth of 500 mm (ignoring the first 50 mm due to a lack of consolidation). 15 test locations were measured and the mean CBR was obtained by converting from mm/blow. A CBR of 9.04 % was measured for the first 250 mm (compacted fill) and 10.37 % from 250 – 500 mm. These data compare well to the measurements taken by the Mexicone.

Classification tests were performed in the laboratory for samples taken during construction. Nine bulk and nineteen tube density samples were extracted on site. Samples were taken from different locations across the test grid. The soil description varied from reddish brown very sandy silt of low plasticity to reddish brown slightly gravelly sandy silt of intermediate plasticity. A bulk density of between 1.78 and 1.88 Mg/m^3 was measured and an associated dry density of between 1.48 and 1.49 Mg/m^3 . The natural moisture content was between 19.0 and 28.0 %.

The large range of results obtained from the test devices indicate that the measured properties of the formation level varied considerably. This can be attributed to the constituent material that occurs naturally and is inherently variable and the different water contents and soil types. However, after analysis of the test grid, row D was found to give higher measurements with the Prima and GDP than the other rows, see Table 5.2. This could indicate that the compaction effort applied over the site may be inconsistent but this is purely speculative as it was not monitored closely enough. Yet on site monitoring did show a difference in the number of passes for each row. It is unclear from the recorded data if such a material could be compacted to reduce the variance, and indeed if this has, or will have any influence both in the short- and long-term on the performance/behaviour of the pitch. A dearth of published information makes it impossible to compare these results to previous installations. However, these data will provide a suitable benchmark to compare with future installations.

5.2.2 Sub-base

The sub-base comprised a quarried angular crushed rock with a particle size distribution to MOT Type 1x (low fines content). The design layer thickness was a minimum of 250 mm but the measured dimensions showed a thickness range of 197 mm to 288 mm (average 239 mm), which shows the installed thickness was less than the design specification. The surface stiffness was measured with the Prima 300 mm plate and GDP, both devices gave similar measurements for stiffness with 28.8 MPa with the Prima and 22.1 MPa with the GDP. The Prima measured slightly more variability with a COV of 41.6 % compared to 32.0 % with the GDP. There is no published data on synthetic turf pitch to compare with these values but the stiffness seems relatively low with respect to measurements taken during road construction (Fleming, 1995). Table 5.2, shows the measurements by row and indicates large variability between them. Row E is particularly low with only 19.0 and 17.0 MPa measured with the Prima and GDP respectively compared with the global mean of the other rows. Concerns were raised by the consultant on this scheme, however, in relation to poor compaction.

5.2.3 Asphalt Layer

The asphalt layer was constructed, in two lifts, with a design thickness of 65 mm. The range of measured thickness was 42 to 83 mm (with one outlier at 107 mm), and an average of 64 mm. The longitudinal surface gradient was 0.2 % and the

transverse was approximately 0 %, which demonstrates the excellent control afforded by modern laser techniques and efficient paving plant

It was observed from the dynamic plate tests that there was a large variation in stiffness between the rows. The measured stiffness of Row E was lower than the other rows with both the Prima (87.1 MPa compared with a global mean of 109.8 MPa) and GDP (107.1 MPa compared with a global mean of 139.9 MPa). This compares with the sub-base layers where row E was measured with a lower stiffness. This highlights the importance of good compaction for the sub-base layer and how it can influence the subsequent layers above it. The measurements for each row are presented in Table 5.2. The measured stiffness for the asphalt and sub-base layers are illustrated in Figure 5.2 by row. It shows how the stiff asphalt layer was influenced by the sub-base and highlights the importance of good compaction and quality control.

5.2.4 Shock Absorbing Layer

The insitu shockpad was specified at a design thickness of $12 \text{ mm} \pm 2 \text{ mm}$. The thickness measurements made were in the range 6 to 21 mm, with a mean of 13 mm. Of the 34 points measured 12 lay outside the design target range of 10-14 mm. However, the accuracy of this optical method is estimated at around $\pm 2 \text{ mm}$. The differences in thickness could also be due to any undulations on the asphalt layer.

The Prima was used to measure the stiffness on the shockpad layer, however, it needed to be dropped from a lower height to reduce the deflections to less than 2.2 mm so the deflection sensor was not overloaded. A stiffness of $56.1 \pm 13.3 \text{ MPa}$ was measured with a COV of 23.7 %, slightly more variation than the asphalt layer but less than the formation and sub-base. The compliance of the shockpad layer made it difficult to operate the Prima and its repeatability or reproducibility on this type of surface is questionable.

The 2.25 kg Clegg impact hammer was used on the shockpad layer. 50 test locations were evaluated with a mean measured value of $236.6 \pm 23.6 \text{ IV}$ and hence a COV of 10.0 %. Similarly, the Artificial Athlete Berlin (AAB) was used to measure 15 test locations and gave a mean value of $38.39 \pm 2.74 \%$ force reduction with a COV of 14.0 %. Comparison between the two devices showed a reasonable relationship between them with an R^2 of 0.60, illustrated in Figure 5.3.

This relationship indicates the Clegg hammer could potentially be used as an alternative to the Berlin. Due to restrictions on the availability of the Berlin only 15 test locations could be measured across the testing grid, therefore the correlation is only based on 15 data points. To give more confidence in the correlation more test positions would be desirable. A comparison between the Berlin and Clegg hammer on completed pitch systems both in the laboratory and on-site was further evaluated and is discussed in sections 5.3 and 5.4.

5.3 LABORATORY ANALYSIS

An extensive programme of controlled laboratory testing was undertaken to investigate pitch behaviour before embarking on the fieldwork programme to establish the efficacy of the testing philosophy and to identify factors that could influence the results. To simulate on-site conditions a 'typical' pitch foundation was produced with similar materials and hence properties to an outdoor water-based pitch. The details and logic behind the box preparation are described in Chapter 3 but in short were to ensure the laboratory situation was similar to in-situ conditions (i.e. similar material properties and layer thickness), whilst also providing the opportunity to control the environmental conditions (in particular the influence of water).

The laboratory conditions were constant throughout testing. The temperature was maintained at $21^{\circ}\text{C} \pm 2^{\circ}\text{C}$ and the humidity was monitored and found to be between 35 and 45 %. The preparation of samples (shockpad and carpet) were also monitored carefully, they were stored in the laboratory at the same temperature ($19 - 23^{\circ}\text{C}$) during the entire testing programme. Where the testing procedure required the application of water, the sample was immersed in tap water at $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for a duration of 30 minutes (± 2 minutes) as outlined in the FIH handbook of performance specifications (1999).

Within the 1 m^2 box a grid was produced to ensure repeat testing took place at the same location. The grid is illustrated in Figure 3.4 and consisted of 16 test locations evenly spaced at 0.2 m intervals. An axis was produced on the box to ensure the correct locations were tested and the same grid was applied to the test samples including shockpad and carpet so they were correctly oriented.

The sub-base and asphalt layers of the box were tested as they were installed to compare with the Loughborough University pitch and ensure they had similar properties. They were measured with the Prima 300 mm plate, 4.5 kg Clegg hammer and DCP. Five shockpad samples and two carpet samples were assessed on the asphalt layer in a parametric fashion, illustrated in Table 3.3. The following test equipment/methods were used to evaluate each system; the AAB, Clegg 2.25 Kg, Clegg 0.5 Kg, ball rebound resilience and rotational traction. A linear friction tested (TRL Portable Friction tester), described in both BS 7044 part 2 and the FIH Handbook of Performance Specifications (1999) was evaluated during initial laboratory trials but was found to be unsuitable and hence is not presented herein. Problems with the device's parts and consequently a lack of repeatability were the main reasons for boycotting the tests.

5.3.1 Box and Sample Preparation

The sub-base was installed in three layers, two at 150 mm and one at 100 mm thick, totalling a target thickness of 400 mm. Three lifts were used to ensure satisfactory compaction of each layer was achieved and make it easier to obtain the target thickness. The depth was measured at 16 locations and found to be 397.7 ± 3.2 mm. The bulk density was 2.32 Mg/m^3 with a dry density of 2.21 Mg/m^3 with a target of 2.34 and 2.24 Mg/m^3 respectively from site measurements. The asphalt layer was installed in one lift and had a measured thickness (16 locations) of 60.2 ± 1.6 mm with a target thickness of 60 mm.

The Prima and 4.45 kg Clegg Impact Hammer were used to compare the properties of the sub-base and asphalt on-site to the samples in the laboratory. Table 5.3 shows the difference between on-site, in box and laboratory floor measurements. The site measurements were lower than the box samples which was lower than the laboratory floor. The asphalt layer on-site was measured as 109.8 MPa compared with 575.8 MPa in the box and 2524.8 MPa on the laboratory floor. Furthermore, the sub-base on-site was 28.8 MPa compared with 266.1 MPa in the box measured with the Prima and 28.8 IV on-site and 39.3 IV in the box measured with the 4.5 kg Clegg Hammer. The difference between the box and site could have been due to the composite effect of the rigid base of the box (no subgrade/formation) and confinement which afforded better compaction, also the sub-base material was a crushed limestone (MOT type 1) which due to a self cementing action became significantly stiffer with time (from 52.2 MPa immediately after installations to 266.1 MPa 6 weeks later just before the asphalt

was laid on top) when measured with the Prima. The magnitude of difference between the box and site measured by the Prima on the asphalt layer was large, however, the difference between the box and laboratory floor was significantly larger (a factor of 5). From these data it is clear there is a difference between the box system and the on-site system. However, the difference is much less than that of the laboratory floor. Therefore, to determine the influence of the differing stiffness between the laboratory floor and box the shockpad and carpet samples were tested on both and a comparison between was investigated.

Five shockpad samples were installed and assessed, three constructed in the laboratory (described in section 3.3.2) of 6 mm, 12 mm and 20 mm thickness, one obtained during the construction of the Loughborough University (LU) pitch (11 mm) and one pre-fabricated (dimpled, hence thickness of between 6 mm and 12 mm, with a mean of 9 mm) sample obtained during the renovation of a local pitch. Two carpet samples were tested, one from the LU pitch and one from Belle Vue (BV). Both carpets were fabricated with nylon but the LU sample had a 12 mm pile height with a 3 mm integral pad and the BV sample had an 11 mm pile height with a 6 mm integral pad. This provided a total of 17 different shockpad/carpet systems for the parametric investigation

5.3.2 The difference between layers

Examination of the sub-base and each subsequent layer was made with the AAB at 16 locations, Figure 5.4 shows a plot of the mean force reduction at each position. The sub-base and asphalt layers had a small force reduction, in relation to the shockpad, of 11.2 and 2.9 % respectively. A force reduction of 41.5 % was measured on the shockpad layer (11 mm LU sample) which highlighted the importance of this layer to reduce surface stiffness and provide comfort during play. The carpet (LU sample 3 mm integral shockpad) completed the pitch system and increased the force reduction (i.e. lower stiffness) to 52.5 %. Similarly the 2.25 Kg Clegg impact hammer (not suitable for use on rigid surfaces i.e. sub-base and asphalt layers) showed a decrease in impact value between the shockpad and carpet layer from 262.8 to 116.3 (Figure 5.5)

Compliance is the inverse of stiffness; consequently the asphalt layer in relation to the shockpad has a low compliance. However, both layers gave similar ball rebound measurements (Figure 5.6). Therefore, compliance is shown to have no specific connection with ball rebound resilience. When the ball impacted the

asphalt layer it was subject to a larger internal deformation than during impact with the shockpad layer. Hence, the elasticity of the ball was the primary influence on the coefficient of restitution on the asphalt. However, during impact with the shockpad and carpet layers the ball deformation is relatively less, and the shockpad and carpet then became the decisive influence of rebound resilience. This indicates that energy storage and return of the surface plays a significant role in ball rebound resilience.

5.3.3 Shockpad Thickness

To determine the influence of the different shockpad samples the Berlin artificial athlete (AAB), Clegg impact hammer and ball rebound resilience tests were used to measure the five shockpad samples both in the box and on the laboratory floor. Evaluation with the AAB identified that the shockpad thickness had a significant affect on force reduction. Figure 5.7 illustrates a plot of the mean force reduction for all five shockpad samples in the box and on the laboratory floor, the shockpads are presented in thickness order with the thinnest first. It illustrates how an increase in thickness improves the shockpads impact absorption and hence an increase in force reduction. Similarly, the 2.25 kg Clegg hammer measured a reduction in impact value (hence greater energy absorption) with an increase in shockpad thickness (Figure 5.8). Figure 5.9 illustrates the difference in ball rebound height for the different shockpad samples, it shows that ball rebound resilience increased in relation to shockpad thickness, except for the dimpled sample which due to its uneven surface prevented the ball from rebounding vertically and because of its age a possible loss of elasticity.

Variability is shown on the Y axis error bars on Figures 5.7, 5.8 and 5.9. No significant connection was established between variability and shockpad thickness using the AAB or ball rebound resilience. However, the 2.25 kg Clegg Hammer measured less variation on the thicker 20 mm shockpad sample indicating the sample was more homogenous. This could be a result of the raw particulate (rubber crumb) used in the construction of shockpads, which had a particle size distribution between 2 – 6 mm. Hence a thin shockpad sample of 6 mm or even 12 mm could have significant voids or disproportionate quantity of binder resulting in irregularities that would be less noticeable in a thicker sample.

A comparison between testing directly on the laboratory floor or test box identified differences between their impact behaviour. The AAB measured a higher force

reduction and the 2.25 kg Clegg impact hammer gave a lower impact value in the box than on the laboratory floor. A similar difference was identified between the ball rebound height on the two surfaces with the laboratory floor giving a slightly higher ball rebound height. This raises issues toward the efficacy of laboratory testing of shockpads directly on a rigid laboratory floor (as done in the industry) as it affects tests results could be different from on-site measurements. Furthermore, analysis of the 2 25 kg Clegg impact hammer on the laboratory floor gave a larger spread of values than in the box. The structural inconsistencies in the shockpad appeared more noticeable on the rigid concrete substrate beneath. However, it should be noted that the difference between the laboratory floor and box are very small in relation to the thickness of the shockpad samples This indicates that the impact absorbing properties of the shockpad are more significant than the layer below and these differences may be further reduced with the carpet layer included.

5.3.4 Carpet Layer (complete pitch system)

Two carpet samples (Loughborough University and Belle Vue) were tested on five shockpad samples, directly on the laboratory floor and in the prepared box. Five pieces of equipment (AAB, 0.5 kg Clegg hammer, 2.25 kg Clegg Hammer, ball rebound restitution and rotational traction) were used to evaluate each of the resulting pitch systems. Furthermore, the samples were tested dry, saturated and at two intermediate levels (20 and 40 minutes after saturation). The results presented in this section are for dry testing unless otherwise stated. An analysis of the influence of water is presented in the following section 5.3.4.1.

The result with all five pieces of equipment show very little difference between the carpet/shockpad system on the laboratory floor and in the prepared box. Table 5.5 shows the data for all carpet/shockpad systems. This indicates that the impact behaviour of the carpet and shockpad layers absorb the force from the AAB, Clegg 0.5 kg, Clegg 2.25 kg hammers and ball rebound tests with little influence from the layers below. The carpet (including its pile, backing and where applicable integral shockpad) and shockpad absorb the impact (by deforming) and do not transmit significant load to the layers below, section 5.3.4.2 further reinforces these results via simple linear elastic modelling.

The combinations of shockpad and carpet are presented in order of ascending shockpad thickness in the test box. Evaluation of the combinations of

shockpad/carpet systems with the AAB are illustrated in Figure 5.10, the solid horizontal lines represent the FIH requirements for 'global' standard accreditation. All of the carpet/shockpad systems fall within the FIH requirements with the exception of the 20 mm shockpad samples (above 65 % force reduction) and carpet samples with no additional shockpad (below 40 % force reduction). It is also evident that the Belle Vue carpet provides more force reduction than the LU carpet, this is due to the additional integral shockpad on the Belle Vue sample of 6 mm in comparison the 3 mm integral shockpad on the LU sample. Typical constructions could comprise the LU carpet with a 12 mm in-situ shockpad or the Belle Vue carpet with no insitu pad. The difference in force reduction between these two systems is 38.2 % (Belle Vue) to 52.5 % (LU & 12 mm shockpad), this highlights a large variability between the different design specifications that are currently in use.

Figure 5.11 demonstrates the Clegg impact values obtained from testing with the 0.5 and 2.25 kg hammers. Similar to the AAB the 2.25 kg Clegg hammer measured a decrease in surface stiffness with an increase in shockpad thickness. However, a similar trend was not so clear with the 0.5 kg Clegg hammer. The results measured with the 0.5 kg Clegg hammer remained similar (141.5 IV for the LU carpet with no shockpad down to 114.3 IV for the LU carpet with a 20 mm shockpad) for each shockpad/carpet system. This maybe due to the low energy of impact compared with the 2.25 kg hammer. The 2.25 kg Clegg impact hammer measured a value of 216.6 down to 78.5 for the LU carpet with no shockpad and 20 mm shockpad respectively. For the 0.5 kg hammer the majority of energy is absorbed by the carpet pile which restricts the transfer of energy to the layers below. Conversely, the energy of impact for the 2.25 kg hammer is only partially absorbed by the carpet pile and as such transfers a larger proportion of its impact energy into the shockpad.

During the ball impact it was observed that an increase in shockpad thickness led to a higher ball rebound height, with the exception of the 9 mm prefabricated sample. Figure 5.12 illustrates the ball rebound height in saturated conditions (these conditions were used for comparison with the FIH requirements), the solid horizontal lines represent the FIH limits for ball rebound. Only three of the shockpad/carpet systems fall within the FIH requirements for ball rebound height with the remaining systems all measuring above the 25 cm upper limit.

Comparison of the AAB and 2.25 kg Clegg hammer measurements identified a strong relationship between the two devices. Figure 5.13a is a correlation graph which illustrates a strong relationship between the pieces of equipment with minor deviations from the trend line. The full range of surface systems were measured, for dry and saturated conditions and their inclusion did not adversely affect their relationship. In the mid-range there are a few outliers that do show slight variation but the number is insignificant compared with the total. However, Figure 5.13b illustrates the same relationship but with the mean value for each shockpad/carpet system and moisture conditions and hence the removal or smoothing of outliers. The relationship between devices is improved from an R^2 of 0.92 to 0.97 using a logarithmic trend/regression line.

The 0.5 kg impact hammer measured a large difference between the first and last drop. Whilst testing a flattening of the carpet pile was observed which led to an increase in impact value. Figure 5.14 demonstrates the increase in impact value between the five drops measured on the LU carpet and different shockpad samples. All six systems show an increase between the first and last drop of approximately 20 Clegg impact values. The deformation of the carpet pile may be responsible for this increase as a similar trend does not occur with the 2.25 kg Clegg hammer with its higher impact energy and hence more influence from the shockpad (or carpet pile flattening occurs immediately).

Consideration was given to the relationship between the 0.5 Kg CIH and ball rebound resilience. Measurement showed that both tests were significantly influenced by the carpet pile. The average mass of 10 FIH accredited balls were measured at 0.16 Kg and when dropped from a height of 1.5 m the kinetic energy at impact would be 2.31 Joules (J). Furthermore, the 0.5 Kg CIH when released from a height of 0.45 m had an estimated impact energy of 2.21 J (energy = mass x gravity x drop height). However, as shown in Figure 5.15 comparison of the measurements obtained show no clear relationship. The 0.5 kg Clegg hammer and hockey ball have different contact areas (and shapes) and the distribution of stresses and hence strains during impact were different and not comparable. Also the ball contact area changes during impact depending on the surface properties. Also the Clegg hammer is measuring the loading of the surface while the ball rebound is measuring the unloading of the surface.

5.3.4.1 Influence of Water

A water-based hockey pitch requires a minimum of 18000 litres (FIH, 1999) of water irrigated onto the playing surface prior to play which is intended to act as a lubricant to improve playing characteristics by reducing the friction between the ball surface and player surface interface. It is unclear how or why this quantity of water is specified by the FIH. The influence of water under controlled conditions in the laboratory was investigated. A comparison between dry, saturated and two time intervals of 20 and 40 minutes after saturation are presented. 20 and 40 minutes were chosen as they represented the time frame for half a game of field hockey, or more importantly the duration between irrigation cycles. Care was taken to ensure the correct level of saturation was achieved during each test and monitored with a stopwatch. The box structure facilitated vertical drainage and a suitable period of time was given between testing, at least 24 hours between saturation tests.

The 0.5 kg Clegg impact hammer measured a significant reduction in impact value for all surface systems when they had been saturated. Figure 5.16 demonstrates the reduction between dry and saturated conditions with the two other conditions in-between. The water in the system reduces the energy to the Clegg hammer by dissipating it and hence reducing the impact value. A similar trend was noticed with the 2.25 kg Clegg hammer (Figure 5.17a) and AAB (Figure 5.17b) although the difference was much smaller. This suggests that the impact behaviour of the lighter weight Clegg hammer is more influenced by the moisture on the carpet pile. The impact behaviour of the 2.25 kg Clegg hammer and AAB are not influenced by water in the pile to the same extent.

Figure 5.18 illustrates the effect of water on the ball rebound height. A significant reduction (mean 10.5 cm) in rebound height was measured for all pitch systems, this represents a mean reduction of 26 %. This change is attributed to the dissipation of impact energy caused by displacing the water which resulted in a reduction in energy available to return to the ball. At the start of a game after irrigation and towards the end of a half a mean rise in vertical rebound height of 10.3 cm, or an increase of 25 % was measured. This raises important issues with regard to the expected variable playing characteristics during a game of field hockey between irrigation systems.

The rotational traction device measured no difference between shockpad/carpet systems. However, Figure 5.19 shows the reduction in torque from dry to saturated conditions. An average decrease of 5.5 Nm (from 31.2 Nm dry to 25.7 Nm saturated) shows the influence water has on reducing the coefficient of traction. This indicates that during a game the friction/traction of the surface can alter as the water in the carpet changes. Furthermore, it highlights the importance of the irrigation system to ensure all sections of the pitch are watered equally for consistency.

5.3.4.2 Linear Elastic Modelling

The shockpad/carpet system was modelled as a 2cm layer with a stiffness ranging from 5 MPa to 1 MPa (backed up by lab compression tests on shockpad samples from the Loughborough pitch which showed at low compression of 0.5 to 1.5mm the stiffness to be around 1-2 MPa and getting stiffer with increased compression-greater than 2 mm stiffness of 3.5 MPa). The results, using the standard foundation, show large deformations within the shockpad/carpet layer, for the standard 200 kPa contact pressure applied through a circular 10 cm diameter bearing plate. The central vertical deflection increases from 52 μ m to 216 μ m for the 5 MPa shockpad/carpet, and to 890 μ m (0.89mm) for the 1 MPa shockpad/carpet.

The sensitivity analysis showed that if either the asphalt stiffness or sub-base stiffness were reduced beneath the shockpad the maximum vertical deformation changed by only 8-12 μ m, which is considered to be insignificant in relation to the maximum values. This would suggest that the level of support provided beneath the shockpad/carpet (i.e. the stiffness) is not vital to the behaviour experienced by the athlete (based on a static analysis). However, the problem is clearly more complex than this. In reality the loading is dynamic, is not on a fixed area, and will vary depending on the athlete and the movement/activity during the foot/surface impact. However, the simple linear elastic analysis does appear to support the findings of the experimental work in this section. The difference between results obtained using the AAB and 2.25 kg Clegg hammer on the laboratory floor (2524.8 MPa) and the prepared box (575.8 MPa) when measuring the shockpad/carpet system were very small, illustrated in Figures 5.20 a & b.

5.4 FIELD WORK AT COMPLETED PITCHES

Six pitches were chosen for site investigation. Their descriptions and construction specifications are shown in Table 5.6. The pitches were selected based on player responses during perceived data collection and were believed (by players) to represent a diverse range of playing characteristics, yet all conforming to the FIH 'global' standard. Players in the EHL premier league and 1st division regularly use each pitch and hence correlating their opinions of the pitches with mechanical data was a key objective (presented in Chapter 6).

The AAB, 0.5 kg Clegg hammer, 2.25 kg Clegg hammer, ball rebound, rotational traction and ball roll tests were used to evaluate each site. Details for each test are provided in section 3.3.4 and with the exception of the Clegg hammers are outlined in the FIH handbook of performance specifications (1999).

Each site was visited on two occasions; however, two main programmes of data collection were undertaken approximately 1 year apart (April 2003 and March 2004). Due to the restricted availability of the AAB, the first programme of data collection was subject to a significant time restriction and only a select number of test locations were achievable in order to test all six pitches in the required time frame, therefore, the FIH spot test locations (shown in Figure 3.5 and described in the FIH handbook, 1999) were selected. Fewer restrictions in March 2004 afforded better global coverage of the pitches facilitating 25 test locations (illustrated in Figures 3.6). Repeat testing was conducted at each location to evaluate both spatial and global variability. Additional monitoring was undertaken at the Loughborough University site, in the first instance to develop the efficacy of the testing programme and secondly to evaluate other factors in more detail and with more control including the influence of moisture.

The measurements on each pitch were conducted under 'typical' game conditions i.e. a full irrigation cycle was applied to the pitch followed by forty minutes of testing then a further application of water. This method was chosen as it replicated what a player would experience when using the pitch and could therefore be compared with perceptions. The devices that were identified in the laboratory investigation as susceptible to moisture effects (ball rebound, 0.5 kg Clegg hammer and rotational traction) along with ball roll distance were monitored closely during testing for any unexpected measurements. In section

5.4.4 an in-depth analysis of the influence water had on the measurements is presented with comparison between dry and fully saturated conditions.

A full investigation was conducted prior to testing to establish the condition of each pitch. Particular note was taken of algae growth, signs of wear, seam damage and line markings. The owner/operators were given a questionnaire to identify the programme of maintenance and usage for each pitch. Furthermore, site conditions were monitored during testing, including the temperature and wind speed/direction

No published data was available to compare against, therefore the measurements are evaluated with the FIH performance standards (1999). Additionally, accreditation data were acquired for all but one site (Old Loughtonians) for comparison. Where appropriate the FIH limits are discussed within each section for a comparison and the result are contrasted with the accreditation results

5.4.1 Construction Specification

Details of the construction specifications for each pitch were obtained and are shown in Table 5.6. There was little difference between the sub-base and asphalt layers between the six sites. All sites used a type 1x aggregate for the sub-base with depths of 200 mm (Cannock and Belle Vue), 250 mm (Loughborough, Bowdon and Old Loughtonians) and 450 mm (Highfields). Type 1x MOT was specified to facilitate rapid drainage through the pitch system. On all sites the asphalt layer was installed in two lifts, a base and wearing course. The dimensions were almost identical between pitches with a 40 mm base course and a 25 mm wearing course, only Cannock was different with a 30 mm wearing course.

Large differences between the construction specifications become evident on the shockpad and carpet layers. Cannock and Belle Vue employed only an integral shockpad of 8 and 6 mm respectively. The remaining four pitches used an in-situ shockpad of either 12 or 15 mm. The exact design, binder content and particle size distribution are unknown and after considerable efforts could not be obtained. The carpet layer included four Astroturf systems (two 'Europa' and two 'System 5') these carpets were fabricated with nylon. The remaining two systems were 'Aquaturf' and 'EDEL Classic' both polypropylene. The pile height of the

polypropylene carpets were greater (13 and 15 mm) than the nylon carpets (11 and 12 mm) but the nylon carpet samples had a significantly higher pile weight, due to the integral backing and greater pile density. The six sites can be paired relating to their construction specifications, Loughborough with Highfields; Cannock with Belle Vue; and Bowdon with Old Loughtonians

5.4.2 Player/Surface Interaction Tests

Tables 5.7a & b present a summary of the testing at each site in April 2003 and March 2004. This section presents the results from the player/surface interaction tests i.e. the AAB, 2.25 kg Clegg hammer and rotational traction device.

Measurements with the AAB identified Cannock as the hardest pitch for both visits with a force reduction of 46.5 % in 2003 and 43.6 % the next year. Highfields was measured as the softest pitch both years with a force reduction of 63.7 % and 61.8 %. These measurements fall just within the upper and lower FIH limits of 40 – 65 % force reduction. Figure 5.21 illustrates the force reduction for all six sites on both visits and the horizontal lines represent the upper and lower FIH requirements. The pitches are presented in order of force reduction. The variability across each pitch for the 2004 data is shown in Figure 5.22. Cannock had the least variability with a COV of 4.0 % compared with the most variability at Old Loughtonians of 7.9 %. Cannock has an integral shockpad which was manufactured under carefully controlled conditions and therefore the improved uniformity may be expected in comparison to in-situ shockpads. Belle Vue which also has an integral shockpad supports this assumption with the next lowest COV of 4.6 %. The data from 2003 don't support this assumption as Cannock has the second highest recorded COV of 8.6 %. However, these data are based on only five locations.

The 2.25 kg Clegg impact hammer measured Cannock (242.8 IV) as the hardest pitch and Highfields (114.8 IV) as the softest. Figure 5.23 illustrates the mean impact value for the six pitches and the Y axis error bar represents one standard deviation, the pitches are presented in order of impact value. The variability across each pitch is quite similar ranging from a COV of 5.9 % for Belle Vue to 11.1 % for Old Loughtonians. Pitch usage (especially over-time) could influence the impact behaviour of the surface, in particular areas of the pitch that experience high frequency use (i.e. goal areas). Figure 5.24 illustrates the impact values measured at each location (on the five by five test matrix, see Figure 3.6)

at Cannock. There is no pattern to indicate that high usage has any influence on the impact value of the 2.25 kg Clegg hammer, and this lack of a trend is similar for all six pitches.

All six pitches were measured in the same order of stiffness with the 2.25 kg Clegg and AAB. This indicates a strong relationship between the two pieces of equipment. Figure 5.25a shows a relationship between the two devices on all six pitches. The graph exhibits a good correlation between the AAB and 2.25 kg Clegg hammer ($R^2 = 0.83$), however there are some minor distributions from the power trend line. These points on inspection were found to belong to the two pitches with polypropylene carpets, therefore the correlation was examined again without these data included and is shown in Figure 5.25b. The relationship between devices is stronger ($R^2 = 0.97$) without the data from the polypropylene carpets and matches closely the relationship between the devices identified in the laboratory (which were also Nylon). The pile properties are different for the polypropylene carpets which may influence the impact behaviour of the surface when loaded with the AAB or 2.25 kg Clegg.

The difference observed between pitches with the rotational traction device is shown in Figure 5.26a. The polypropylene carpets at Bowdon and Old Loughtonians had the lowest traction with 25.4 and 28.2 Nm respectively. The nylon carpets proved more resistance to turning with a traction between 28.8 and 32.6 Nm. The polypropylene carpets had a lower pile weight (see Table 5.6) and density than the nylon carpets. Furthermore, polypropylene has a lower tensile strength than nylon which makes it more compliant. Figure 5.27 illustrates for Cannock the range of results spread over the testing grid across the pitch. Site investigation of Cannock found large quantities of algae growth in zone E and the device identified this by measuring a lower traction (26.6 Nm compared with a mean of 29.3 Nm for the remaining four columns).

5.4.3 Ball/Surface Interaction Tests

This section presents the results from the ball/surface interactions tests including the ball rebound height and ball roll distance. Tables 5.7 a & b summarise the data presenting the mean, standard deviation and COV for each test in both 2003 and 2004.

The FIH requirements for global standard ball rebound height is between 10 and 25 cm from a drop height of 150 cm. Figure 5.28 illustrates the mean rebound height on all six pitches during site investigation in 2004. It can be seen from the FIH requirements (represented by the bold horizontal lines in the figure) that five of the six pitches would fail. However, it was shown during the laboratory testing that ball rebound height was sensitive to water on the surface. There is a large discrepancy between the FIH accreditation results and the measured test data which could be a result of different amounts of water on the surface. Pitches with similar construction specifications had ball rebound heights in the same range. The pitches that were paired Loughborough with Highfields; Cannock with Belle Vue; and Bowdon with Old Loughtonians all had similar measurements.

Algae growth appears to significantly reduce ball rebound height, as shown in Figure 5.29 for the variability across Cannock. Column E had a lower rebound height than the other columns and in particular test grid location 1E was noted as having large quantities of algae has reduced the ball rebound height to an average of 10.6 cm.

Ball roll distance could not be measured in the laboratory because of the large roll distances experienced. Due to the nature of the test the only layer with a significant influence on roll distance is the carpet. However, little difference was measured between the six pitches with the smallest distance recorded at Highfields of 13.6 m and largest at 15.5 m at Old Loughtonians (shown in Figure 5.30). Similar to the ball rebound result the FIH accreditation data observed does not match well the measurements test data. There was a noticeable directional influence during the ball roll testing. Table 5.7b shows a breakdown of the mean roll distance for the four roll directions. During testing at Highfields a wind speed reading of 4.6 ms^{-1} was recorded which resulted in a difference of 6.3 m. In comparison a wind speed of 0.4 ms^{-1} was recorded at Bowdon which resulted in a difference of 0.7 m. The gradient of the pitch may have influenced the roll distance however, it was not possible to test due to the influence of the wind.

5.4.4 Influence of Water (Loughborough University Pitch)

A satisfactory method to quantify the amount of water on a pitch surface during testing was not identified. Hence, an investigation was undertaken at the Loughborough University pitch to determine the influence of moisture on 'real' pitch behaviour.

The pitch was tested in three conditions; dry, match day and fully saturated, this gave a comparison between the two extremes. Dry testing was done without the application of any water on the surface (although there was a slight dew on the surface) Match day testing involved the same methodology as described in the section above, a full application of water from the irrigation cycle followed by forty minutes of testing. Pitch saturation involved the application of 4 litres of water over a 1 m² area followed by immediate testing, this was repeated for each location and piece of test equipment to ensure the test location was fully saturated. The time constraints of equipment hire made it unfeasible to replicate this experiment at other test locations.

The 0.5 kg Clegg impact hammer measured a large difference between the moisture conditions with a mean impact value of 170.9 dry and 124.7 saturated. This finding supports laboratory analysis and indicates the 0.5 kg Clegg hammer is sensitive to water and hence a useful tool to evaluate the amount of water on the pitch and could be a useful tool to identify the uniformity of the irrigation system. Figure 5.31 illustrates the variability across this pitch and shows the difference between the three moisture conditions.

Figure 5.32 illustrates the difference in ball rebound resilience for the three moisture conditions and similar to the laboratory testing shows a significant difference between each. Match conditions are much more variable than the other two sets of data. This indicates that the uniformity of the irrigation system has a significant influence on the rebound behaviour of the ball. The solid horizontal lines represent the FIH requirements for ball rebound and it can be seen that when the pitch is fully saturated it falls within this requirement with a mean rebound height of 23.4 cm. However, the other two conditions fail the FIH requirements with rebound height of 40.3 cm (dry) and 32.8 (match).

For practicality ball roll could only be measured for the two conditions of dry and match. As previously stated the roll distance is significantly affected by environmental conditions such as the wind. It was found that a dry pitch had a mean roll distance of 13.9 m and an irrigated distance of 14.4 m. This indicates that the water increases ball roll distance by reducing the friction between the ball/surface interface.

Rotational traction was measured for each of the three conditions; it was identified that water had a significant influence the recorded data. Figure 5.33 shows the difference between the three different moisture conditions ranging from a global average of 32.3 Nm dry down to 28.5 Nm fully saturated. This supports the laboratory findings that water on the pitch acts as a lubricant and reduces the rotational traction.

The AAB and 2.25 kg Clegg impact hammer measured only a small difference between the three moisture levels. The 2.25 kg Clegg measured a difference of between 120.2 IV dry and 114.8 IV saturated and the AAB measured a force reduction difference of 58.5 % dry and 61.4 % saturated. The impact behaviour of the AAB and 2.25 kg Clegg hammer are influenced by moisture on the surface but not to the same extent as the other pieces of equipment (in particular the ball rebound and 0.5 kg Clegg hammer). This is due to their larger impact energy which is less influenced by the dissipation of energy caused by the water i.e. the lower energy ball rebound and 0.5 kg Clegg hammer lose a higher proportion of their energy at impact and hence are influenced more by water.

5.4.3 Age Influence

To establish if there was a significant difference between the two programmes, analysis between the data collection in 2003 and 2004 was performed, Table 5.7a & b show the average data from each year for all tests. The AAB data shows that all but one (Old Loughtonians) of the pitches showed an increase in surface stiffness (hence less force reduction) between visits. Old Loughtonians was rejuvenated between visits which may explain the decrease in stiffness. No other pattern could be attributed to pitch age. However, the pitches have only been visited on two occasions and to obtain a more conclusive insight additional testing needs to be completed to ascertain the influence of age.

A pitch will become worn (the carpet pile will start to flatten and fibrillate) with usage and environmental influences such as UV radiation can weaken the material properties of the carpet. Furthermore, the elastomeric properties of the shockpad layer may reduce with time. Consequently, there is a need to monitor these pitches over a longer period of time to fully understand the influence age and usage has on their playing behaviour. A fundamental factor that can influence the longevity of a pitch is appropriate maintenance.

5.4.4 Maintenance and Usage

The method employed by the operators of the six pitches was brushing between 2 and 4 week intervals. Brushing removes detritus from the playing surface but if performed too frequently can lead to accelerated ageing. Some manufactures offer a rejuvenation package to extend the life of a pitch. It involves a combination of vacuum cleaning, carpet stretching and seam/line (re)alignment. However, the effectiveness of these procedure is unclear

5.5 SITE INVESTIGATION AND LABORATORY COMPARISON

To validate the laboratory analysis a comparison between the results obtained on-site (at the Loughborough University water-based pitch) and in the laboratory were analysed. Loughborough University was chosen as the site for comparison as it matched the construction specifications used in the laboratory. Furthermore, additional data had been obtained from Loughborough in relation to the influence of water on the surface. Table 5.8 shows a comparison between the site and laboratory constructions. The carpet and shockpad samples were taken from site during construction and hence exactly matched

The site at Loughborough University was tested in three conditions dry, match and saturated. This was comparable to the laboratory data which were tested in four conditions dry, saturated, 20 minutes after saturation and 40 minutes after saturation. The two extremes of dry and fully saturated were assumed to constitute the full range of playing conditions

The results obtained from the 2.25 kg Clegg hammer suggest the outdoor surface is stiffer, illustrated in Figure 5.34. The reason for this difference may have been the usage of the Loughborough university pitch, the laboratory samples had not been used whereas the Loughborough pitch had been subject to an estimated 1300 hours usage (Table 5.6). Conversely, the AAB measured a higher force reduction on site, hence lower stiffness. This may indicate that the impact behaviour of the AAB is different to the 2.25 kg Clegg. However, as the two devices have shown a strong relationship for other testing it may indicate that the AAB is more susceptible to temperature variations than the 2.25 kg Clegg hammer. The outdoor testing was done on three consecutive days in March with a temperature range of 4.6 – 8.4°C compared with 21°C ± 2°C in the laboratory

The ball rebound height was lower on site than in the laboratory, these data are shown in Figure 5.36. The impact behaviour of the Loughborough pitch may have changed since its installation i.e. loss of elasticity from the shockpad and/or carpet pile fibrillation/flattening).

The rotational traction was lower in the laboratory than on site. In the laboratory the traction was lower for all moisture conditions, Figure 5.37 shows the difference. The carpet samples were unused and consequently may have still had the wax coat applied during the manufacturing procedure. Hence, the rotational traction results are lower in the laboratory

5.6 Summary of Field and Laboratory Work

Examination of synthetic turf pitches within the field combined with laboratory testing has enabled a more complete picture to be developed. The quantity of water on the surface was found to have a significant influence on its behaviour, in particular ball rebound height (the water dissipates the energy) and reduces the rotational traction. This raises the issue of the watering system and if a pitch is not correctly irrigated prior to play then it may behave different across the pitch. Furthermore, the speed at which a pitch changes its properties as it dries from drainage and evaporation was found to be significant over a 20 and 40 minute period.

The difference between carpet types were identified, the Nylon based carpets were found to produce more rotational traction than the polypropylene carpets. The carpet pile was also found to reduce the height of ball rebound by absorbing the energy of the ball during impact.

The impact behaviour of the surface when measured with the AAB and 2.25 kg Clegg impact hammer was dependent on the shockpad layer. It was found that the pitches evaluated with a relatively thin integral system had a much higher stiffness than pitches with an in-situ shockpad system. The shockpad was found to improve the impact absorption properties of the surface.

The role of the asphalt and layers below were not found to be as critical to the performance of the pitch when measured with the current mechanical tests. The shockpad and carpet layers were more influential on performance.

The following Chapter utilises the information gathered from the fieldwork of completed pitches in 2004 and compares them to players perceptions (Chapter 4). This is then used to formulate relationships between the mechanical and perceived behaviour of synthetic turf pitches for field hockey.

Table 5.1 - Global characteristics of the pitches constituent layers by device

| Test Device | | Pitch Layer | | | |
|---------------|-------------|-------------|----------|-----------|------------|
| | | Formation | Sub-base | Asphalt | Shockpad |
| Prima (300mm) | <i>Mean</i> | 28.1 MPa | 28.8 MPa | 109.8 MPa | 56.1 MPa |
| | <i>SD</i> | 18.2 MPa | 12.0 MPa | 23.5 MPa | 13.3 MPa |
| | <i>COV</i> | 64.7 % | 41.6 % | 21.4 % | 23.7 % |
| | <i>N</i> | 24 | 38 | 50 | 58 |
| GDP | <i>Mean</i> | 12.0 MPa | 22.1 MPa | 139.9 MPa | - |
| | <i>SD</i> | 3.8 MPa | 7.1 MPa | 27.6 MPa | - |
| | <i>COV</i> | 31.4 % | 32.0 % | 19.8 % | - |
| | <i>N</i> | 27 | 35 | 62 | - |
| Clegg 4.5 Kg | <i>Mean</i> | 11.9 IV | 28.1 IV | - | - |
| | <i>SD</i> | 4.5 IV | 16.2 IV | - | - |
| | <i>COV</i> | 37.6 % | 57.6 % | - | - |
| | <i>N</i> | 23 | 38 | - | - |
| Clegg 2.25 Kg | <i>Mean</i> | - | - | - | 236.6 IV |
| | <i>SD</i> | - | - | - | 23.6 IV |
| | <i>COV</i> | - | - | - | 10.0 |
| | <i>N</i> | - | - | - | 50 |
| AAB | <i>Mean</i> | - | - | - | 38.39 % FR |
| | <i>SD</i> | - | - | - | 2.74 % FR |
| | <i>COV</i> | - | - | - | 14.0 % |
| | <i>N</i> | - | - | - | 15 |

Key:

SD = Standard deviation

COV = Coefficient of variation

N = Number of test locations

Table 5 2 - Spatial characteristics of the Loughborough University pitch constituent layers by device

| Pitch Layer | Row | Test Device (mean) | | | |
|-------------|-----|--------------------|-----------|-------------------|--------------------|
| | | Prima (MPa) | GDP (MPa) | Clegg 4.5 Kg (IV) | Clegg 2.25 Kg (IV) |
| Formation | A | - | 10.3 | 5.7 | - |
| | B | 20.9 | 9.2 | 14 8 | - |
| | C | 17 0 | 10.7 | 14.3 | - |
| | D | 43 0 | 17 2 | 13 9 | - |
| | E | 23.1 | 14.5 | 11.8 | - |
| | F | 26.3 | 11.1 | 9 8 | - |
| | G | - | - | - | - |
| Sub-base | A | - | - | - | - |
| | B | 39.2 | 25.1 | 17.6 | - |
| | C | 30 4 | 25.0 | 15.1 | - |
| | D | 25.1 | 24.5 | 14 7 | - |
| | E | 19.0 | 17.0 | 16 4 | - |
| | F | 29 4 | 18.4 | 41 9 | - |
| | G | 22 8 | 20 4 | 41.5 | - |
| Asphalt | A | 147.5 | 147.1 | - | - |
| | B | 104.8 | 169.3 | - | - |
| | C | 109.4 | 144.2 | - | - |
| | D | 110.9 | 138.8 | - | - |
| | E | 87.1 | 107.1 | - | - |
| | F | - | 139.2 | - | - |
| | G | 112.0 | 133.5 | - | - |
| Shockpad | A | 51.3 | - | - | - |
| | B | 60 9 | 9.7 | - | 234 0 |
| | C | 58 6 | - | - | 243 7 |
| | D | 65.7 | 9.8 | - | 238 3 |
| | E | 46 0 | - | - | 211.2 |
| | F | 53.7 | 7.9 | - | 266.2 |
| | G | 53.2 | - | - | 221.8 |

Table 5.3 - Global characteristics of the sub-base and asphalt layers on-site and in the laboratory

| Device | Site | | Box | | Laboratory Floor |
|--------------|----------|---------|----------|---------|---------------------|
| | Sub-base | Asphalt | Sub-base | Asphalt | Reinforced Concrete |
| Prima (MPa) | 28.8 | 109.8 | 266.1 | 575.8 | 2524.8 |
| CIH (4.5 Kg) | 28.1 | - | 39.3 | - | - |

Table 5.4 - Global characteristics of the sub-base and asphalt layers in the laboratory

| Location | Sub-base | | Asphalt |
|----------|----------|--------------|---------|
| | Prima | 4.5 kg Clegg | Prima |
| Mean | 266.1 | 39.3 | 575.8 |
| SD | 77.5 | 4.1 | 103.3 |
| COV | 29.1 | 10.4 | 17.9 |

Table 5 5 - The mean and COV for five pieces of test equipment on twelve carpet/shockpad systems on the laboratory floor and in the box

| Test Device/Method | | | | | | | | | | |
|---|-------------------------|------|---------------------------|-------|--------------------------|-------|--------------------------|------|--------------------------|------|
| Mean | AAB (Force Reduction %) | | 2 25 kg Clegg Hammer (IV) | | 0 5 kg Clegg hammer (IV) | | Ball Rebound Height (cm) | | Rotational Traction (Nm) | |
| | Lab | Box | Lab | Box | Lab | Box | Lab | Box | Lab | Box |
| Pitch System | | | | | | | | | | |
| LUC | 29 1 | 29 0 | 222.1 | 216 6 | 144 1 | 141.5 | 31 5 | 31 8 | 31 4 | 31 4 |
| BVC | 39 8 | 39 2 | 161 0 | 151 7 | 140 6 | 140 6 | 31 7 | 32 8 | 31 4 | 31 3 |
| LUC & 6 mm SP | 46.3 | 46 3 | 144 0 | 140 2 | 127.6 | 127 9 | 41 4 | 41.7 | 31 3 | 30 8 |
| BVC & 6 mm SP | 51.7 | 52 4 | 134 1 | 126 5 | 124.2 | 124.5 | 39 2 | 41 3 | 31 9 | 31.2 |
| LUC & 9 mm SP | 47 0 | 46 9 | 132 2 | 128 5 | 126.4 | 123 5 | 41 7 | 42.5 | 31 6 | 31.0 |
| BVC & 9 mm SP | 49 6 | 49 5 | 126 8 | 122 2 | 125.9 | 126 0 | 41 3 | 42 0 | 31.5 | 31.1 |
| LUC & 11 mm SP | 53 2 | 52 5 | 120.7 | 116 3 | 128 6 | 126 3 | 44 1 | 45.1 | 31.6 | 30 9 |
| BVC & 11 mm SP | 52 2 | 52 5 | 109 6 | 105.1 | 129 5 | 129 2 | 42 2 | 44.2 | 31.5 | 31 5 |
| LUC & 12 mm SP | 56 5 | 56 3 | 117 5 | 111.7 | 121 5 | 119 7 | 44 7 | 46.2 | 31 9 | 31 4 |
| BVC & 12 mm SP | 61 3 | 61 6 | 97 2 | 93 4 | 116 4 | 113 8 | 45 2 | 47.3 | 31 5 | 31 4 |
| LUC & 20 mm SP | 67 6 | 67.5 | 83 9 | 78 5 | 113 7 | 114.3 | 46 5 | 47.3 | 31 2 | 31 6 |
| BVC & 20 mm SP | 68 7 | 69 5 | 76 7 | 72 2 | 108 4 | 106 0 | 44 5 | 46 8 | 31.4 | 31.3 |
| COV | | | | | | | | | | |
| Pitch System | Lab | Box | Lab | Box | Lab | Box | Lab | Box | Lab | Box |
| LUC | 2 6 | 5 8 | 3 1 | 3 5 | 3.7 | 4 2 | 2 6 | 1 6 | 1.7 | 1 6 |
| BVC | 2 4 | 2 9 | 3 7 | 3 8 | 6.0 | 5 8 | 1.5 | 1.3 | 1.1 | 2 0 |
| LUC & 6 mm SP | 2 7 | 4 4 | 4 8 | 5 2 | 3.4 | 3 5 | 1 6 | 1 1 | 1 4 | 1 8 |
| BVC & 6 mm SP | 2 0 | 4 4 | 4 7 | 5 3 | 4.3 | 4 3 | 2 7 | 1 4 | 1.1 | 2 1 |
| LUC & 9 mm SP | 2 4 | 3 0 | 6 1 | 6 1 | 2.6 | 2 7 | 1 2 | 1 7 | 3.2 | 3 3 |
| BVC & 9 mm SP | 3 3 | 4 9 | 4 9 | 5 0 | 4.0 | 3 8 | 1.5 | 1.7 | 1.4 | 3 6 |
| LUC & 11 mm SP | 2 3 | 4 2 | 4 3 | 5 1 | 2.4 | 3 1 | 0 9 | 2.2 | 2 1 | 3 0 |
| BVC & 11 mm SP | 2 6 | 3 8 | 7 8 | 8 4 | 2.4 | 2 9 | 1.0 | 1.5 | 1 8 | 2 0 |
| LUC & 12 mm SP | 2 4 | 3 3 | 6 7 | 7 1 | 5 0 | 5 3 | 1.7 | 1.7 | 1.7 | 2 5 |
| BVC & 12 mm SP | 2 7 | 3 2 | 1 2 | 1 6 | 3 4 | 4 1 | 1 4 | 0 9 | 1.7 | 2 0 |
| LUC & 20 mm SP | 2 5 | 3 5 | 6 0 | 6 3 | 3.7 | 4 4 | 2 1 | 0 9 | 2 4 | 2.0 |
| BVC & 20 mm SP | 2 0 | 2 9 | 2 3 | 2 3 | 3 8 | 4.1 | 1.1 | 0 8 | 2 0 | 3 0 |
| Key: | | | | | | | | | | |
| LUC = Loughborough University Carpet | | | | | | | | | | |
| BVC = Belle Vue Carpet | | | | | | | | | | |
| SP = Shockpad | | | | | | | | | | |
| Lab = Samples tested directly on the laboratory floor | | | | | | | | | | |
| Box = Samples tested in the prepared box | | | | | | | | | | |

Table 5.6 – A description of the construction specification and details of the six pitches identified for site investigation

| | Loughborough University | Highfields | Cannock | Bowdon | Belle Vue | Old Loughtonians |
|--|-----------------------------|------------------------------------|-------------------------------|-----------------------------|-------------------------------|-----------------------------|
| Installation | February 2002 | December 2001 | November 1999 | October 2001 | January 2002 | January 1999 |
| FIH Accreditation Test | February 2003 | September 2002 | January 2000 | November 2001 | July 2002 | N/A |
| Estimated Usage Per Week ¹ | 50h/week | 60h/week | 55h/week | 75h/week | 75h/week | 60h/week |
| Estimated Usage Since Installation 2003/2004 testing | 750h/1300h | 1020h/1680h | 2310h/2915h | 1350h/2175h | 1200h/2025h | 3120h/3780h |
| Maintenance Programme | Brush every 2 weeks | Vacuum once week, Brush once month | Brush once month ² | Brush once month | Brush once month | Brush once month |
| Rejuvenation | none | none | none | none | none | July 2003 ³ |
| Construction Specification | | | | | | |
| Sub-base | 250 mm type 1 aggregate | 450 mm type 1 aggregate | 200 mm type 1 aggregate | 250 mm type 1 aggregate | 200 mm type 1 aggregate | 250 mm type 1 aggregate |
| Asphalt | 40 mm base 25 mm wearing | 40 mm base 25 mm wearing | 40 mm base 30 mm wearing | 40 mm base 25 mm wearing | 40 mm base 25 mm wearing | 40 mm base 25 mm wearing |
| Shockpad | | | | | | |
| Type | In-situ & Integral | In-situ & Integral | Integral | In-situ | Integral | In-situ |
| Thickness | 15 mm ⁴ | 15 mm ⁴ | 8 mm | 15 mm | 6 mm | 15 mm |
| Carpet | | | | | | |
| System | Astroturf Europa | Astroturf Europa | Astroturf System ⁵ | Aquaturf | Astroturf System ⁵ | EDEL Classic |
| Pile Material | Nylon | Nylon | Nylon | Polypropylene | Nylon | Polypropylene |
| Pile Height (mm) | 12 mm | 12 mm | 11 mm | 15 mm | 11 mm | 13 mm |
| Pile Weight (kg/m ²) | 3.95 kg/m ² | 3.95 kg/m ² | 5.10 kg/m ² | 2.64 kg/m ² | 5.10 kg/m ² | 2.01 kg/m ² |
| Fabrication Method | Knitted and Curled | Knitted and Curled | Knitted and Curled | Tufted | Knitted and Curled | Tufted |
| Integral Pad | Yes, 3 mm | Yes, 3 mm | Yes, 8 mm | No | Yes, 6 mm | No |

¹ based on information from owner/operator. ² used to be weekly but pile started to show signs of wear ³ Carpet stretched and glued in place ⁴ combination of 12 mm in-situ and 3 mm integral shockpad thickness

Table 5 7a - A summary of the data collected for all six sites in April 2003

| | | Site | | | | | |
|--|------|---|-------|-------|-------|-------|-------|
| | | LU | HF | CN | BD | BV | OL |
| Temperature (°C) | | 8.3 | 9.5 | 10.4 | 8.8 | 10.4 | 12.6 |
| Wind Speed (ms ⁻¹) | | - | - | - | - | - | - |
| Test Method | | | | | | | |
| AAB (FR %) | Mean | 62.4 | 63.7 | 46.5 | 53.1 | 47.8 | 51.3 |
| | SD | 3.0 | 3.3 | 3.9 | 3.2 | 2.1 | 4.6 |
| | COV | 4.8 | 5.2 | 8.6 | 6.0 | 4.4 | 9.0 |
| 2.25 kg Clegg Hammer (IV, gms ⁻²) | Mean | 119.9 | 112.9 | 243.7 | 134.9 | 224.0 | 123.5 |
| | SD | 13.4 | 12.0 | 40.0 | 13.4 | 14.1 | 12.6 |
| | COV | 11.2 | 10.6 | 16.4 | 9.9 | 6.3 | 10.2 |
| 0.5 Kg Clegg Hammer (IV, gms ⁻²) | Mean | 122.2 | 131.0 | 224.9 | 149.3 | 192.4 | 134.2 |
| | SD | 12.6 | 8.2 | 35.9 | 16.78 | 9.3 | 15.8 |
| | COV | 10.3 | 6.2 | 16.0 | 11.23 | 4.9 | 11.8 |
| Ball Rebound Height (cm) | Mean | 31.5 | 33.2 | 26.9 | 40.09 | 18.8 | 31.6 |
| | SD | 0.8 | 3.4 | 1.2 | 1.38 | 2.8 | 2.2 |
| | COV | 2.7 | 10.3 | 4.4 | 3.45 | 14.7 | 7.1 |
| Rotational Traction (Nm) | Mean | - | - | - | - | - | - |
| | SD | - | - | - | - | - | - |
| | COV | - | - | - | - | - | - |
| Ball Roll Distance (m) | Mean | 14.6 | 15.4 | 16.2 | 14.9 | 13.6 | 13.7 |
| | SD | 0.7 | 0.6 | 0.8 | 1.7 | 1.2 | 1.4 |
| | COV | 4.9 | 3.7 | 5.0 | 11.6 | 8.5 | 10.5 |
| Key: | | | | | | | |
| | | LU = Loughborough University, HF = Highfields, CN = Cannock, BD = Bowdon, BV = Belle Vue, OL = Old Loughtonians | | | | | |

Table 5 7b - A summary of the data collection for all six sites in March 2004

| | | Site | | | | | |
|--|------------------------------|-------|-------|-------|-------|-------|-------|
| | | LU | HF | CN | BD | BV | OL |
| Temperature (°C) | | 5.9 | 5.9 | 10.5 | 10.9 | 5.6 | 5.9 |
| Wind Speed (ms ⁻¹) | | 1.8 | 4.6 | 2.2 | 0.4 | 1.6 | 1.1 |
| Test Method | | | | | | | |
| AAB (FR %) | Mean | 60.4 | 61.8 | 43.6 | 55.5 | 45.4 | 52.7 |
| | SD | 3.0 | 3.8 | 1.7 | 3.5 | 2.1 | 4.2 |
| | COV | 5.0 | 6.1 | 4.0 | 6.3 | 4.6 | 7.9 |
| 2.25 kg Clegg Hammer (IV, gms ⁻²) | Mean | 116.1 | 114.8 | 242.8 | 125.3 | 208.9 | 119.8 |
| | SD | 9.0 | 11.3 | 16.9 | 8.3 | 12.3 | 13.3 |
| | COV | 7.7 | 9.8 | 7.0 | 6.6 | 5.9 | 11.1 |
| 0.5 Kg Clegg Hammer (IV, gms ⁻²) | Mean | 145.3 | 136.7 | 228.3 | 160.2 | 216.2 | 135.6 |
| | SD | 10.1 | 7.8 | 18.9 | 13.0 | 17.6 | 17.4 |
| | COV | 7.0 | 5.7 | 8.3 | 8.1 | 8.2 | 12.9 |
| Ball Rebound Height (cm) | Mean | 32.8 | 36.8 | 20.7 | 41.1 | 26.2 | 32.2 |
| | SD | 2.4 | 3.2 | 5.2 | 1.0 | 0.7 | 2.2 |
| | COV | 7.2 | 8.6 | 25.0 | 2.5 | 2.8 | 6.8 |
| Rotational Traction (Nm) | Mean | 31.4 | 32.6 | 28.8 | 25.4 | 31.1 | 28.2 |
| | SD | 0.9 | 2.1 | 1.8 | 1.0 | 1.2 | 1.7 |
| | COV | 3.0 | 6.6 | 6.3 | 3.8 | 3.8 | 5.9 |
| Ball Roll Distance (m) | Mean | 14.5 | 13.6 | 15.4 | 15.1 | 14.0 | 15.5 |
| | SD | 1.0 | 2.1 | 1.8 | 1.6 | 1.1 | 3.1 |
| | COV | 7.2 | 15.6 | 11.8 | 10.3 | 8.1 | 20.0 |
| | <i>D₁ (north)</i> | 14.62 | 11.84 | 17.53 | 14.90 | 13.49 | 14.12 |
| | <i>D₂ (east)</i> | 13.70 | 14.05 | 15.36 | 15.12 | 13.67 | 12.54 |
| | <i>D₃ (south)</i> | 14.76 | 18.12 | 14.01 | 15.58 | 15.98 | 15.07 |
| | <i>D₄ (west)</i> | 15.28 | 12.07 | 15.09 | 15.06 | 13.75 | 19.21 |

Key:

LU = Loughborough University, HF = Highfields, CN = Cannock, BD = Bowdon, BV = Belle Vue,
OL = Old Loughtonians

Table 5 8 - A comparison between the construction specifications on site and in the laboratory

| Layer | Loughborough University | Laboratory System A |
|-----------------|------------------------------------|----------------------------|
| Sub-base | 250 mm | 400 mm |
| Asphalt | 65 mm | 60 mm |
| Insitu | 12 mm | 12 mm |
| Shockpad | | |
| Carpet | Astroturf Europa | Astroturf Europa |
| System | | |

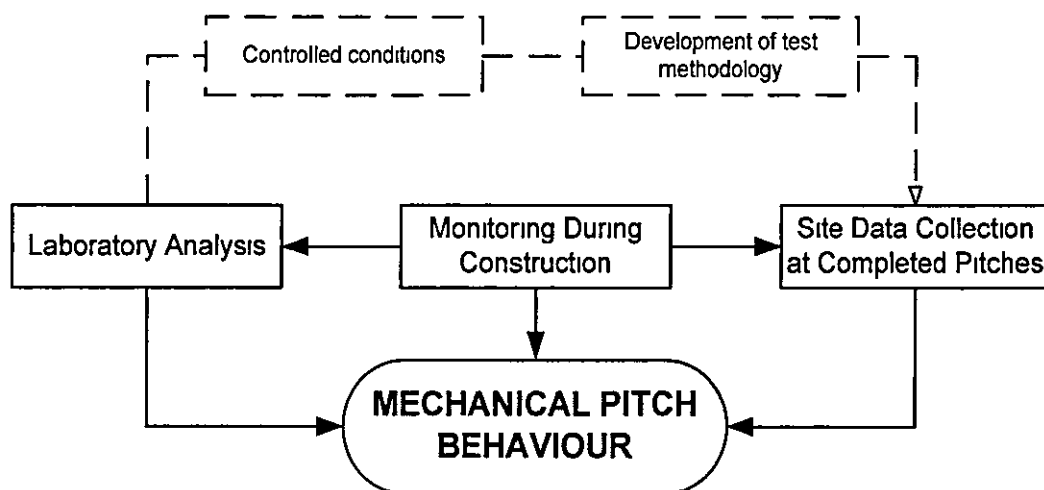


Figure 5.1 - The flow of data between the three data collection methods for mechanical behaviour; monitoring during construction, laboratory analysis and site investigation of completed pitches

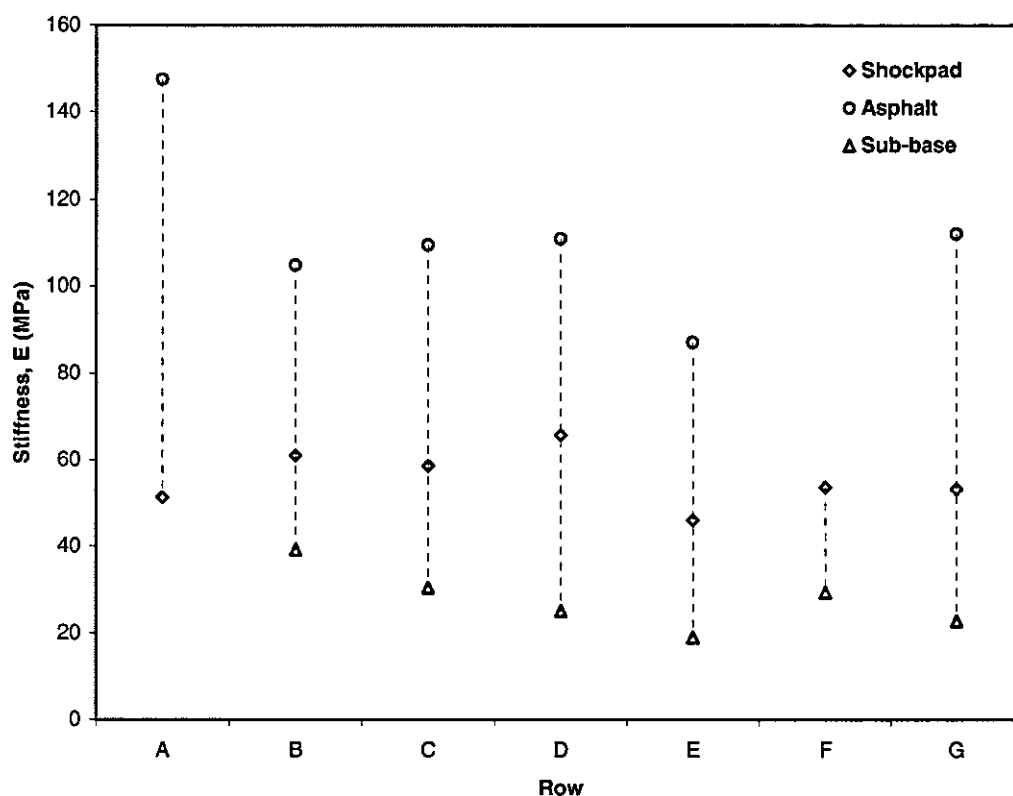


Figure 5.2 - Row characteristics measured by the Prima (300 mm) on the sub-base, asphalt and shockpad layers during construction at the Loughborough University site

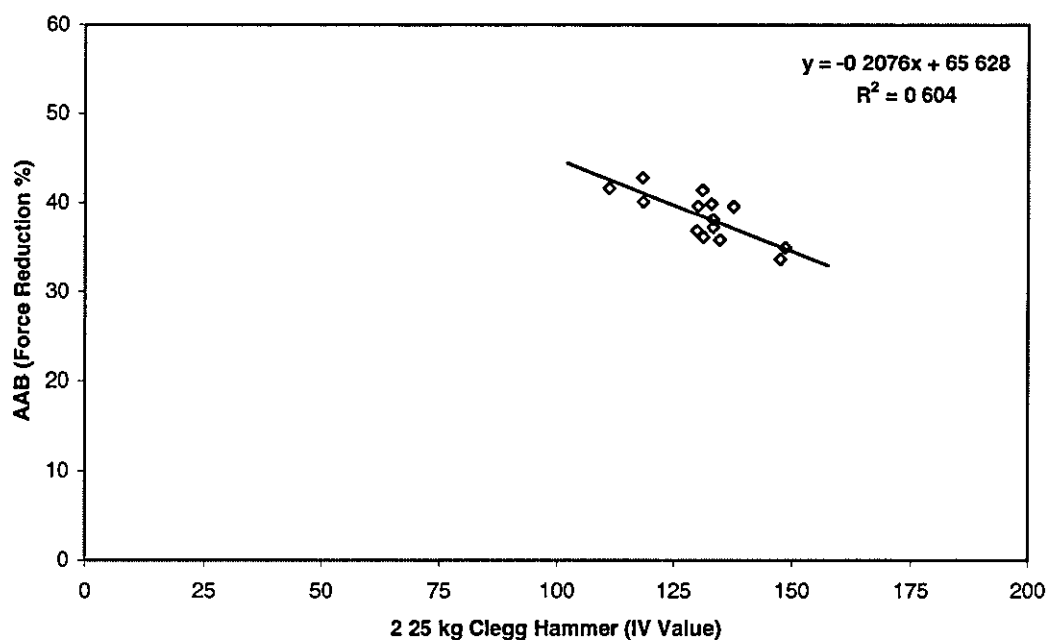


Figure 5.3 - A correlation between the AAB and Clegg 2.25 Kg impact hammer on the shockpad layer during construction

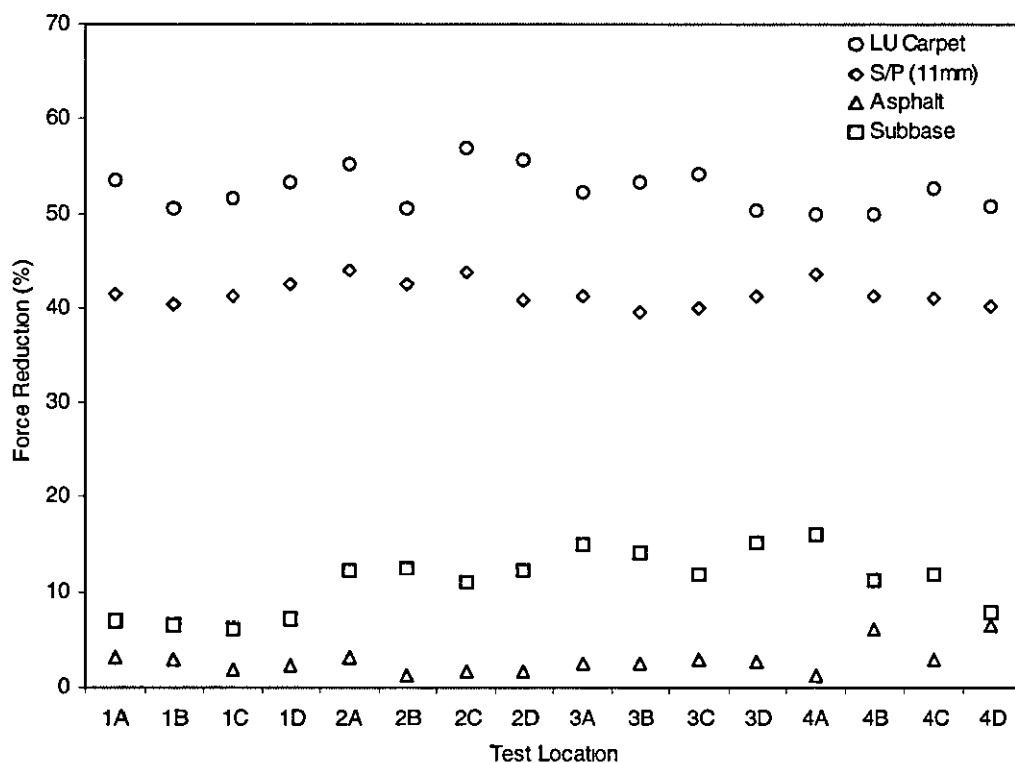


Figure 5.4 - The difference between layers measured with the Berlin Artificial Athlete during laboratory testing in the box at 16 test locations

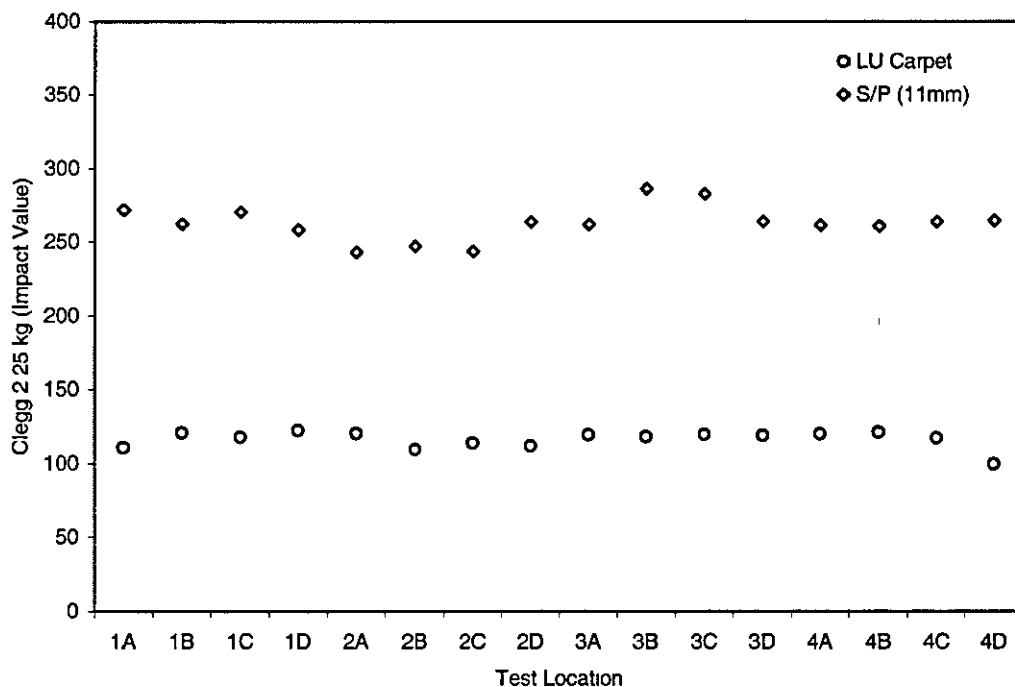


Figure 5.5 - A Comparison between the LU carpet sample and the 11 mm shockpad sample layers when measured with the 2.25 kg Clegg impact hammer in the laboratory at 16 test locations

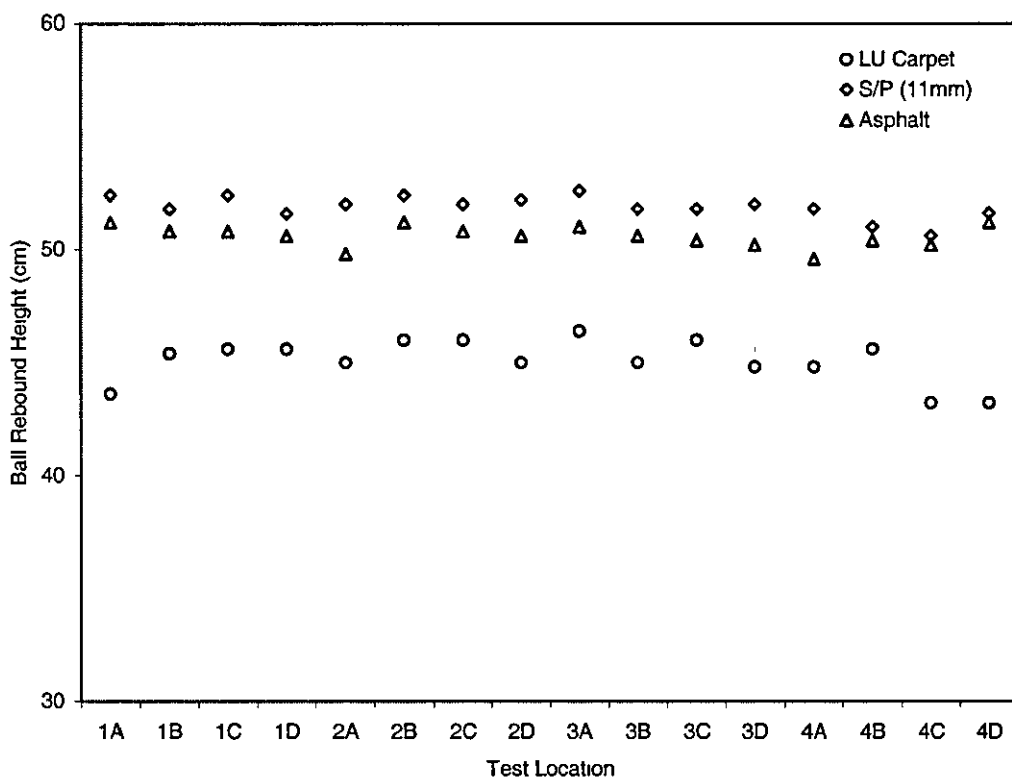


Figure 5.6 - The difference in ball rebound height (cm) between layers in the laboratory at 16 test locations

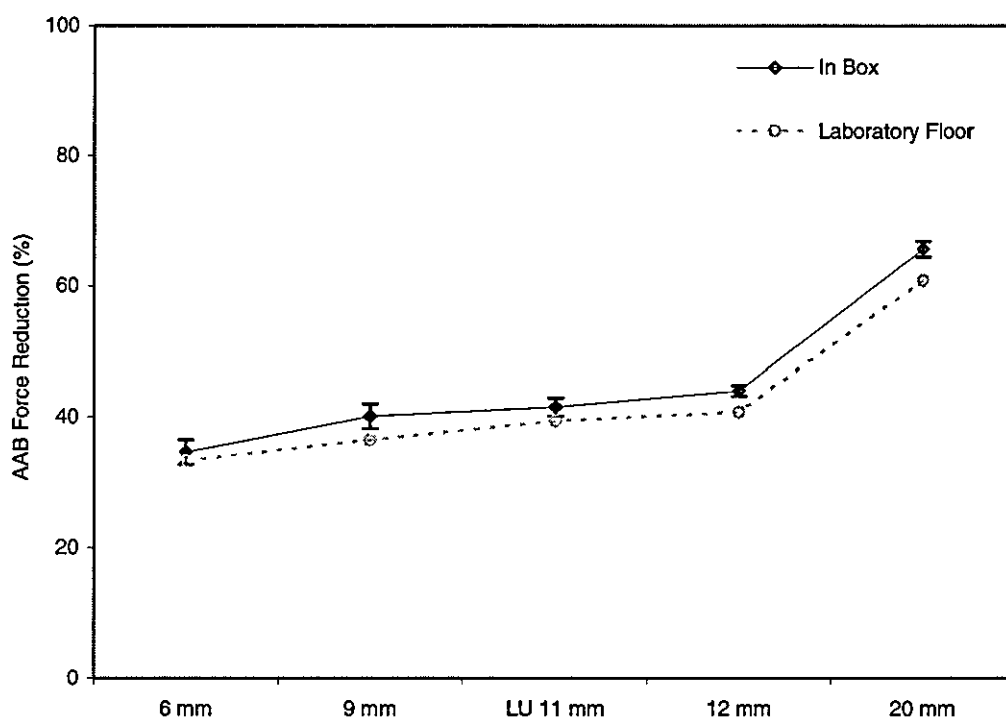


Figure 5.7 - The difference in force reduction (%) measured with the Berlin artificial athlete for five shockpad samples in the laboratory, directly on the floor and in the box

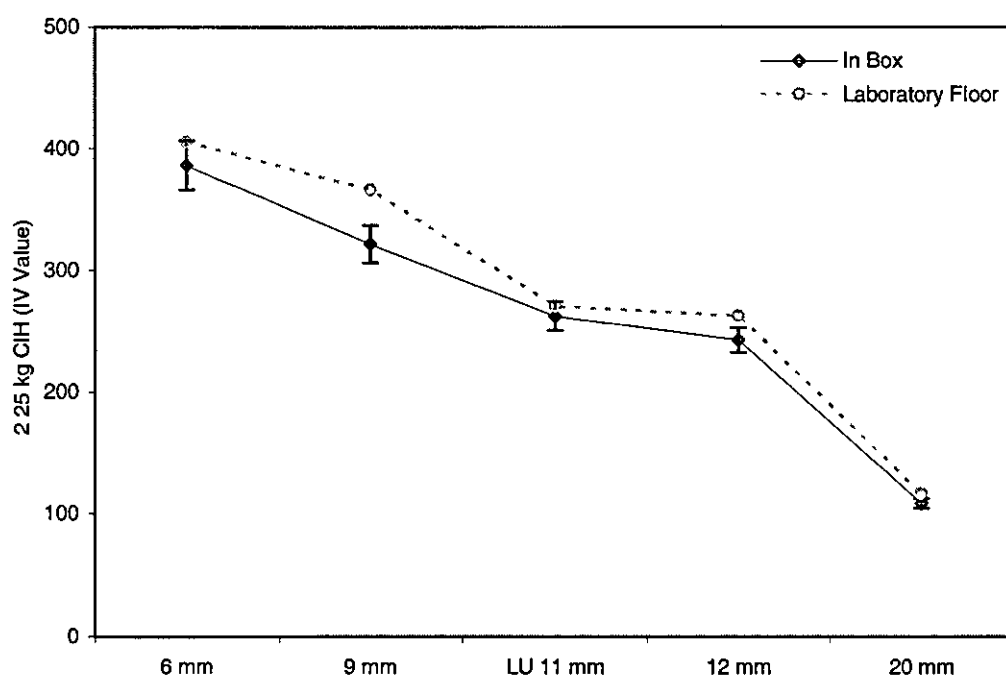


Figure 5.8 - The difference in Clegg impact value (CIV) measured with the 2.25 kg Clegg hammer for five shockpad samples in the laboratory, directly on the floor and in the box

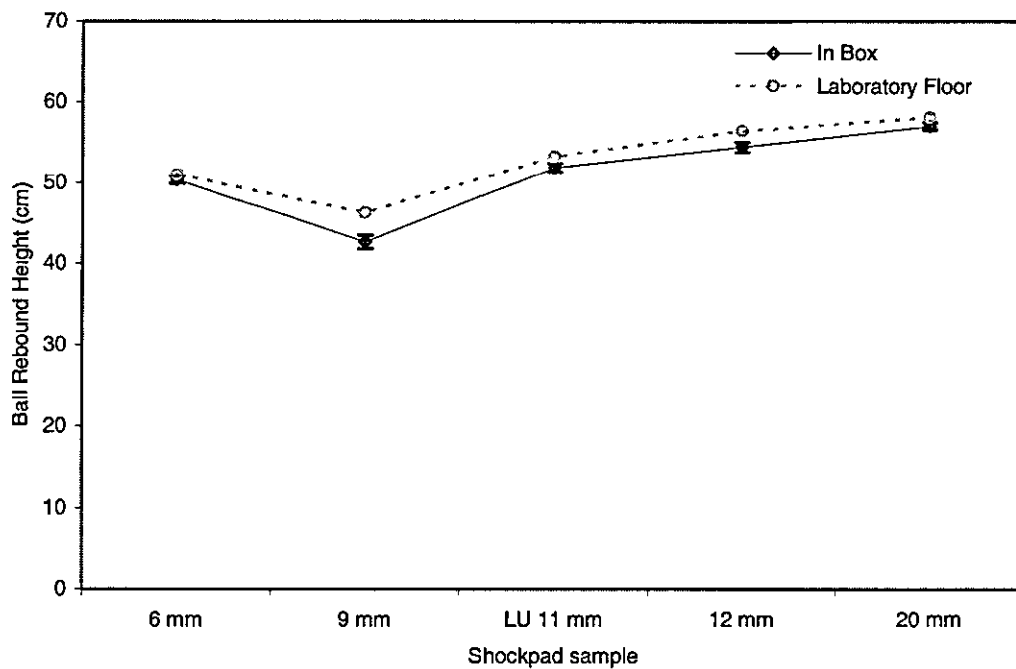


Figure 5.9 - The difference in ball rebound height (cm) on the laboratory floor and in the box for five shockpad samples

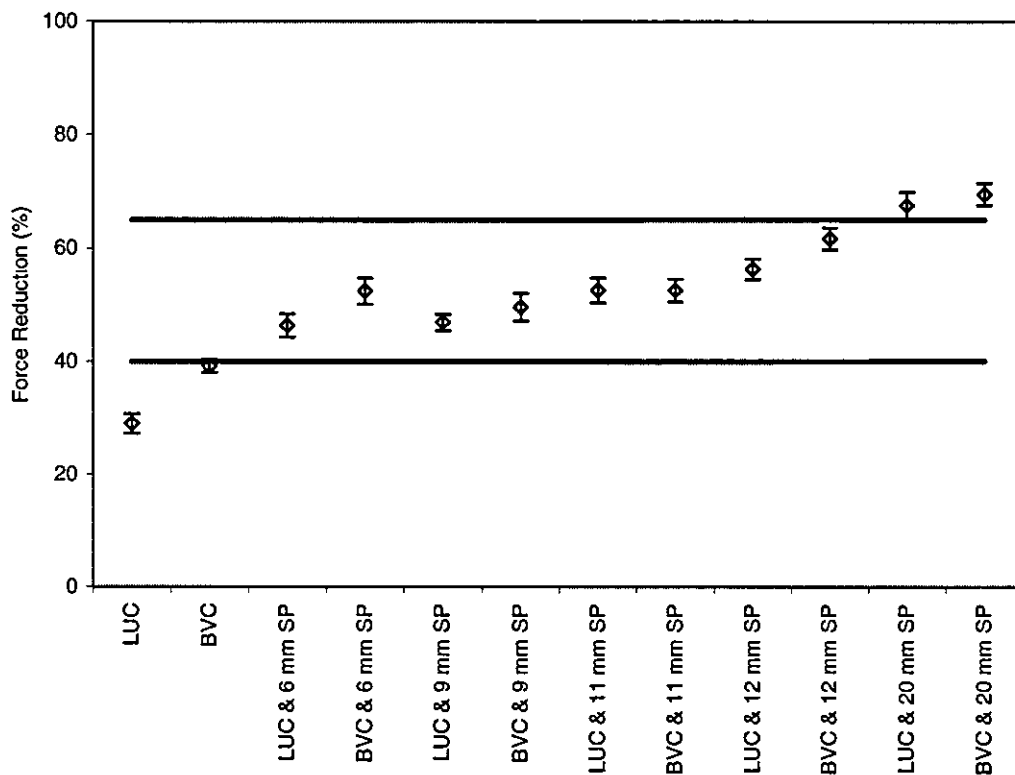


Figure 5.10 - Mean force reduction measured by the AAB on twelve shockpad/carpet systems in the laboratory with standard deviation error bars

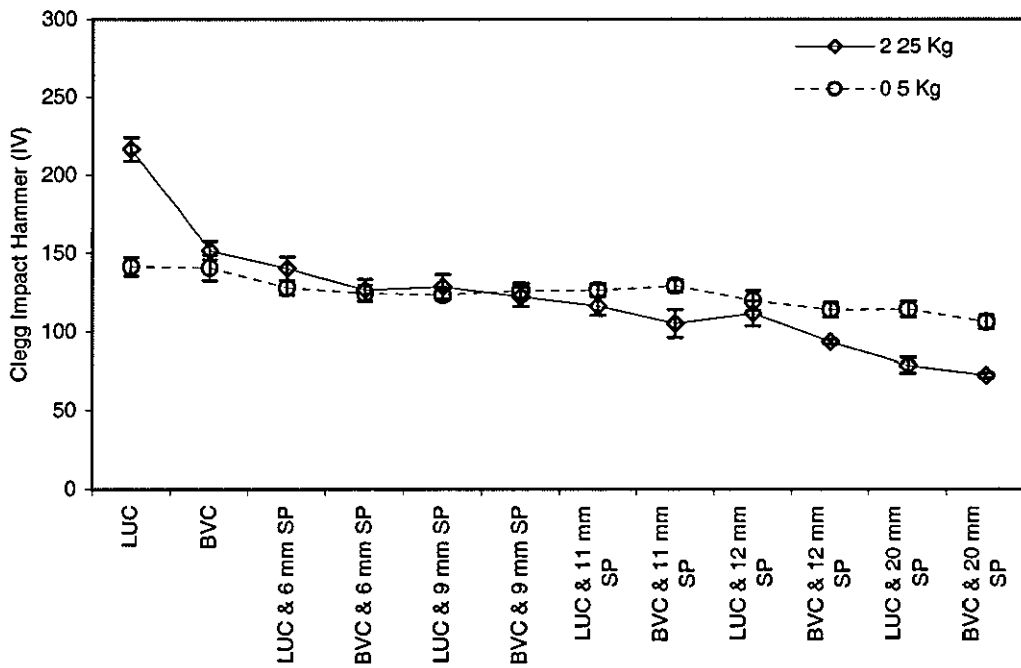


Figure 5 11 - Mean Clegg Impact Value measured by the 0.5 and 2.25 kg Clegg hammers on twelve shockpad/carpet systems in the laboratory with standard deviation error bars

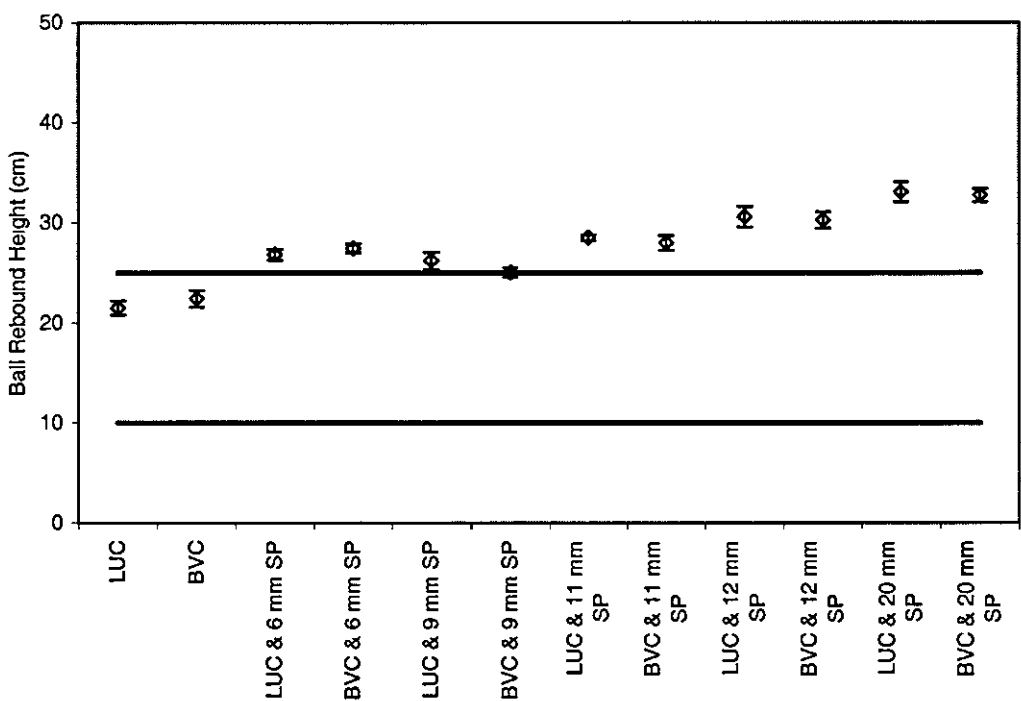


Figure 5 12 - Mean ball rebound height on twelve shockpad/carpet systems in the laboratory with standard deviation error bars (saturated conditions)

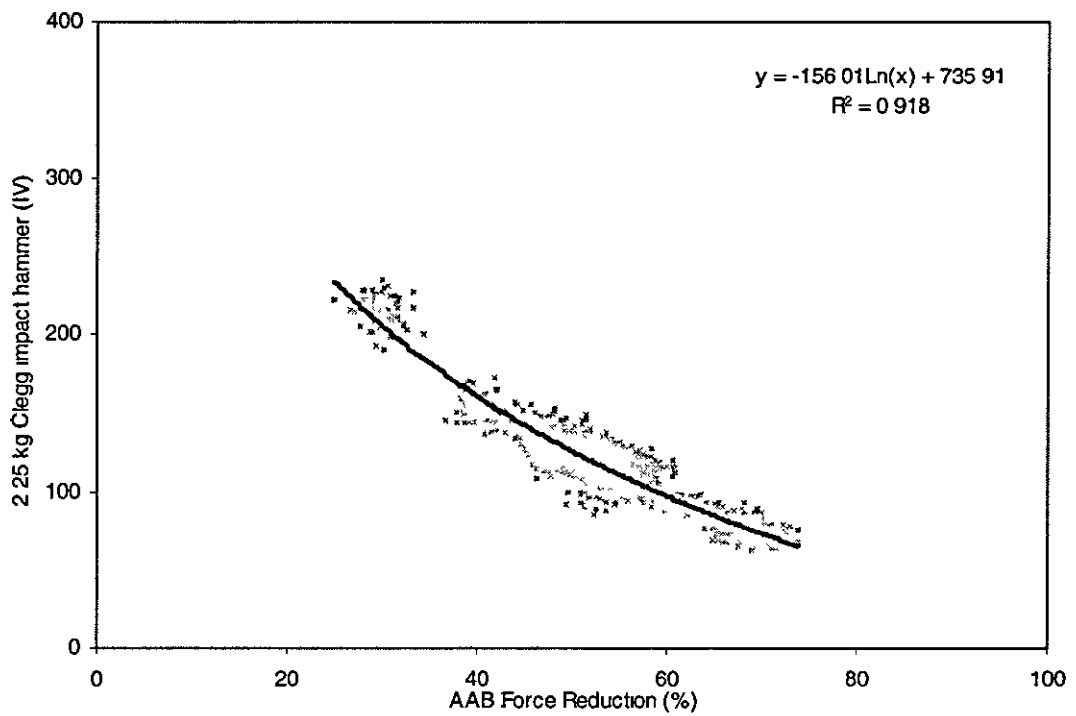


Figure 5.13a - The relationship between the 2.25 kg Clegg impact hammer and AAB on all surface systems in the laboratory

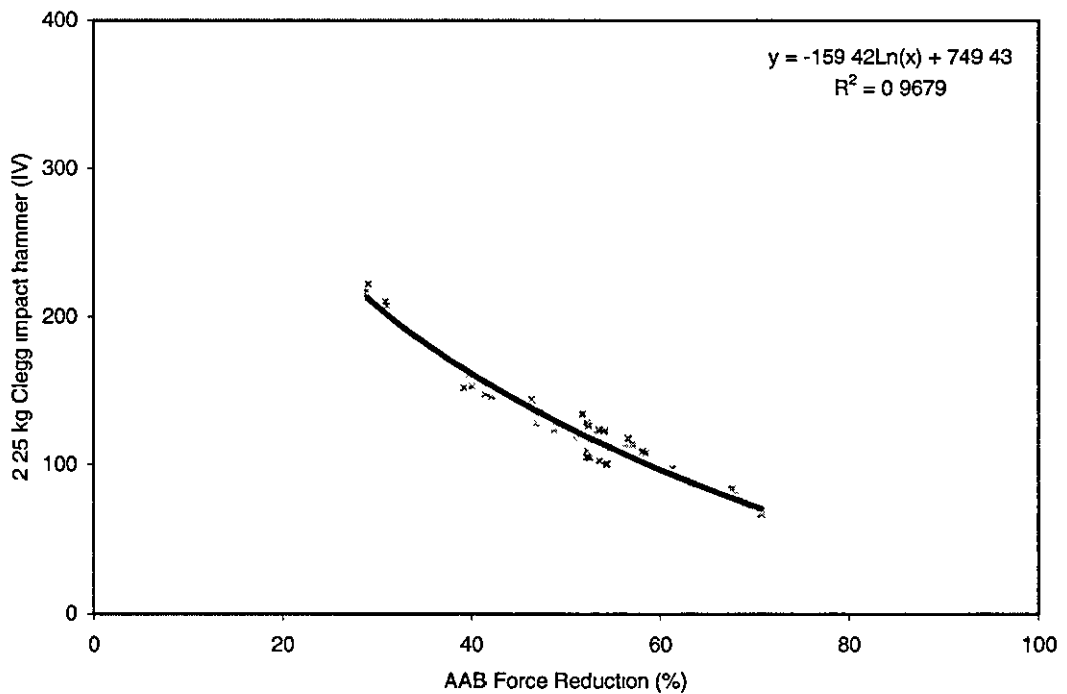


Figure 5.13b - The relationship between the mean results for the 2.25 kg Clegg impact hammer and AAB on all surface systems in the laboratory

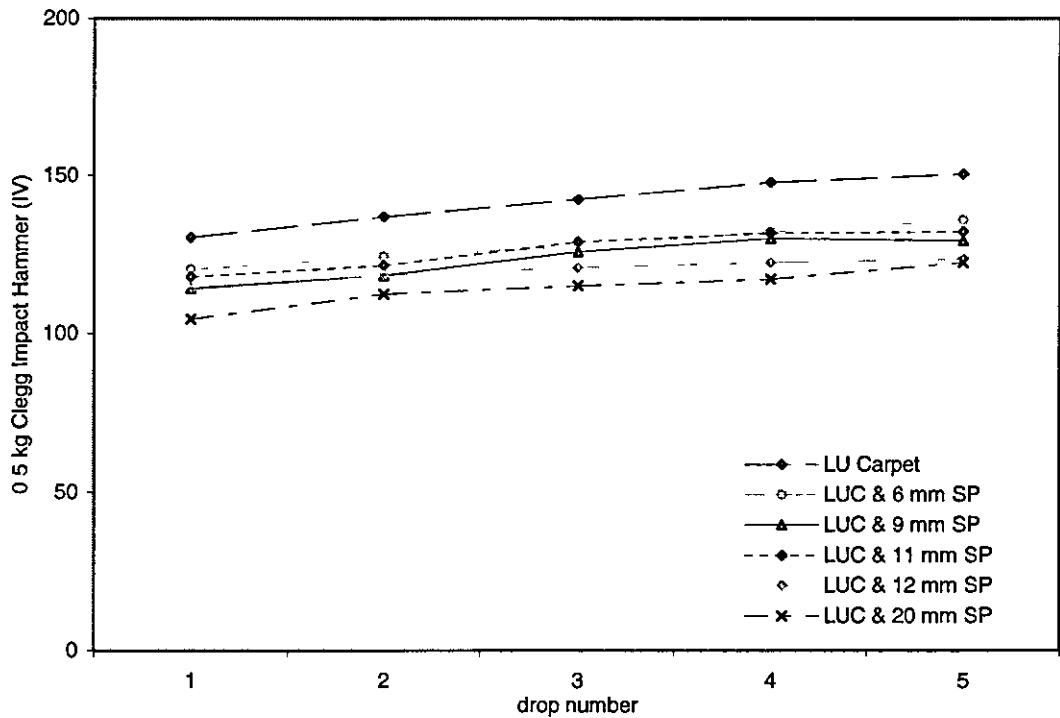


Figure 5.14 - The difference between drops measured with the 0.5 Kg Clegg impact hammer on the LU carpet with different shockpad systems

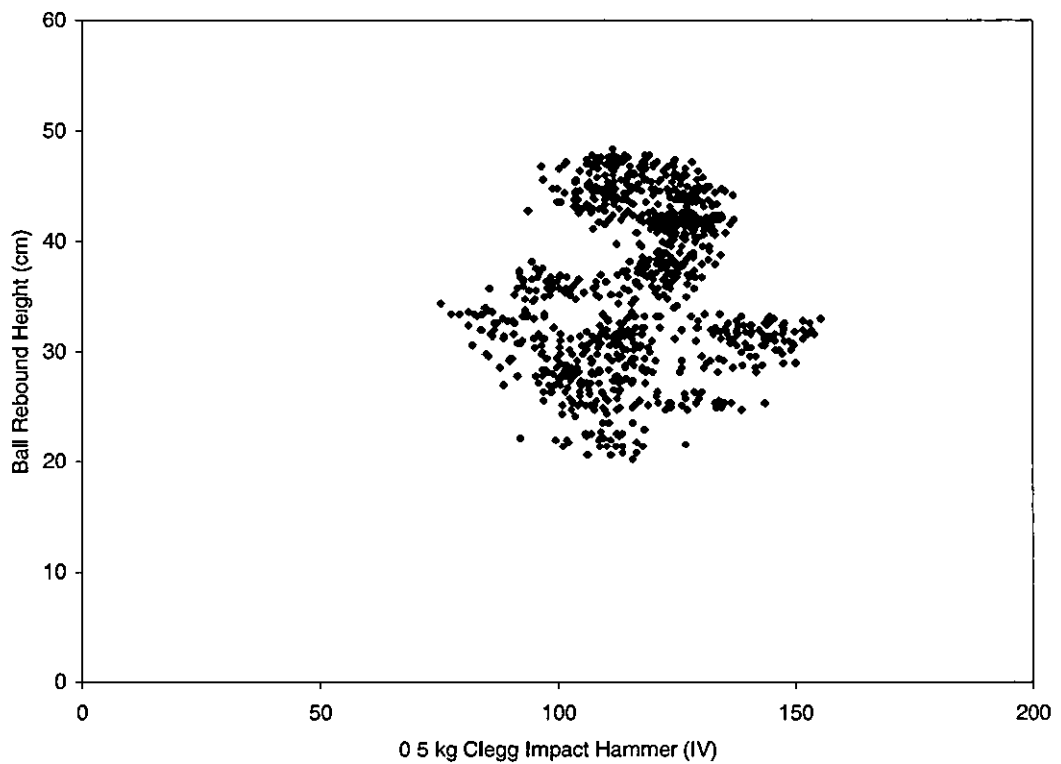


Figure 5.15 - Correlation between the 0.5 Kg CIV and ball rebound height

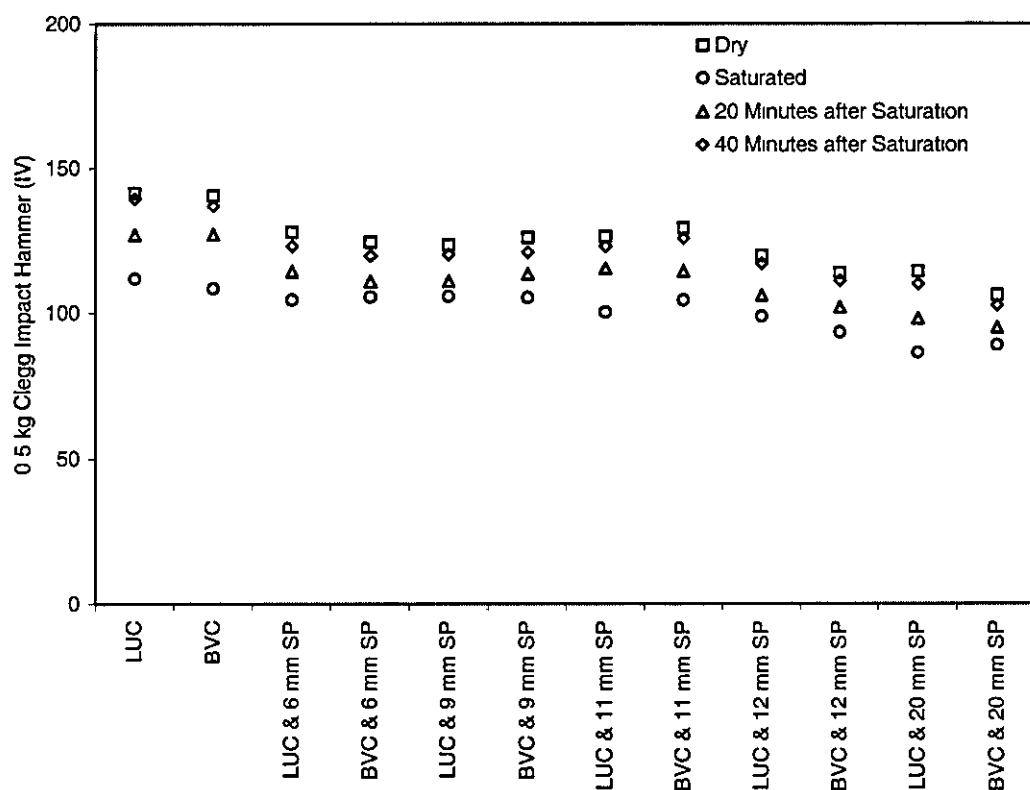


Figure 5.16 - The influence of moisture measured by the 0.5 Kg Clegg impact hammer on twelve carpet and shockpad systems in the laboratory

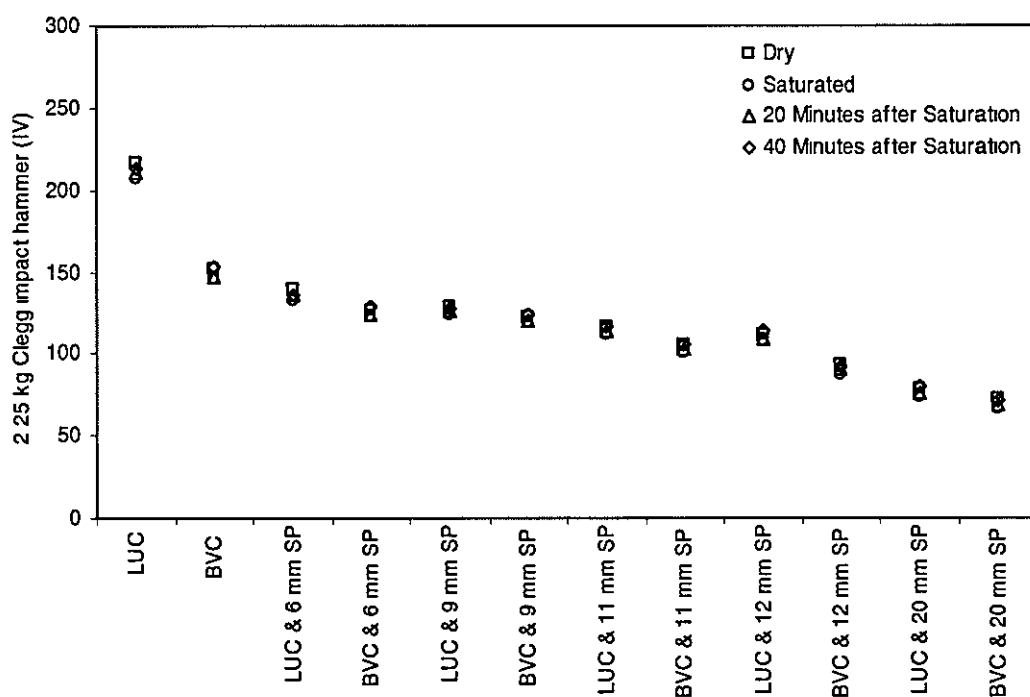


Figure 5.17a - The influence of moisture measured by the 2.25 kg Clegg impact hammer on twelve carpet and shockpad systems in the laboratory

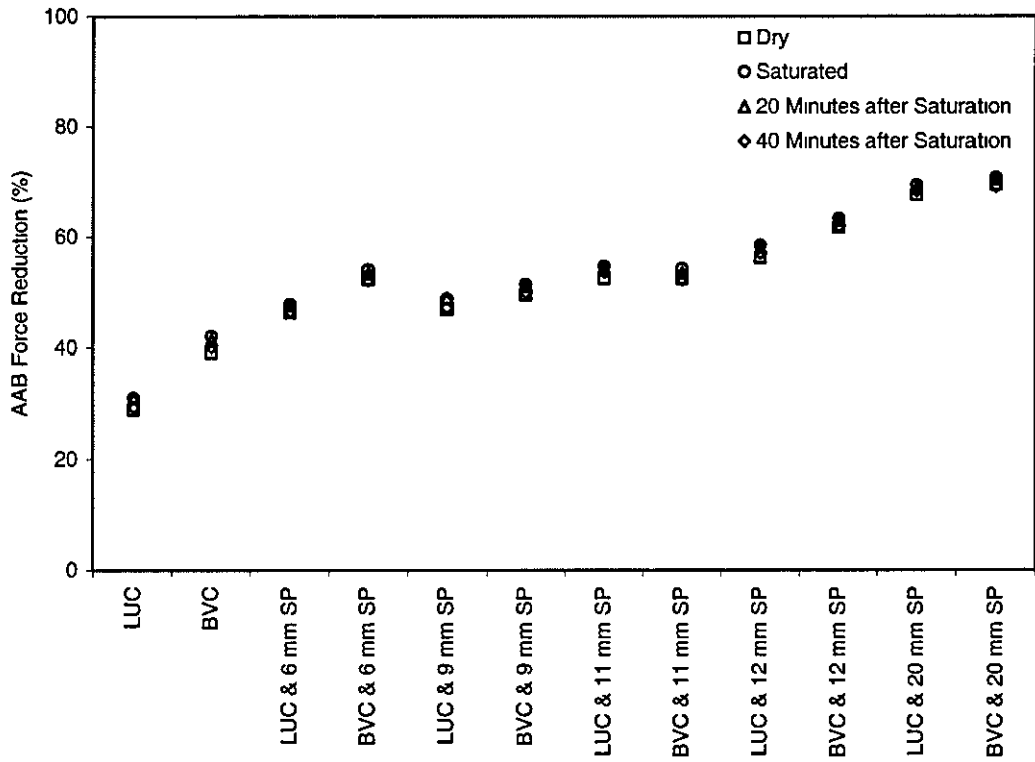


Figure 5.17b - The influence of moisture measured by the AAB on twelve carpet and shockpad systems in the laboratory

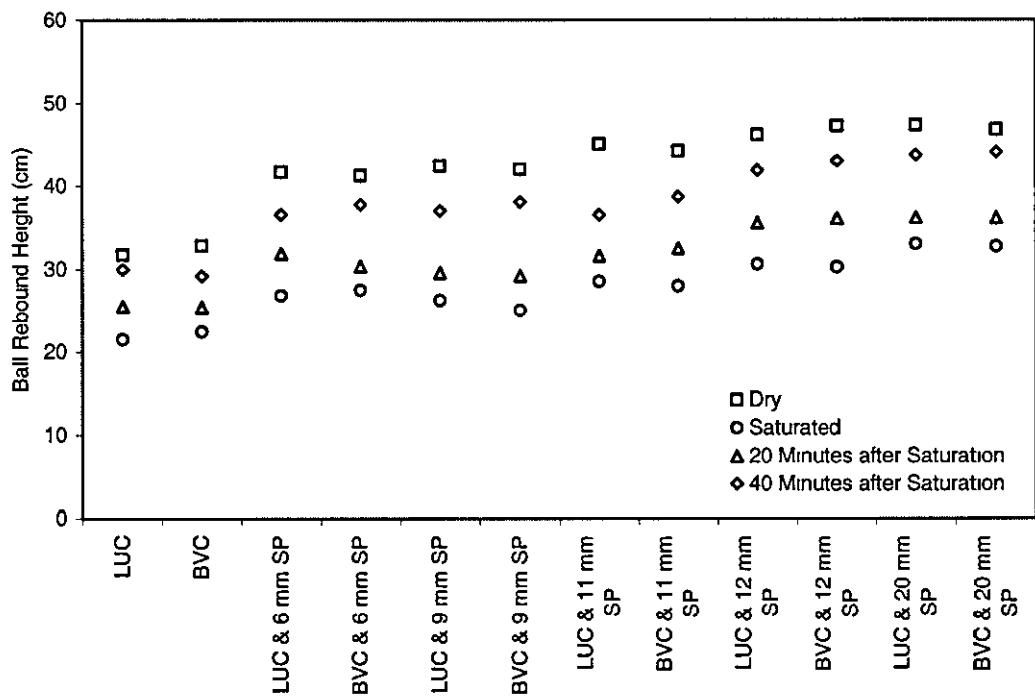


Figure 5.18 - The influence of moisture on the ball rebound height for twelve carpet and shockpad systems in the laboratory

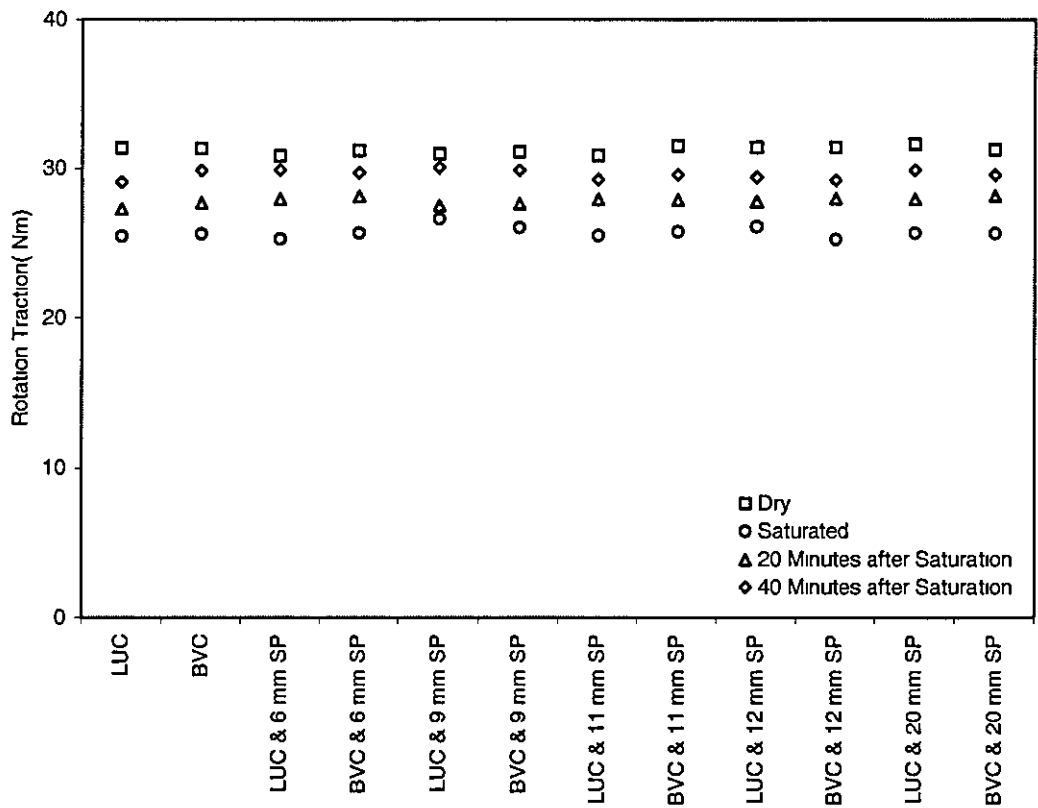


Figure 5.19 - The influence of moisture measured by rotational traction tester for twelve carpet and shockpad systems in the laboratory

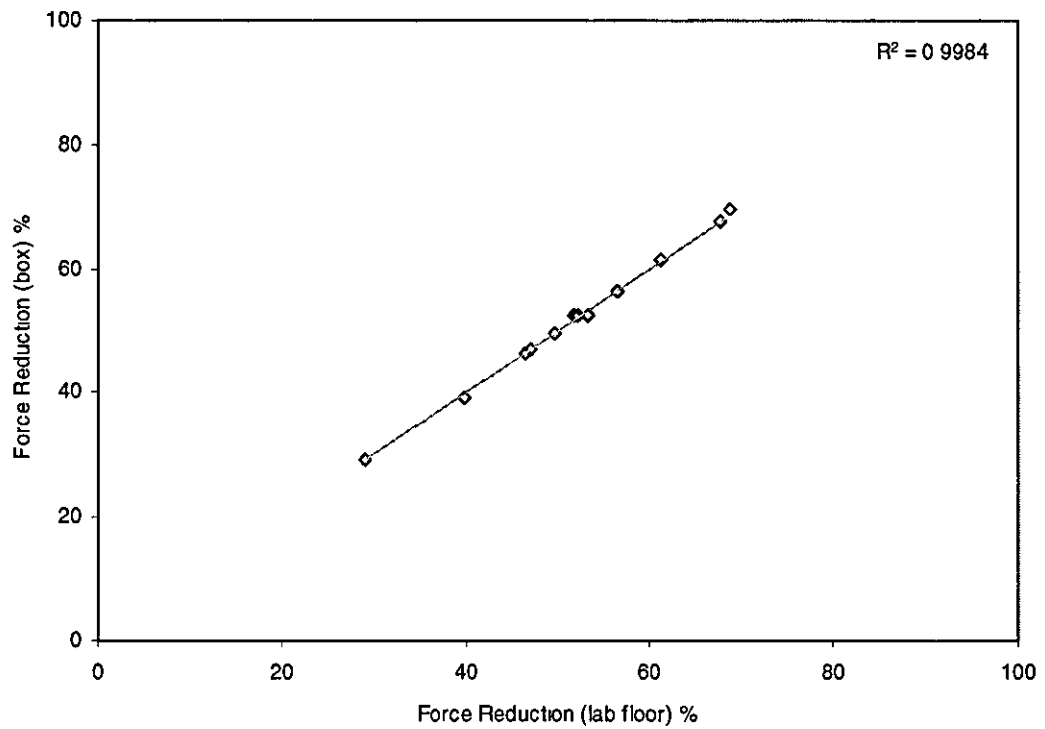


Figure 5.20a - The difference between the laboratory floor and prepared box measured by the AAB on twelve shockpad/carpet systems

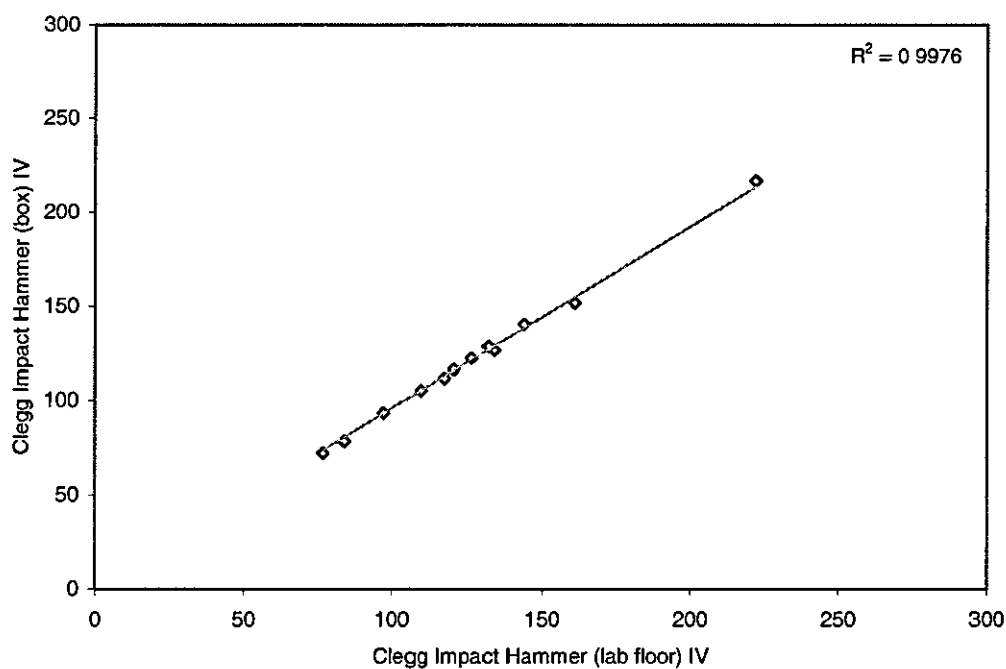


Figure 5.20b - The difference between the laboratory floor and prepared box measured by the 2.25 kg Clegg hammer on twelve shockpad/ carpet systems

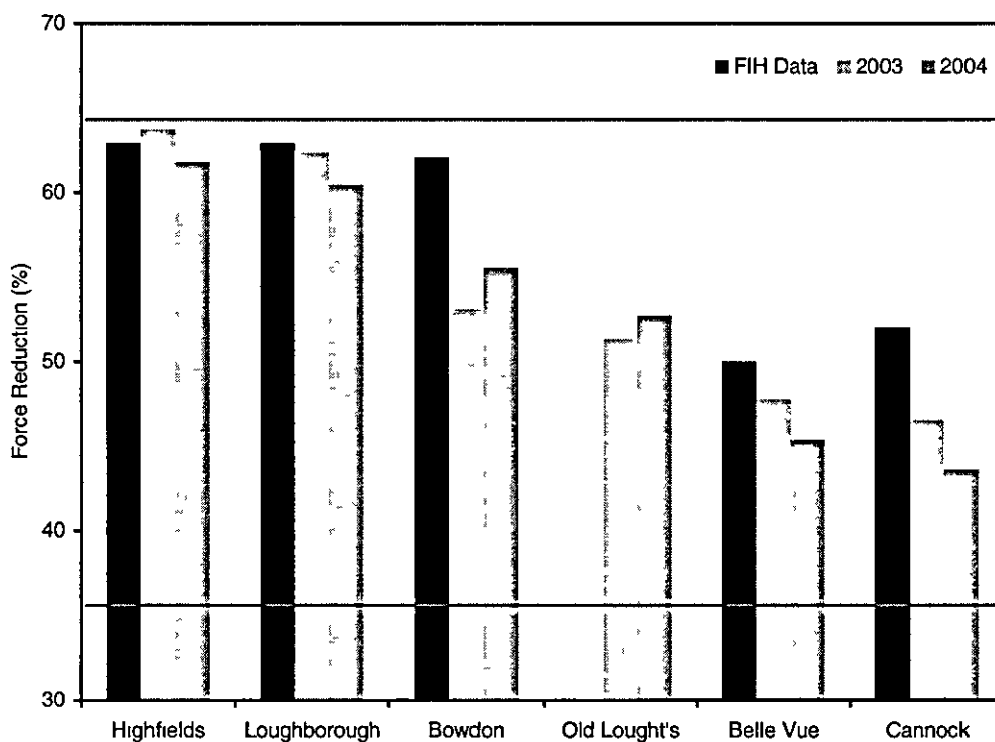


Figure 5.21 - The force reduction measured by the AAB on the six pitches for 2003 and 2004 and compared to the FIH accreditation data and requirements

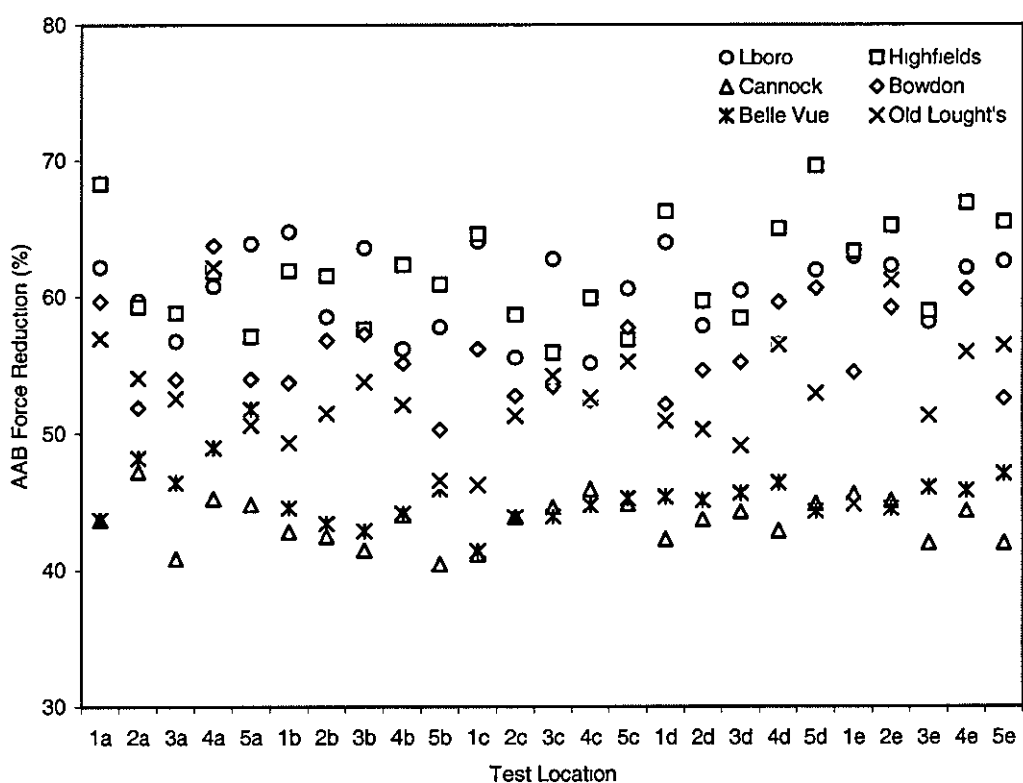


Figure 5.22 - The global variability measured in force reduction on the six pitches

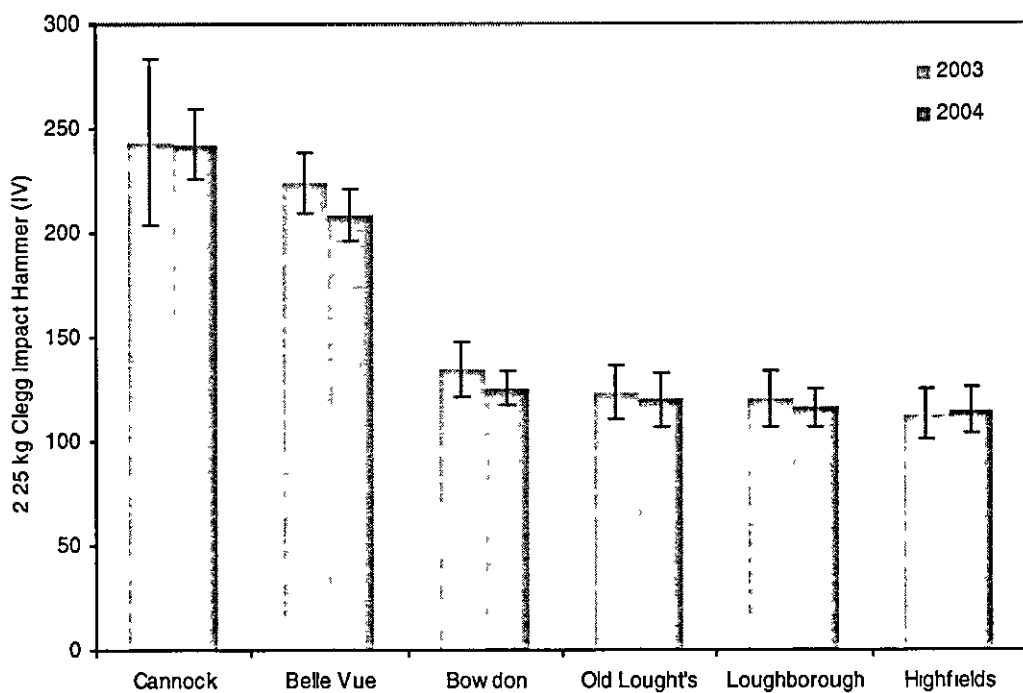


Figure 5.23 - The mean impact value measured by the 2.25 kg Clegg hammer on six pitches in 2003 and 2004 with a standard deviation error bar

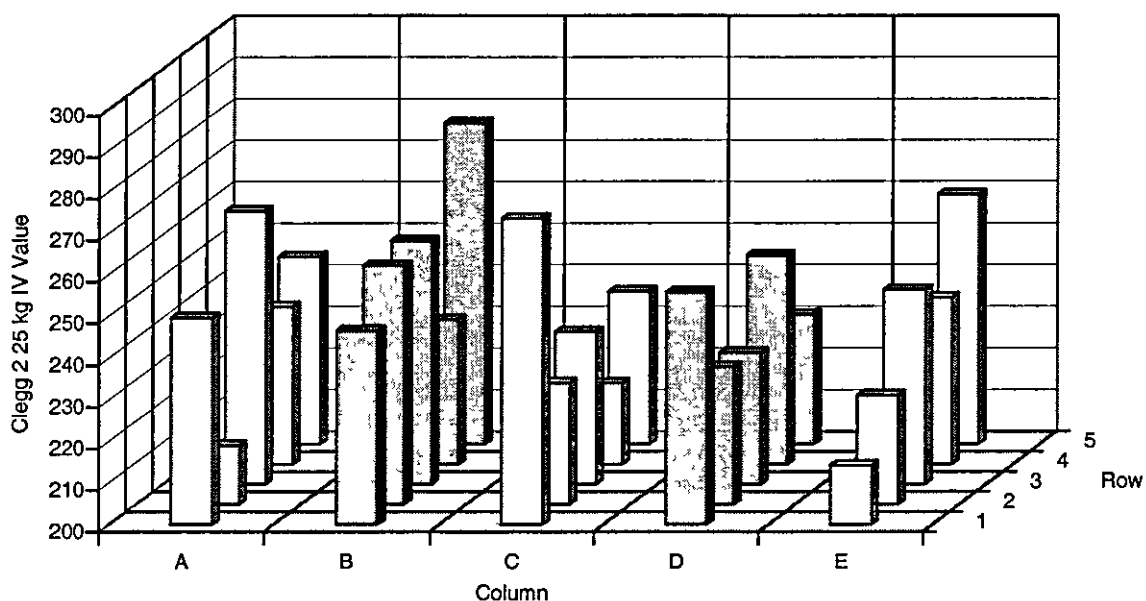


Figure 5.24 - The impact value measured by the 2.25 kg Clegg hammer at Cannock hockey pitch on a 25 location test grid

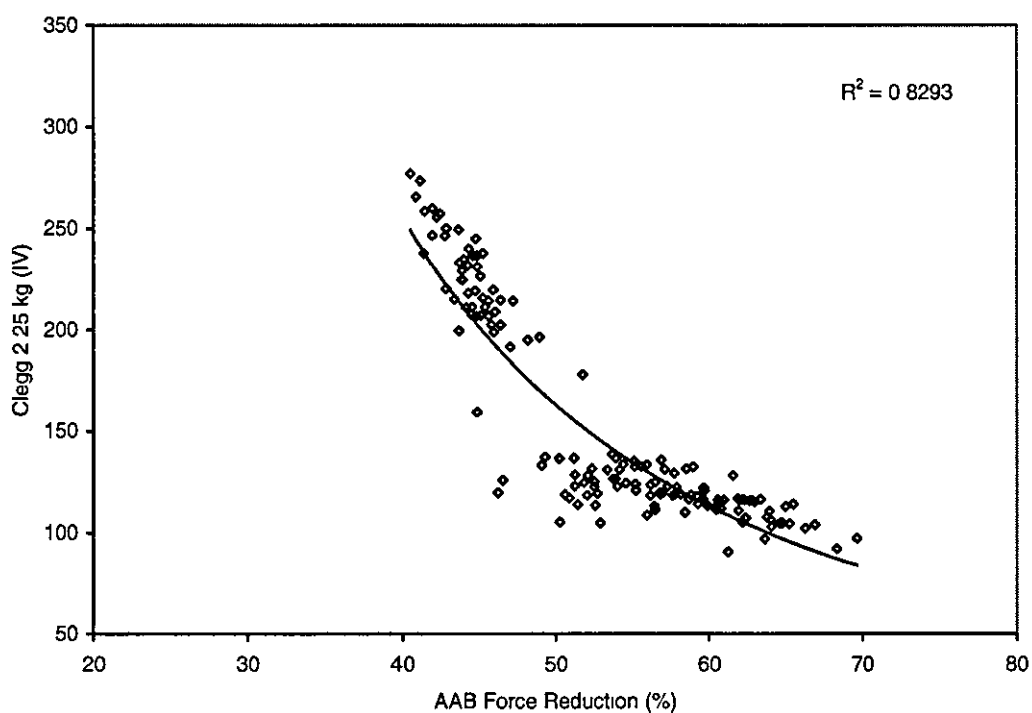


Figure 5.25a - The relationship between the 2.25 kg Clegg impact hammer and AAB on all six pitches

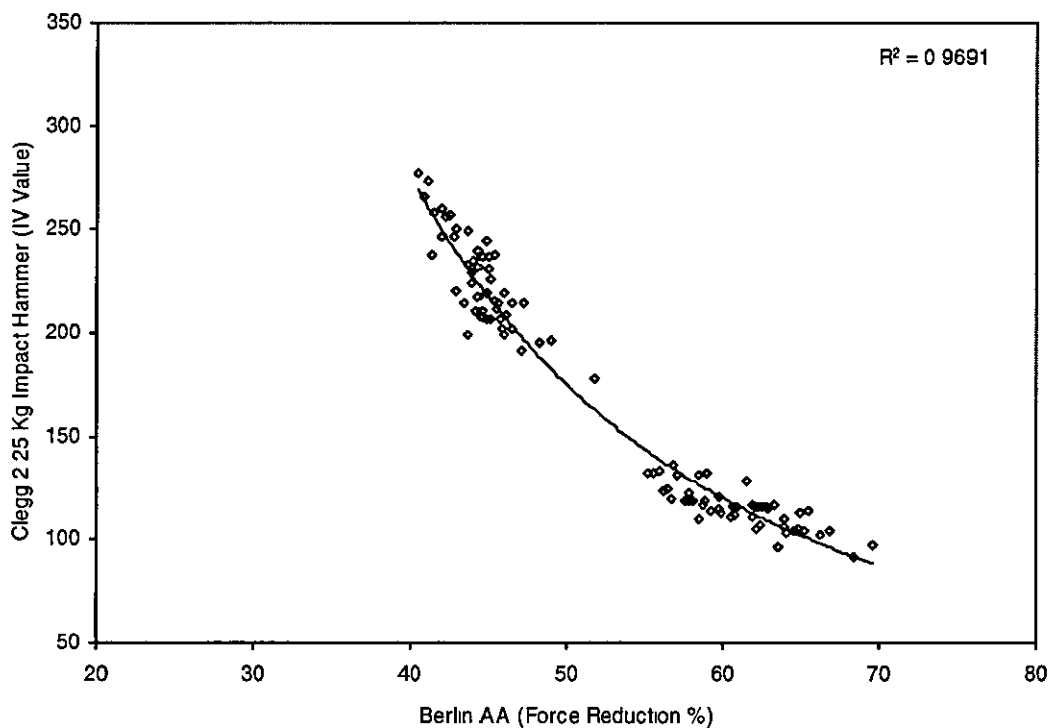


Figure 5.25b - The relationship between the 2.25 kg Clegg impact hammer and AAB on the four Nylon pitches

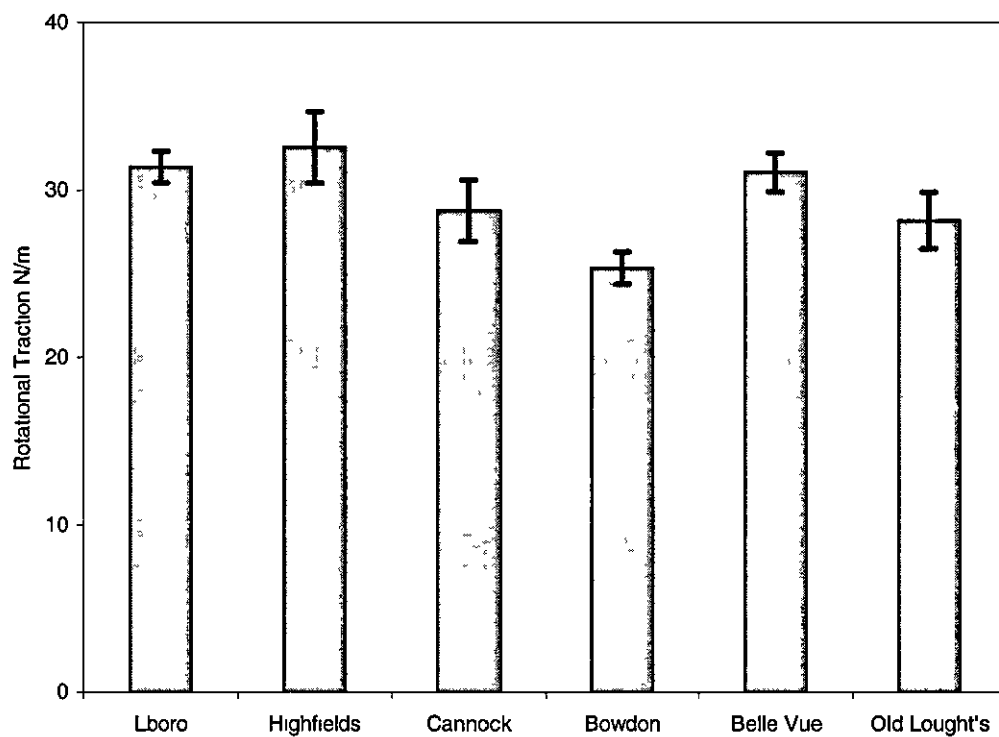


Figure 5.26 - The mean rotational traction (Nm) and standard deviation for each pitch

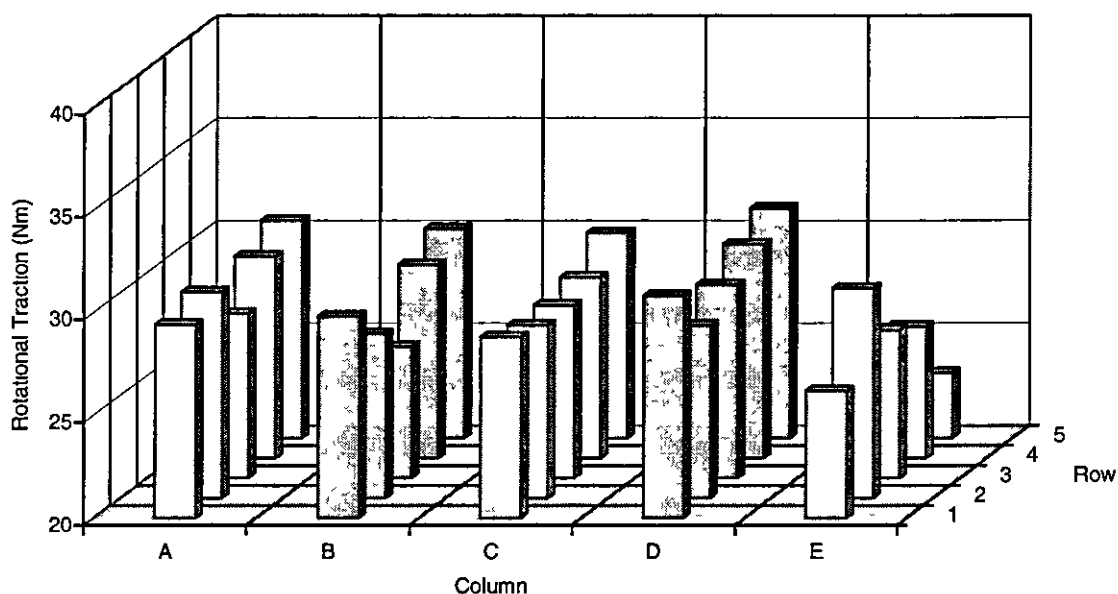


Figure 5 27 - The rotational traction measured for each test location at Cannock

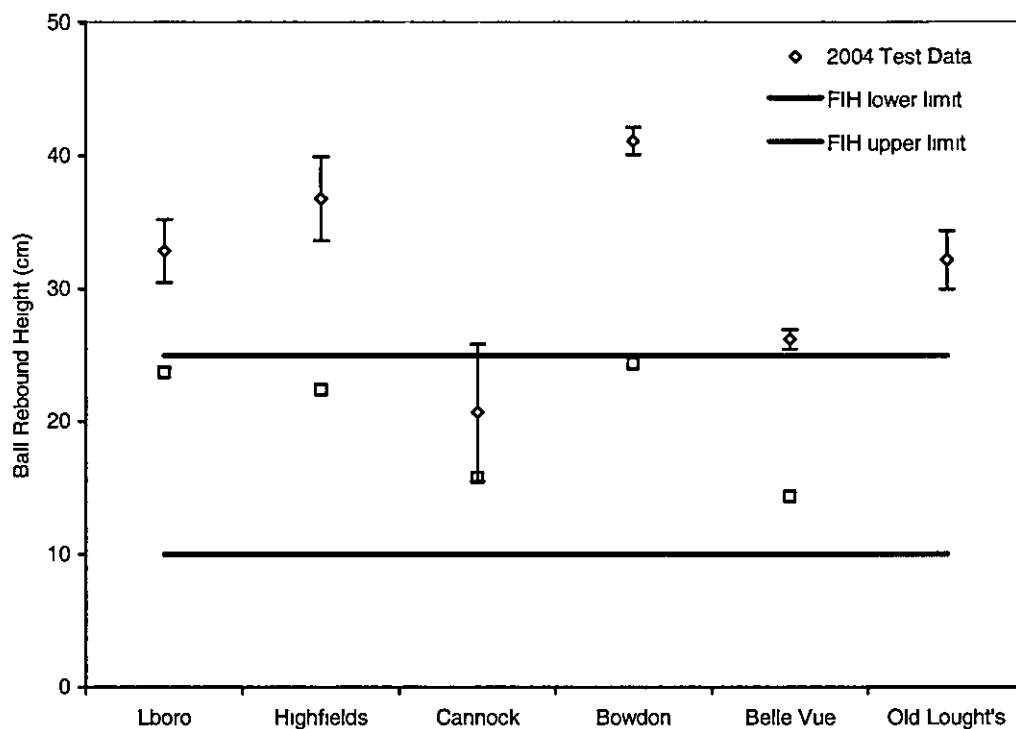


Figure 5.28 - The mean ball rebound height with standard deviation error bars for six pitches during the 2004 site investigation and the FIH accreditation data

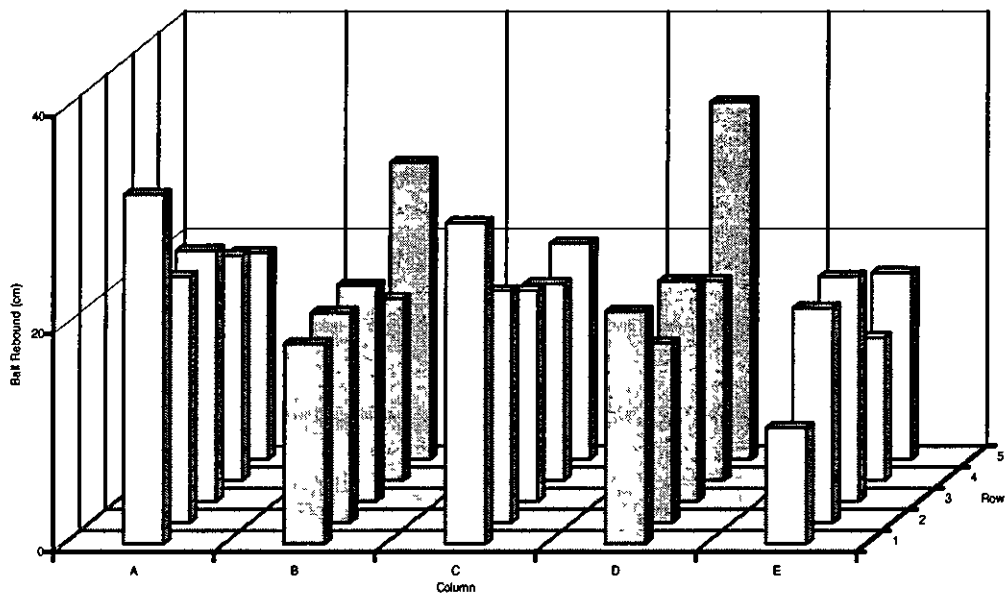


Figure 5.29 - The variability in ball rebound height across Cannock in 2004

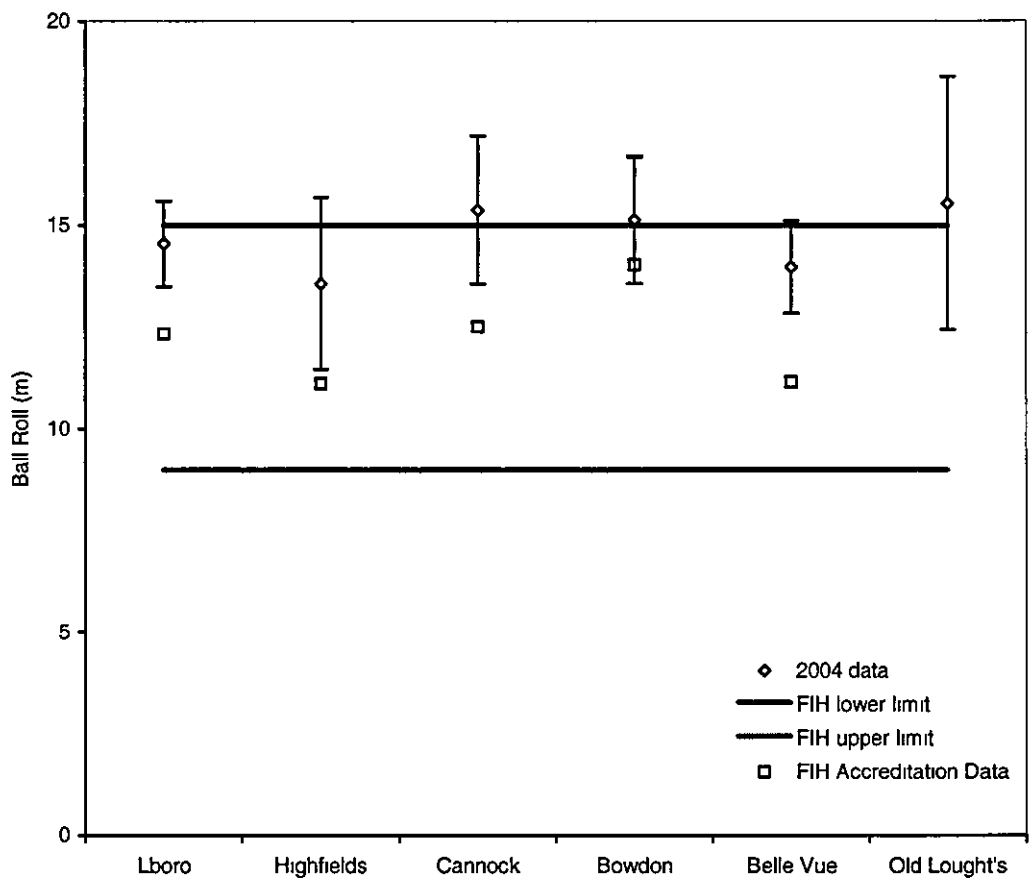


Figure 5 30 - The mean ball roll distance with standard deviation error bars for six pitches during the 2004 site investigation and the FIH accreditation data

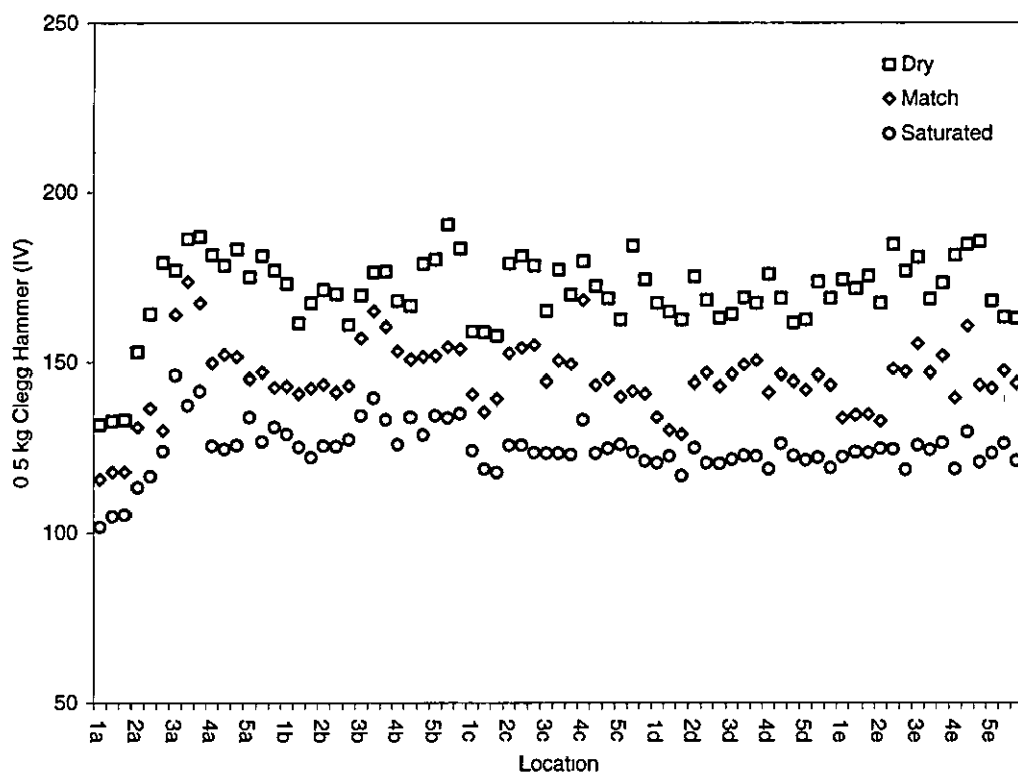


Figure 5 31 - The influence of moisture on the 0.5 kg Clegg impact hammer at the Loughborough University pitch

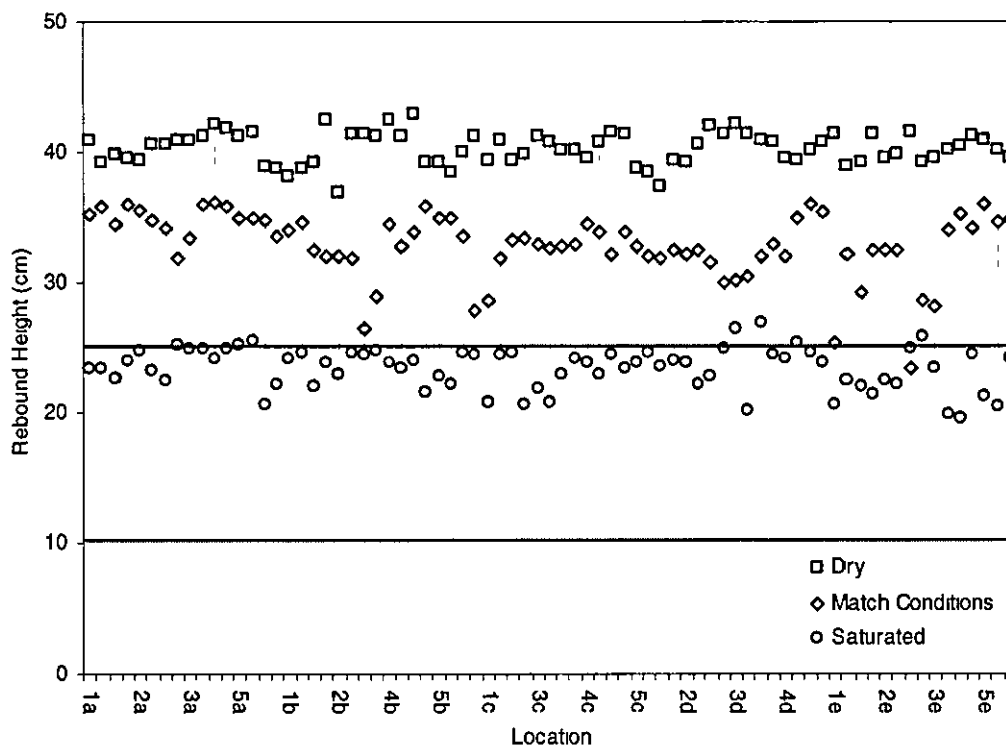


Figure 5.32 - The influence of moisture on the ball rebound height at the Loughborough University pitch

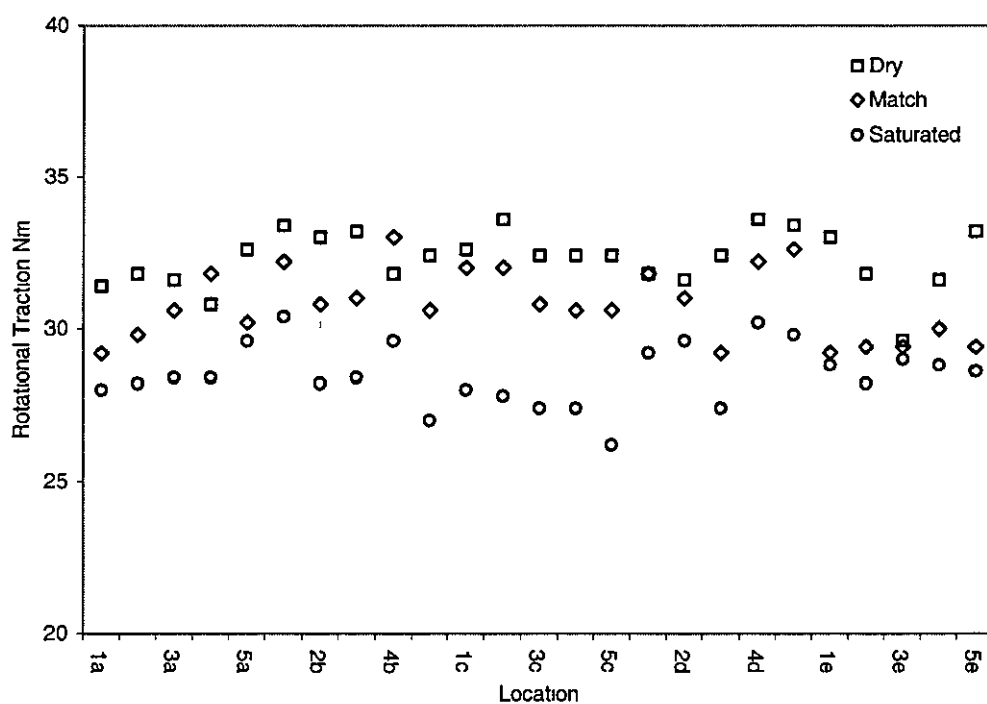


Figure 5.33 - The influence of moisture on rotational traction at the Loughborough University pitch

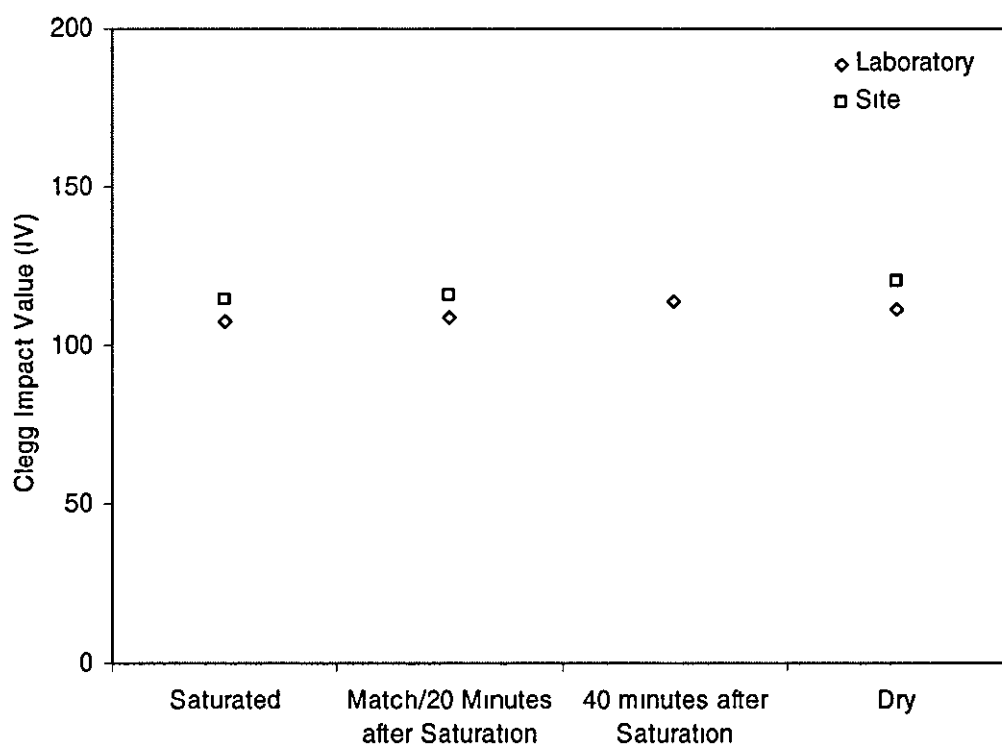


Figure 5.34 - The difference between laboratory and field data on the Loughborough University pitch measured by the 2.25 kg Clegg impact hammer

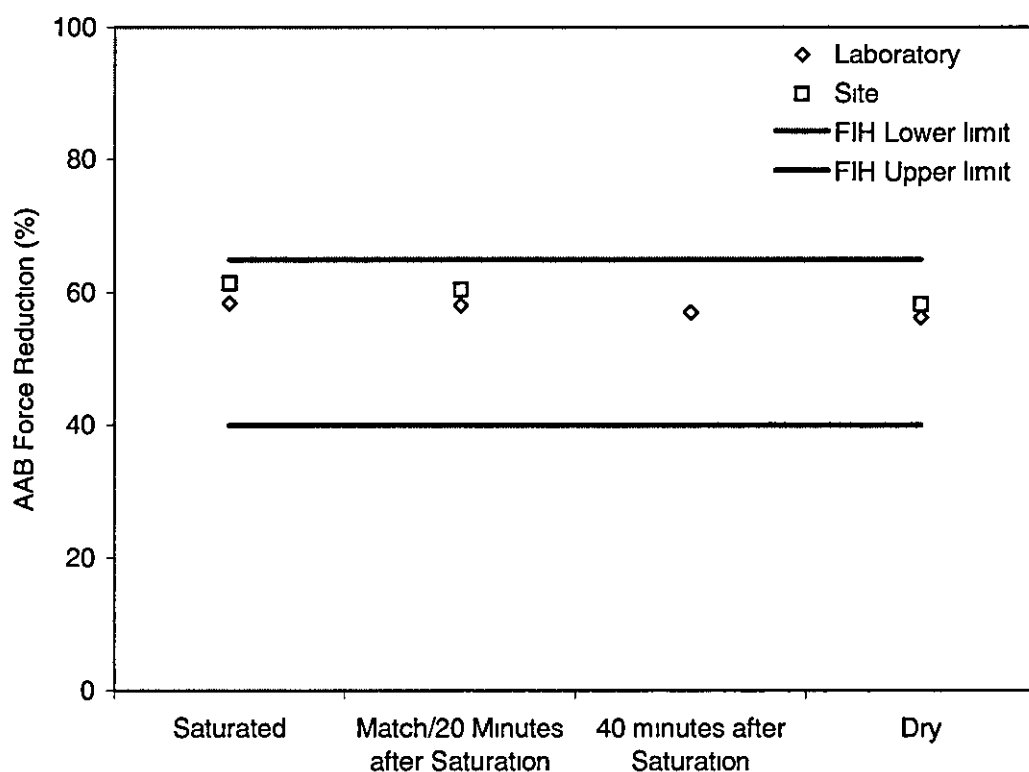


Figure 5.35 - The difference between laboratory and field data on the Loughborough University pitch measured by the AAB

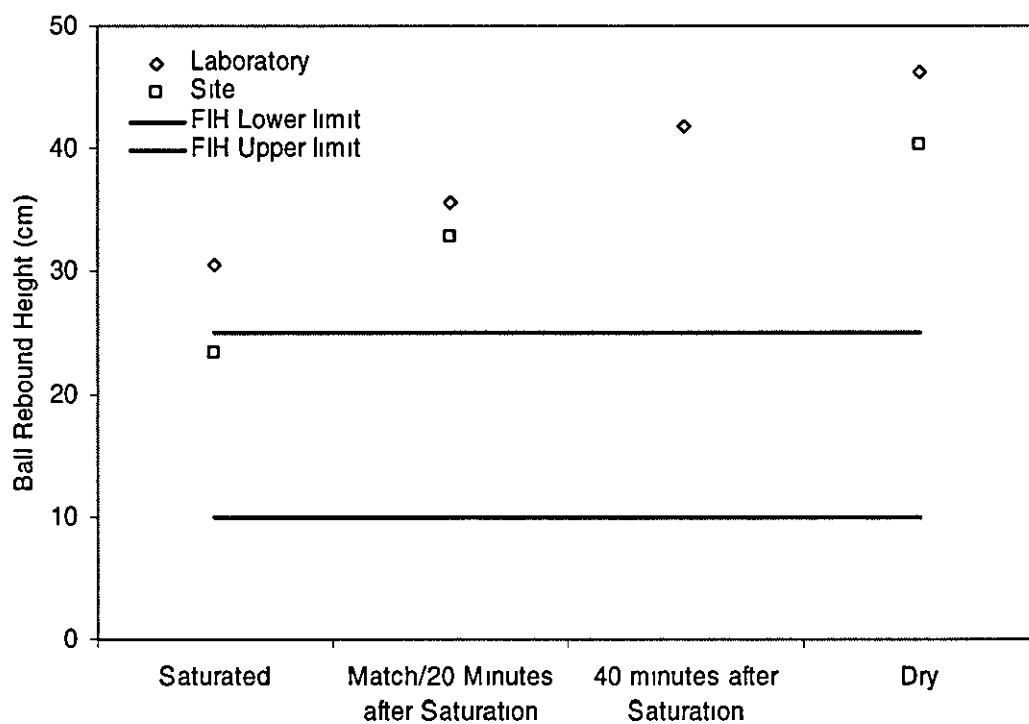


Figure 5.36 - The difference in ball rebound height between laboratory and field data on the Loughborough University

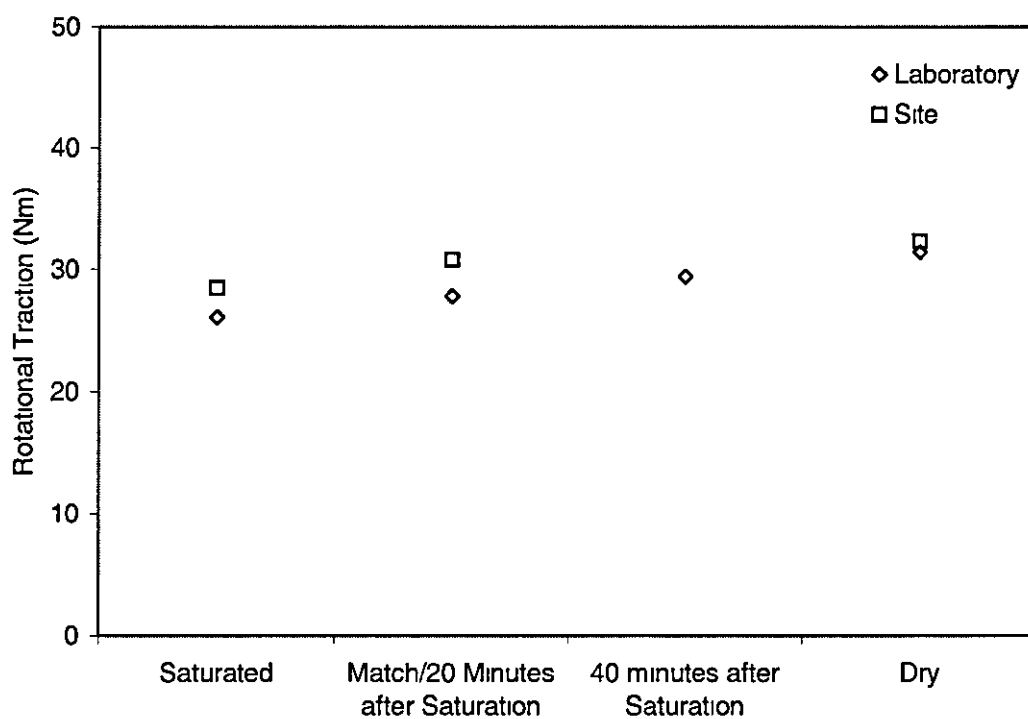


Figure 5.37 - The difference between laboratory and field data on the Loughborough University pitch measured by the rotational traction device

THE RELATIONSHIP BETWEEN MECHANICAL AND PERCEIVED BEHAVIOUR OF ARTIFICIAL HOCKEY PITCHES

6.1 INTRODUCTION

This Chapter discusses the relationship between perceived and mechanical behaviour of artificial surface for field hockey. The findings from Chapters 4 and 5 are combined together to establish a link between how the players perceive a pitch plays and the mechanical measurements taken on site by test equipment. Perceptions were elicited via a quantitative questionnaire. Six pitches were selected for comparison and each was rated against four key playing characteristics that were identified from the findings in Chapter 4. The four playing characteristics were; ball rebound height, underfoot grip, surface pace and surface hardness. To identify a relationship with the perceived behaviour mechanical tests were used to evaluate each characteristic, these were ball rebound height, rotational traction, ball roll distance, AAB and the 2.25 kg Clegg impact hammer.

6.2 PITCH SPECIFICATIONS

The six pitches selected for evaluation were, Loughborough University, Highfields, Cannock, Bowdon, Belle Vue and Old Loughtonians. Table 5.6 shows the construction specifications, age, frequency of use and maintenance programme for each pitch. The six pitches can be grouped into three pairs based on the similarities between their construction specifications; Loughborough with Highfields; Bowdon with Old Loughtonians and Cannock with Belle Vue. Loughborough and Highfields both have the same carpet system (Astroturf Europa) as do Cannock and Belle Vue (Astroturf System 5), these four carpets are all Nylon and manufactured by Astroturf. The remaining two pitches (Bowdon and Old Loughtonians) have polypropylene carpets. Cannock and Belle Vue have only an integral shockpad system compared with an in-situ system used by the other four pitches.

6.3 PERCEIVED DIFFERENCES BETWEEN THE PITCHES

Players perceptions were elicited for each of the six pitches via a questionnaire (Appendix 3). 78 questionnaires were returned from a sample of 140 participants. The players were asked to rate each of the six pitches on a series of playing characteristics which could then be compared with the result obtained at each site via mechanical tests. The playing characteristics were; height of ball rebound, underfoot grip, surface pace and surface hardness. Each characteristics was scored on a scale of 1 to 7 and Table 6 1 shows the mean rating attributed to each pitch. The 1 to 7 scale was designed using descriptors from the qualitative analysis (interview data) Analysis of the results showed no indication of a difference in opinion between male and female respondents or those from different clubs or playing positions.

Bowdon with a mean of 6.29 ± 0.85 was rated by players as the pitch with the highest ball rebound and Cannock with a mean of 1.73 ± 0.68 was considered the pitch with the lowest. Belle Vue was perceived to have the next lowest rebound height with a mean 2.12 ± 0.79 . Cannock and Belle Vue have a similar construction specification with an integral shockpad which may explain the lower perceived ball rebound height Figure 6.1 shows the frequency in responses for Cannock and Bowdon The responses for Cannock are on the left side of the histogram indicating the players perceived a 'low' ball rebound height and Bowdon's rating is on the right hand side illustrating 'high' perceived ball rebound height.

There was little difference in opinion between Loughborough (4.36 ± 1.39), Highfields (4.53 ± 1.37) and Belle Vue (4.37 ± 1.33) for the perceived amount of underfoot grip However, the spread in responses (illustrated by the standard deviation and Figure 6 2) from the participants indicated there was a difference of opinion between the players. Bowdon (2.31 ± 0.76) and Old Loughtonians (2.35 ± 0.92) were perceived to provide the least underfoot grip which can be attributed to their carpet material (polypropylene). Figure 6 2 demonstrates the difference in responses for Bowdon and Highfields.

Bowdon and Old Loughtonians were considered the 'slowest' pitches with mean perceived values of 2.67 ± 1.20 and 2.41 ± 1.19 respectively. This could be attributed to the carpet material (polypropylene) as the pitches with nylon carpets

were perceived to behave 'faster'. Cannock with a mean perceived rating of 5.55 ± 1.03 was perceived to have the fastest 'surface pace'. The range of responses from the players for Old Loughtonians and Cannock are illustrated in Figure 6.3.

Players perceived Cannock (6.50 ± 0.62) and Belle Vue (5.96 ± 0.80) as the hardest pitches. This relates to the construction of the pitches as these surfaces only have an integral shockpad. The players perceived Loughborough and Highfields as the softest pitches with a hardness of 2.23 ± 0.95 (Loughborough) and 2.15 ± 0.74 (Highfields). Both pitches had the same shockpad/carpet system, the similarities between responses are shown in Figure 6.4

6.4 PITCH DIFFERENCES MEASURED WITH MECHANICAL TESTS

This section provides a comparison of the six pitches from the 2004 site investigation. A full analysis of mechanical behaviour is presented in Chapter 5. However, this section provides an overview of the differences between the six pitches. The equipment/tests used to compare each pitch were, ball rebound height, rotational traction, ball roll distance, AAB and the 2.25 kg Clegg impact hammer. Table 6.2 shows the mean and standard deviation for each test on all six pitches. The testing was conducted at each pitch 'in game' or 'match' conditions. These conditions were achieved by a full irrigation cycle prior to testing followed by repeat irrigations every forty minutes until testing was finished.

Cannock (20.69 ± 5.17 cm) recorded the lowest rebound height followed by Belle Vue (26.20 ± 0.72 cm). The highest ball rebound height was measured at Bowdon with 41.11 ± 1.02 cm. The range of ball roll distance was between 13.57 ± 2.11 m (at Highfields) and 15.53 ± 3.10 (at Old Loughtonians). The lowest rotational traction was recorded at Bowdon 25.37 ± 0.96 Nm and Old Loughtonians next lowest with a measurement of 28.21 ± 1.68 Nm, Highfields (32.57 ± 2.14 Nm) and Loughborough (31.40 ± 0.95 Nm) measured the highest rotational resistance. The force reduction of the six pitches were evaluated with the AAB. Cannock and Belle Vue were measured as the stiffest pitches with force reductions of 43.62 ± 1.73 % and 45.37 ± 2.10 % respectively. Loughborough (60.44 ± 3.00) and Highfields (61.79 ± 3.80) were the least stiffest, these results were verified by the 2.25 kg Clegg impact hammer.

6.5 RELATIONSHIP BETWEEN THE PERCEIVED AND MECHANICAL BEHAVIOUR

The playing characteristics were grouped together with the mechanical test(s) that measured their behaviour. For each characteristic the following test was used, Height of ball bounce was measured by ball rebound height, underfoot grip was measured by the rotational traction device, surface pace was assessed by ball roll distance, and surface hardness was measured by the AAB and 2 25 kg Clegg impact hammer

Using the mean perceived and measured values the pitches were ranked for each of the four playing characteristics from 1 to 6, i.e. for surface pace the slowest pitch would be 1 and the fastest pitch would be 6 Table 6.3 shows the ranking for each pitch.

6.5.1 Ball rebound height

The radar diagram (Figure 6 5) illustrates the relationship between mechanical and perceived behaviour for ball rebound height The scale 1 to 6 represents the ranking order of the pitches, the diamond shaped symbol illustrates the measured ranking and the square shaped symbol corresponds to the perceived ranking It shows that Cannock was perceived and measured to have the lowest ball rebound height and Bowdon was measured and perceived to have the highest ball rebound height. Old Loughtonians was perceived to have the 5th highest bounce height but only measured as the 3rd, this represents a difference between the measured and perceived behaviour However, looking at Figure 6 6 it can be seen that the magnitude of difference between Old Loughtonians, Loughborough and Highfields is very small and the standard deviation of the results show cross over. On the graph each pitch is illustrated by its relevant symbol with an X (measured) and Y (perceived) error bar. The error bars represent one standard deviation and show the amount of cross-over between pitches

The test for ball rebound height is sensitive to what the players perceive The tests doesn't replicate what occurs in a 'typical' game situation i.e. the tests consists of a ball dropped from a 1 5 m height directly onto the surface. In a game the speed and angle of contact between the ball and surface will be very different from the test However, given that the test (with the exception of Old Loughtonians) identified the same ranking as the players then it must be

considered appropriate. An R^2 of 0.89 suggests there is a strong correlation between the two and further reinforces the similarities between perceived and mechanical behaviour. The variability of the watering/irrigation system can lead to different results. In Chapter 5 the influence water had on the pitch was highlighted and given that the irrigation systems are susceptible to wind the coverage of water may not be even. Figures 6.7a and b illustrate the watering system at Highfields and show the uneven coverage of water after irrigation.

6.5.2 Underfoot Grip

The perceptions of underfoot grip match well with the mechanical data for underfoot grip. Both the players and the tests identified Highfields as the pitch with the highest grip with a mean score of 4.53 and 32.57 Nm respectively. Similarly, both identified Bowdon as the pitch with the least underfoot grip. Figure 6.8 shows the ranking of the six pitches for perceived and mechanical behaviour. The magnitude of difference between each pitch is illustrated in Figure 6.9 which shows correlation of 0.85 (R^2). Loughborough, Highfields and Belle Vue are all perceived and measured very close to each other and all have a similar carpet type. Cannock which also has a similar carpet was scored and measured much lower, however, this was likely due to the algae growth on sections of the pitch which reduced the measurement and perception of underfoot grip, see Figure 6.10.

The rotational traction device is not used by the FIH to evaluate field hockey pitches but based on these findings it could be a valuable addition to surface classification. It correlates well with players' perceptions and it is sensitive to difference between pitches as well as across pitches. While the device may not measure biomechanically valid information, its use for indexing pitches against one another for the purpose of surface accreditation is considered appropriate. The speed of movement, contact time and rotational force of a real human turning are very different from the test device. However, given that this simplified test can measure what a player perceives then it is considered suitable.

6.5.3 Surface Pace

The perception of surface pace did not match what was measured by the ball roll distance. Figure 6.11 shows the ranking for surface pace from the players compared with ball roll distance for each pitch. This suggests that the test is inappropriate to identify what players perceive. The ball velocity does not match

that during a game situation consequently the test may be measuring the wrong parameters. The applicability of the test to determine surface pace is limited. The ball travels at a slow pace until it comes to rest. However, in the game of field hockey the ball very rarely comes to rest and travels at much greater velocities. Figure 6.12 illustrates the small spread in measurements between pitches, from 13.57 m at Highfields to 15.53 m at Old Loughtonians. The test appears to be relatively insensitive to surface properties compared with the influence of the wind speed/direction. Also the spread in measurements for mechanical data across each pitch is large which could be a result of the wind or other extraneous variables.

In field hockey the ball is often struck with a large force, unfortunately no data was found to evaluate the speed, direction or angle of impact between the ball and the surface. It is clear that a full game analysis is required to identify what shots are commonly played to identify 'typical' velocities and angles to help in the design of a new test that would be more representative of players' perceptions and in-game actions.

6.5.4 Surface Hardness

The six pitches were ranked in order of perceived and mechanical behaviour for surface hardness. Players' perceptions for each pitch were rated against the AAB and 2.25 kg Clegg hammer. The relationship between perceived surface hardness and measured force reduction was exactly the same, all 6 pitches were ranked in the same order for both, shown in Figure 6.13. The magnitude of difference between each pitch is illustrated in Figure 6.14 and shows an even spread of pitches demonstrated by an excellent R^2 of 0.97. This indicates that the AAB closely matches what players perceive and consequently measures what players perceive.

The relationship between perceived surface hardness and the 2.25 kg Clegg hammer is illustrated in Figure 6.15. The Clegg matched well with the players' perceived opinions of the pitches. All but two pitches were in the same order, these were Old Loughtonians and Bowdon which were the wrong way round. However, Figure 6.16 shows the difference between rankings; it can be seen that the surface hardness for Old Loughtonians is lower with the Clegg than the players perceived. In Chapter 5 it was highlighted that the 2.25 kg Clegg hammer may be influenced by the polypropylene carpets more than the Nylon carpets.

Figure 6 17 a and b illustrate a close-up of the two carpet types and show the difference in structure. It can be seen that the pile is wider and consequently the 2.25 kg hammer does not produce the same impact value. More energy from the impact maybe lost (dissipated/attenuated) in the polypropylene carpet pile than the Nylon carpet pile explaining the difference between its measurements and the AAB's.

6.6 SUMMARY OF THE RELATIONS BETWEEN PERCIVED AND MECHANICAL BEHAVIOUR

The aim of this Chapter was to evaluate six water-based field hockey pitches via mechanical tests and players perceptions and from this identify relationships between the two data collection methods to evaluate their suitability for pitch accreditation. It was found that ball rebound height, underfoot grip and surface hardness correlated well with the mechanical tests of ball rebound height, rotational traction, AAB and the 2.25 kg Clegg hammer. However, there was no obvious relationship between surface pace and ball roll distance.

The pitches were ranked in order of perceived and mechanical behaviour and illustrated with radar diagrams to highlight correlations. However, this did not show the magnitude of difference between the measurements. i.e the impact value of four pitches measured with the 2.25 kg Clegg impact hammer were very similar and significantly different from the other two pitches. A second method was used to illustrate the magnitude of difference between pitches for both sets of data. These figures illustrated the range of results to show how the difference between pitches for both data collection types.

It is argued that some mechanical tests do not fully represent what a player or ball experiences during a game situation and that to fully understand the mechanism of pitch behaviour test methods are required that simulate in-game conditions. However, the results in this section provide verification of the tests that correlate well with players perceptions. If the test measures what the a player (or group of players) perceive then its appropriateness to compare and index pitches against one another is valid. If a test method did not match to with player perceptions, for example, a test method identified a playing surface as 'hard' yet a player perceives the pitch to be 'soft' then the validity of the equipment is questionable

Table 6.1 - The perceived behaviour of six field hockey pitches for each playing characteristic

| | | Playing Characteristic | | | |
|--|------------------|---------------------------|-------------------|--------------|---------------------|
| | | Height of Ball Rebound | Underfoot Grip | Surface Pace | Surface Hardness |
| Pitch | Loughborough | 4.01 ± 0.76 | 4.36 ± 1.39 | 4.96 ± 0.97 | 2.23 ± 0.95 |
| | Highfields | 5.24 ± 0.69 | 4.53 ± 1.37 | 5.09 ± 0.90 | 2.15 ± 0.74 |
| | Cannock | 1.73 ± 0.68 | 2.76 ± 1.22 | 5.55 ± 1.03 | 6.50 ± 0.62 |
| | Bowdon | 6.29 ± 0.85 | 2.31 ± 0.76 | 2.67 ± 1.20 | 2.73 ± 1.09 |
| | Belle Vue | 2.12 ± 0.79 | 4.37 ± 1.33 | 5.68 ± 1.17 | 5.96 ± 0.80 |
| | Old Loughtonians | 5.33 ± 1.00 | 2.35 ± 0.92 | 2.41 ± 1.19 | 3.94 ± 0.97 |
| Note. each characteristic is scored on a scale of 1 to 7 | | | | | |

Table 6.2 - The behaviour of six field hockey pitches for each playing characteristic measured with mechanical tests

| | Playing Characteristic | Height of Ball Rebound | Underfoot Grip | Surface Pace | Surface Hardness | |
|----------------------------|---------------------------|------------------------------|-----------------------------|---------------------------|------------------|-------------------|
| | | Mechanical Test | Rotational Traction (Nm) | Ball Roll Distance (m) | AAB (%) | 2.25 kg CIH* (IV) |
| Pitch | Loughborough | Ball Rebound Height (cm) | 31.40 ± 0.95 | 14.55 ± 1.05 | 60.44 ± 3.00 | 116.06 ± 8.99 |
| | Highfields | 32.84 ± 2.37 | 32.57 ± 2.14 | 13.57 ± 2.11 | 61.79 ± 3.80 | 114.83 ± 11.25 |
| | Cannock | 20.69 ± 5.17 | 28.78 ± 1.82 | 15.37 ± 1.81 | 43.62 ± 1.73 | 242.79 ± 16.92 |
| | Bowdon | 41.11 ± 1.02 | 25.37 ± 0.96 | 15.13 ± 1.55 | 55.55 ± 3.48 | 125.33 ± 8.27 |
| | Belle Vue | 26.20 ± 0.72 | 31.09 ± 1.17 | 13.98 ± 1.13 | 45.37 ± 2.10 | 208.89 ± 12.35 |
| | Old Loughtonians | 32.16 ± 2.20 | 28.21 ± 1.68 | 15.53 ± 3.10 | 52.74 ± 4.16 | 119.76 ± 13.28 |
| *CIH = Clegg Impact Hammer | | | | | | |

Table 6 3 - The perceived and mechanical ranking of each characteristic for all six pitches

| Ball Rebound Height (Ball rebound height) | | Surface Pace (Ball roll distance) | | Underfoot Grip (Rotational Traction) | | Surface Hardness (AAB & CIH) | |
|--|-----------------------------------|--------------------------------------|-----------------------------------|---|-----------------------------------|------------------------------------|-----------------------------------|
| <i>Perceived</i> <i>Highest</i> | <i>Measured</i> <i>Highest</i> | <i>Perceived</i> <i>Fastest</i> | <i>Measured</i> <i>Fastest</i> | <i>Perceived</i> <i>Highest</i> | <i>Measured</i> <i>Highest</i> | <i>Perceived</i> <i>Hardest</i> | <i>Measured</i> <i>Hardest</i> |
| BD | BD | BV | OL | HF | HF | CN | CN |
| HF | OL | CN | CN | BV | LU | BV | BV |
| LU | HF | HF | BW | LU | BV | OL | OL |
| OL | LU | LU | LU | CN | CN | BW | BW |
| BV | BV | BW | BV | OL | OL | LU | LU |
| CN | CN | OL | HF | BW | BW | HF | HF |
| <i>Perceived</i> <i>Lowest</i> | <i>Measured</i> <i>Lowest</i> | <i>Perceived</i> <i>Slowest</i> | <i>Measured</i> <i>Slowest</i> | <i>Perceived</i> <i>Lowest</i> | <i>Measured</i> <i>Lowest</i> | <i>Perceived</i> <i>Softest</i> | <i>Measured</i> <i>Softest</i> |
| Key | | | | | | | |
| LU = Loughborough University | | | | | | | |
| HF = Highfields | | | | | | | |
| CN = Cannock | | | | | | | |
| BD = Bowdon | | | | | | | |
| BV = Belle Vue | | | | | | | |
| OL = Old Loughtonians | | | | | | | |

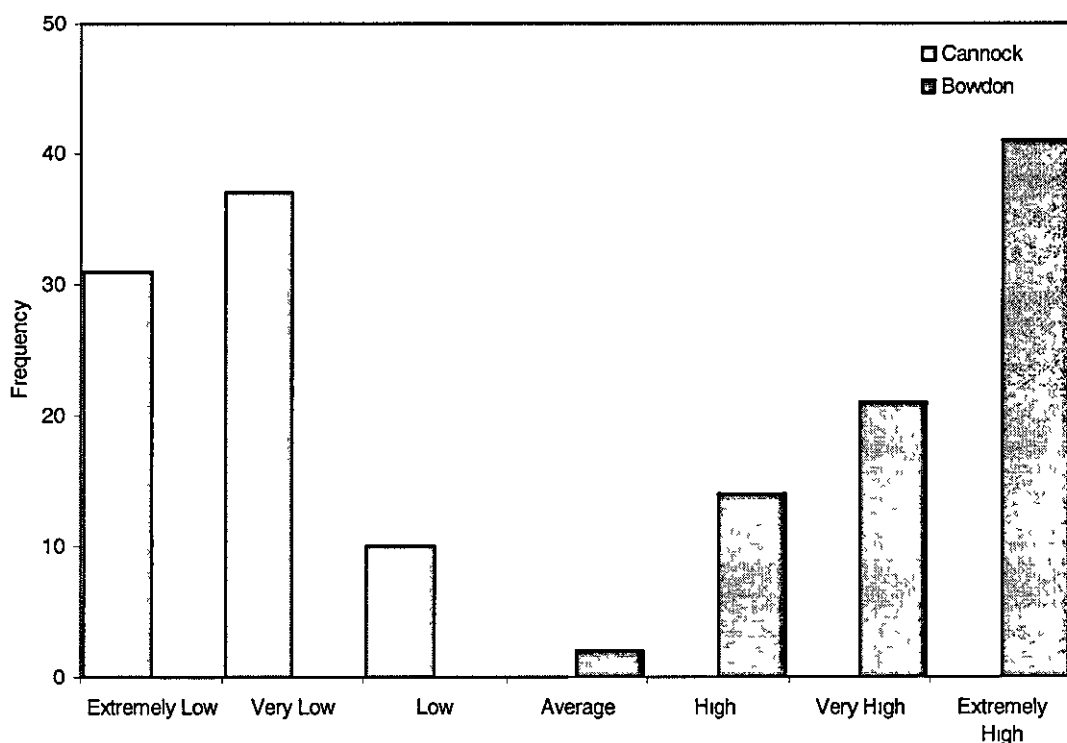


Figure 6.1 - A histogram showing the frequency of responses for ball rebound height at Cannock and Bowdon

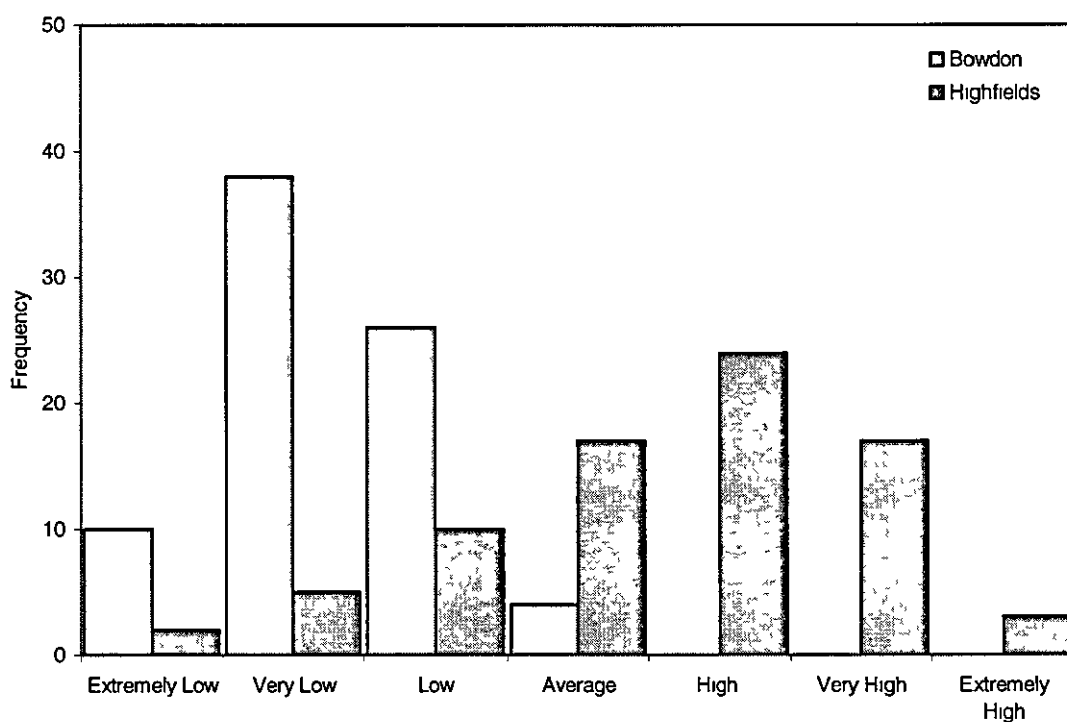


Figure 6 2 - A histogram showing the frequency of responses for underfoot grip at Bowdon and Highfields

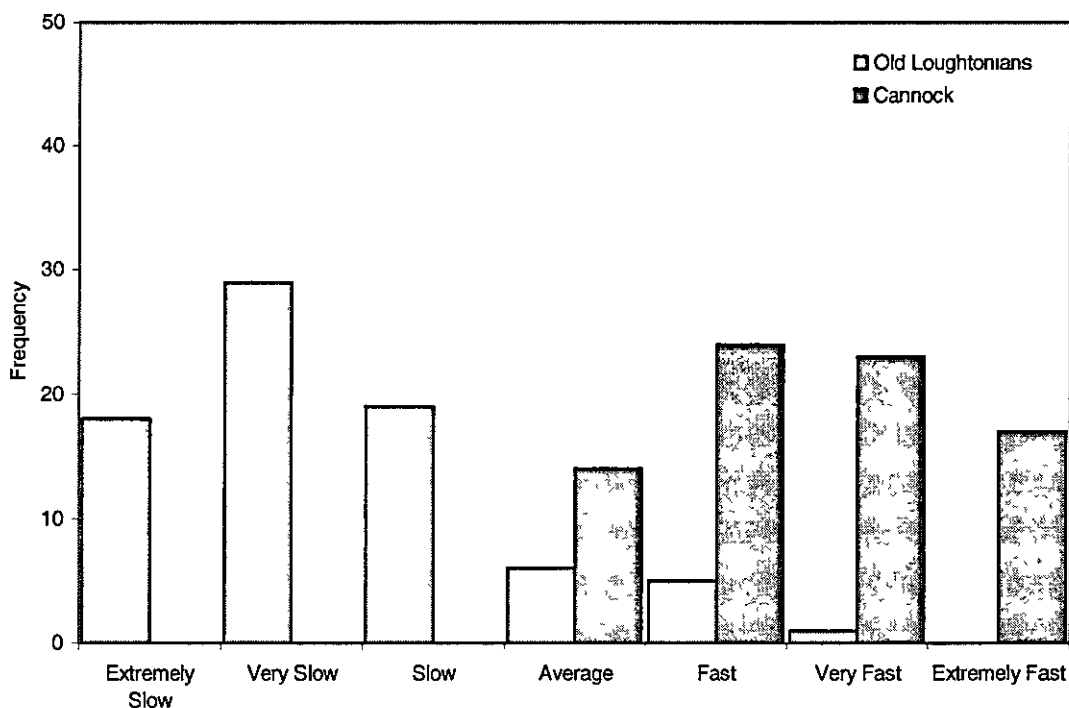


Figure 6.3 - A histogram showing the frequency of responses for surface pace at Old Loughtonians and Cannock

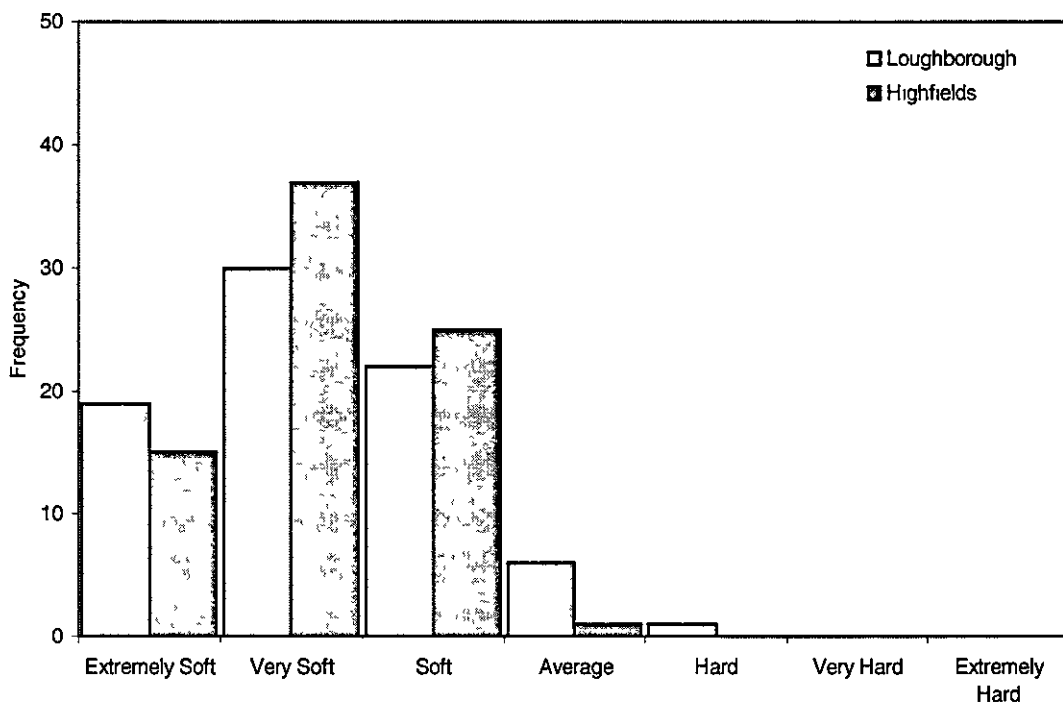


Figure 6.4 - A histogram showing the frequency of responses for surface hardness at Loughborough and Highfields

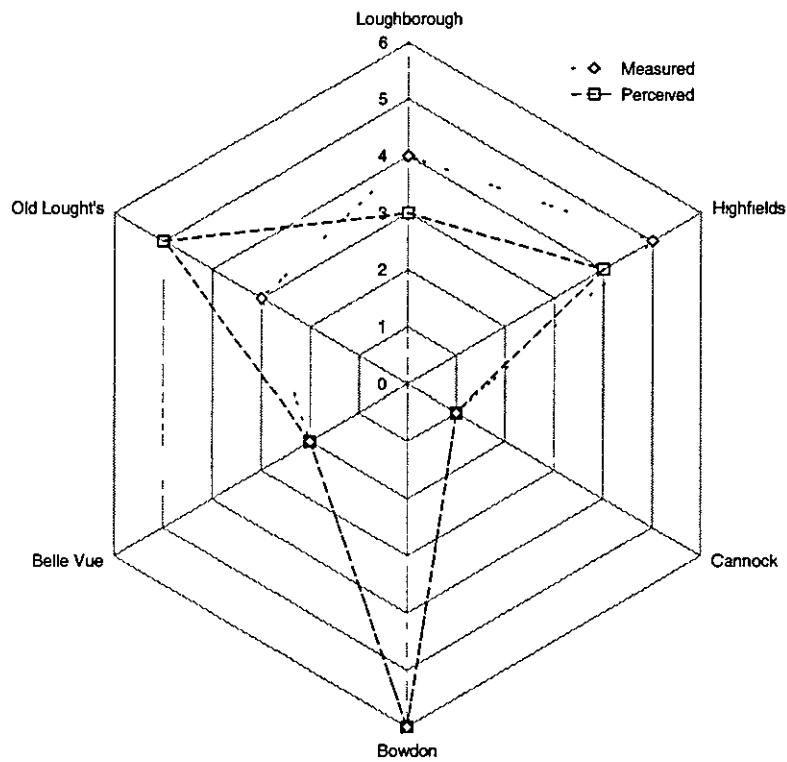


Figure 6.5 – A comparison between mechanical and perceived ball rebound behaviour

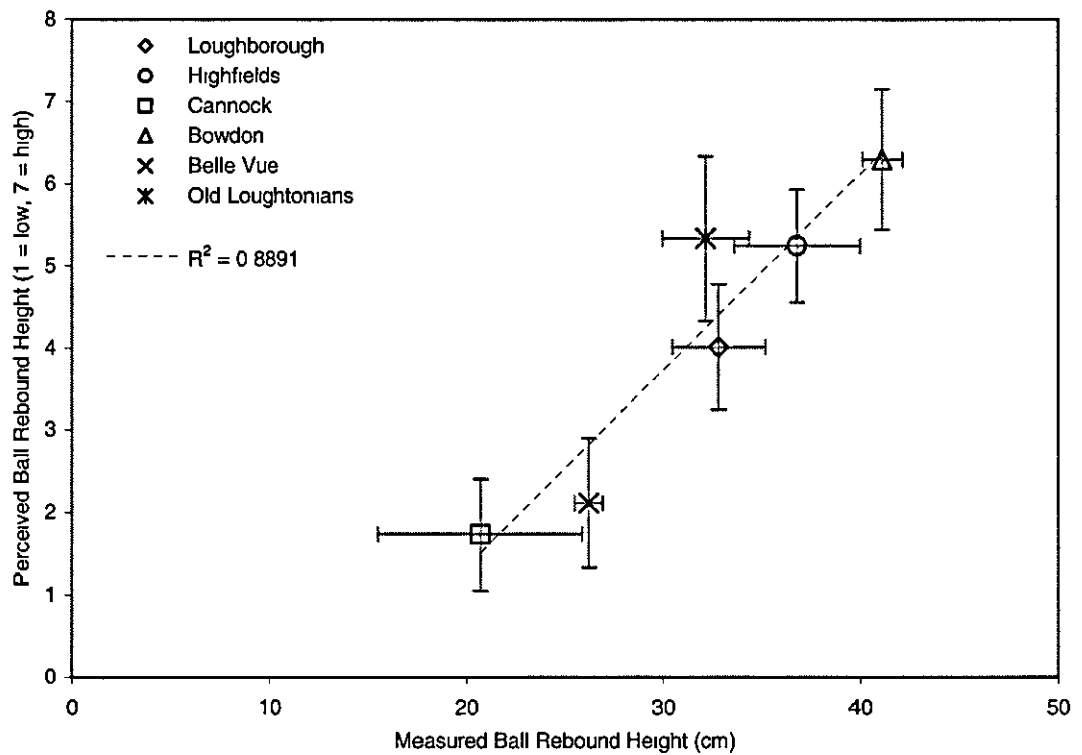


Figure 6.6 – The relationship between measured and perceived ball rebound height

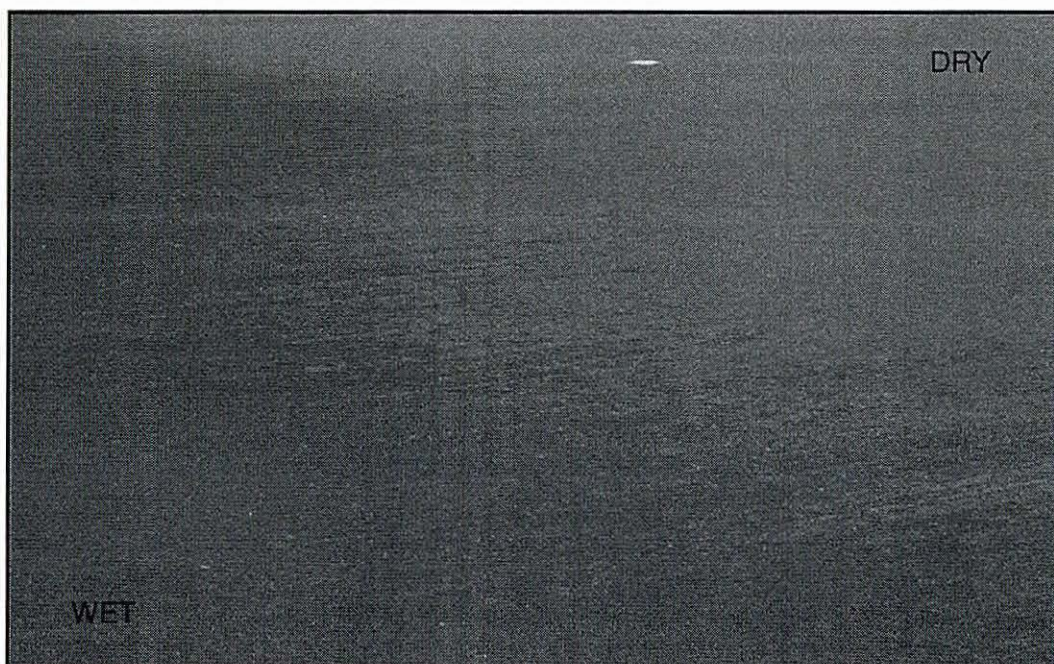


Figure 6.7a – The coverage of water on Highfields pitch after one full irrigation cycle (12 minutes)



Figure 6.7b – The irrigation of Highfields water-based hockey pitch

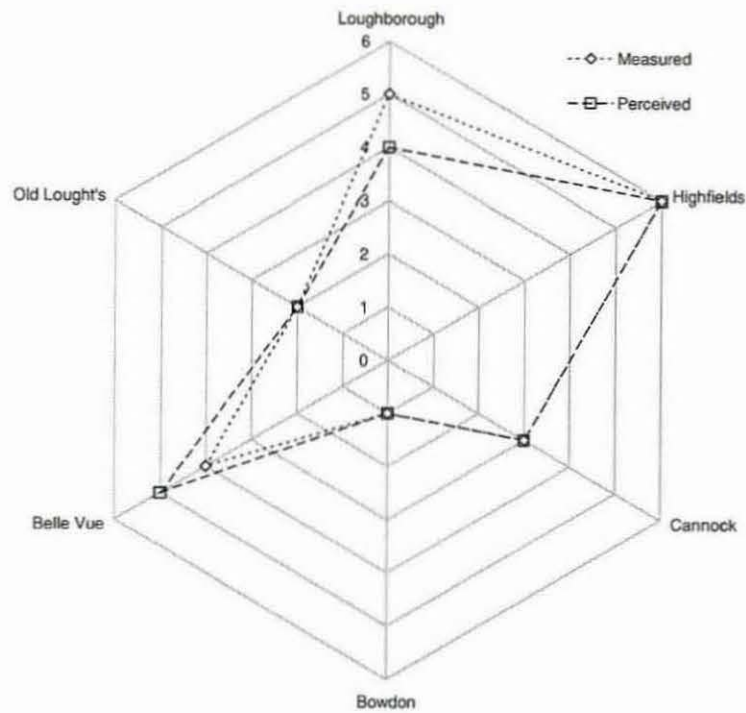


Figure 6.8 – A comparison between mechanical and perceived underfoot grip

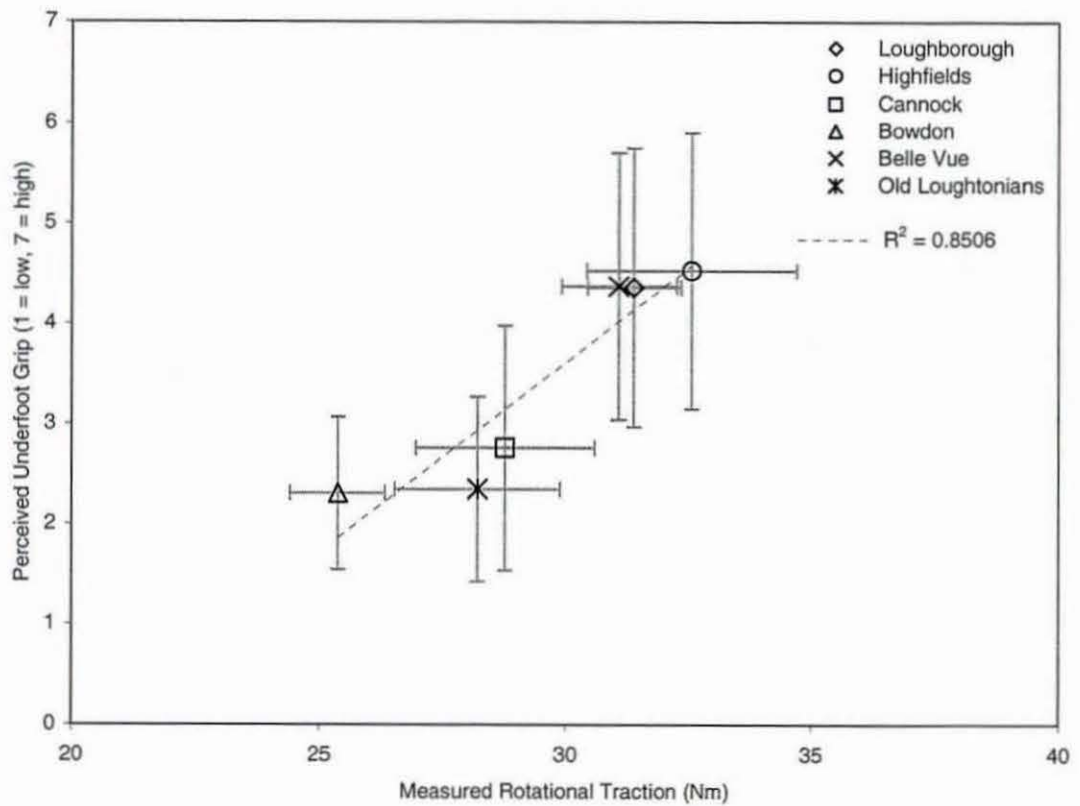


Figure 6.9 – The relationship between measured and perceived underfoot grip



Figure 6.10 – Algal growth on the Cannock water-based hockey pitch (dark areas illustrate algal growth)

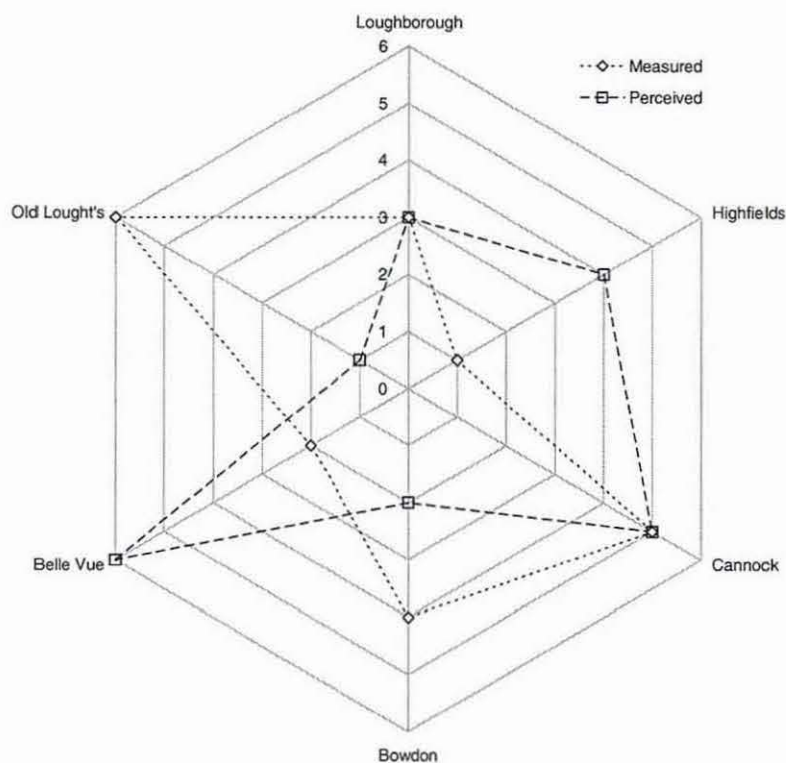


Figure 6.11 – A comparison between mechanical and perceived surface pace

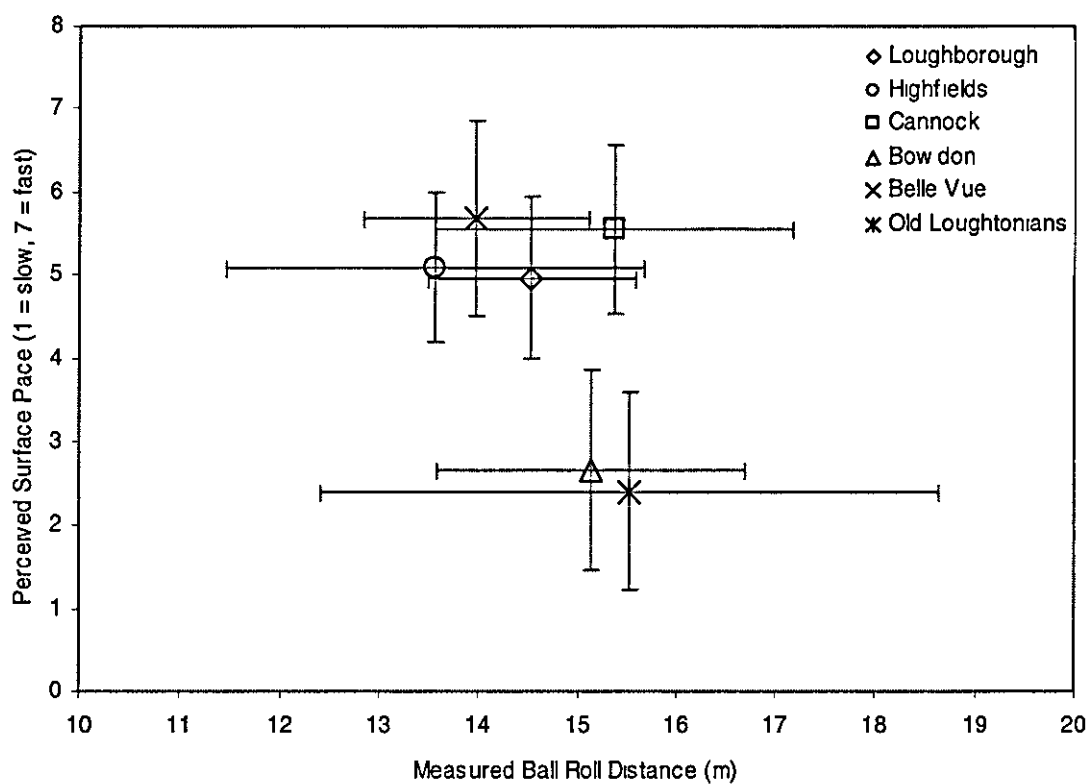


Figure 6.12 – The relationship between measured and perceived surface pace

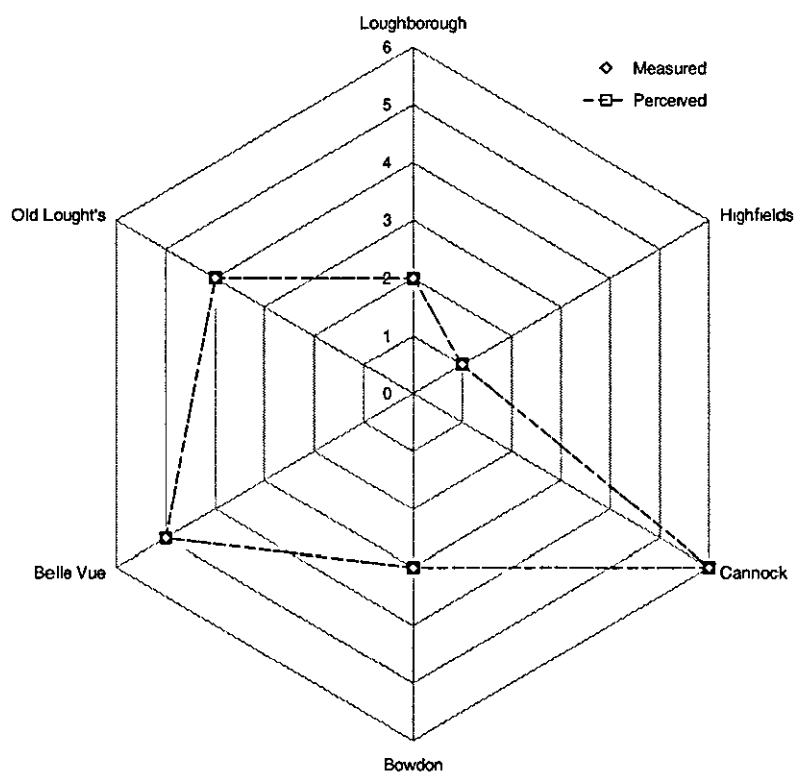


Figure 6.13 – A comparison between mechanical and perceived surface hardness measured by the AAB

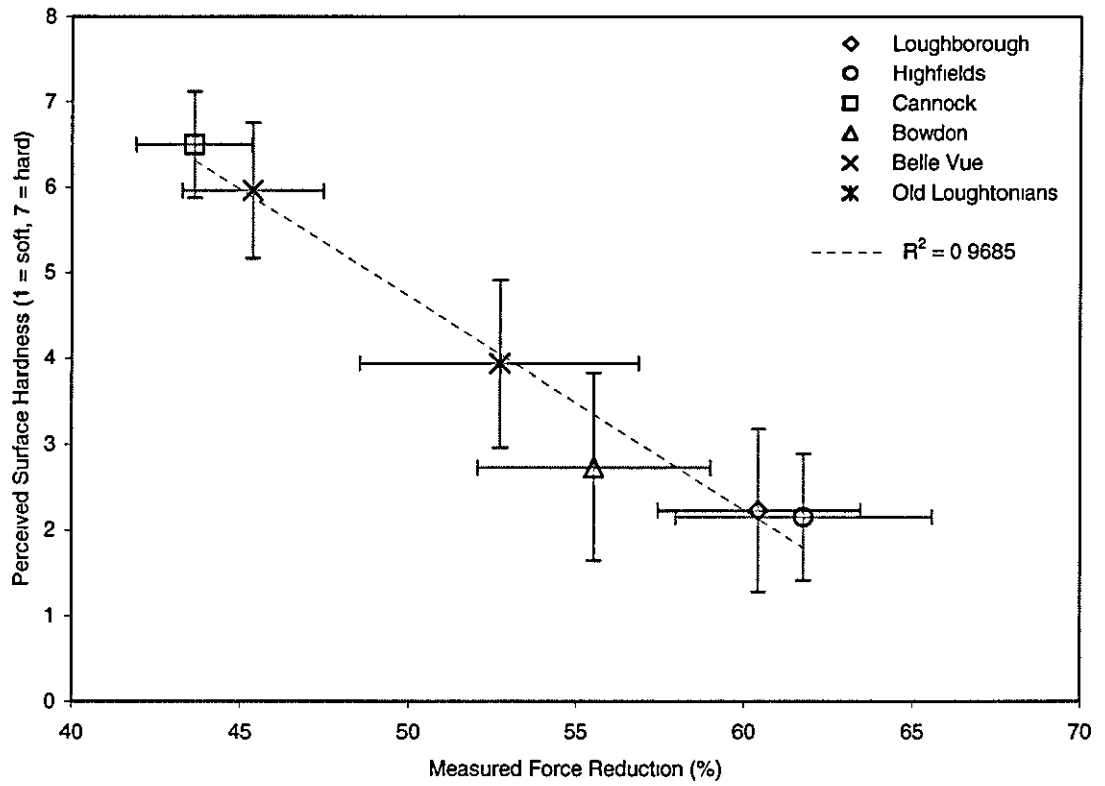


Figure 6.14 – The relationship between measured and perceived surface hardness using the AAB

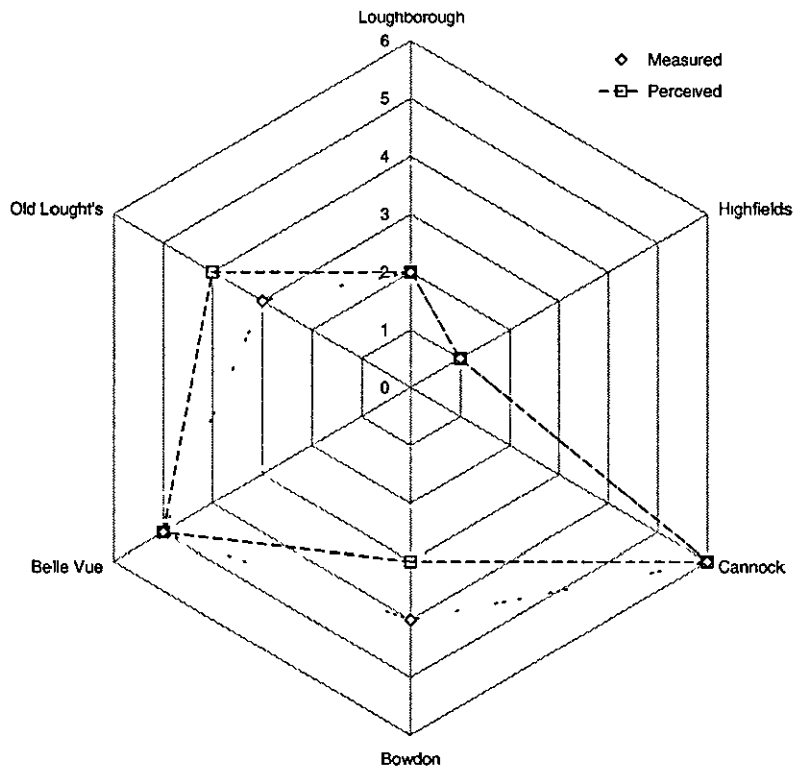


Figure 6 15 – A comparison between perceived and mechanical surface hardness measured by the 2 25 kg Clegg impact hammer

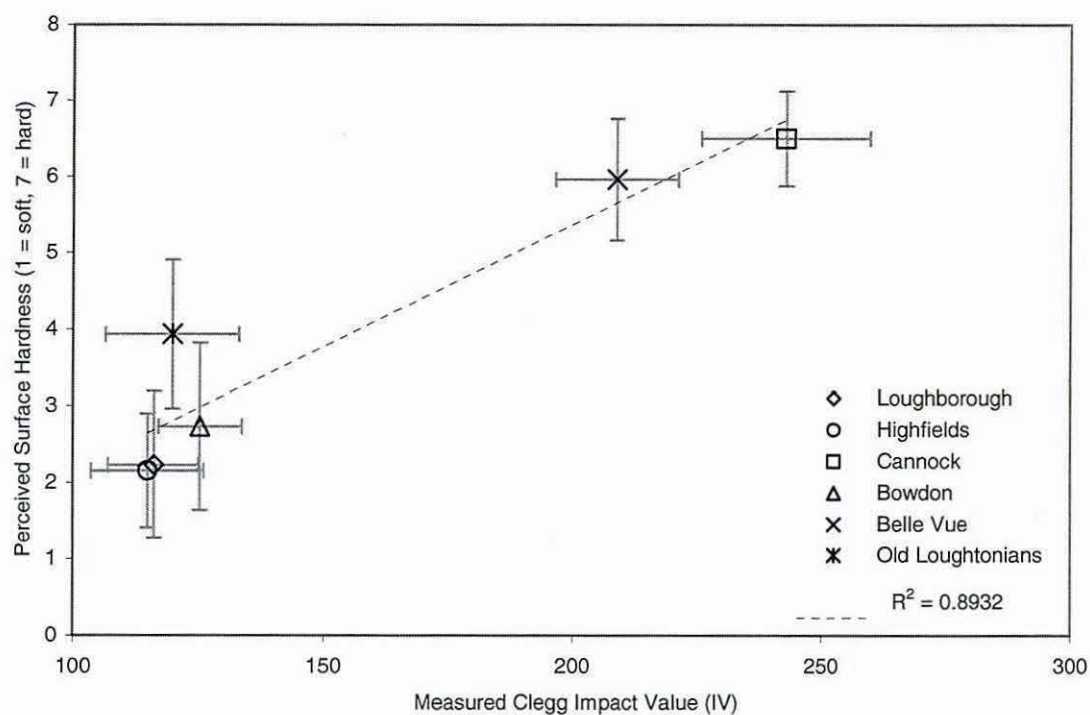


Figure 6.16 – The relationship between measured and perceived surface hardness measured by the 2.25 kg Clegg impact hammer



Figure 6.17a – A close view of the Cannock carpet pile (Nylon)



Figure 6.17a – A close view of the Old Loughtonians carpet pile (Polypropylene)

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

7.1 INTRODUCTION

A review of the current knowledge of synthetic turf pitches for field hockey highlighted the need to improve understanding of their behaviour. Much of the literature reviewed did not focus on field hockey surfaces and a lack of recent research has identified gaps in knowledge

This Chapter presents the conclusions from the field and laboratory investigation of mechanical behaviour, and the quantitative and qualitative data collection methods of perceived behaviour. Conclusions are also presented on the relationship between perceived and mechanical behaviour.

7.2 PERCEIVED BEHAVIOUR

The aim of this research was to develop a suitable method for eliciting player perceptions of field hockey pitches. Using a qualitative approach five dimensions emerged as part of an inductive analysis, they were; Ball/Surface interaction, Player/Surface Interaction, Pitch Properties, Player Performance and Playing Environment. A structured relationship model was developed which for the first time graphically represents how the base themes fit into the dimensions and illustrates interactions between several dimensions.

The elicitation of players perceptions identified their preferred playing characteristics for field hockey pitches. Although it was shown that the players have different requirements, the ideal characteristics from the majority of elite players were identified as a 'fast' pitch with a 'low' ball rebound, 'good level' of underfoot grip and an intermediate surface hardness that was not too 'hard' or 'soft'. The two most important characteristics of pitch behaviour identified by the players were 'surface consistency' and a pitch that was conducive to 'skilful play'.

It is clear that not all players will have the same ideal requirements. This research has shown that at the elite level players are more concerned with the quality of play, facility to demonstrate skill and winning than the potential for discomfort and/or injury during a game.

7.3 MECHANICAL BEHAVIOUR

Measurements from field and laboratory investigation utilising test equipment have established that large difference exists between pitches and pitch systems. The differences between pitches have been attributed to their construction specifications and it has been found that the shockpad and carpet layers have the most significant influence on pitch behaviour. Furthermore, the type of shockpad and carpet (material) have been found to influence pitch behaviour.

The repeatability and reproducibility of the test equipment was good. Controlled laboratory investigation and repeat testing on-site have validated the equipment. However, environmental conditions were found to have a large influence on the measurement of ball rebound height, rotational traction and ball roll tests.

The amount of water on the surface has been shown to significantly influence its behaviour. Ball rebound height was found to be sensitive to small differences in water on the surface. The uniformity of the irrigation systems at some pitches were observed to be poor and very susceptible to windy conditions.

A correlation was found to exist between measurements for surface hardness on some pitches with the AAB and 2.25 kg Clegg impact hammer. The 2.25 kg Clegg, which is easier to use, widely available and quick, could be useful as a spatial monitoring tool and to evaluate the condition of a pitch over time.

The pitches tested appear to get harder with age, from the limited data of two years, five of the six pitches showed an increase in surface stiffness over a 12 month period.

7.4 RELATIONSHIP BETWEEN MECHANICAL AND PERCEIVED BEHAVIOUR

The aim of this research was to establish the relationship between players opinions and mechanical test devices for six water-based field hockey pitches. Four playing characteristics were identified for comparison: ball rebound height, underfoot grip, surface pace and surface hardness.

The differences between pitches were identified by test equipment and players perceptions. Correlations between ball rebound height, underfoot grip and surface hardness indicted that the players identified similar difference to the test equipment. However, the measurement of surface pace did not correlate well with ball roll distance.

7.5 CONTRIBUTION TO KNOWLEDGE

This research has introduced a method of eliciting players perceptions of synthetic turf field hockey surfaces. Players requirements, preferences and the importance they perceive for different playing characteristics have been obtained and the use of a quantitative questionnaire has allowed each characteristic to be quantified and its relative importance obtained.

The laboratory and fieldwork has identified many factors that can influence the behaviour of synthetic turf pitches and a better understanding of the mechanisms that influence pitch behaviour has been established. Understanding of the role of each layer of the pitch and in particular the shockpad and carpet layers has been improved.

Players opinions of six world class water-based field hockey surfaces have been obtained and compared with mechanical test data. This has shown that both players and test equipment can establish differences between pitches and it reinforces the validity of both approaches.

7.6 RECOMMENDATIONS FOR FUTURE RESEARCH

The focus of this research was on elite players and 'top quality' surfaces. The behaviour of pitches for lower standard usage is still unclear. Water-based pitches are designed for elite use. However, at lower ability levels field hockey is played on sand based pitches. It is considered timely to evaluate how these

surfaces behave and in particular the role of the sand infill in the carpet pile. How this influences both player and ball interactions, the uniformity across the surface and other playing requirements need to be considered. There are significantly more sand based and 3rd generation rubber crumb pitches in common usage in England and a better understanding of the factors that influence their performance is considered essential.

The methods used to investigate players perceptions could be modified to elicit perceptions from other sports and different ability players. Understanding the requirements of the end user is key to the development of good quality pitch that meet their requirements. Though, the playing requirements for all sports will be different, the methodology developed in this research could be applied to other sports, and/or different abilities of player. Whether a beginner requires the same pitch characteristics as an elite performer or whether they have different requirements is unclear at this time.

It is recommended that in future design there is a consultation with the players prior to a pitch being built to ensure all of their requirements are met. A questionnaire could be designed that would help identify what characteristics the players require from the surface and then a pitch could be built to match them. However, for this to work a significant amount of research is required to build a database of pitches with design specification and test results as a reference point.

Surface classification or accreditation is essential for safety and performance. In that respect, detailed biomechanical understanding of human locomotion and complex consideration of material properties, while essential for pioneering research, is not necessary for everyday sports surface analysis. If a simplified test can be used that closely matches what players feel or perceive then its suitability is valid. However, this may not be appropriate for certain player surface interactions as players may not perceive what may be best for them. For example, they may like the 'feel' or behaviour of a surface in respect of its compliance or resilience but they would not be consciously aware of potential damage being done to their muscular-skeletal system.

The rate of injury of field hockey players is unclear as are the potential injuries caused by the surface. It is therefore recommended that a detailed

epidemiological study be undertaken to ascertain the occurrence of injuries and their causes in relations to sports surfaces.

A long-term study into the influence of ageing is required to establish how long (or indeed amount of usage) a pitch can performance to a satisfactory level. This should encompass the role of maintenance and its effect on pitch behaviour. Monitoring at evenly spaced intervals to determine how the pitches behaviour changes with time and usage is desirable.

The standard test methods are considered valid for indexing pitches; however, they are not appropriate to replicate the game playing scenario. The development of tests that can simulate in-game actions is required to understand their behaviour. In field hockey the ball is struck with huge force, but unfortunately no data was found to evaluate the speed, direction or angle of impact between the ball and the surface. It is clear a full game analysis is required to identify what shots are commonly played, and to identify 'typical' velocities and angles to help in the design of a more suitable tests

Shockpads help to attenuate and reduce the force applied by the athlete to the surface to protect them from injury. However, it is unclear how the non-linear and repeated loading of many thousands of impacts will effect the longevity of the shockpad. Consequently more detailed analysis is required considering the complex behaviour of the shockpad and factors that can influence its design such as binder content, binder type, rubber type, rubber grading which could all have a significant influence of the performance of the shockpad layer.

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APPENDIX A

INTERVIEW GUIDE

Interview Guide

Name: _____ Date: _____

Section 1:

Introduction

I would like to begin by thanking you for agreeing to participate in this interview study. As part of this project between Loughborough University and English Hockey we are talking to national league standard hockey players, to determine their perceptions of numerous hockey pitches.

I am going to use a mini disc player to record the interview in order to obtain complete and accurate information, thereby making the interview process more efficient. The interview will be recorded so that I will be able to make a typed transcript for later scrutiny and reference. For this reason could you please speak clearly and in the direction of the microphone when responding.

I would like to draw your attention to a number of points from the interview summary you received earlier. It is your perception of the playing qualities of the pitch that is of interest in this study. We want you in your own words to describe your thoughts and feelings about the pitch and how important certain factors are to you.

This interview will last for approximately 20 minutes. I would just like to re-emphasise that your participation in this interview is entirely voluntary, and you are free to decline to answer any questions or to stop the interview at any time.

Do you have any questions so far?

Section 2:

Having just finished a full match I would like you to describe your perceptions of the pitch you have just played on. Drawing specific comparisons with your home pitch.

Compare:

Ball Interaction:

Question 1: How did the ball interact with the pitch?

Question 1.1: How much control did you feel with the ball?

Question 1.2: How did you find dribbling the ball?

Question 1.3: How did you find passing the ball?

Additional Questions:

1/. In comparison with your own home pitch, how would you describe the way in which the ball interacts with this pitch?

- 2/. Are there any other factors about ball interaction that have come to mind by playing on this pitch.
- 3/. In comparison with your own pitch, what are the similarities and differences with regards ball interaction?
- 4/. What factors do you prefer about how the ball interacted on this pitch?
- 5/. What factors do you prefer about how the ball interacts on your own pitch?
- 6/. Is there anything else about the way in which the ball interacted with this pitch that you think is important?

| | | | |
|---|-------------------|----------------------|---------------------|
| <i>Roll Distance</i> | <i>Roll Speed</i> | <i>Bounce Height</i> | <i>Bounce Angle</i> |
| <i>Ball Friction</i> | <i>Ball Spin</i> | <i>Roll Line</i> | <i>Consistency</i> |
| If mentioned ask for importance/ideal values | | | |

I would now like to turn to the way in which you, the player, interacted with the pitch.

Player Interaction:

Question 2: How did YOU feel on the pitch?

Question 2.1: How did you find starting and stopping?

Question 2.2: How did you find turning on the pitch?

Question 2.3: How did you feel moving on the pitch?

Question 2.4: How comfortable did you find the pitch?

Additional Questions:

- 1/. In comparison with your own home pitch, how would you describe the way in which you interacted with this pitch?
- 2/. Are there any other factors about interaction that have come to mind by playing on this pitch.
- 3/. In comparison with your own pitch, what are the similarities and differences with regards player interaction?
- 4/. What factors do you prefer about how you interacted on this pitch?
- 5/. What factors do you prefer about how you interact on your own pitch?
- 6/. Is there anything else about the way in which you interacted with this pitch that you think is important?

| | | | |
|---|-----------------|---------------|--------------------|
| <i>Friction</i> | <i>Traction</i> | <i>Burn</i> | <i>Shock level</i> |
| <i>Grip</i> | <i>Comfort</i> | <i>Injury</i> | |
| If mentioned ask for importance/ideal values | | | |

Pitch Issues:

Question 3: What do you think of the pitch itself?

Question 3.1: How well did the pitch play?

Question 3.2: Did the pitch have any `bad` parts?

Question 3.3: Did anything interfere with you whilst playing the game?

Question 3.4: Did you have any problems playing on the pitch?

| | | | |
|--|-------------------|-------------------|-------------------|
| Pitch Evenness | Pitch Consistency | Irrigation System | Drainage |
| Floodlights (if night) | Location | Stick/Surface | Pitch/Ball Colour |
| If mentioned ask for importance/ideal values | | | |

Section 3

Now I would like to ask you a few questions about your background and pitch preferences.

Age: _____

Position: _____

Height: _____ Weight: _____ Fitness level: _____

At what age did you start to play hockey?

How often do you play hockey?

Compared to the last few matches, how well did you personally play during this match?

How much of the game did you play? _____

What type of stick do you use? _____

What type of shoes did you wear? _____

How old are your shoes? _____

Which is your favourite pitch in the league? (Why?)

What are the positive things about the pitch?

What are the less good things about the pitch?

Which is your least favourite pitch in the league? (Why?)

Why don't you like it?

Are there any positive aspects about the pitch at all?

Do you have a ball (type) preference?

To conclude the interview I would like to ask you about the interview itself.

Are there any other important factors about the pitch which we failed to discuss?

Did I lead your responses in any way?

Have you any comments or suggestions about the interview itself?

Are there any ways in which we could improve the interview structure?

Thank you for helping out with this interview

APPENDIX B

**POSTAL QUESTIONNAIRE 1: PREFERENCES AND
IMPORTANCE**

A STUDY OF SYNTHETIC HOCKEY PITCHES

Please Return Completed Questionnaires to:

Colin Young
Department of Civil & Building Engineering
Loughborough University
Loughborough
Leicestershire
LE11 3TU

Contact Information:

C.Young@lboro.ac.uk
(01509) 263171 ext 4133
07984497279

This questionnaire is part of a three-year study to investigate the performance requirements for synthetic turf pitches. The determination of perceptions from elite level hockey players is a vital part of this study; therefore your participation is greatly appreciated. It is envisaged that this questionnaire will take approximately 10 minutes to complete, thank you for your time.

SECTION 1: PERSONAL INFORMATION

Name Age

Club Position

Shoe type, manufacturer and age

Stick type, manufacturer and age

Have you suffered from any serious surface related injuries? Yes ☐ No ☐

If yes, please give details?

Home Pitch Details:

Pitch Type: Sand Based ☐ Water Based ☐
Carpet Material: Nylon ☐ Polypropylene ☐ Polyester ☐ Don't know ☐

Pitch Age:

Additional Information:
(e.g. shockpad thickness)

SECTION 2: PREFERENCES

Circle the number that best fits your preference.

Question 2.1/. What height do you prefer the ball to bounce from the surface?

Low, ball stays low to surface 1 2 3 4 5 6 7 High, ball comes high from surface

Question 2.2/. What speed do you prefer the ball to roll across the surface?

*Slow,
ball rolls slowly
along the surface*

1 2 3 4 5 6 7

*Fast,
ball rolls quickly
along the surface*

Question 2.3/. What level of spin do you prefer for the ball on the surface?

*None,
ball doesn't
Spin*

1 2 3 4 5 6 7

*Lots,
ball spins
easily*

Question 2.4/. What level of underfoot grip do you prefer from a surface?

*Slippy,
Little grip*

1 2 3 4 5 6 7

*Sticky
lots
of grip*

Question 2.5/. What level of 'hardness' do you prefer from a surface?

*Extremely
soft*

1 2 3 4 5 6 7

*Extremely
hard*

SECTION 3: IMPORTANCE

Circle the number that best fits, in your opinion, the level of importance.

Question 3.1/. How important is the bounce height of the ball?

1
*Not at all
Important*

2 3 4 5 6

*Moderately
Important*

7
*Extremely
Important*

Question 3.2/. How important is the speed of the ball roll?

1
*Not at all
Important*

2 3 4 5 6

*Moderately
Important*

7
*Extremely
Important*

Question 3.3/. How important is the spin of the ball on the surface?

1
*Not at all
Important*

2 3 4 5 6

*Moderately
Important*

7
*Extremely
Important*

Question 3.4/. How important is the underfoot grip of the surface?

1
*Not at all
Important*

2 3 4 5 6

*Moderately
Important*

7
*Extremely
Important*

Question 3.5/. How important is the hardness of the surface?

1
*Not at all
Important*

2 3 4 5 6

*Moderately
Important*

7
*Extremely
Important*

Question 3.6/. How important is the effect of the surface on the ability to perform skills?

1
*Not at all
Important*

2 3 4 5 6

*Moderately
Important*

7
*Extremely
Important*

Question 3.7/. How important is the uniformity of the watering system?

1
*Not at all
Important*

2 3 4 5 6

*Moderately
Important*

7
*Extremely
Important*

SECTION 4: RELATIVE IMPORTANCE

Tick the box that relates to the statement that you believe is the most important.

| | | | | |
|---|--------------------------|----|----------------------------------|--------------------------|
| Question 4.1/. Soft, slow pitch | <input type="checkbox"/> | Or | Hard, fast pitch | <input type="checkbox"/> |
| Question 4.2/. Soft, fast pitch | <input type="checkbox"/> | Or | Hard, slow pitch | <input type="checkbox"/> |
| Question 4.3/. Slow, high bouncing pitch | <input type="checkbox"/> | Or | Fast, low bouncing pitch | <input type="checkbox"/> |
| Question 4.4/. Slow, low bouncing pitch | <input type="checkbox"/> | Or | Fast, high bouncing pitch | <input type="checkbox"/> |
| Question 4.5/. High bouncing, slippery pitch | <input type="checkbox"/> | Or | Low bouncing, grippy pitch | <input type="checkbox"/> |
| Question 4.6/. High bouncing, grippy pitch | <input type="checkbox"/> | Or | Low bouncing, slippery pitch | <input type="checkbox"/> |
| Question 4.7/. Slippery, abrasive pitch | <input type="checkbox"/> | Or | Grippy, non-abrasive pitch | <input type="checkbox"/> |
| Question 4.8/. Slippery, non-abrasive pitch | <input type="checkbox"/> | Or | Grippy, abrasive pitch | <input type="checkbox"/> |
| Question 4.9/. Soft, high bouncing pitch | <input type="checkbox"/> | Or | Hard, low bouncing pitch | <input type="checkbox"/> |
| Question 4.10/. Soft, low bouncing pitch | <input type="checkbox"/> | Or | Hard, high bouncing pitch | <input type="checkbox"/> |
| Question 4.11/. Slow, slippery pitch | <input type="checkbox"/> | Or | Fast, grippy pitch | <input type="checkbox"/> |
| Question 4.12/. Slow, grippy pitch | <input type="checkbox"/> | Or | Fast, slippery pitch | <input type="checkbox"/> |
| Question 4.13/. Soft, slippery pitch | <input type="checkbox"/> | Or | Hard, grippy pitch | <input type="checkbox"/> |
| Question 4.14/. Soft, grippy pitch | <input type="checkbox"/> | Or | Hard, slippery pitch | <input type="checkbox"/> |
| Question 4.15/. Slow, abrasive pitch | <input type="checkbox"/> | Or | Fast, non-abrasive pitch | <input type="checkbox"/> |
| Question 4.16/. Slow, non-abrasive pitch | <input type="checkbox"/> | Or | Fast, abrasive pitch | <input type="checkbox"/> |
| Question 4.17/. High bouncing, abrasive pitch | <input type="checkbox"/> | Or | Low bouncing, non-abrasive pitch | <input type="checkbox"/> |
| Question 4.18/. High bouncing, non-abrasive pitch | <input type="checkbox"/> | Or | Low bouncing, abrasive pitch | <input type="checkbox"/> |
| Question 4.19/. Soft, abrasive pitch | <input type="checkbox"/> | Or | Hard, non-abrasive pitch | <input type="checkbox"/> |
| Question 4.20/. Soft, non-abrasive pitch | <input type="checkbox"/> | Or | Hard, abrasive pitch | <input type="checkbox"/> |

Please turn over for the last section.

SECTION 5: PITCH PREFERENCES

Question 5.1/. Which are your 3 **favourite** pitches in the EHL?

| | | |
|-----|-----|-----|
| 1/. | 2/. | 3/. |
|-----|-----|-----|

Question 5.2/. What **do** you like about each? (e g consistency)

| | | |
|-----|-----|-----|
| 1/. | 2/. | 3/. |
|-----|-----|-----|

Question 5.3/. Which are your 3 **least** favourite pitches in the EHL?

| | | |
|-----|-----|-----|
| 1/. | 2/. | 3/. |
|-----|-----|-----|

Question 5.4/. What **don't** you like about each? (e g poor drainage)

| | | |
|-----|-----|-----|
| 1/. | 2/. | 3/. |
|-----|-----|-----|

Question 5.5/. Please further elaborate on your answers or comment on any other pitch issues not covered during this questionnaire? (e g weather conditions)

| |
|--|
| |
|--|

THANK YOU FOR YOUR TIME WITH THIS STUDY.

APPENDIX C

POSTAL QUESTIONNAIRE 2: PITCH SPECIFIC QUESTIONNAIRE

A STUDY OF SYNTHETIC HOCKEY PITCHES

Please Return Completed Questionnaires to:

Colin Young
Department of Civil & Building Engineering
Loughborough University
Loughborough, Leicestershire, LE11 3TU

Contact Information:

C Young@lboro.ac.uk
(01509) 263171 ext 4133
07984497279

This questionnaire is part of a three-year study to investigate the performance requirements for synthetic turf pitches. The determination of perceptions from elite level hockey players is a vital part of this study, therefore your participation is greatly appreciated. It is envisaged that this questionnaire will take approximately 5 minutes to complete, thank you for your time.

SECTION 1: PERSONAL INFORMATION

Name _____ Age _____
Club _____ Position _____

SECTION 2: PITCH INFORMATION

When was the last time you played on the following pitches, tick the box that applies.

| | Under 1 week | Under 1 month | Under 3 months | Under 1 year | Over 1 year | Never played at this pitch |
|----------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|-------------------------------|
| Loughborough University | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Highfields (Beeston Hockey Club) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Cannock | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Bowdon | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Belle Vue | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Old Loughtonians | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

SECTION 3: PITCH COMPARISON

Circle the number that best fits, in your opinion, the way each pitch plays.

Height of ball bounce

| | Very low | Low | Average | High | Very high |
|------------------|----------|-------|---------|------|-----------|
| Loughborough | 1 2 | 3 4 5 | 6 7 | | |
| Highfields | 1 2 | 3 4 5 | 6 7 | | |
| Cannock | 1 2 | 3 4 5 | 6 7 | | |
| Bowdon | 1 2 | 3 4 5 | 6 7 | | |
| Belle Vue | 1 2 | 3 4 5 | 6 7 | | |
| Old Loughtonians | 1 2 | 3 4 5 | 6 7 | | |

Underfoot Grip

| | Very slippery | Slippery | Average | Grippy | Very grippy |
|------------------|---------------|----------|---------|--------|-------------|
| Loughborough | 1 2 | 3 4 5 | 6 7 | | |
| Highfields | 1 2 | 3 4 5 | 6 7 | | |
| Cannock | 1 2 | 3 4 5 | 6 7 | | |
| Bowdon | 1 2 | 3 4 5 | 6 7 | | |
| Belle Vue | 1 2 | 3 4 5 | 6 7 | | |
| Old Loughtonians | 1 2 | 3 4 5 | 6 7 | | |

Speed of ball roll

| | Very slow | Slow | Average | Fast | Very fast |
|------------------|-----------|-------|---------|------|-----------|
| Loughborough | 1 2 | 3 4 5 | 6 7 | | |
| Highfields | 1 2 | 3 4 5 | 6 7 | | |
| Cannock | 1 2 | 3 4 5 | 6 7 | | |
| Bowdon | 1 2 | 3 4 5 | 6 7 | | |
| Belle Vue | 1 2 | 3 4 5 | 6 7 | | |
| Old Loughtonians | 1 2 | 3 4 5 | 6 7 | | |

Coverage of watering system

| Coverage of watering system | | | | Poor | Average | Good | Excellent | |
|-----------------------------|------------|---|--|------|---------|------|-----------|---|
| | Inadequate | | | | | | | |
| Loughborough | 1 | 2 | | 3 | 4 | 5 | 6 | 7 |
| Highfields | 1 | 2 | | 3 | 4 | 5 | 6 | 7 |
| Cannock | 1 | 2 | | 3 | 4 | 5 | 6 | 7 |
| Bowdon | 1 | 2 | | 3 | 4 | 5 | 6 | 7 |
| Belle Vue | 1 | 2 | | 3 | 4 | 5 | 6 | 7 |
| Old Loughtonians | 1 | 2 | | 3 | 4 | 5 | 6 | 7 |

Hardness of the surface

| | <i>Very soft</i> | | <i>Soft</i> | <i>Average</i> | <i>Hard</i> | <i>Very hard</i> | |
|------------------|------------------|---|-------------|----------------|-------------|------------------|---|
| Loughborough | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Highfields | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Cannock | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Bowdon | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Belle Vue | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Old Loughtonians | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Overall surface consistency

| Overall Fanfare Consistency | Inadequate | Poor | Average | Good | Excellent | | |
|-----------------------------|------------|------|---------|------|-----------|---|---|
| Loughborough | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Highfields | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Cannock | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Bowdon | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Belle Vue | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Old Loughtonians | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

SECTION 4: PITCH RANKINGS

Rank the following pitches for each option between 1 and 6 i.e. for 'height of ball bounce' the pitch with the lowest bounce would be 1 and the pitch with the highest bounce would be 6

| | Height of ball bounce Lowest = 1 Highest = 6 | Underfoot grip Most Slippery = 1 Most Grippy = 6 | Speed of ball roll Slowest = 1 Fastest = 6 | Coverage of watering system Best = 1 Worst = 6 | Hardness of the surface Softest = 1 Hardest = 6 | Overall surface consistency Best = 1 Worst = 6 |
|------------------|--|--|--|--|---|--|
| Loughborough | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |
| Highfields | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |
| Cannock | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |
| Bowdon | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |
| Belle Vue | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |
| Old Loughtonians | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |

SECTION 5: ADDITIONAL INFORMATION

If you have any comments or suggestion about the contents and/or structure of this questionnaire please feel free to elaborate below

THANK YOU FOR YOUR TIME WITH THIS STUDY

