

Morphological and skill-related fitness components as possible predictors of injuries in elite female field hockey players

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DECLARATION

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Morphological and skill-related fitness components as possible predictors of injuries in elite female field hockey players

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Abstract

Introduction: The incidence of injury in female field hockey players is high, but there is little data on the physical demands of the game or the injury risk factors.

Objective: To establish an athletic profile of elite female field hockey players and to determine if morphological or skill-related factors measured in the pre-season can predict injury in the in-season.

Methods: Thirty female field hockey players comprising the South African national field hockey team underwent pre-season testing. These tests included anthropometry, balance, flexibility (sit and reach test), explosive power (vertical jump test), upper and lower body strength (bench and leg press), core strength, speed (10 m, 40 m and repeated sprint test with and without a hockey stick), agility (Illinois test) and isokinetic testing of the ankle. Also included was a questionnaire to collect information on demographic data, elite-level experience, playing surface, footwear and injury history. Injuries in training and matches were recorded prospectively in the subsequent season using an injury profile sheet. Players reporting an injury were contacted to collect data regarding injury circumstances. Univariate and multivariate regression analyses were used to calculate odds ratios (ORs) and 95% confidence intervals (CIs) for ± 1 standard deviation of change.

Results: A total of 87 injuries were recorded with ligament and muscle injury the most frequent. The highest incidence of injury was the ankle joint followed by the hamstring muscles and lower back respectively. Univariate analyses showed that ankle dorsiflexion strength was a very strong predictor of ankle injuries ($p=0.0002$), and that ankle dorsiflexion deficit ($p=0.0267$) and eversion deficit ($p=0.0035$) were significantly good predictors of ankle injury. All balance indices, i.e. anterior/posterior ($p=0.0465$), medial/lateral ($p<0.0001$) and overall ($p<0.0001$), constituted the other pre-season performance measures showing significant potential to predict ankle injury. For lower leg injuries, univariate associations were found with ankle inversion deficit ($p=0.0253$), eversion deficit ($p=0.0379$) and anterior/posterior balance index ($p=0.0441$).

Conclusion: Dorsiflexion strength and all balance indices were strong predictors of ankle injury while ankle inversion deficit, eversion deficit and anterior/posterior balance were associated with lower leg injuries in elite female field hockey players.

Key words: Female, Field Hockey, Elite, Injury, Risk Factors

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CHAPTER 1

INTRODUCTION AND PROBLEM STATEMENT

1.1 INTRODUCTION

The game of field hockey is thought to have originated in Asia about 2000 BC with the simple use of a ball and a stick. It has since been modified, first by the Egyptians and then by the Greeks, the Romans and finally by the Europeans to the game we see today. The game spread to South Africa around 1897 and is now a common field sport in a vast majority of primary and high schools, sports clubs and universities. Field hockey, however, was only brought into the Olympics in 1908 where only men played, while the first introduction of women's field hockey to the Olympics games was in 1980. The South African women's field hockey team made their first Olympic appearance in Sydney 2000 and continued to qualify for the games in Athens (2004), Beijing (2008) and London (2012). The once amateur game of field hockey has become increasingly popular and has developed into a professional sport undergoing radical changes. Konarski (2010) stated that field hockey is one of the oldest sports games which underwent very dynamic changes during history and especially in the last years (rules, equipment, quality of field). One of the most important changes was the swap from natural to artificial grass. The optimal physical preparation of elite field hockey players, has become an indispensable part of the professional game, especially due to the increased physical demands of match-play, this being observable during, for example, the Olympic Games or European Division (Konarski, 2010).

According to Holmes (2010), coaches at the elite level recognise that the achievement of today's athletes is a result of the integration of several factors. Each may contribute a variable amount to the final outcome. The recognition that an optimal performance is dependent upon the interaction of these complex factors varies greatly both inter- and intra-sport, with the final performance being resultant of factors such as genetics, training, general health, psychology, physiology, biomechanics, skills and the tactics used. Such continuing development of sport has led to an increased emphasis on the provision of scientific support to assist the coaching process. Scientific elements of sport play an important part in the coaching process, as the devising of training programmes, the monitoring of performances,

establishment of techniques, and the preparation of the athletes for competition are all informed by this scientific knowledge. Each sport has its own specific physiological profile and characteristics. It is therefore important that coaches understand the requirements of their sport and adjust the intensity and duration of training accordingly (Holmes, 2010).

According to Reilly and Borrie (1992) some of these changes, however, have increased the incidence rate of injuries. In recent history the introduction of the synthetic playing surface has also increased the pace of the game and has changed its tactical and technical aspects, placing greater physiological demands on the players (Reilly & Borrie, 1992).

This synthetic surface, "Astroturf", allows a more consistent playing surface area providing players with more ball possession, and allowing them to run more with the ball and to execute team skills more easily compared to grass pitches (Hughes, 1988). The ball also travels at a much faster pace. Thus, players are required to adapt to this quicker pace by changing their style of play as well as the team's style of play. All these factors have affected the physiological requirements of the game (Malhotram, Ghosh & Khanna, 1983). Sudden changes of direction and rapid stop-start actions are frequently performed during the course of a game. This places a considerable amount of strain on the lower leg. Although not a true contact sport when compared to boxing and rugby, collisions do occur in hockey and can also give rise to the potential for additional injuries (Verow, 1989).

Furthermore, advances in stick design and construction have also made more precise and powerful manipulation of the ball possible, while increasing hitting power (Reilly & Borrie, 1992). These authors go on to explain that the crooks of the sticks are much tighter and smaller to allow improved ball control. Furthermore, field hockey sticks have changed from the purely wooden sticks, to sticks constructed from man-made materials such as Kevlar and Aluminum. This increases the rigidity of the sticks and allows for greater pace to be imparted to the ball.

The greater degree of the bow in modern-day sticks furthermore contributes to the higher speeds achieved from drag-flick strokes (an important stroke for scoring

goals). In addition the increased bow increases the angle at which the head of the stick strikes through the ball, allowing the ball to be lifted more easily during a normal stroke (Sports Trader, Nov. 2010). All of these factors contribute to the game being played at a faster pace as a result of better ball control, passing accuracy and speed across the turf. This places greater physiological stress on the player and is also accompanied by increased stressors on the musculoskeletal system, and in particular the lower limb joints, as the player is required to move faster and with greater agility to keep up with the pace of play. Ultimately this increases the risk of injury.

Moreover, a recent rule change, where players must touch the ball with their stick in the circle area before netting a goal, also now allows more play in and around the attacking and competitive circle area. Field hockey has therefore developed into a faster game with greater potential risk of injury.

Despite the popularity of this Olympic sport, recent data on injury incidence among female field hockey players are limited. However, particularly the ankle joint has been identified as a frequently injured site of the body among female field hockey players (Petrick, Laubscher & Peters, 1992; Murtaugh, 2001; Dick, Hootman, Agel, Vela, Marshall & Messina, 2007; Naicker, McLean, Esterhuizen & Peter-Futre, 2007). Other common areas of injury among female hockey players are the lower back (Rishiraj, Taunton & Niven, 2009), knees (Petrick *et al.*, 1992; Dick *et al.*, 2007), upper leg muscles (i.e. strains) (Dick *et al.*, 2007) and hands (Murtaugh, 2001; Dick *et al.*, 2007). Some of these injuries could be explained by players running and playing the ball in a stooped body position with their sharp sprints and sideways movements placing considerable strain on the musculoskeletal structures of the lower leg and lower back (Verow, 1989). Oro-facial injuries among female field hockey players have also raised concern and highlighted the need to stress the use of protective equipment (Hendrick, Farrelly & Jagger, 2008; Hendrickson, Hill & Carpenter, 2008).

In terms of playing position, Verow (1989) states that in field hockey, goalkeepers have the greatest potential to be injured by direct trauma from sticks and balls. This is confirmed by Murtaugh (2001) who reported goalkeepers to have the highest rate

of injury (0.58 injuries/athlete-year) among Canadian high school, university and national-level female field hockey players (n=158). Conversely midfielders were the most injured field players (0.36 injuries/athlete-year).

Dick *et al.* (2007) found, from their 15 year-long (1988-2003) surveillance of injuries among collegiate female field hockey players, that different types of injuries occurred during games as compared to practices. Similarly Rishiraj *et al.* (2009) observed, in their five year-long study of seventy-five under-21 aged female field hockey players, that there was also a significantly higher risk of injury during the second half of a game or practice.

These studies clearly indicate the high incidence of injuries in female field hockey and certainly confirm the need to investigate and understand these injuries further. Neither of the above studies, however, investigated the possible aetiology or risk factors which might have precipitated this high incidence of injuries among female field hockey players. According to Merrett (2003) the treatment of sport injuries is often difficult, expensive and time consuming. Therefore, preventative strategies and activities are justified on medical as well as economic grounds. However, risk factors that predispose female field hockey players to injury should be understood before an intervention to reduce the incidence of these injuries is implemented. Predicting injuries not only helps to reduce the risk of these injuries, but in a game that is fast becoming more popular, professional and demanding, it will ensure that professionals consistently perform at their peak. Furthermore, if injuries can be reduced it would reduce health care costs and perhaps create more funds for the development of sport.

This research attempts to find a clearer understanding of injury risk factors particularly as they pertain to the South African national women's field hockey team. This will be done by conducting tests in the pre-season of their hockey calendar to determine if pre-season assessments of morphological and skill-related components can predict injuries sustained in-season.

1.2 Clarifying the problem

It can be concluded from the above that changes in equipment, changes to the rules of the game of hockey and the quick-paced synthetic surface all contribute to the increase in the pace of the modern game of field hockey and therefore an increase in the physical demands of female field hockey players. These factors may explain the high incidence of injuries in female field hockey players.

1.3 Objectives of the study

The objectives of the proposed research are therefore:

- 1.3.1 To profile each national female field hockey player in their pre-season in terms of morphological factors of: age; height; weight; body fat percentage; player position; number of playing years; playing surface; and footwear.
- 1.3.2 To profile each national female field hockey player in their pre-season in terms of skill-related factors of: muscle strength; balance; flexibility; speed; and agility.
- 1.3.3 To conduct an analysis of injuries sustained by the national female field hockey team during the following in-season and to determine the incidence, severity and mechanism of these injuries.
- 1.3.4 To conduct an analysis of injuries sustained during the in-season by the national female field hockey team and to establish the morphological and skill-related factors, measured in the pre-season, that best predict injury.

Hypotheses to be tested:

Null hypothesis: Morphological and skill-related factors assessed in the pre-season cannot predict injury in-season in a population of national female field hockey players.

Hypothesis: Morphological and skill-related factors assessed in the pre-season can predict injury in-season in a population of national female field hockey players.

1.4. Scope of the study

This study was restricted to 30 national female field hockey players that made up the South African women's field hockey squad from 2010 to 2012. The national hockey team is chosen from the nine representative provinces in South Africa. Thus, female players chosen from the provincial hockey teams comprise the elite hockey population in South Africa which represented the total population of this study.

1.5. Significance of the study

The study attempts to identify injury risk factors in female field hockey players which will allow both medical personnel and their athletes to possibly safeguard against these injuries by means of an injury prevention protocol. A decrease in the number of injuries will not only increase the overall team performance but also avoid time and money being spent on the injuries. Players will be more confident in their game and coaches will enjoy having a healthy squad of players to choose from.

2.1 Introduction

Field hockey is a team sport played by both men and women, with major international tournaments including the Champions Trophy (CT), World Cup, Commonwealth and Olympic games. In South Africa, the Interprovincial Hockey Tournament is the highest standard of domestic competition and provides a pathway to international representation. In comparison with other team sports, there have been relatively few attempts to determine the activity profile of high-level field hockey (Lothian & Farrally, 1994; Spencer, Lawrence, Rechichi, Bishop, Dawson & Goodman, 2004; Spencer, Rechichi, Lawrence, Dawson, Bishop & Goodman, 2005; MacLeod, Bussell & Sunderland, 2007; Gabbett, 2010). Understanding the physical demands and the activity profile necessary for success in field hockey players according to their positional role during competitive matches (i.e. distance covered and intensity) is necessary to develop sport-specific training protocols (Mohr, Krstrup & Bangsbo, 2003). Moreover, it may be possible to determine if suboptimal physical characteristics that encompass the unique demands of the game of field hockey, predisposes its athletes to injury.

Field hockey players are exposed to many hours of training and competition every week, and thus are under enormous physical and psychological pressure. Consequently, injury rates are considerably high and vary widely in magnitude as well as duration of impact. For many years, the science of sport injuries was perceived merely through the lenses of physiological and medical research, largely ignoring the (imperative) role of psychological factors (Devantier, 2011). However, throughout the last two decades a substantial body of research has investigated the role of psychological antecedents of sport injuries (Johnson, Ekengren & Andersen, 2005; Stephan, Deroche, Brewer, Caudroit & La Scanff, 2009; Johnson & Ivarsson, 2010). Most findings support the assumption that psychological factors are strongly related to vulnerability to sport injuries. Thus, psychological factors play a substantial role in a comprehensive understanding of sport injuries. However, the researcher in this study will only concentrate on the physiological factors.

2.2 Physical demands of the game of field hockey

Each sport has its own specific physiological profile and characteristics. It is well-documented that the greatest training benefits occur when the training stimulus simulates the movement patterns, biomechanics and physiological demands of the sport. According to Holmes (2010) the demands of a game are partly a result of the structure and rules imposed, as well as the tactical ability and skill of all players involved. In order to identify the demands placed on players when competing at the highest level, it is important that an analysis is conducted of the game itself, since these factors are major constraints on the individual performance. The part that any one individual plays in a game may also be constrained by their fitness. Thus the analysis of one individual may severely underestimate the physical demands of the game (McLean, 1992). To ensure this, analysis of the sport in terms of overall movement patterns, including technical considerations and time on task should be undertaken. Within this, there must also be some recognition of the duration, intensity and frequency of exercise associated with successful performances (Holmes, 2010). It is therefore important that coaches understand the requirements of their sport and adjust the duration and intensity of training to suit for both optimal performances and perhaps injury prevention.

Field hockey is similar to other field-based invasive games. However, field hockey has some unique features such as the use of a stick and moreover, the design of the stick and the rules governing the use of it. Thus, allowing the use of only the flat side of the stick gives the game an inbuilt asymmetry and forces players into un-ergonomic postures whilst dribbling a ball. While field hockey involves co-ordinated multi-joint movements of strength, speed, power and endurance, limited information exists about the movement patterns of field hockey players. The game is played on both grass fields and on watered down artificial turf (Astroturf). Astroturf is currently used more commonly because it is totally flat and faster than grass (Verow, 1989.) The advent of this synthetic playing surface has demanded a change in the technical, tactical and more importantly the physiological requirements of the field hockey player, especially at elite level (Reilly & Borrie, 1992).

Field hockey is a physically demanding sport requiring specific training regimes and programmes to be followed throughout the pre-season and in-season by all those at

the elite level. Players are also expected to attend club, provincial and national training sessions, and to play competition and pre-season games. This workload indicates that overuse injuries could prove to complicate any player's hockey season.

A number of intrinsic and extrinsic factors have been associated with sport injuries, such as posture and body mechanics, age, flexibility, core strength, running speed, endurance, power, muscle imbalances, and even the periodization cycle of the competition (Reilly & Borrie, 1992; Wassmer & Mookerjee, 2002; Ellenbecker & Roetert, 2003; Keogh, Weber & Dalton, 2003; Astorino, Tam, Rietschel, Johnson & Freedman, 2004; Anders & Myers, 2008; Sharm, Tripathi & Koley, 2012). Injury prevention programmes and pre-season conditioning are often based upon the assumption that improvements in these factors will result in a reduction in the incidence of sports injuries.

According to Brukner and Khan (2001) there is no literature to support the concept that performance of a pre-participation physical examination (PPE) predicts who will develop an orthopaedic injury, or prevents or reduces the severity of an orthopaedic injury in a sportsperson. However, despite this, there is research regarding individual components that could be included in a PPE (medical screening, musculoskeletal screening and performance testing) to guide training in an effort to reduce risk of future injury. Brukner and Khan (2001) also concluded that at higher levels of competition, it is important to consider assessing psychological, nutritional and social factors that may affect performance. Overall, the PPE provides considerable information that is relevant, practical, and beneficial for the sportsperson in optimising both sport performance and overall health.

Therefore, an elite field hockey player wanting to participate at the elite level needs to be of minimum physiological, physical and psychological fitness in order to meet the demands of competition and to reduce the risk of injury. The overall goal of pre-participation screening is to identify people with conditions that may predispose them to serious injury and to refer them to appropriate specialists for further evaluation. Pre-participation screening aims to evaluate participants' posture, joint integrity,

flexibility, muscular strength, muscle balance and the analysis of normal movement and technique (Brukner & Khan, 2001).

2.2.1 Anthropometric characteristics of female field hockey players

Successful performance in field hockey is influenced by morphological and anthropometric characteristics such as body size and composition. Anthropometric measurements of height, body mass and body fat percentage, provide a clear appraisal of the structural status of an athlete at any given time and are valuable in describing the characteristics of elite athletes. Increased fat mass is detrimental to performance as excess body fat increases the load that the musculoskeletal system must absorb during movement, thus increasing the potential for injury. In a sport like field hockey that requires speed and explosive power, an increase in body mass will decrease acceleration (Keogh et al., 2003). Heuch, Hagen and Zwart (2010) reported that high values of body mass index may predispose individuals to chronic lower back pain. Although this study did not focus on elite athletes, they also found a significant positive association between body mass index and recurrence of lower back pain among women. Nilstad, Andersen, Bahr, Holme and Steffen (2014) reported that a greater BMI was associated with lower extremity injuries in elite female soccer players when they studied the Norwegian female soccer league (N=12 teams).

According to Marshall and Harber (1996) there is also evidence that elite female field hockey players demonstrate a high level of body dissatisfaction and an elevated drive for thinness. Benell, Malcolm, Wark and Brukner (1997) recommended that female athletes should be monitored for menstrual irregularities, as these have been associated with risk of osteoporosis which in turn has been linked to an increased risk of stress fractures, especially in the lumbar region of the lower back.

In a study by Wassmer and Mookerjee (2002), 37 female field hockey players were tested. They reported a mean height, weight and body fat percentage of 164.26 (+/- 5.17) cm, 63.06 (+/-8.60)kg, 17.29 (+/-3.79)% respectively. In a later study by Astorino *et al.* (2004), the mean height, weight and body fat percentage was 164 (+/- 0.06) cm, 60.70(+/- 5.84)kg and 19.21 (+/-4.45)% respectively when they tested 13 elite female university field hockey players. Keogh *et al.* (2003), however, reported

that female representative field hockey players had a body fat percentage of 24.8(+/- 0.7)%.

Regarding female field hockey players on the national level, two studies were found. Calò, Sanna, Pirasi, Pavani and Vona (2009) found the mean fat percentage of 24 female members of the Italian field hockey national team to be 15.7%. This result was lower than the 16.9% mean body fat percentage reported for members of the USA 1996 Olympic women's field hockey team by Sparling, Snow, Rosskopf, O'Donnell, Freedson and Byrnes (1998). This discrepancy highlights the increase in the physical demands of female field hockey players over the years which could be attributed to the increase in pace of the game due to the now exclusive use of the quick-paced artificial surface, AstroTurf, and the increase in the popularity and professionalism of the game. Both these results, however, are lower than those reported in the studies above, indicating that the level of the game seems to determine and influence the body fat percentage. This confirms the findings of Keogh *et al.* (2003) who reported that female field hockey players playing in a higher standard of the game were leaner and faster, recording much faster times for the 10m and 40 m sprints as well as the Illinois agility run. This could be attributed to the greater physical demand at higher levels and perhaps therefore a more stringent conditioning programme with possibly higher endurance training decreasing the body fat percentage.

Wassmer and Mookerjee (2002) also reported that goalkeepers were significantly ($p < 0.05$) heavier and had a higher body fat percentage. However, no significant differences were found between any of the player positions in height, limb length, 50-yard dash time, predicted VO_{2max} , grip strength, agility, or in the field hockey specific tests. Calò *et al.* (2009) also reported higher body fat percentage for the goalkeepers. The heavier goalkeepers are perhaps exposed to high levels of training and conditioning and proportional increases in force are possibly applied to compensate for and overcome the increase in body mass (Wassmer & Mookerjee, 2002). The results of this study indicate that there are significant differences in anthropometric features and in body composition between positional groups, stressing the importance of a specific training programme.

Each of the literature studies used a slightly different method of calculating body fat percentage. Astorino *et al.* (2004) calculated body fat percentage using the Jackson, Pollock and Ward (1980), four-site skinfold measure. Keogh *et al.* (2003) used a four-site skinfold measure designed by Norton and Olds (1996). Calò *et al.* (2009) used nine skinfold thicknesses and bioelectrical impedance analysis to calculate body fat percentage. It would be easier to compare studies if there was a better standardised test to be administered when designing studies.

Anthropometric profiling of elite female field hockey players is limited. It is therefore difficult to draw an exact conclusion as to what the body fat percentage profile of an elite player should be in current times. There is a need to conduct further profiling of elite female field hockey players. None of the above studies related the anthropometry of field hockey players with injury incidence and its possible influence on these injuries.

2.2.2 Cardiovascular fitness

Past research (Reilly & Borrie, 1992) demonstrates that field hockey requires a substantial amount of muscular endurance, strength, power, and cardiovascular fitness. According to Manna, Khanna and Dhara (2009) the game of field hockey is an intermittent endurance sport involving short sprinting as well as movement with and without a ball. However, it is appropriate to view the game at the elite level as aerobically demanding with frequent though brief anaerobic efforts superimposed. Anaerobic work capacity requires very powerful and efficient muscle contraction for an athlete to be able to cover a distance in a short period of time (Amusa & Toriola, 2003). Sharkey (1986) classified the game as bordering on the aerobic side (40% anaerobic, 60% aerobic) of the energy continuum, stating that the game, with its potential for continuous activity, appears to be aerobically more demanding than previously thought.

While intermittent in nature, field hockey requires players to sustain 70 minutes of high intensity intermittent exercise with just one 5-10 minute half time break. This places a high demand on the aerobic and anaerobic energy delivery pathways (Manna *et al.*, 2009). Energy expenditure during a game has been estimated to

range from 36 to 50kJ/min (Reilly & Borrie, 1992). According to Reilly and Borrie (1992) anaerobic power output has also been shown to be a discriminating factor between elite and county-level players while aerobic power in excess of 60 ml/kg/min is required for elite-level play.

An analysis of the physiological cost and energy expenditure places hockey in the heavy exercise category with reported VO_{2max} (maximum oxygen consumption) values during a game of 2.26 L/min (Reilly & Borrie, 1992) and 9-12 kcal.min; values that are markedly higher than the average VO_{2max} in young women (Astorino *et al.*, 2004).

This level of high-intensity exercise makes this sport quite physically demanding. Whether VO_{2max} is altered during the competitive season and match-play in response to training has yet to be determined. In-season, VO_{2max} was comparable to previously reported values in field hockey athletes. Results from several studies administering treadmill tests to elite women field hockey players demonstrated VO_{2max} values ranging from 42.9–59.3 ml·kg⁻¹·min⁻¹. (Maksaud, Canninstra & Dublinski, 1976; Rate & Pyke, 1978; Cheetham & Williams, 1987; Murtaugh, 2001). Stick skills and the semi-crouched running position with a stick, increases the energy expenditure and may account for these high values.

2.2.3 Strength and power

In field hockey, running is characterized by sharp changes of direction, sprinting, jogging, running backwards and forwards, as well as power-step footwork at various distances and speeds, where the best players are the ones who can move with the most proficiently and most explosively for more than 70 minutes (Anders & Myers, 2008). The frequent, high-intensity bursts of activity with rapid acceleration, deceleration and turning require explosive power output from the legs (Reilly & Borrie, 1992). Explosive movements in hockey also include sprinting, tackling, hitting the ball, jumping, turning, cutting, changing pace, and diving (Khanna, Majumdar, Malik, Vrinda & Mandal, 1996). Lower body muscular strength capacity is very influential in the performance of powerful, speed-related activities (Peterson, Alvar & Rhea, 2006). This was confirmed by Comfort, Stewart, Bloom and Clarkson (2014) who sought to determine the relationships between strength, sprint, and jump

performances in well-trained youth soccer players who performed a predicted maximal squat test, 20-metre sprints, squat jumps and countermovement jumps. Absolute strength showed the strongest correlations with 5-metre sprint times whereas relative strength demonstrated the strongest correlation with 20-metre sprint times. The results of this study illustrate the importance of developing high levels of lower body strength to enhance sprint and jump performance, with the stronger athletes in this study demonstrating superior sprint and jump performances. While this study involved soccer players, Spiteri, Nimphius, Hart, Specos, Sheppard and Newton (2014) studied elite female basketball players and found that change of direction ability was significantly correlated to maximal dynamic, isometric, concentric, and eccentric strength, with eccentric strength identified as the sole predictor of change of direction performance. They suggested that coaches should aim to develop a well-rounded strength base in athletes; ensuring eccentric strength is developed as effectively as the often-emphasised concentric or overall dynamic strength capacity. The game of field hockey encompasses both high levels of sprinting as well as constant changes in direction. It is therefore beneficial for a hockey player to have a high muscular strength, which also diminishes the risk of injury (Reilly & Borrie, 1992; Gorger, Oettl & Tusker, 2001). It has been proposed that strength imbalances or specific muscle weaknesses might be a factor predisposing players to muscle strain (Safran, Seaber & Garrett, 1989). A stronger muscle will absorb more energy than a weak muscle prior to failure, therefore reducing the likelihood of muscle strain. According to Safran *et al.* (1989) strength must also be balanced between antagonistic muscle groups. If quadricep muscles, for example, are over 10% stronger than the hamstrings, there is increased risk of hamstring muscle strain under maximal load.

2.2.4 Speed

High-speed running is an important discriminator between elite and sub-elite team sport athletes (Mohr *et al.*, 2003). Repeated back-to-back sprints make speed an important characteristic in field hockey players (Reilly & Borrie, 1992). The requirement to accelerate and sprint at maximal or near-maximal intensity is an important aspect of hockey. Time-motion analyses of international men's hockey

indicates that field players perform on average 30 sprints per game, with mean sprint duration of approximately 2 seconds (Spencer *et al.*, 2004). However, field players are occasionally required to perform sprints of 30 to 40 metres. Keogh *et al.* (2003) recorded that elite female players ran a 10-metre and 40-metre sprint in a time of 2.01(+/-0.02)s and 6.53(+/-0.09)s respectively, confirming the fast pace of the game.

The level of competition seems to determine the amount of high-speed running and total distance covered by players across all positions with reports of the higher level players having 13.9% and 42.0% more total distance covered and high-speed running respectively (Jennings, Cormack, Coutts & Aughey, 2012). The higher level competition is perhaps not only played at a faster pace and more demanding level, but may offer greater rewards and therefore more motivation for players to perform at their highest ability. Elite field hockey players also need a high level of technical skills such as being able to dribble without losing running speed. For a technically good player, dribbling is essentially an automatic process, and the better players distinguish themselves by their running speed while dribbling the ball (Reilly & Borrie, 1992).

2.2.5 Agility

Field hockey is also multidirectional in nature with complex movements such as dribbling, passing and intercepting often necessitating quick and large changes in speed and direction. The ability to change direction rapidly while maintaining balance without loss of speed, i.e. agility, is therefore an important physical fitness component necessary for successful performance in field hockey.

Agility is described by Sheppard and Young (2006) as "a rapid whole body movement with change of velocity or direction in response to a stimulus" and is a determinant of sport performance in field hockey (Keogh *et al.*, 2003). This ability to change direction while running or staying on the balls of your feet requires quick, reactive, and explosive movements from the quadriceps, gastrocnemius and soleus muscles. Ankle strength is also imperative for stability and proper movement in field hockey during the sudden changes of direction and side-to-side swerving which occurs during tackles and when competing to gain possession of the ball from

members of the opposing team, as these movements place excessive strain on the musculoskeletal structures of the ankle complex (Verow, 1989). It was therefore decided to include isokinetic testing of the ankle in this study.

2.2.6. Core strength

The concept of core strength and stability has been advocated as an important consideration for maintaining dynamic joint stability from the foot to the lumbar spine (Akuthota & Nadler, 2004; Barr, Griggs & Cadby, 2007; Borghuis, Hof & Lemmink, 2008). The core has been defined as the lumbopelvic-hip complex, which is composed of the lumbar vertebrae, pelvis, and hip joints and the active and passive structures that either produce or restrict movements of these segments (Wilson, Dougherty, Ireland & Davis, 2005). The core has also been described as a box with the abdominals in the front, paraspinals and gluteals in the back, the diaphragm as the roof and the pelvic floor and hip girdle musculature as the bottom, all of which serves as a muscular corset that works as a unit to stabilise the body and spine (Brukner & Khan, 2001). Core stability is imperative to control the position and motion of the trunk over the pelvis and leg to allow optimum production, transfer, and control of force (Kibler, Press & Sciascia, 2006) and has been referred to as the “powerhouse” where all movements are generated from the core and translated to the extremities (Brukner & Khan, 2001).

Lower back injuries account for 10% to 15% of all athletic injuries and most frequently involve the soft tissue surrounding the spine (Greene, Cholewicki, Galloway, Nguyen & Radebold, 2001). Poor core stability could be either the cause or the result of low back dysfunction (Ebenbichler, Oddsson, Kollmitzer & Erim, 2001). Muscles are the focus of core stability training programmes, which are believed to enhance performance capabilities and reduce injury risk (Nadler, Malanga, Bartoli, Feinberg, Prybicien & DePrince, 2002). Lower extremity dysfunction increases susceptibility to low back injury (Nadler, Wu, Galski & Feinberg, 1998) and susceptibility to lower extremity injury appears to be increased by low back dysfunction (Hart, Fritz, Kerrigan, Saliba, Gansneder & Ingersoll, 2006).

In field hockey, players are to bend forward to the ground for the maximum groundwork and to cover a wider range all around during the game (Sodhi, 1991). Thus, maximum strain comes over the back muscles as well as abdominal muscles during the entire duration of the game (Sharm *et al.*, 2012). Van Oostrom, Verschuren, de Vet, Boshuizen and Picavet (2012) found an increased incidence of chronic lower back pain in the general public exposed to awkward postures in daily activities. The awkward postures in a high-intensity fast-paced game like field hockey will certainly increase the strain on the lower back of these players. A large amount of strain is also placed on the intervertebral discs when players assume a semi-crouched posture while dribbling the ball (Reilly & Borrie, 1992). Good core stability will assist to stabilise the body centre against dynamic movements of the extremities and absorb repetitive loading forces in the trunk. There is therefore a need for a standard test to be used in calculating core muscle strength; and to test hockey players for core strength to be able to profile them and prevent lower back injuries.

2.2.7 Balance

Anders and Myers (2008) stated that to effectively perform hockey movements, the player must maintain balance. Balance is the body's ability to assume or maintain body position with control and stability making interrelated groups of muscles and joints work in unison. The field hockey player is required to control her own body weight and centre of gravity in the various activities required in field hockey. Regardless of playing position, field hockey players must squat with a low centre of gravity and then move and control that low centre of gravity as with lunging and power footwork required in the field hockey game. According to Anders and Myers (2008) balance is also the foundation for the performance of hockey techniques and superior balance is a trait of the best hockey players who have developed speed co-ordination and power. Balance is achieved through functional training that builds strength in the core stabilising muscles.

Balance/postural sway was investigated by Wang, Chen, Shiang, Jan and Lin (2006) in the pre-season of forty-two players competing in the first league of the High School Basketball Association. Of the eighteen ankle injuries recorded for the 42

players during the follow-up season, a high variation of postural sway in both anteroposterior and mediolateral directions corresponded to occurrences of ankle injury. Both Witchalls, Blanch, Waddington and Adams (2012), as well as Amaral De Noronha, Refshauge, Herbert, Kilbreath and Hertel (2006), from their review of eligible studies, reported that postural sway was also a good predictor of ankle injury. No literature has been found regarding balance in female field hockey players and therefore poor balance has not been established as a predisposing factor to injury in elite female field hockey players.

2.2.8 Flexibility

Flexibility is an essential component that enables field hockey players to maintain balance. Improved flexibility assists the field hockey player because body control is reinforced throughout the range of movement (ROM). Stabilising and balancing the body while moving at the required speed is crucial for executing hockey skills and the body will only allow for the ROM that it can control. Although it is an essential component, very little data exists with regards to the flexibility of elite female field hockey players. Ellenbecker and Roetert (2003) reported an increased incidence of low back pain in female field hockey players, commonly accompanied by decreased trunk range of motion and strength. They suggested that pre-season screening of trunk strength and the lumbosacral ROM should be assessed in the pre-season, and in-season trunk extension stretching and strengthening is needed in the training regimes of these athletes. Both Willems, Witvrouw, Delbaere, Philipaerts, De Bourdeaudhuij and De Clercq (2005), as well as Amaral De Noronha *et al.* (2006) reported that the dorsiflexion range of the ankle joint strongly predicted risk of ankle sprain. Flexibility is therefore an important component in injury prevention.

According to Baechle and Earle (2000), flexibility is defined as the range of motion possible around a body joint and can be classified as either static or dynamic. Static flexibility refers to the degree to which a joint can be passively moved to the end-points in the range of motion. Dynamic flexibility refers to the degree which a joint can be moved as a result of a muscle contraction. The concept that an increased static range of movement results in more pliant mechanical elastic

properties of the muscle suggests that static stretching is beneficial to sports performance. There are optimal ranges of flexibility for different sports and injury risks maybe increased when the athlete is outside this range (Wathan, Baechle & Earle, 2000). Athletes in different sports have varying flexibility profiles and thus varying flexibility is needed in order to avoid injuries and optimise sports performance (Gleim & McHugh, 1997). This study attempts to provide a clearer understanding of flexibility in female field hockey players.

2.2.9 Time-motion analyses in field hockey

The demands of competition have been primarily reported with the use of time-motion analysis and, more recently, global positioning systems. According to Deutsch, Maw, Jenkins and Reaburn (1998) time-motion analysis provides an objective, non-invasive method for quantifying work rate, and provides information that can be used in the design of physical conditioning programmes and testing protocols (Deutsch *et al.*, 1998). However, according to McKenzie, Holmyard and Docherty (1989) time-motion analysis is a time-consuming process inherently prone to measurement error. This is due to the fact that observations are influenced by an observer's knowledge, focus of attention, perceived importance of competition, state of arousal and preparing for anticipated events. Hopkins (2000) stated in this regard that although researchers using time-motion analysis have reported the reliability of their methods, none have reported the Typical Error of Measurement (TEM) which is a requirement in other physiological tests.

Lames and McGarry (2007) reported that the reliability of measurements or assessments made during time-motion analysis research is considered as vital. According to these researchers, the results must be considered with caution if the reliability of the testing method was not established, either within previous literature or in the study. Due to the similarities between some movement patterns during match-play, e.g. running and jogging, it is understandable that in the majority of video-based time-motion analysis studies, some form of subjective judgment

regarding the categorisation of each individual movement is applied (Tenga & Larsen, 2003). Lames and McGarry (2007) emphasise that the decision of accurately coding each movement is solely placed on the interpretation of the observers or analysers.

Time-motion analysis has been implemented for over 30 years, with research published for many different sports (Reilly & Thomas, 1976; Hughes & Knight, 1995; Deutsch, Kearney & Rehrer, 2002; Cabello & Gonzalez-Badillo, 2003; Roberts, Trewartha, Higgitt, El-Abd & Stokes, 2008; Vaz, Van Rooyen & Sampaio, 2010; Hughes, Hughes, Williams, James, Vučković & Locke, 2012; Quarrie, Hopkins, Anthony & Gill, 2012). Many of the aims of this research have been to increase the knowledge and understanding of the physiological demands of the specific sport to assist with the development of training regimes (McLean, 1992). In this regard, Roberts *et al.* (2008) stated that in addition to using time-motion data to improve training specificity, there is also a need to accurately quantify match demands for the purposes of designing more specific exercise protocols that allow the investigation of issues specific to the sport. Time-motion analysis involves video recording match-play that is analysed at a later stage by the researcher with the use of computer program software that can track several different movement categories (Roberts *et al.*, 2008).

Roberts *et al.* (2008) concluded that for the analysis of complex movement patterns, video recording is optimal, as it can be slowed down or repeated as needed. Players are normally filmed throughout an entire game, providing a continuous recording of the frequencies, means and total durations of each activity. This allows for work rate and percentage game calculations.

Female hockey has been analysed and described by many since the inception of time-motion analysis (Lothian & Farrally, 1994; Robinson, Murphy & O'Donoghue, 2001; Boddington, Lambert, St Clair Gibson & Noakes, 2002; Gabbett, 2010; Macutkiewicz & Sunderland, 2011). However, it is important to note, there have been some significant rule changes within the sport that make the findings of these studies inappropriate to hockey today (Holmes, 2010).

However, time-motion analysis provides valuable information regarding the activity profiles of players within team sports. Manual video-based, time-motion analyses demonstrated that international male field hockey players spend most of the match exercising at lower speeds (standing, walking, jogging) with a small proportion of the time (5.6%) at higher speeds (striding and sprinting), and an occasional bout of repeated sprint exercise (Spencer *et al.*, 2004).

Similar observations were made when match-play activity patterns of twenty-five elite female field hockey players were analysed by Macutkiewicz and Sunderland (2011) over thirteen international matches using global positioning systems (GPS). They reported that 55.5 \pm 6.3% of match time was spent performing low-intensity exercise (standing and walking), while 38.1 \pm 5.0% accounted for moderate intensity exercise (jogging and running) and the remainder of the time made up high-intensity exercise (fast running and sprinting). Lythe and Kilding (2011) used GPS units to quantify the physical outputs of 18 elite male field hockey players over five matches. They recorded a mean total distance covered by each individual player of 6798 \pm 2.009km, with a mean total distance covered per position for 70 minutes at 8160 \pm 0.428km. High-intensity running (>19 km.h⁻¹) accounted for 6.1% (479 \pm 108m) of the total distance covered and involved 34 \pm 12 sprints per player. Average heart rate in this study was higher in the first half (86.7%) than the second half (84.4%); a finding that was attributed to fatigue, confirming the physical demands of the sport. Gabbett (2010) reported similar results from a GPS analysis of 14 elite female field hockey players with the players covering an average of 6.6 km over the course of a match but added that midfielders covered greater distances in high-intensity running than strikers and defenders. It can be concluded from these studies that the pace of the game for men and women is very similar.

2.3 Periodization in field hockey

The unique demands of the sport mean that strength endurance is just as crucial as explosive power. Careful planning is required to ensure that both muscular power and muscular endurance can be effectively developed alongside each other without leading to over-training and fatigue. To achieve the best possible performance, the training has to be formulated according to the principles of periodization (Bompa,

1999). Periodization has been defined as the methodical planning and structuring of the training process that involves a logical and systematic sequencing of multiple training variables (intensity, volume, frequency, recovery period and exercises) in an integrative fashion aimed to optimise specific performance outcomes at predetermined time points (Naclerio, Moody & Chapman, 2013).

The traditional periodization model partitions the overall programme into specific time periods. The largest division is a macro-cycle, which typically constitutes an entire training year divided into preparatory (general and specific), competitive and transition phases (Bompa & Haff, 2009). It may also be a period of many months up to 4 years (e.g. for Olympic athletes). Depending upon the length of the macro-cycle, type of sport and the athlete's level of performance, the preparatory phase can last for more than 2 until 6 months. Even if this phase is usually broken down into a general and specific preparation, both general and specific sub-phases should always be considered an interconnected unit (Siff, 2004). The general preparatory phase is aimed to provide fundamental physical and technical conditioning (basic strength, endurance, flexibility, aerobic or anaerobic endurance and basic motor skills) in order to support the further development of the specific capacities and motor sport skills (Verchoshansky, 1996; Siff, 2004). It is also the phase in which testing will be done, to establish a platform of the individual and overall team fitness levels so that an appropriate training regime can be formulated and injury incidence can be related to these findings. The field hockey pre-season is approximately six weeks before competition and includes the late stages of the preparatory phase and first transition period.

Within the macro-cycle there are 2 or more meso-cycles, each lasting several weeks to several months. The number depends on the goals of the athlete or team and, if applicable, the number of sports competitions contained within this period. A meso-cycle is a training cycle of medium duration that typically contains more than two to six interrelated micro-cycles. Every micro-cycle within each particular meso-cycle should have its own specific objectives, which have to be consistently integrated with the general purpose of the entire meso-cycle and phase. Therefore, the meso-cycle

involves a specific and fundamental period of time over which the training objectives should be subsequently established across the season (Verchoshansky, 1996).

The in-season contains all the competitions scheduled for the year which in field hockey usually spans from April to October. Most sports have multiple micro-cycles arranged around the most important competitions. The micro-cycle focuses on daily and weekly training. This structure targets very specific training objectives that serve as a basis for achieving the goals set forth in the meso-cycle structure (Haff, 2013). It is generally accepted that a micro-cycle can range from a few days to 14 days in length (McHugh & Tetro, 2003), with the most common length being 7 days (Turner, 2011).

Strength and power, together with endurance, are important in terms of basic physiological capacities in many athletes (Siff, 2004) and has been established from the literature above to be an important characteristic of field hockey. This periodisation model also lends itself to the establishment of training and performance objectives and the emphasis of training and test standards for each determined period of training, thereby eliminating the random approach that may lead to excessive increases of training loads, and insufficient regeneration (Smith, 2003). Thus, determining strength and weaknesses early on in the field hockey season will allow the development of explosive strength to be based on the maximal strength performances achieved from the athletes and can be progressed in a more unidirectional elevation of performance to a higher and more stable work capacity (Siff, 2004). In soccer and other team sports including field hockey, a minimum level of maximal strength is usually connected with an improvement of power, sprint and specific skills performance (Hoff, 2006) in addition to lower injury rates (Reilly, Drust & Clarke, 2008). Thus, by increasing the available force at the end of preparatory period, team athletes would be better prepared for supporting specific performance enhancement and reduce injury rate during competition. Considering meso-cycles as a key period where measurable effects can be assessed, it is only after gaining a greater understanding of how an individual athlete adapts and responds to the applied training stimulus (load/volume/intensity/frequency/duration) that a realistic objective for the next phase can be set and that the most appropriate training method for the following meso-cycles or phases can be designed (Verchoshansky,

1996). Therefore, the success of the training process as a whole will depend on a full understanding of the objectives and the most appropriate individualised training methodology to get the intended results for each specific phase.

A comprehensive monitoring of athletes is necessary along the entire training process. This approach will allow a coach or medical personnel to make informed decisions regarding the effects and consequent planning of subsequent training programmes. The attainment of consistent high performance as in the case of elite female field hockey players requires effective training that is carefully designed and monitored and is accompanied by planned recovery. The training-induced changes observed in various parameters can be attributed to appropriate load dynamics, and correct training will help to minimise injury risk.

In a study by Astorino *et al.* (2004) the changes of various physical parameters during a hockey season were studied. They found that $\dot{V}O_2$ and $\dot{V}CO_2$ increased from pre-season to post-season. They also noted that muscular strength (both one repetition maximum [RM] leg press and bench press) decreased as the competitive season progressed. Stagno, Thatcher and van Someren (2005) confirmed that $\dot{V}O_{2max}$ increases from pre-season to in-season. It is therefore very important to develop a well-periodised training program, to ensure that the players are maintaining their peak physical parameters with intensity training and adequate recovery. A loss of muscular strength and cardiovascular fitness may subject athletes to greater risk of injury (Astorino *et al.*, 2004).

This study will assess evidence-based physical parameters appropriate to the physical demands of field hockey in the pre-season and monitor the athletes throughout the in-season, to determine possible predisposing factors to injury.

2.4. Incidence of injuries in field hockey players

2.4.1 Incidence of injuries in female field hockey players

Bahr and Holme (2003) argue that despite the benefits of regular physical activity, each sporting activity has an inherent risk of injury. In some instances this can lead to permanent damage. However, coaches, strength and conditioning coaches/athletic trainers throughout the world are increasingly pushing the limits of

human adaptation and training loads with the aim of achieving top performances. Despite the benefits of these scientific conditioning programmes, each sporting code has an inherent risk of injury (Smith, Damodaran, Swaminathan, Campbell & Barsley, 2005). The demands placed on athletes are physically and mentally challenging, and injuries occur when the physical load breaches a threshold (Van Tiggelen, Wlickes, Stevens, Roosen & Witvrou, 2008). It is therefore important to understand the frequency and nature of sports injuries to assist in the development of effective injury prevention strategies. The role of any strength and conditioning/athletic development coach is not only to get the athlete fit and ready to take the field of play, but also to prevent injuries. Proactive prevention of injuries is often neglected. Therefore, governing bodies should be aware of the epidemiological evidence of injury risk in sport and that effective preventative measures are available (Fuller & Drawer, 2004).

According to Järvinen, Järvinen, Kääriäinen and Kalimo (2005), muscle injuries are one of the most common injuries affecting athletes. Furthermore, it accounts for up to 28% of injuries in sports events (Woods, Hawkins & Maltby, 2004). Contusion and strain are two common causes of muscle injuries. Earlier studies (Orchard, 2001; Warren, Gabbe, Schneider-Kolsky & Bennell, 2010) have identified several factors that predispose one to muscle injury, including a history of muscle strain, increasing age and leg dominance.

Very little recent data are available regarding the incidence of injuries in female field hockey players. In a four-year study (1976 to 1979), Rose (1981) reported ankle sprains to be the most common injury of the 81 minor injuries reported in female hockey players at the California State University. A second-degree ankle sprain was also the most common injury in the 16% of the injuries that were considered to be serious injuries and caused a two- to three-week disability. These authors also reported fewer injuries with an increase in team performance and attributed this to players who had a mental desire to do well and therefore more enthusiastic training and condition programmes. Petrick, Laubscher and Peters (1992; 1993) also found that overuse injuries of the ankle, knee and lower leg were the most commonly reported by a sample of 157 female high school first team players of the Southern Transvaal and Griqualand West (18%) during the 1990 hockey season (mean age of

16 ± 1.06). Seventy-five of the 157 players (47.8%) reported incurring an injury during the 1990 season (0.48 injuries/player/year). The most common injury occurring during their career was an ankle injury which was reported in 27% of the sample, while the most frequent injuries reported during the 1990 season were lower leg overuse injuries (27.4%), as well as knee (12.7%) and ankle (10.8%) injuries. They found that more ankle injuries occurred amongst the Griqualand West players (33.3% vs. 17.9%) and attributed this to the harder, drier playing surfaces in Griqualand West and the greater length of time these school girls spent playing on the less resilient surfaces. Griqualand West players also did not wear any hockey boots which give a greater grip on the surface, allowing for the quick change of direction and acceleration needed for the game of hockey and placing less strain on the ankle.

Eggers-Stroder and Hermann (1994) studied elite male and female collegiate field hockey players in the United States and found that injuries were also determined by the playing surface, with Astroturf being especially dangerous. They also found that injury risk during matches exceeded the risk during practice by 10.4%. Injury related to the lower limb accounted for 62% of injuries reported, although these were not detailed. Injury patterns among female field hockey players were examined by Murtaugh (2001) in Canada among 158 high school, university and national-level female field hockey players. Forty-nine percent (49%) of these players reported that they regularly trained and played on artificial turf, 21% participated on grass and 30% indicated that they used both surfaces equally. At least one acute injury that had occurred during a practice or match was reported by 74.7% of the players. The most frequently injured site of the body was the lower limb (51%), followed by the head/face (34%), upper limb (14%) and torso (1%). The most common injury was a ligament sprain (39.7% of total injuries), with ankle sprains being the most prevalent, followed by hand fractures as well as head and face injuries. Goalkeepers had the highest rate of injury (0.58 injuries/athlete/year), followed by midfielders (0.36 injuries/athlete/year). Ankle sprains were common in both groups. Forwards and backfield players had similar rates of injuries (0.37 and 0.36 injuries/athlete/year respectively). The high number of head and face injuries was also seen as an area of concern and the author recommended further examination of the injuries she had identified.

According to Murtaugh (2001) the most prevalent injuries in field hockey are ankle sprains, hand fractures, and head or face injuries. Murtaugh (2001) also revealed that, not only is there a difference in the rate of injury between the playing positions, but also in the types of injuries sustained at different positions. Research suggests that goalkeepers are at highest risk for injury in field hockey, followed by midfield players, especially to the head/face and upper limbs (Murtaugh, 2001). Murtaugh (2001) and Merrett (2003) also mentioned that more than 45-50% of hockey players experienced back pain predominantly in the lumbar region.

Dick *et al.* (2007) reported, from their 15 year surveillance of collegiate women's field hockey injuries (1988-2003), that ankle ligament sprains were common (13.7% of game and 15.0% of practice injuries) and a frequent cause of severe injuries (resulting in 10+ days of time-loss activity). They also reported that the risk of sustaining a concussion in a game was 6 times higher than the risk of sustaining one during practice. Overall, injury rates in this study were twice as high in games as in practices, while most head/neck/face (71%) and hand/finger/thumb (68%) injuries occurred when the player was near the goal or within the 25-yard line and were caused by contact with the stick or ball.

Rishiraj *et al.* (2009) observed that there was a significantly higher risk of injury during the second half of a game or practice in their five-year study of seventy-five under-21 female field hockey players. The combined injury rate in this study was 70 injuries per 1 000 player game and practice exposures, with defenders experiencing the highest percentage and having a higher risk of injuries. The lower back and ankle/foot were the most vulnerable to injury, followed by the knee. It is interesting to note that although a high incidence of lower back injuries has been associated with field hockey (Murtaugh, 2001; Merrett, 2003; Rishiraj *et al.*, 2009), Bakker, Verhagenvan Trijffel, Lucas and Koes (2009) found no studies, thus no evidence, indicating an association between sleeping or sporting on a professional level and lower back pain. Perhaps there is indeed a lack of cohort studies involving lower back pain and professional sportsmen.

Tully (2003), a hockey player himself, discussed the new field hockey rule that was introduced by the international Hockey Federation on 1 January 2003. The rule applies to the penalty corner shot that states that it is no longer necessary for attackers to stop the ball before taking a shot at goal. Of the three games that the author played under the new rule, there were several players that required hospital attention because of knee and ankle injuries as a result of defending a shot before stopping it. The decreased time now required to take a shot, leaves defenders with little reaction time to avoid being struck by an incorrectly hit ball, which may be lifted off the ground.

In an earlier study (Naicker *et al.*, 2007) the incidence of ankle injuries was investigated in forty-seven provincial senior, under-21 and high school female field hockey teams. While the incidence of injury for the season in this study was 0.98 per player, 25.5% of players (n=12) reported sustaining injuries to the ankle joint. All ankle injuries occurred on artificial turf and 75% occurred during a match. Forwards and midfielders that had been playing for six to seven years presented with the highest incidence of ankle injuries. Injured players were able to maintain balance on a proprioceptive board for 10.31seconds compared to the 23.9 seconds in matched, uninjured controls (p=0.078). Peak isokinetic torque of the dorsiflexors of injured legs was significantly lower than in uninjured, contra-lateral legs of the injured players (p=0.01). Although the testing in this study was done retrospectively, it was concluded that poor peak dorsiflexion torque was a factor associated with ankle injury in this sample of injured, elite female field hockey players. The high incidence of ankle injuries in all of the above studies warrants further investigation of ankle injuries in female field hockey players.

There have, however, been other studies that have focused on ankle injuries. Milgrom, Schlamkovitch and Finestone (1991), investigating 390 military recruits, found that recruits who were taller and heavier had a higher lateral ankle sprain incidence in training. Tyler, McHugh, Mirabella, Mullaney and Nicholas (2006) investigated ankle sprains in 152 athletes from 4 high school football teams over 3 seasons and recorded an ankle injury incidence of 0.52 injuries/player/season for players with a normal body mass index, 1.05 for players at risk of being overweight

and 2.03 for overweight players. McHugh, Tyler, Tetro, Mullaney and Nicholas (2006) supported this finding when a higher body mass index in male athletes (basketball and soccer) was associated with increased risk of ankle sprains. Fousekis, Tsepis and Vagenas (2012) in their study of 100 professional soccer players, also reported that an increased body mass index and body weight raise the propensity for ankle sprains.

In terms of muscle strength and ankle injury, functional strength asymmetries of the ankle flexors has been identified as an ankle injury risk factor (Fousekis *et al.*, 2012), while Witchallis *et al.* (2012) reported that higher concentric plantar flexion strength at faster speeds and lower eccentric eversion strength at slower speeds also increased the risk of ankle injury.

Beynnon, Renstrom, Alosa, Baumhauer and Vacek (2001) proposed that when an athlete is in an at-risk position for inversion ankle trauma, an increase in either height or weight proportionally increases the magnitude of the inversion torque that must be resisted by the ligaments and muscles that span the ankle complex. When these researchers investigated their 118 collegiate athletes, they found that height and weight were not independent risk factors for ankle sprains. Sitler, Ryan, Wheeler, McBride, Acrceiro, Anderson and Horodyski (1994) reported similar findings. In contrast, Watson (1999) investigated male football players over a four-year period and found that those players who sustained ankle sprains had greater height but a lower body mass index than those who did not. These diverse findings suggest that although an increase in weight or height increases the load placed on the ankle, the activity (speed and nature of the movement) and mechanism of injury involved also contributes to the incidence of ankle injury.

Although field hockey is classified as a non-contact sport, acute injuries may result from contact with a stick, the ball, another player or the playing surface or goal cage. Some common injuries in women's field hockey include hand and wrist injuries as they are extremely vulnerable to injury from contact with the ball or an opponent's stick. Hand fractures, especially in the fingers, are common injuries. Accidental contact with a ball or an opponent's stick may result in injury to the face. While the majority of these injuries are minor cuts and bruises, more severe injuries

such as facial fractures, penetrating eye injuries, and broken teeth have been reported.

Ankle sprains are the most frequent injury in sports. Inversion-type ankle sprains have been estimated to comprise roughly 15% of all injuries sustained during field hockey participation. Knee injuries and muscle strains, particularly of the quadriceps and hamstrings, also occur. While acute injuries are often more dramatic in nature, chronic injuries such as low back pain, tendonitis of the hip, knee or ankle, and stress fractures of the leg and foot typically result from repetitive activity and overuse.

The incidence of dental-facial traumas among international field hockey players is high (Bolhuis, Leurs & Flögel, 1987). This study surveyed the facial injuries over three important international tournaments for men (n=162) and women (n=117) and found 54% had sustained injuries necessitating a visit to a physician and/or a dentist. Of these victims, 20% sustained serious dental damage at least once (women 16% and men 22%). Only 20% of the international players wear a mouth protector consistently during training and matches while women use the apparatus almost twice as much as men. In a more recent study of 140 elite English female field hockey players, oro-facial injuries were still commonly reported with 19% having sustained dental injury and five percent (5%) of the respondents had at least one tooth avulsed (Hendrick *et al.*, 2008). Eighty-eight percent (88%) of the players in this study possessed a mouthguard worn regularly during matches by 69% of players but used less frequently during training. It has, however, become popular now to wear protective eyewear which is said to lower the incidence of head and facial injuries (Kriz, Comstock, Zurakowski, Almquist, Collins & d'Hemecourt, 2012). Perhaps with such protective measures and good awareness and education, facial injuries can be decreased.

There is significant and consistent evidence in the literature to support the use of injury-prevention strategies in adolescents. These include pre-season conditioning, functional training and education, as well as strength and balance programmes that are continued throughout the playing season (Abernethy & Bleakley, 2007). It is therefore important to identify the causes and nature of sports injuries in field hockey

and to introduce a proactive injury prevention programme in South African field hockey accordingly.

2.4.2 Other possible influencing factors of injuries in field hockey

2.4.2.1 Gender and age

2.4.2.1.1 Gender

The first study to compare the incidence and patterns of injury by gender was that of Lindgren and Maguire (1985). They reviewed the injuries of a small group of elite Australian Institute of Sport hockey players over a 12-month period (16 males and 12 females). Male players sustained an average of 3.1 injuries per player compared to 5.0 injuries per female player. The authors concluded that female hockey players had a higher rate of injury than their male counterparts. This finding is not consistent with later research which shows a higher frequency of injury for males compared to females (Egger-Stroder & Hermann, 1994).

It has been suggested that women may be predisposed to a greater incidence of lower limb joint injuries than men because of anatomical differences (Egger, 1990). When compared to men, women have a greater angle at the knee, a higher rate of ankle pronation, and greater joint mobility (Beck & Wildermuth, 1985). The relationship between anatomical differences and the patterns of injury in male and female hockey players requires further investigation.

2.4.2.1.2 Age

Le Gall, Carling, Reilly, Vandewalle, Church and Rochcongar (2006) investigated age-related injury incidence in elite youth soccer over a 10-season period and found no significant difference in injury frequency between age groups. They found, however, that the youngest group sustained more training injuries and fewer match injuries than did the oldest group. This was attributed to more growth-related disorders in the youngest group as these injuries in training sessions are perhaps more overuse injuries (to which they are more susceptible) than acute injuries that

can occur during a match. Ostenberg and Roos (2000) investigated 123 senior female football players in the European league and found that athletes over the age of 25 were at a higher risk of injury. Arnason, Sigurdsson, Gudmundsson, Holme, Engebretsen and Bahr (2004) supported this when they found that older players were generally at a higher risk of injury. This could be attributed to the fact that tendons degenerate with age (Lycholat, 2006), so an acute rupture or injury is more likely in the older athlete.

The increased participation of women in sport has resulted in an interest in gender-related injury patterns. Beynnon *et al.* (2001), in their study of collegiate athletes, found the number of ankle injuries per 1000 person-days of exposure to sport was 1.6 for men and 2.2 for women. There were 13 injuries among 68 women (19%) and seven injuries among 50 men (13%), but these rates were not significantly different. Hosea, Carey and Harrer (2000) performed a study comparing male and female basketball players at interscholastic and intercollegiate level over a two-year period and found that female athletes were at 25% increased risk of suffering a grade I ankle sprain compared with male athletes. However, the relative risk between the sexes for more serious injuries was not significant. Beynnon, Vacek, Murphy, Alosa and Paller (2005) reported 0.68 and 0.97 ankle sprains per 1000 days of exposure to sport for men and women respectively. They also reported that among female athletes, the ankle injury is associated with the type of sport. The risk was highest in female basketball athletes who were at significantly greater risk than male basketball athletes and female lacrosse athletes. Female athletes are also at a higher risk of knee injury than their male counterparts in jumping and cutting sports (Dugan, 2005).

2.4.2.2 Years of playing

Regular training over a prolonged period has been shown to increase the tensile strength of ligaments (Tipton, Matthes, Maynard & Carey, 1975). Amiel, Akeson, Harwood and Frank (1983) attribute the increase in tensile ligament strength, following regular exercise, to an increase in collagen deposition or an increase in the synthesis of new fibres during exercise. It seems, therefore, that athletes participating in sport for longer may develop a protective effect that may reduce their

risk of injury. Experienced players also have the advantage of having the knowledge of different high-risk situations during play and techniques known to prevent injuries, which may reduce the injury incidence in players that have been playing for a number of years (Upton, Roux & Noakes, 1996).

Murtaugh (2001), in Canada, among 158 high school, university and national-level female field hockey players, showed that the injured athletes had an average age of 20.4 (\pm 3.2) and 7.4 (\pm 3.3) years of playing experience while, interestingly, the uninjured players were younger with an average age of 18.0 (\pm 2.6) and 5.4 (\pm 3.5) years of experience.

2.4.2.3 Level of play

According to Jennings *et al.* (2012) the level of competition can determine the amount of high-speed running and total distance covered by players across all positions with the higher level players having 13.9% more total distance covered and 42.0% more high-speed running. It seems that the higher level competition is perhaps not only played at a faster pace and is more demanding, but may offer greater rewards and therefore more motivation to perform at their highest ability.

A concomitant increase in incidence of injury with increasing level of play has been reported by both Nathan, Goedeke and Noakes (1983) as well as Hosea *et al.* (2000). Nathan *et al.* (1983) in a study conducted on schoolboy rugby players, found that the highest level of play had the highest risk of injury. These researchers reported that the level of play influenced the incidence of injury, with the highest in the A teams at all ages (20% of all injuries) and lowest in the D teams (3% of injuries). They suggested that the highest level of play perhaps demands more from the athlete in terms of performance and in the case of adults is career dependent for most and therefore involves a greater intensity of training. In 2000, these findings were confirmed by Hosea *et al.* (2000) who reported that male and female athletes doubled their risk for sustaining an ankle injury at the intercollegiate level compared with the interscholastic level.

In a recent study, Shariff, Ashril and Razif (2013) also reported that the most injuries (90.0%) occurred among national-level athletes participating in various sports – track

and field (30.3%), field hockey (17.8%), racket sports (11.4%), martial arts (6.7%), soccer (5.3%), weightlifting (5.0%), gymnastics (4.7%), swimming (4.2%) and others (14.4%). It is interesting to note that field hockey comprised the second highest incidence of injuries.

2.4.2.4 Stage of hockey season

In terms of the stage of the season, Nathan *et al.* (1983) reported that the injuries with the greatest incidence occurred during the beginning of the season and were attributed to the period when players are likely to be under-prepared for match-play. They suggested that more attention be paid to improving the players' match fitness at start of season and maintaining this fitness during the off-season. Upton *et al.* (1996) also emphasised the importance of pre-season endurance and strength training when they found that fewer than 40% of the 2330 South African schoolboy rugby players surveyed in this study trained adequately in the pre-season. On the other extreme, Lee, Garraway and Arneil (2001) cautioned against over training during the pre-season when they found a relative increase in injury risk for each additional week of pre-season training.

The latter stages of the season, however, seem to produce a higher incidence of injury and particularly in the second half of matches (Ostenberg & Roos, 2000; Rishiraj *et al.*, 2009; Gabbett, 2010). This could be the result of fatigue at the end of a season and the increased effort given towards the end of matches and the season to win leagues and tournaments.

2.4.2.5 Duration and intensity of match-play and training

In terms of exposure to sport or the intensity of competition compared with that of training/practice and its relation to ankle injury, Arnason, Gudmundsson, Dahl and Johannsson (1996) reported 4.4 ankle sprains per 1000 hours of participation in soccer games of the two highest divisions in Iceland and only 0.1 sprains per 1000 hours of practice. Willems *et al.* (2005), however, found only 0.75 ankle sprains per 1000 hours of sports exposure when they followed 159 physical education students from the beginning of their academic year. Furthermore, Tyler *et al.* (2006) found 1.08 ankle sprains in high school football players per 1000 hours of sport exposure.

This difference could be related to the fact that this exposure was not as competitive and as high a level of sport as in previous studies. Ekstrand, Gillquist, Moller, Oberg and Liljedahl (1983) observed 12 soccer teams over one year and reported that twice as many injuries occurred in soccer games as in practice sessions. For the individual player, the incidence of injury was 7.6/1000 practice hours and 16.9/1000 game hours. Ostenberg and Roos (2000) reported similar findings of a total injury score of 14.3 per 1000 game hours and 3.7 per 1000 practice hours in female soccer players in the European league. They also stated that the risk of sustaining moderate and major injuries increased in the later part of the game or practice. This could be related to the increase in effort and exertion that usually occurs to win a match. Nathan *et al.* (1983) supported these findings and reported 79 injuries, 29 of which occurred during practice and 50 during matches when they studied the incidence and nature of rugby injuries at one school during the 1982 rugby season. Le Gall *et al.* (2006) documented an overall injury rate of 69.1% in training and 30.9% in matches in soccer players over a 10-season period. However, when divided into hours, a total of 4.8 injuries per 1000 hours of total exposure time were recorded as well as 11.2 and 3.9 injuries per 1000 hours for matches and training were documented respectively.

2.4.2.6 Playing surface

According to Pasanen, Parkkari, Rossi and Kannus (2008), the playing surface is an extrinsic factor that can play a major role in injury rates. The hardness and the surface-to-shoe interface resistance seem to be two factors that need to be considered in sports injuries. An increase in resistance of the interface seems to be a risk factor for traumatic injuries in sports that require rotational movements (Pasanen *et al.*, 2008). It is the opinion of Murphy, Connolly, and Beynnon (2003) that the hardness of the surface can influence the ground reaction forces and can contribute to overloading of tissues, for example bone, ligaments, muscle and tendons. Brukner & Khan (2001) also concluded in this regard that studies on the incidence of injuries on different playing surfaces have shown that harder play surfaces are associated with overuse injuries (Brukner & Khan, 2001), while playing surfaces with higher friction have an increased risk for Anterior Cruciate Ligament (ACL) injuries (Olsen, Myklebust, Engebretsen, Holme & Bahr, 2003; Orchard, Chivers, Aldous, Bennell & Seward, 2005).

Arnason *et al.* (1996) found a twofold increase in the incidence of injuries on artificial turf compared with grass or gravel in elite male soccer athletes. Dragoo, Braun & Harris (2013) also reported that the rate of ACL injury on artificial surfaces is 1.39 times higher than the injury rate on grass surfaces in National Football League (NFL) players and that non-contact ACL injuries occurred more frequently on artificial turf surfaces. Previous researchers hypothesised that more injuries may occur on artificial turf compared to other surfaces because of its stiffness and the increased frictional force at the shoe/surface interface (Inklaar, 1994). The effect of the playing surface on injury rates in netball was also assessed by Langeveld, Coetzee and Holtzhausen (2012). Langeveld *et al.* (2012) reported that even though the majority of games were not played on cement surfaces, 500 injuries per 1000 playing hours occurred on cement surfaces, while only 260 injuries per 1000 playing hours occurred on synthetic surfaces. This represents a 1.9 times higher injury rate on cement surfaces than on synthetic surfaces. The results also indicate that 148 knee injuries per 1000 playing hours (80%) occurred on the cement surface compared to only 26 knee injuries per 1000 playing hours (20%) on the synthetic surface. Furthermore, the majority (88.9%) of serious injuries resulting in players being out of action for more than seven days, occurred on the cement surface (Langeveld *et al.*, 2012).

One of the first studies investigated injury among 'elite' Australian female hockey players playing on different surfaces, Jamison and Lee (1989) compared the incidence of injury in two successive national championships, the first played on a grass surface and the second on Astroturf. During the tournament played on grass, 110 players reported 86 injuries (0.78 injuries per player), while 95 players on Astroturf reported 92 injuries (0.97 injuries per player). Jamison and Lee (1989) concluded that injury rates on Astroturf were significantly higher than those on grass ($p < 0.0001$), but the types of injuries were similar. It is clear that playing on a synthetic surface has also created a greater risk of injury in hockey. The players run faster on these surfaces due to the evenness of the surface and are exposed to greater rotational torque which places greater strain on the supporting structures of the ankle joint. Grass surfaces, on the other hand, have been reported to absorb approximately 10% more energy, contributing to a greater cushioning effect on

impact with the ground (Reilly & Borrie, 1992) making the speed of play on grass slower and the external torque on the lower limb less.

Orchard *et al.* (2005) stated in this regard that potential mechanisms for differing injury patterns on different surfaces include increased peak torque properties and rotational stiffness properties of shoe-surface interfaces, differing foot loading patterns, decreased impact attenuation properties and detrimental physiological responses compared with natural turf.

A comparison of performances in international women's matches between synthetic and grass surfaces revealed greater possession of the ball on the synthetic surface, suggesting that team skills are more easily executed on synthetic surfaces than natural pitches and that tactics adopted on synthetic turf differ from tactics on grass (Reilly & Borrie, 1992). Verow (1989) reported an increase in the number of ankle inversion injuries with the more widespread use of synthetic pitches. He attributed the increase of ankle injuries to the use of studded shoes on a synthetic surface. This increases the risk of ankle injury as shoes with studs create greater frictional resistance between the foot and the ground surface, and during turning motion the axis of rotation (i.e. pivot point) is transferred from the ground/shoe interface to the ankle joint.

In a study conducted on the NFL during the 1980 to 1989 seasons, Powell and Shootman (1992) investigated the injury rates for natural grass and synthetic surfaces and the risk factors of game position and type of play in football players. These authors showed that there were statistically significant differences between the higher synthetic surface injury rates for knee sprains, particularly for ACL injury, and significantly more knee injuries occurred to backs on rushing plays.

Naunheim, McGurren, Standeven, Fucetola, Laurysen and Deibert (2002) investigated three surfaces used by high profile professional football players in their league viz. an indoor artificial turf field, a grass outdoor field and an artificial field at a domed stadium. The artificial surface of the domed stadium was the hardest surface and contributed to the highest incidence of concussion injuries in football players. Surfaces with artificial turf have also been shown to produce non-severe injuries

more frequently than natural grass surfaces, while severe injuries seem to occur as frequently on natural grass as on artificial turf (Nigg & Segesser, 1988). Keene, Narechania, Sachtien and Clancy (1980) supported this finding when they found that significantly more serious sprains and torn ligaments occurred on grass than on tartan turf. Nigg and Segesser (1988) also pointed out that the shoe surface combination which determines the frictional forces is connected with the injury frequency, and surfaces with low frictional resistance are assumed to cause fewer injuries than surfaces with high frictional resistance.

Meyers and Barnhill (2004) studied the incidence of football injuries of eight high schools over five competitive seasons. Although this study showed similarities between natural grass and synthetic surfaces (total injury rates of 15.2% versus 13.9% on synthetic surface versus natural grass respectively), they found that both surfaces exhibited unique injury patterns which they suggested warranted further investigation.

It must be kept in mind that the methodologies of these studies differ in terms of the sex, age and ability level of the subjects. Also, the large variation in results may be due to differences in the method of collecting injury data; the definition of “injury” used; the level of severity; and the surface played on.

2.4.2.7. Playing position

Not many studies related position of play and injury. Hockey players are exposed to various injuries during running, turning, twisting and stretching, with vulnerability at many body sites. At each site, injuries can include lacerations, haematomas, miscellaneous other soft tissue injuries, fractures and dislocations. Ekstrand *et al.* (1983) found no difference in risk of ankle injury among soccer player positions, and Sitler *et al.* (1994) also found no difference in risk of ankle injury among basketball player positions. However, In field hockey players, Verow (1989) as well as Murtaugh (2001) found goalkeepers to have the highest rate of injury; mostly the result of direct trauma either from the ball or sticks. Murtaugh (2001), in a study on 158 high school, university and national-level female field hockey players, also found that those players who played in multiple positions had the highest total injury rate. Shiv Jagday, the United States men’s national field hockey team coach, identified in

his article that forwards and those defenders who defend from the left are most vulnerable to injury (Jagday, 2006).

Reilly and Borrie (1992) reported that the speed and ability to accelerate, along with the power and strength necessary in attacking play, was a good combination of characteristics for forward players to perform their field duties. These requirements, i.e. high-intensity bursts of activity involving acceleration, deceleration and cutting movements, along with high-intensity play in the goal circle, may be attributed to the high number and types of injuries sustained by players in the forward position. However, Merrett (2003) did not find that one position is more likely to incur a specific type of injury, and mentioned that perhaps this was due to the low number of injuries sustained in his playing group of all women hockey players selected for the 2002-2003 State Hockey Team.

2.4.2.8 Previous history of injury

Several studies have examined the risk factor of previous injury history. Disruption of muscle and joint mechanoreceptors from trauma results in partial differentiation of musculature, predisposing it to further injury (Lephart, 1993). Possible reasons for risk of injury are that partial differentiation alters proprioception and the muscle's ability to provide co-contraction (dynamic stabilisation) which is imperative in sports that involve rapid changes in direction. Furthermore, these sensory deficits contribute to the aetiology of degenerative joint disease through pathological wearing of a joint with poor sensation (Lephart, 1993). Ekstrand *et al.* (1983) examined 124 soccer athletes at the beginning of the year and then followed them for a year. They reported an increased risk for ankle ligament injury in athletes who had suffered a prior ankle ligament sprain. They also reported that a minor injury was often followed by a major one within two months and those allowed to resume play with poorly rehabilitated or clinically unhealed injuries are more apt to sustain further injury. McHugh *et al.* (2006) supported this finding when they studied athletes from soccer, basketball and gymnastics and found that the incidence of grade II and grade III sprains was higher in athletes with a history of previous ankle sprain. Milgrom *et al.* (1991) also supported this finding, when they reported that recruits with prior history of ankle sprain had higher ankle sprain morbidity in basic training. McKay, Goldie, Payne and Oakes (2001) investigated basketball players and reported that those

players with a history of ankle injury were almost five times more likely to sustain an ankle injury. Tyler *et al.* (2006) stated that football players who had a previous ankle sprain and a high body mass index were 19 times more likely to sustain an ankle sprain. Baumhauer, Alosa, Renstrom, Trevino and Beynnon (1995), however, found no relation between previous ankle injury and risk of re-injury. Tropp, Ekstrand and Gillquist (1984) also stated that a history of previous ankle joint injury did not run a higher risk compared to players without previous injury, and that an ankle injury did not result in a persistent functional instability. The differences found may lie in the fact that the condition of the joint after injury not only depends on the severity of the injury and damage to ligaments, muscles and differentiation, but also on the type of rehabilitation that was administered and whether the ankles had recovered fully. These findings suggest that ankles should be completely rehabilitated before return to sport and that compliance with the rehabilitation programme is imperative.

2.4.2.9 Return to play

Schmikli, Backx, Kemler and van Mechelen (2009) stated that in professional sports, muscle injuries can lead to significant pain and disability, resulting in time away from participation (training and competition) and high medical costs. However, return-to-play (RTP) decision making in sport has long since been a topic of uncertainty with no structures or transparency (Beardmore, Handcock & Rehrer, 2005; Creighton, Shrier, Shultz, Meeuwisse & Matheson, 2010). It is well known that athletes and coaches are often concerned about the time to full recovery and RTP. Fisher (1988) mentioned that unfortunately, issues on duration to return-to-play (DRP) are often not directly discussed during consultation with the medical team. Predicting DRP is not only important for planning the rehabilitation programme, but also for enabling the coaching staff to restructure the team for competitions.

In the absence of RTP criteria, management often make decisions based on their own perceived strengths and expertise (Handcock, Beardmore & Rehrer, 2009). To devise a structured and appropriate rehabilitation programme and eventually RTP criteria, a thorough understanding of the demands on the players is necessary (Eaton & George, 2006). Injuries in collegiate ice hockey can result in time lost from play ranging from minutes to a month or more. On average, the combined lost time

for all players on one team injured in one year is equal to the loss of one player for almost the entire season (Ferrara & Schurr, 1999).

A model for RTP decision making in sport has been introduced by Creighton *et al.* (2010)(see figure 3). The model consists of three steps, namely: Step 1: health status or medical factors; Step 2: participation risks or participation modifiers; and Step 3: decision modifiers.

During the first step of evaluating health status, factors taken into account include symptoms, personal medical history, signs, laboratory tests, functional tests, physiological state and potential seriousness (Creighton *et al.*, 2010). Symptoms such as pain, joint stiffness and instability are indicative of incomplete tissue healing. According to Creighton *et al.* (2010), objective evidence regarding tissue healing can be obtained by laboratory tests such as Magnetic Resonance Imaging (MRI) or Computerized Tomography (CT) scans, and the interaction of muscular strength, range of movement, endurance, confidence and proprioception should be tested through functional testing specific to the sport's demands. During the second step, Creighton *et al.* (2010) model takes into account the type of sport, position played, competitive level, ability to protect and limb dominance. Gabbett (2010) stated that in field hockey, variations exist between the demands of the goalkeeper, midfielders, strikers and defenders. Creighton *et al.* (2010) also mentioned that competitive athletes are more likely to take risks, and they also have greater speed, strength and size, resulting in higher forces and stresses. In the third step, Creighton's model involves decision modification. This includes the timing and season, pressure from the athlete, external pressure, masking the injury, conflict of interest and the fear of litigation. Creighton *et al.* (2010) also stated that financial or performance advantages during a certain time in-season could outweigh the potential disadvantages. External pressure from coaches, team mates, relatives, team administrators, agents, fans and media can provide additional information for RTP, but also undue pressure and misinformation. Creighton *et al.* (2010) concluded that, legally, the final decision has to be made by the team clinician or physician, even if the athlete is of age. It is thus very important that the team's best interest is also aligned with the athlete's best interest. It is also important to remember that previous injuries and premature RTP are the strongest predictors for future injury (Beardmore *et al.*, 2005).The high incidence of re-injury in field hockey could therefore potentially

be reduced through the use of standardised RTP assessment procedures. Literature regarding the demands of field hockey should therefore be incorporated into functional rehabilitation and gradual progression into sport-specific tasks over a period of time to allow tissue to adapt to specific demands posed explicitly by each position in hockey. However, Creighton *et al.* (2010) model helps clarify the processes that clinicians use consciously and subconsciously when making RTP decisions. Providing such a structure should decrease controversy, assist physicians, and identify important gaps in practice areas where research evidence is lacking.

Decision-Based RTP Model

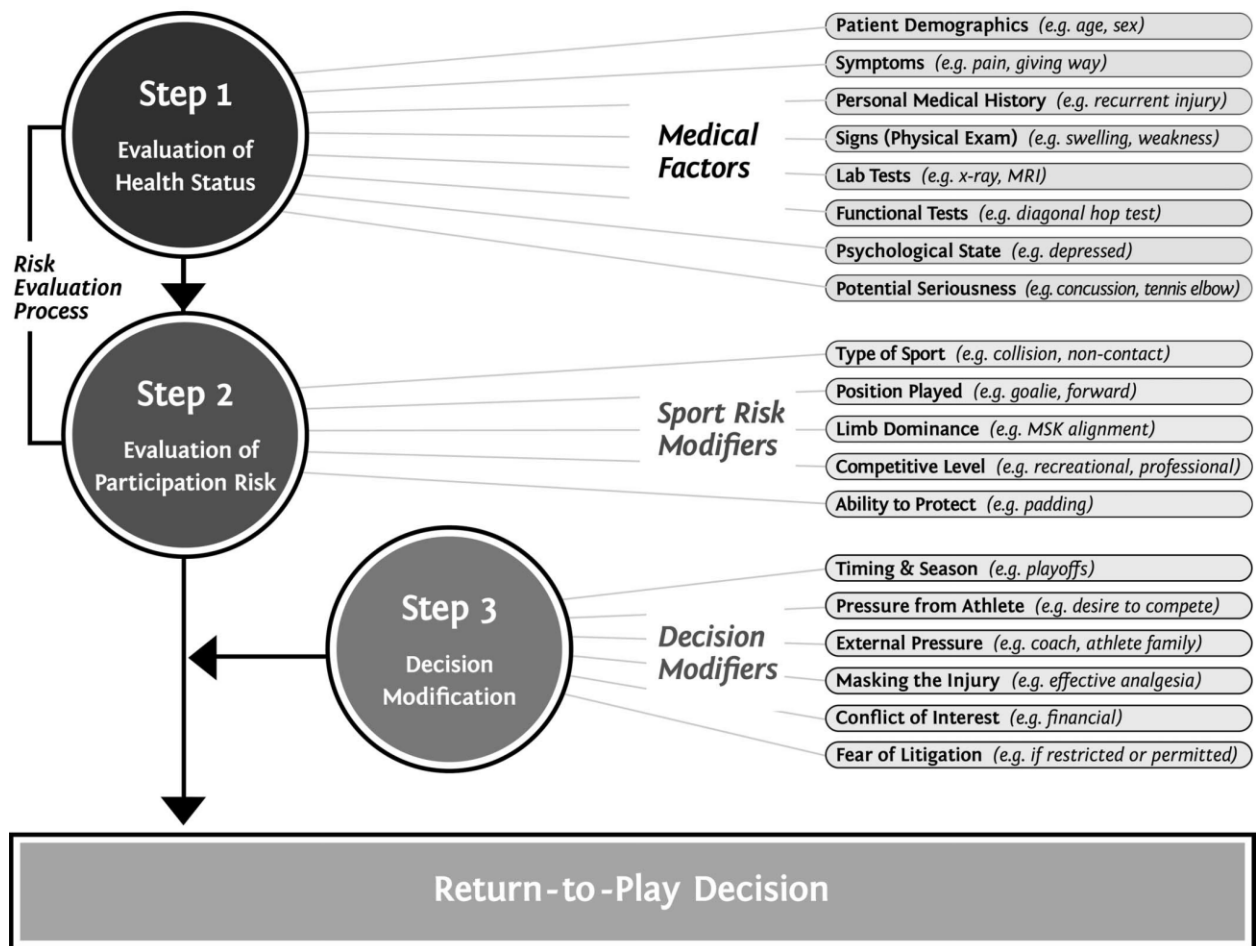


FIGURE 2.1. Decision-based RTP model. The decision-based RTP model for an injury or illness is specific to the individual practitioner making the RTP decision. The large black circles represent the states of nature elements (the circumstances under which a decision is made). The RTP square represents the final decision that actually results in an action being taken. The texts on the far right are individual factors or components identified from the literature that contribute information to the states of nature. These factors are grouped into Medical Factors, Sport Risk Modifiers, and Decision Modifiers and are on the left because they represent the general concepts the clinician should focus on when making a decision (the details are provided on the right). In Step 1, the health status of the athlete is assessed through the evaluation of Medical Factors. For example, symptoms, signs, and

testing provide information on how much healing of the injury or illness has occurred. In Step 2, the clinician evaluates the risk associated with participation. For example, the health status is usually heavily weighted when the known re-injury and long-term sequel risks are high (e.g. if an athlete participates with only partial healing). However, there are Sport Risk Modifiers that also affect the risk associated with participation. For example, it may be possible to protect the injury with padding or to minimise risk by changing the position of the player. Although the RTP decision is fundamentally based on the risk associated with participation, decision making in all fields is based on a risk-benefit balance. There may be benefits to an athlete that affect what is considered an acceptable risk. For example, play-off competitions may result in significant financial and nonfinancial gains. Accounting for these Decision Modifiers (Step 3) is the final step in the process that leads to the actual RTP decision. Decision Modification is set aside from the other steps because Participation risk does not contribute information about Decision Modification, and Decision Modification cannot be used to determine RTP, except in the context of participation risk. Finally, the process is recursive; decisions to not clear an athlete for participation are revisited as the healing process continues, and decisions that allowed an athlete to play are revisited if symptoms or signs recur or if the status of any of the Sport Risk Modifiers or Decision Modifiers are changed (Creighton *et al.*, 2010).

2.5 Conclusion

The modern game of hockey with the more popular Astroturf has become more physically demanding with a greater potential risk of injury. There is also a vast increase in popularity of the sport with several countries now playing the sport at a professional level. The above studies clearly indicate the high incidence of injuries in field hockey and stress the need to scientifically investigate possible predisposing injury risk factors with the attempt of adequately preparing athletes and preventing these injuries from occurring.

Many sports injuries are accidents that simply happen, whereas others follow a predictable pattern. When the circumstances of an injury are predictable, there might be a way of avoiding them. If an injury can be prevented, there will be healthier players who can stay on the pitch and, in doing so, become better players. Preventing injury improves the development of a player.

The literature above clearly describes field hockey as a physically demanding sport requiring explosiveness as well as endurance. There is therefore a need to assess field hockey players, more so elite players, to determine if there are any weaknesses in an individual or perhaps the entire team that might prevent an optimal performance, and also to identify possible predisposing factors to injury, all of which will ultimately affect the team's overall performance. Considering the demands of the

game, it was decided to screen players in the pre-season for morphological factors as well as skill-related factors of speed, muscle strength, isokinetic testing of the ankle, flexibility, core strength, and balance.

CHAPTER 3

METHOD OF RESEARCH

3.1 Introduction

This chapter describes the protocol that was designed to investigate the objectives stated in Chapter 1. A description of the instruments that were used as well as the technique for every measurement will be discussed. In preparation for this thesis, literature was collected from electronic databases such as Pubmed, EbscoHost (Academic Search Elite and Medline), academic journals, and textbooks.

3.2 Study design

This study was a cohort-analytical study on certain variables associated with the morphological and skill-related physical characteristics of elite female field hockey players and injury incidence. After completing a survey, all participants (eligibility defined in participants) completed a battery of pre-season fitness tests in the pre-season to their competitive season. Injury data was obtained retrospectively using a self-administered injury report survey completed by participants at post-season team meetings, attendance of which was mandatory for all athletes. Fitness tests were conducted according to accepted protocols and were administered in the same order for all athletes to control for the effects of accumulating fatigue on a subsequent performance test. All the fitness tests included have shown adequate reliability in order to draw inferences regarding pre-season testing and injury incidence in-season.

3.3 Study participants

Before the study commenced and before the subjects were recruited, the study was approved by the Ethics Committee of the University of Stellenbosch. A meeting with the head coach of SA Hockey and the South African Hockey Association was arranged in order to get full permission for execution of the investigation as well as to explain the procedures that followed (Appendix A). The study includes all players of the South African senior women's field hockey team. The national women's hockey team is selected from the representation of each of the nine provinces in South Africa. A select group of female players are chosen based on their performance in

the inter-provincial tournaments. This number is further narrowed down at several training camps where the national team is ultimately decided. This group of players therefore comprises the elite female field hockey population in South Africa. A group of 30 national-level female hockey players were tested in this study over a two-day period.

All participants provided written informed consent to participate in the research. To be eligible for inclusion, the participant must have participated in a game or practice during the 2011-2012 season and have data for both the pre-season fitness testing and the post-season injury survey. At the time of the pre-season fitness testing, all participants were medically cleared to participate by the researcher so that no current injuries influenced the data collected.

3.4 Survey

The general questionnaire completed by all players (Appendix B) in the pre-season, elicited information regarding their age, weight, height, playing position, number of years playing, playing surface and footwear. A second injury profile sheet (Appendix D) was handed to players at the end of the competition season to establish incidence, mechanism and severity of the injury/injuries sustained during competition. These questionnaires were handed to and collected from players via the investigator at a post-season team meeting. All questionnaires in this study were completed by all players in the presence of the investigator in the team meeting room should there have been a need for any further clarification regarding the questions.

3.5 Measurements

From the physiological profile established in the literature above, the following physical parameters were selected to be assessed on day one in a laboratory (Exercise and Sport Science Centre) in the following order: Anthropometry (height, mass, body fat percentage), flexibility (sit and reach test), balance (single leg), strength (1RM leg press, 1 RM bench press, core strength, isokinetic testing of the ankle joint and explosive power (vertical jump test). On the second day of testing, they performed the on-field tests, which were speed (10 m and 40 m linear sprints), agility (Illinois Agility Test) and anaerobic capacity (5 m multi-shuttle run test).

3.5.1 Laboratory testing

3.5.1.1 Anthropometry measurements

Anthropometric measurements of height, body mass, and sum of skinfolds provide a clear appraisal of the structural status of an individual at any given time (Ross & Marfell-Jones, 1991). Detailed athletic profiles are also valuable in describing the characteristics of elite athletes across sports and at various stages throughout a yearly training cycle. Selected skinfolds included chest (pectoral), quadriceps, triceps, subscapula, abdomen, midaxillary and suprailiac. The first measurement that was taken was height, and was calculated in centimetres. Each player's mass was measured using a triple beam balance scale.

Body fat percentage was then calculated using the Jackson and Pollock method (Jackson et al., 1980). This was done at the beginning of the testing session before the players completed the rest of the test and started sweating. This method measures 7 sites. The following sites were used:

- **Pectoral: Diagonal fold**
One-third of the way between upper armpit and nipple.
- **Abdominal: Vertical fold**
One inch to the right of navel.
- **Quadricep: Vertical fold**
Midway between supra-patella and hip joint.
- **Tricep: Vertical fold**
Midway between elbow and shoulder joint.
- **Subscapula: Diagonal fold**
One inch below the inferior border of the scapula.
- **Suprailiac: Diagonal fold**
Directly above the iliac crest.
- **Midaxilla: Vertical fold**
Directly below the armpit, midway between anterior and posterior of the body.

The sum of the 7 sites was calculated and converted into a percentage, using the equation below:

Body fat percentage = $1.097 - (0.00046971 \times \text{sum of skinfolds}) + (0.00000056 \times \text{square of the sum of skinfold sites}) - (0.00012828 \times \text{age})$, where the skinfold site is measured in millimetres (Jackson *et al.*, 1980).

3.5.1.2 Explosive strength

Explosive strength refers to the ability to exert a maximal amount of force in the shortest possible time interval. Explosive muscle strength was assessed using the vertical or Sargent jump test (Sargent, 1921) as a measure of lower body explosive power (Da Costa Mendes de Salles, Do Amaral Vasconcellos, De Costa Mendes de Salles, Fonseca & Dantas, 2012).

The vertical jump test is an established measure of explosive and anaerobic power of the lower limbs and hips that is easy to perform, requires limited equipment, and is common to many power-related sports, allowing easy comparison (Wathan *et al.*, 2000). Anaerobic capacity measured by vertical jump testing is strongly correlated with athletic performance (Ostojčić, Stojanović & Ahmetović, 2010) and has been used by other investigators (Balsalobre-Fernández, Tejero-González, Campo-Vecino & Alonso-Curiel, 2013).

The player stood with her side to a wall and reached up with the hand closest to the wall. Keeping the feet flat on the ground, the point of the fingertips was marked and recorded. This was called the standing reach height. The athlete then stood away from the wall, and leapt vertically as high as possible using both arms and legs to assist in projecting the body upwards. The player then attempted to touch the wall at the highest point of the jump. The difference in distance between the standing reach height and the jump height was calculated as the score. The best of three attempts was recorded (Sargent, 1921).

3.5.1.3 Flexibility

Flexibility was assessed using the standard sit and reach test for calculating flexibility (Baltaci, Un, Tunay, Besler & Gerceker, 2003). This is a common measure of flexibility, and specifically measures the flexibility of the lower back and hamstring muscles. This test is important because tightness in this area is implicated in lumbar lordosis, forward pelvic tilt and lower back pain. This test was first described by Wells and Dillon (1952) and is now widely used as a general test of flexibility.

All players performed a three-minute warm-up and static stretch routine, emphasising the lower body. Immediately after the stretching the flexibility tests are performed. This test requires a player to sit flat on the floor with the legs extended straight in front of them. Their feet are pushed flat against the standard sit and reach box. The hands are placed on top of the other. The player then slowly reached forwards with one sliding movement, and slides the hands as far forward on the box, keeping the middle fingers aligned and knees straight. The player was asked to exhale as they reach forward and reminded to keep the movement smooth and pain free to avoid muscle strains. The score was calculated in centimeters and was calculated as the furthest point at which the player could slide their hands along the tape measure on the standard sit and reach box.

3.5.1.4 Balance

Balance was assessed using the Biodex Balance System (See Figure 2). Balance index scores have been a good indicator of lower sports results (Vrbanić, Ravlić-Gulan, Gulan & Matovinović, 2007). The Biodex Balance System has been tested and found reliable (Cachupe, Shifflett, Kahanov & Wughalter, 2001) and has been used by several investigators for assessment of balance (Alonso, D'Andréa Greve & Camanho, 2009; Pereira, de Campos, Santos, Cardoso, Garcia Mde & Cohen, 2008; Durmus, Altay, Ersoy, Baysal & Dogan, 2010).

The Biodex Balance System testing protocol that was used consisted of a double leg, eyes open test. The testing protocol used is one of the more common ways to test balance. The protocol required the player to stand on the balance plate with both feet flat on the balance plate, and standing with their eyes open. Firstly, the player's

details were entered into the Biodex Balance System (height, weight and age). The timer was set for the test to run for 30 seconds, on a platform firmness score of 8. The player's foot position was then recorded by getting the player to hold onto the hand rails and asking the player to centre their balance to the middle of the target on the screen. Once this was recorded and complete the test was started. The test required the player to stand on both feet, with eyes open and arms crossed across their chest and the platform set to start. The tracing on the screen was turned off so as not to give feedback to the player while they tried to balance on both legs for 30 seconds with the balance platform moving in an unstable fashion. The first test was a trial run while the second test gave a more reliable score. Each player's score was recorded with standard deviation scores for statistical analysis.



Figure 3.1: Balance test on Biodex Balance System SD

3.5.1.5 Strength

The maximal bench press test was used as an indicator of upper body strength (Seo, Kim, Fahs, Rossow, Young, Ferguson, Tiebaud, Sherk, Loenneke, Kim, Lee, Choi, Bembem & Bembem 2012). The players performed an upper body warm-up. They then rested two to four minutes, and subsequently performed a 1 RM attempt with proper technique. They rested for another two to four minutes and increased the load by 5-10%, and then attempted another lift. We kept increasing and decreasing the weight until a maximum lift was performed. Selection of the starting weight was

crucial so that the maximum lift was completed within approximately five attempts after the warm-up sets. The maximum weight lifted was recorded. To standardise the score, we calculated a score proportional to the player's bodyweight.

The maximal Leg Press test was used as a indicator of lower body strength (Seo *et al.*, 2012).The players performed a lower body warm-up. They then rested two to four minutes, and then performed a one-rep-max press attempt with proper technique using both legs to press the plate up. They then rest for another two to four minutes and increase the load 5-10%, and attempted another press. We keep increasing and decreasing the weight until a maximum leg press was performed. Selection of the starting weight was crucial so that the maximum press was completed within approximately five attempts after the warm-up sets. The maximum weight pressed was recorded. To standardise the score, we calculate a score proportional to the player's bodyweight.

3.5.1.6 Core strength

Core strength was calculated using a grading system where each player performed each level of the test. If they were able to perform the specific grade, they would obtain that score and could then attempt the following grade of higher difficulty. The grades were as follows:

Grade 0: The player lies flat on their back, on a firm surface, whilst placing the blood pressure cuff under the back on the L3 vertebra. Inflate the blood pressure cuff to 40 mmHg. Perform the test by telling the player to breathe deeply in and out, while maintaining pelvic stabilisation and the cuff pressure may not compress or decompress more than 5 mmHg. The player must use abdominal breathing (breathe in 'force' abdominals out, exhale start contracting 'pelvic floor', and draw naval to spine). If the player could maintain a steady pressure on the cuff, they were graded as a zero (0). If they could not maintain the pressure on the cuff they then got a grading of negative one (-1).

Grade 1: Lie flat on your back, on a firm surface, place the blood pressure cuff under back on L3 vertebra inflate blood pressure cuff to 40 mmHg. Perform the test by telling the player to breathe deeply in and out, while maintaining pelvic stabilisation and the cuff pressure may not compress or decompress more than 5 mmHg. The player must use abdominal breathing (breathe in 'force' abdominals out, exhale start

contracting 'pelvic floor', and draw naval to spine). The player must be able to hold this contraction and pressure for 10seconds. If the player can hold this contraction for 10 seconds they then improve their grading to achieve a score of one (1). If they cannot hold this contraction for 10 seconds they revert back to their original grading of zero (0).

Grade 2: The player lies flat on their back, on a firm surface, placing the blood pressure cuff under the back on L3 vertebra. Inflate the blood pressure cuff to 40 mmHg. Perform the test by telling the player to breathe deeply in and out, while maintaining pelvic stabilisation. Now the player must slowly perform leg slide movements along the floor while maintaining the pressure of the blood pressure cuff at 40 mmHg. It should not compress or decompress in pressure by more than 10 mmHg. The player must be able to perform this test correctly to be able to achieve a grading of two (2).

Grade 3: The player lies flat on their back, on a firm surface, placing the blood pressure cuff under the back on L3 vertebra. Inflate the blood pressure cuff to 40 mmHg. Perform the test by telling the player to breathe deeply in and out, while maintaining pelvic stabilisation and lift both legs up in the air, bent at 90°. Now read the pressure gauge of the blood pressure cuff. Place a goniometer on the greater trochanter, instruct the player to slowly lower 1 leg down to the floor (keep knee bent, foot in dorsiflexion) and raise it back to start position. The player must be able to hold this contraction and keep the pressure constant for not more than a 10 mmHg pressure change when completing 1 repetition on each leg. Secondly, measure a 45° angle with the goniometer while moving the bent knee in air, then read the pressure gauge. If the player is able to maintain an isometric contraction without inappropriate movement of the core while performing slow movements (1 repetition on each leg, pressure gauge constant or not more than 10 mmHg change), they then achieve a grading of three (3).

Grade 4: The player lies flat on their back, on a firm surface, placing the blood pressure cuff under the back on L3 vertebra. Inflate the blood pressure cuff to 40 mmHg. Perform the test by telling the player to breathe deeply in and out, while maintaining pelvic stabilisation and lift both legs up in the air, bent at 90°. Now read the pressure gauge of the blood pressure cuff. Place a goniometer on the greater trochanter, instruct the player to slowly lower both legs down to the floor (keep knees bent, feet in dorsiflexion) and raise them back up to the start position. The player

must be able to hold this contraction and keep the pressure gauge constant or at not more than a 10 mmHg pressure change when completing 1 repetition. Secondly, measure a 45° angle with goniometer while moving bent knees in air, then read the pressure gauge again. If the player is able to maintain an isometric contraction without inappropriate movement of the core while performing slow movements (1 repetition using double leg lowering, pressure gauge constant or not more than 10 mmHg change), they then achieve a grading of four (4).

Grade 5: The player lies flat on their back, on a firm surface, placing the blood pressure cuff under the back on L3 vertebra. Inflate the blood pressure cuff to 40 mmHg. Perform the test by telling the player to breathe deeply in and out, while maintaining pelvic stabilisation and lifting both legs up in the air, bent at 90°. Now read the pressure gauge of the blood pressure cuff. Place a goniometer on the greater trochanter, instruct the player to slowly lower both legs straight down to the floor (keep legs straight, feet in dorsiflexion) and raise them back up to start position. The player must be able to hold this contraction and keep the pressure gauge constant or at not more than a 10 mmHg pressure change when completing 1 repetition. Secondly, measure a 45° angle with goniometer while moving legs straight in the air, then read the pressure gauge again. If the player is able to maintain an isometric contraction (for at least 20 seconds) without compensation/inappropriate movement of the core while performing fast movements of the limbs or trunk and maintaining a specific joint angle, they then achieve a grading of five (5).

3.5.1.7 Ankle muscle strength

The gastrocnemius and soleus muscles, together with the tibialis anterior and peronei muscles are responsible for movement of the ankle (Moore,1985). Ankle strength was calculated by performing isokinetic testing using the Biodex System 3 Pro. A maximal torque score was obtained in four movements. The players were tested for peak strength in plantar flexion, dorsiflexion, inversion and eversion of the ankle joint. Absolute data were expressed in Newton metres (Nm). Isokinetic ankle strength for the motion of dorsiflexion and plantar flexion were assessed by a professional Biokineticist using the Biodex System 3 Pro isokinetic dynamometer (Biodex, New York, USA). This is an isokinetic strength testing dynamometer with an integrated computer and the appropriate software to provide precise strength measurements and storage of data from isokinetic muscular actions. In terms of the

validity of this instrument, calibration of the system was followed as per the recommendations of the manufacturers. Calibration was routinely conducted by the professional Biokineticist, who was responsible for the testing at monthly intervals. In addition, the instrument was calibrated on the morning prior to the laboratory testing session. A standard warm-up was followed prior to testing. This warm-up comprised a five-minute cycle on a cycle ergometer. This was followed by two stretches of the gastrocnemius muscles (extended back leg and lunge on front leg) and soleus muscle (flexed back leg and lunge on front leg), each of which was held for twenty seconds on both legs. All tests were performed with the players barefooted and the ankle in the neutral position. All tests were performed at a velocity of 60 degrees per second. The subject was asked to familiarise herself with the movement of testing by doing five repetitions of each movement prior to the test. A 30-second rest period was provided at the end of the practice session. The subject was then asked to do six maximal repetitions of the test. The peak torque value was taken as the average of these scores and this was used for further statistical analysis. Following a rest period of 1 minute, the subject was then tested for the other movements in the same manner. Consistent verbal encouragement was given throughout the testing. In each test, the right ankle was tested first, with both ankles being tested in this study.

ANKLE: PLANTAR/DORSIFLEXION (SEATED)

The ankle joint or talocrural joint is really three joints (tibiotalar, fibulotalar, and tibiofibular) formed by the superior portion of the body of the talus fitting within the cavity created by the combined distal ends of the tibia and fibula. The subtalar joint is the articulation between the talus and calcaneus. Motions of the ankle are rarely true single plane motions. This holds for dorsiflexion/plantarflexion, which usually occurs in conjunction with other movements.

The following procedure was used for testing the player's ankle plantar/dorsiflexion: For both ankles, the limb support pad was positioned in the positioning chair front right receiving tube, with the support facing towards the chair. The player was seated on the chair. The chair was rotated to 90 degrees. The back seat tilt was set to 70-85 degrees. The support pad was aligned under the distal femur and secured with the strap. The pad was positioned under the calf (distal to the knee) allowing for approximately 20° to 30° of knee flexion (Note: Because the origin of insertion of the

gastrocnemius is above the knee, the extent of ankle dorsiflexion will generally increase with increased knee flexion and decrease with knee extension). The dynamometer was rotated to 90 degrees with a tilt of 0 degrees. The ankle attachment was connected to the dynamometer, using the P/D engraving facing outwards and rotated footplate so that P/D aligned with the dynamometer shaft red dot. The dynamometer was aligned to the ankle's axis of rotation. The player was then moved into position and the player's ankle axis of rotation was aligned with the dynamometer shaft. The foot was strapped into the footplate and the player's upper body was stabilised with the appropriate straps. The ankles plantar/dorsiflexion ROM was set.

The strength test protocol was then followed, using 5 repetitions to familiarise the player, followed by 6 maximal exertion repetitions in both directions (plantarflexion and dorsiflexion). Both left and right feet were tested before the test was complete.

ANKLE: EVERSION/INVERSION

The ankle is vulnerable to inversion injuries, making injuries to the anterior talofibular complex a common occurrence that may be difficult to rehabilitate. Recurrent injuries to the lateral ligamentous complex have been shown to decrease proprioception of the ankle and athletic performance.

The following procedure was used for testing the player's ankle inversion and eversion: The limb support pad was positioned in the positioning chair receiving tube, on the side being tested, with the support facing towards the chair. The player was seated on the chair. The chair was rotated to 90 degrees. The back seat tilt was set to 70 degrees. The support pad was aligned under the distal femur and secured with the strap. The pad was positioned under the calf (distal to the knee). The dynamometer was rotated to 0 degrees with a tilt of 60-70 degrees. The height of the dynamometer was dropped right down to the bottom of the pedestal, in line with the limb support. The ankle attachment was connected to the dynamometer, using the I/E engraving facing outwards. The right ankle and left ankle were orientated with the input shaft straight up. The shaft's red dot was aligned with the respective R or L for the foot being tested. The foot plate was attached and aligned so that I/E were in-line with the dynamometer shaft's red dot. The dynamometer was aligned to the ankle's

axis of rotation. The player was then moved into position and the player's ankle axis of rotation was aligned with the dynamometer shaft. The foot was strapped into the footplate and the player's upper body was stabilised with the appropriate straps. For this test the player's lower leg was parallel with the floor. The ankle's inversion and eversion ROM were set.

The strength test protocol was then followed, using 5 repetitions to familiarise the player, followed by 6 maximal exertion repetitions in both directions (inversion and eversion). Both left and right feet were tested before the test was complete.



Figure 3.2: Ankle inversion/eversion testing using BiodeX

3.5.2 On-field testing

3.5.2.1 Speed

All players participated in a 10 and 40 metre sprint test. As in the study by Durandt, Evans, Revington, Temple-Jones and Lamberts (2007), the 10 m and 40 m sprint tests were chosen as they were the most appropriate for team sports such as hockey and soccer. These sports require long and short maximal sprints throughout the game. The test was set up using electronic timing gates. Four gates were placed on a 40-metre field of grass. Two of the gates were placed at the 10 metre mark and the other two gates were placed at the 40 metre mark. Before the players started their

sprint test, a sub-maximal warm-up was done for 10 minutes prior to testing, followed by an appropriate stretch regime and a few sprints to familiarise themselves with the test. A player then lined up on the start line with their front foot on the electronic start pad. They started in an upright position, with a standing start. The player was then asked to sprint as fast as possible without tapering off before the 40 metre mark. The 10 m and 40 m times were recorded. The player was then given 5 minutes of full rest and performed the test again to get an accurate score, with the best time of the two used to calculate the results. The player then repeated the above test, however, this time holding the hockey stick in the dominant hand. The results were then again recorded for maximum 10 m and 40 m linear speed.

3.5.2.2 Agility

The Illinois Agility Test was used as a measure of the player's agility (Getchell, 1979). It tests the ability to turn in different directions and at different angles and has proved a reliable test of agility in several studies (Váczai, Tollár, Meszler, Juhász & Karsai, 2013; Lennemann, Sidrow, Johnson, Harrison, Vojta & Walker, 2013; Stewart, Turner & Miller, 2012).

The length of the course was 10 metres and the width (distance between the start and finish points) was 5 metres. Four cones are used to mark the start, finish and the two turning points. Another four cones were placed down the centre, an equal distance apart. Each cone in the centre was spaced 3.3 metres apart. Subjects would lie on their front (head to the start line) with their hands at their shoulders. On the 'Go' command the stopwatch was started, and the athlete got up as quickly as possible and ran around the course in the direction indicated, without knocking the cones over, to the finish line, at which the timing was stopped. Each player performed the test twice and the best of the two times was used in the results.

3.5.2.3 Cardiovascular – Anaerobic: Repeated sprint test

The repeated sprint test was used as a calculation of the player's anaerobic capacity (Boddington, Lambert, St Clair Gibson & Noakes, 2001). The repeat sprint test was administered by setting up 6 cones, 5 metres apart in a straight line. The player lined up behind the first cone, and when given the command to 'go', the timer starts and she runs forwards and backwards from the first cone, back to the start, then to the

second and then back to the start. The player was timed for 30 seconds (running up and down the shuttles) and the tester then calculated the number of metres covered from the start until the finish point, 30 seconds later. The players then rested for 35 seconds, and repeated the shuttle running once more, until they had run and rested six times in a row. The total distance ran, adding all six 30-second runs together, was calculated and used as a score for the player. Each player only repeated this test once. Batches of players were tested together for logistical purposes, to complete the testing as quickly as possible.

3.6 Methodological and measurement errors

Errors were minimised by training the assistants and utilising the same assistant for taking each of the readings. In order to minimise errors each participant was weighed with the same calibrated scale.

3.7 Pilot study

A pilot study with five players was conducted three months prior to the present study. It consisted of testing vertical jump, balance, ankle muscle strength, speed, agility and repeated sprint tests to determine the effectiveness of the proposed data sheets, equipment, and protocols. Additionally, the duration of testing per player as well as the continuity of testing was evaluated in order to properly plan testing schedules for the study. Data sheets, equipment, and protocols were found to be effective in testing the proposed objectives.

3.8 Analysis of the data

Data was captured electronically by the researcher in Microsoft Excel (Microsoft Office 2007). The statistical analysis described below was done by a biostatistician, using the SAS statistical software package (version 9.22) (see SAS, 2009).

Descriptive statistics, namely means, standard deviations, as well as minimum and maximum values were calculated for all variables. The following binary dependent variables, recording various types of injury, were analysed:

1. Ankle injury
2. Lower leg injury (knee or lower leg injury)
3. Thigh injury (thigh back or thigh front injury)

4. Hand injury (wrist or finger or hand injury)
5. Lower back injury (hip or lower back injury)
6. Upper arm injury (elbow or shoulder injury)

The combined dependent variables 2-6 were formed in order to balance the resulting outcome variable, with approximately, or more nearly, half the subjects having an injury.

The independent variables (potential predictors of injuries) were as follows:

1. Mass (kg)
2. Height (cm)
3. Sum of 7 skinfold sites (n)
4. Body Fat Percentage (%)
5. Sit and Reach (cm)
6. Vertical Jump (cm)
7. Illinois Agility Test (s)
8. Illinois Agility Test with hockey stick (s)
9. Strength: Bench Press (%)
10. Strength: Leg Press (%)
11. Repeat Sprint (m)
12. Plantar Flexion Right (Nm)
13. Plantar Flexion Left (Nm)
14. Plantar Flexion Deficit (%)
15. Dorsiflexion Right (Nm)
16. Dorsiflexion Left (Nm)
17. Dorsiflexion Deficit (%)
18. Eversion Right (Nm)
19. Eversion Left (Nm)
20. Eversion Deficit (%)
21. Inversion Right (Nm)
22. Inversion Left (Nm)
23. Inversion Deficit (%)
24. Anterior/Posterior Balance (n)
25. Medial/Lateral Balance (n)

26. Overall Balance (n)

3.8.1 Univariate analyses

Each binary dependent variable was analysed using one-way logistic regression, fitting (one at a time) each of the independent variables. A likelihood ratio chi-square statistic and associated P-value is reported testing the null-hypothesis that the effect of the independent variable in question is zero. Furthermore, a point estimate and associated 95% confidence interval for the odds ratio of injury, associated with each independent variable, are reported.

Software: SAS Proc Logistic.

3.8.2 Multivariate analysis

Each binary dependent variable was analysed using multiple logistic regression with stepwise variable selection. Initially, the logistic regression model contained only the intercept. Stepwise model selection was applied as follows: At each step, among the independent variables not yet in the model, that variable was entered into the model which was most significantly associated with the dependent variable, providing that the P-value was smaller than 0.1. Similarly, at each step, among the independent variables already in the model, a variable could be removed from the model if it was not significantly associated with the dependent variable (that is, P-value is larger than 0.1).

For the final selected model, point estimates and associated 95% confidence intervals are reported for the odds ratios of injury associated with each independent variable in that final model.

Software: SAS Proc Logistic.

3.9 Ethics

Before the study commenced and the subjects were recruited, the study was approved by the Ethics Committee of the University of Stellenbosch (ethics nr. 497/2011). Informed consent forms approved by the Ethics Committee of the University of Stellenbosch were handed out and had to be signed by the players (See Appendix C). The form contained all the necessary information and basic

elements as specified by Thomas in the *Research Quarterly for Exercise and Sport* (1983) and as is advised for use by Thomas, Nelson and Silverman (2011).

3.10 Limitations of the study

Although this study focused on a specific population, the small sample size did complicate the detection of significant findings. The conclusions drawn had to be based mostly on trends that were apparent. Due to the lack of funds for the research, it was decided to only assess ankle strength which appeared to have a high incidence of injury in field hockey according to the literature. Ideally, it would have been interesting to assess the knee as well.

4.1 General survey of the players

4.1.1 Participants

Thirty national female field hockey players completed the general questionnaire. A 100% response rate was obtained from players for this part of the study. The age of the total sample ranged from 20–31 years with a mean of 23.8 (\pm 3.16) years. The mean height was 164.5 cm, while mean body mass was 62.5 kg. Fifty-seven percent (57%; n=17) of this sample was under the age of 25. All of the participants reported playing the game at provincial level for more than six years with 6.67% (n=2) of the players having less than five caps, 23.3% (n=7) of the players between 11 and 20 caps and 70% (n=21) of the players reported having more than twenty caps for South Africa. Ten players reported playing as strikers, while nine players reported that they played in the midfielder position, seven in the defender position and four as goalkeepers.

4.2 Pre-season testing

4.2.1 Measurements

4.2.1.1 Body fat percentage

The individual body fat percentages of the players are presented in Figure 4.1. The total mean body fat percentage for the national female hockey players (n=30) was 15.6%. Figure 4.2 illustrates the body fat percentage ranges for the different positions in hockey: strikers (n=10) 15.1%, midfielders (n=9) 15.3%, defenders (n=7) 15.7% and goalkeepers (n=4) 17.2%.

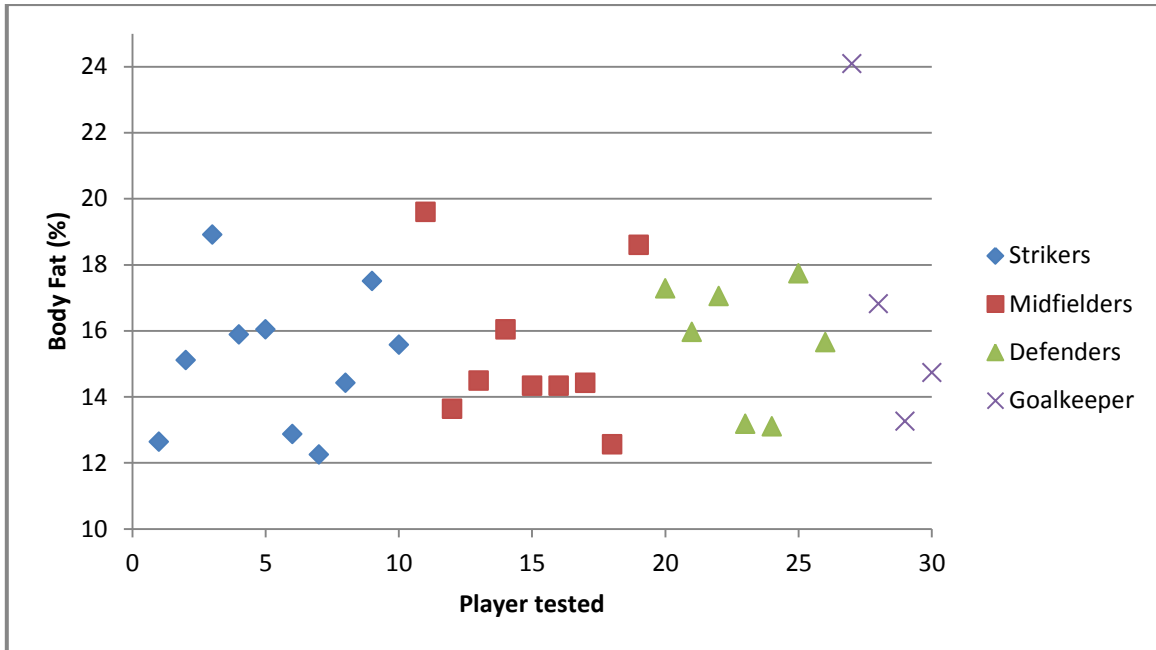


Figure 4.1: Individual body fat score

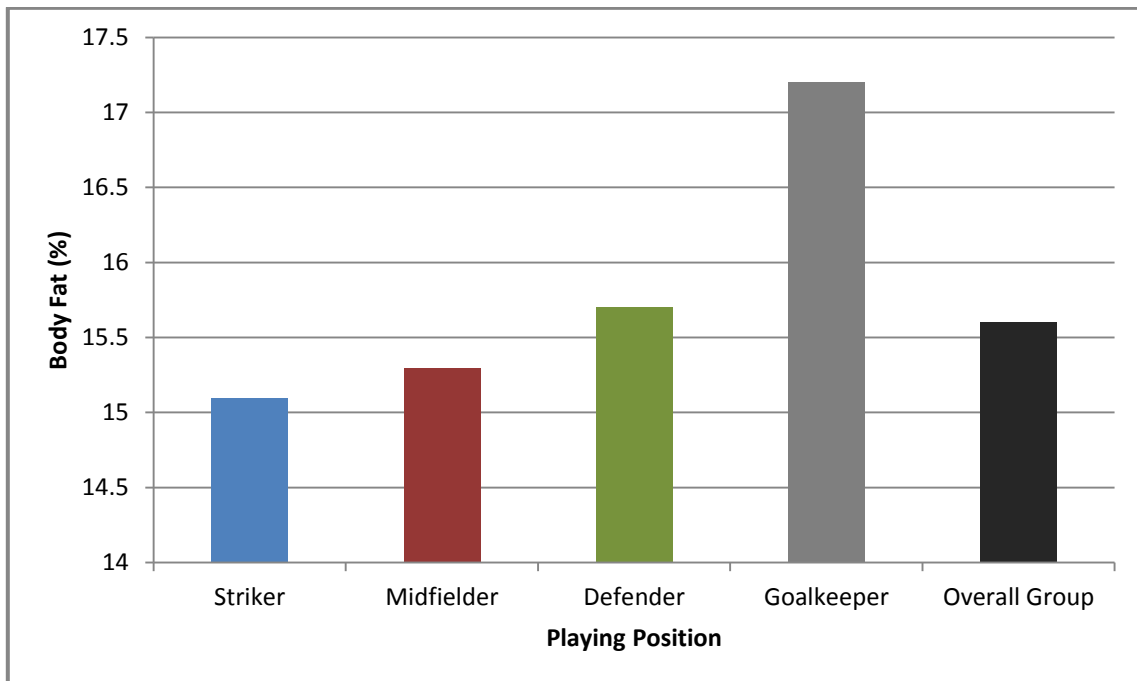


Figure 4.2: Mean body fat score by playing position

4.2.1.2 Explosive power - Vertical jump test

Figure 4.3 shows the vertical jump score for each player in their playing position. The overall mean vertical jump score was 44 cm. Figure 4.4 indicates that the mean vertical jump score for midfielders (n=9) 41.7 cm and goalkeepers (n=4) 41.9 cm was the lowest, followed by strikers (n=10) 43.9 cm, and with defenders scoring highest (n=7) 48.2 cm.

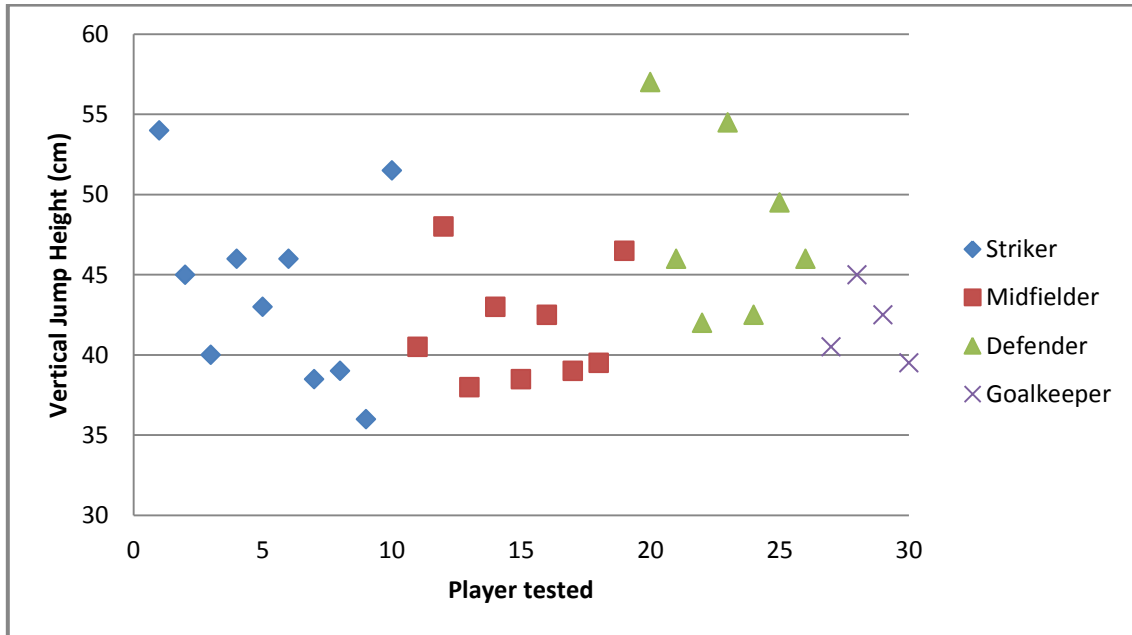


Figure 4.3: Individual vertical jump score

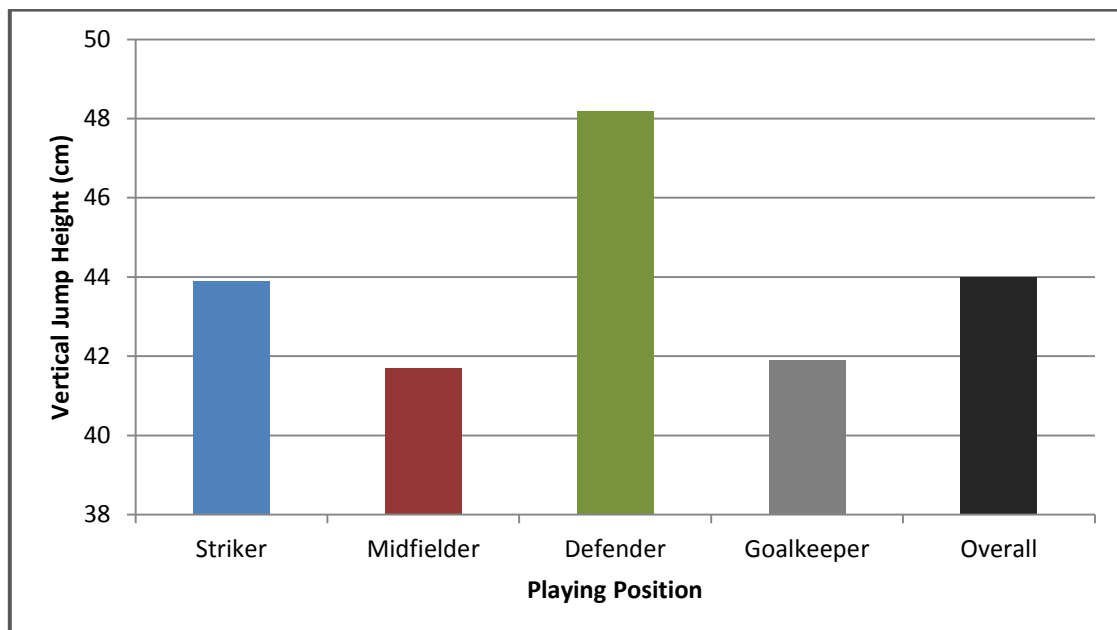


Figure 4.4: Mean vertical jump scores by different playing position

4.2.1.3 Flexibility -Sit and reach test

Figures 4.5 and 4.6 show that mean sit and reach scores for the different playing positions were very similar, with strikers (n=10) lowest at 40.1 cm, followed by midfielders (n=9) at 42.9 cm, goalkeepers (n=4) at 42.4 cm and defenders (n=7) at 44.8 cm.

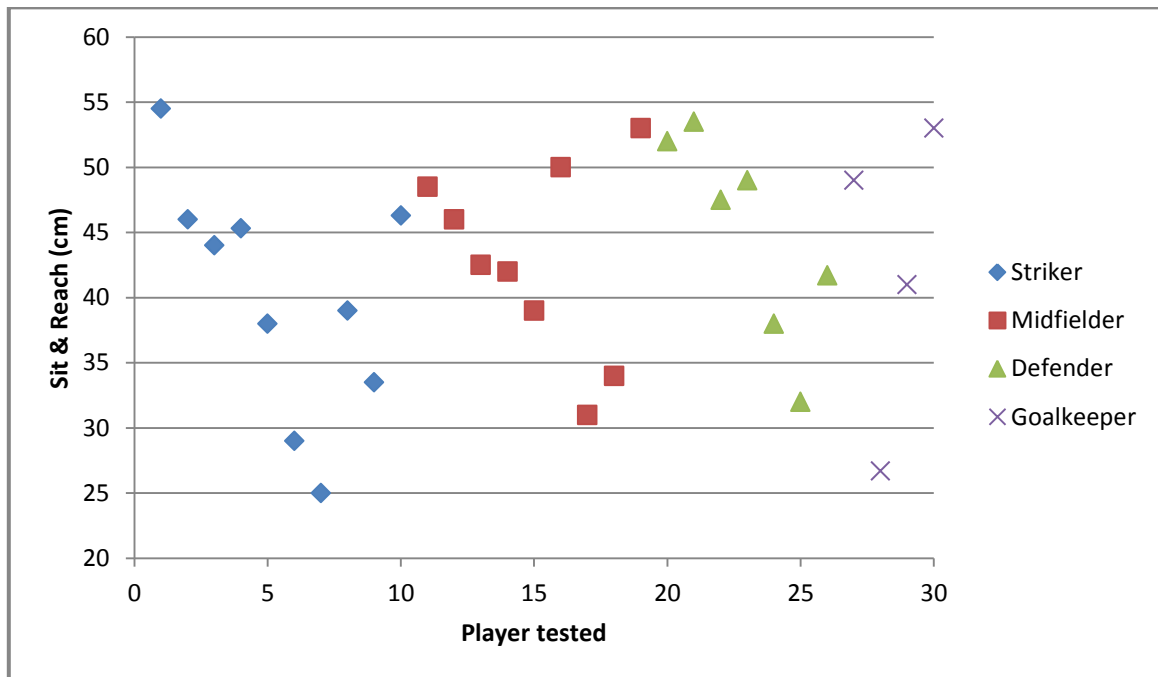


Figure 4.5: Individual sit and reach score

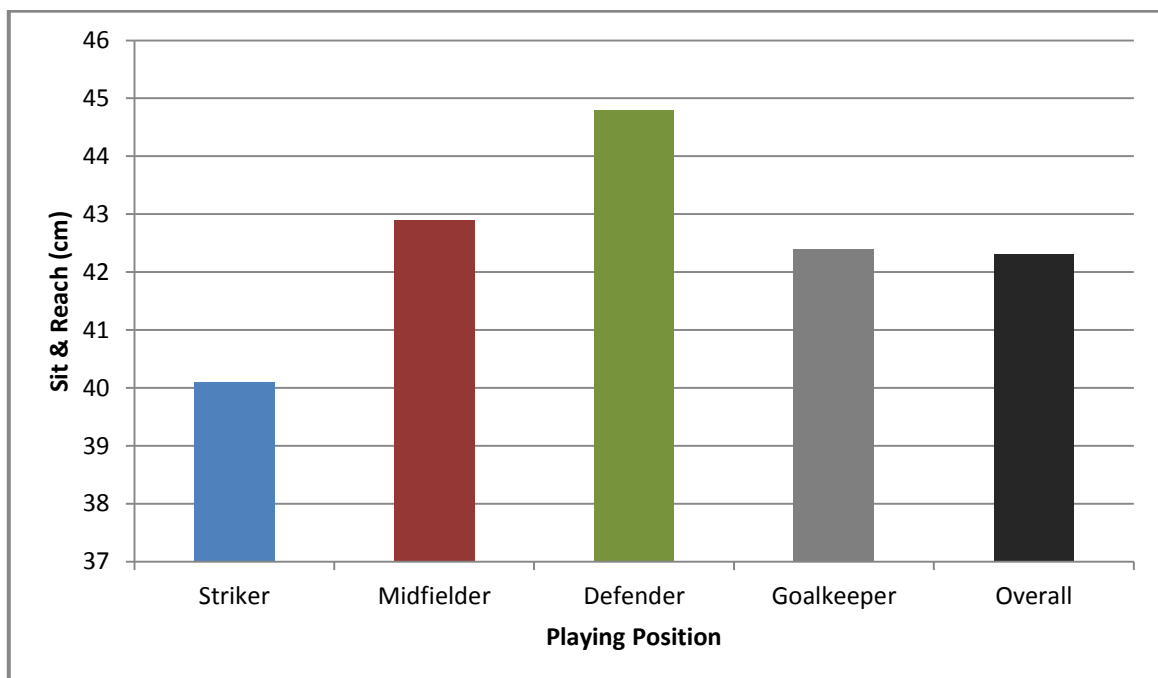


Figure 4.6: Mean sit and reach score by playing position

4.2.1.4 Upper body strength -Bench press test

Figures 4.7 and 4.8 provide the individual players' maximum bench press score as a percentage of their own body weight (Relative strength: kg/body weight). This is the player's upper body strength test score in relation to their body weight. The overall mean for the group of 30 players was 0.77 kg/body weight. The mean upper body relative strength of each playing position was: strikers (n=10) at 0.77, midfielders (n=9) at 0.73, defenders (n=7) at 0.82 and goalkeepers (n=4) at 0.78 (Figure 4.8).

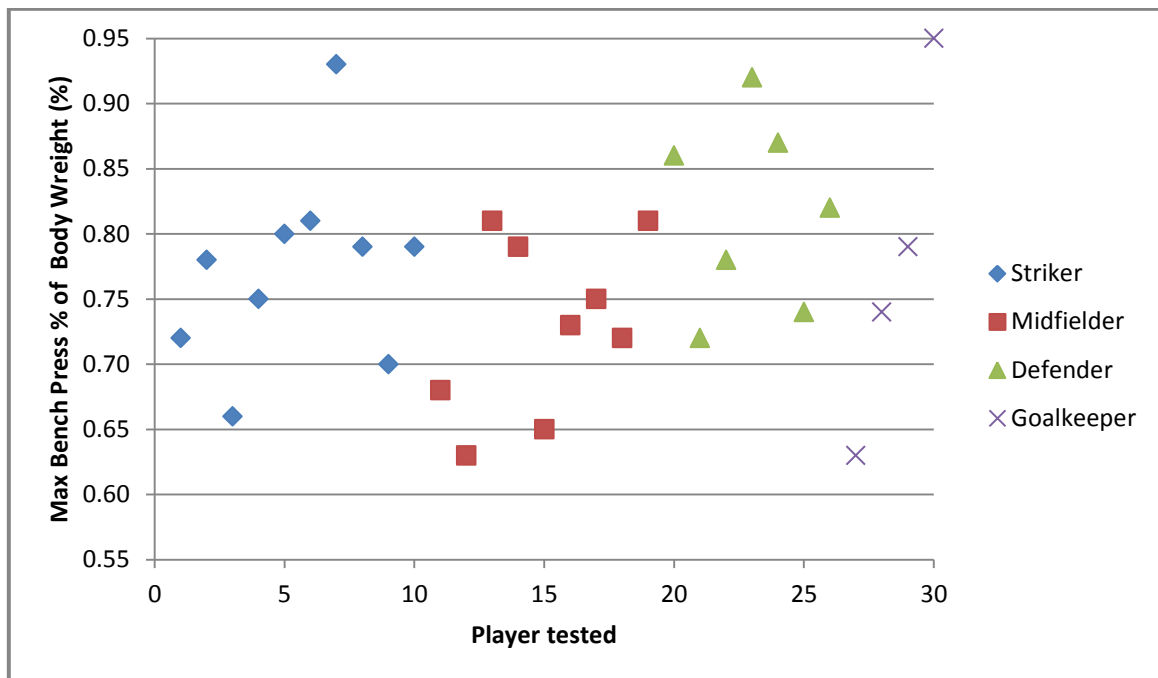


Figure 4.7: Individual bench press score

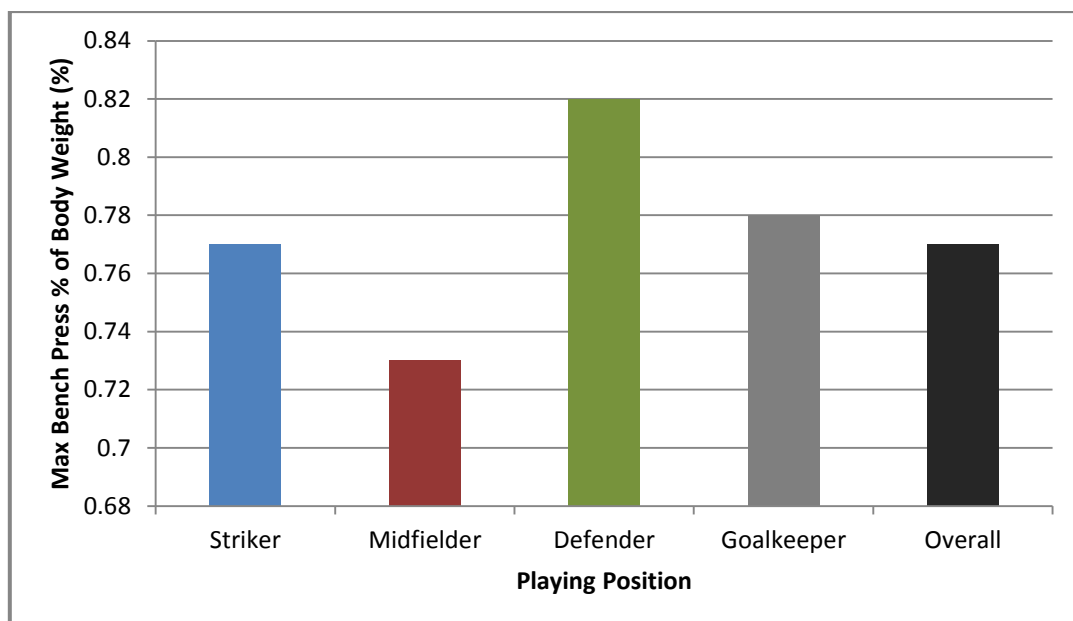


Figure 4.8: Mean bench press score by playing position

4.2.1.5 Lower body strength – Leg press

Figure 4.9 shows the individual maximum lower body strength as a percentage of body weight (Relative strength: kg/body weight), and categorised into playing position. The mean for the overall group of players tested was 3.98 kg/body weight. The mean for each group of players was respectively: strikers (n=10) at 4.0, midfielders (n=9) at 4.15, defenders (n=7) at 4.07 and goalkeepers (n=4) at 3.36.

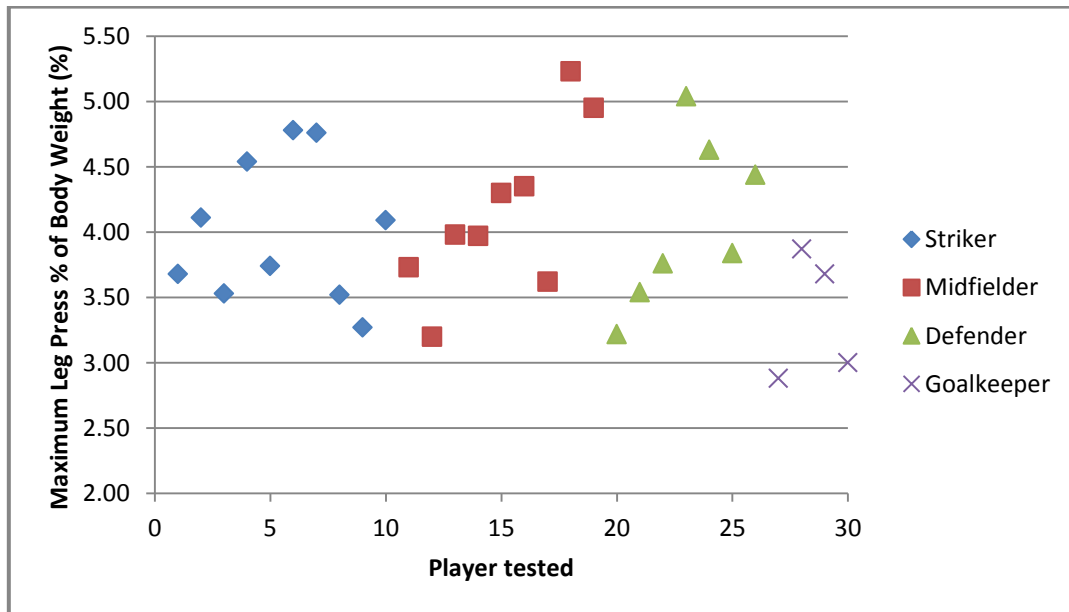


Figure 4.9: Individual leg press score

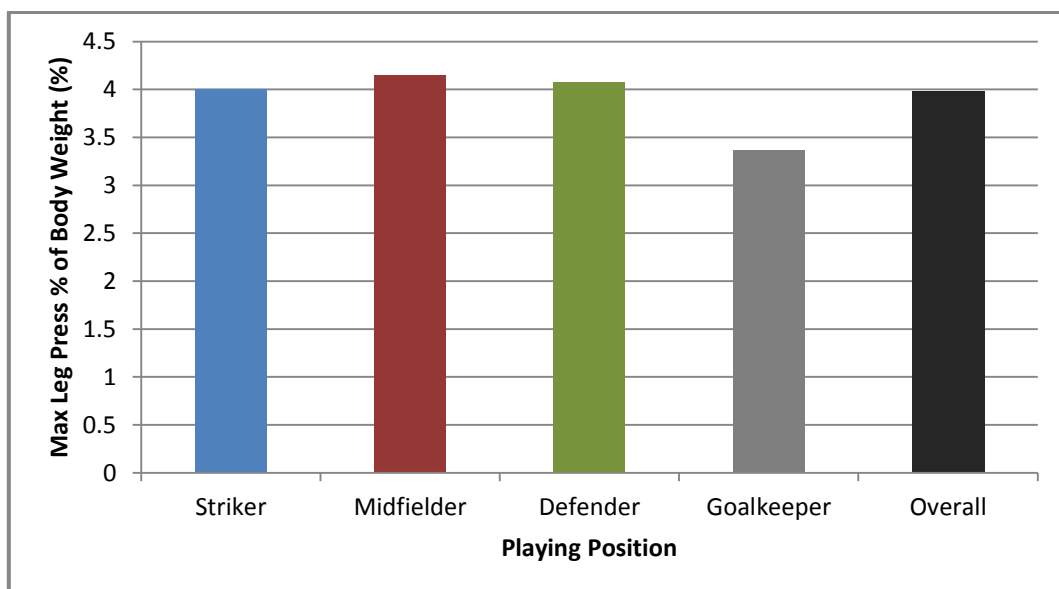


Figure 4.10: Mean leg press scores by playing position

4.2.1.6 Core strength

The individual core strength scores for the group of female hockey players are presented in Figures 4.11 and 4.12. A score of -1 indicates that a player could not even perform the most basic core activation technique and thus failed the test. The overall mean for the group (n=30) was 1 (Figure 4.11). The positional mean scores were respectively: strikers (n=10) with a score of 1, midfielders (n=9) with a score of 2, defenders (n=7) with a score of 1, and goalkeepers (n=4) with a score of 1 (Figure 4.12).

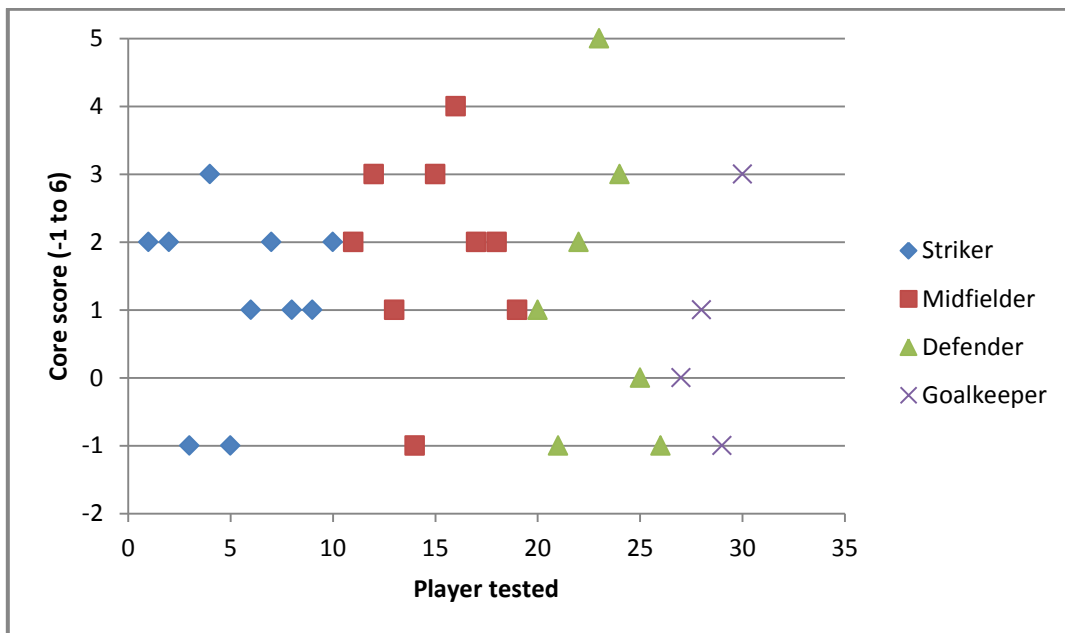


Figure 4.11: Individual core strength score

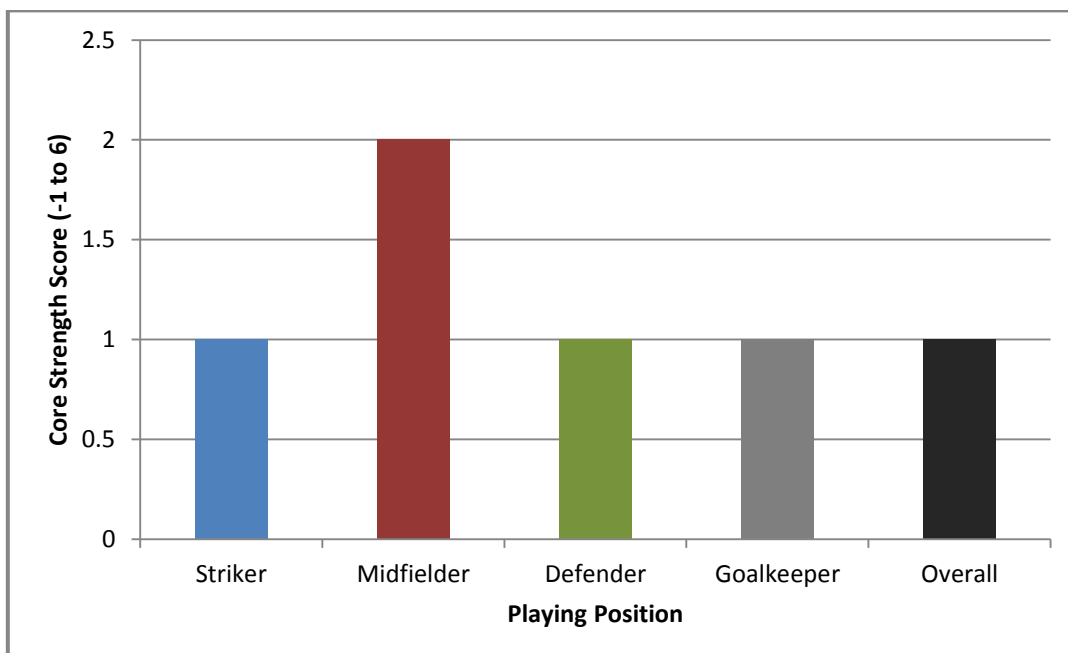


Figure 4.12: Mean core strength score by playing position

4.2.1.7 Anaerobic ability -Repeated sprint test

Figure 4.13 shows the repeat sprint test scores of the individual player as well as in their playing position. The overall mean for the group (n=29) was 717metres run. The means for each playing position group were: strikers (n=10) 730 m, midfielders (n=9) 729m, defenders (n=6) 713m and goalkeepers (n=4) 665m. These results are shown in Figure 4.14.

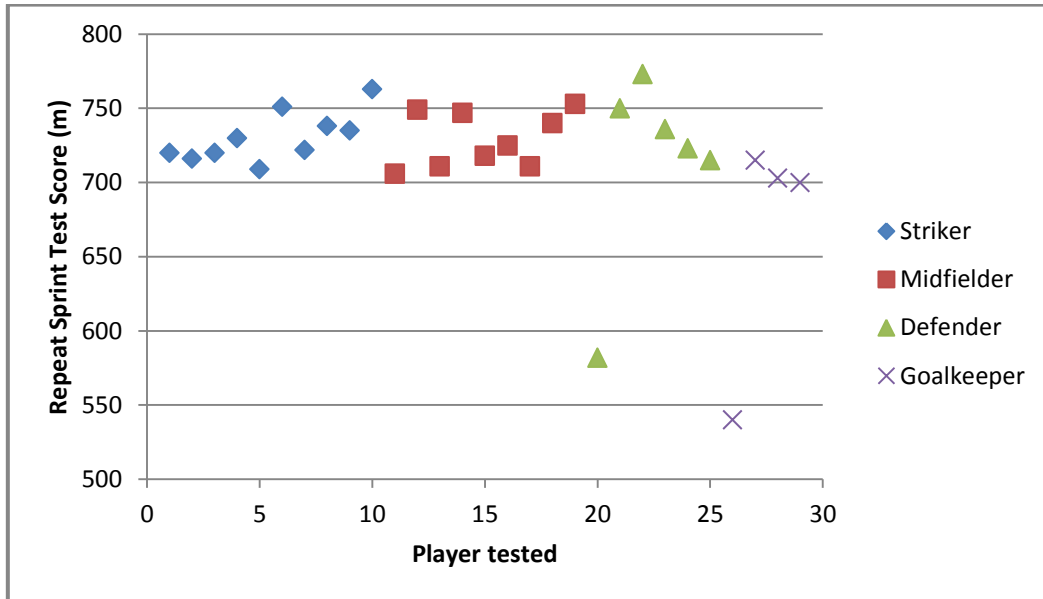


Figure 4.13: Individual repeat sprint test score

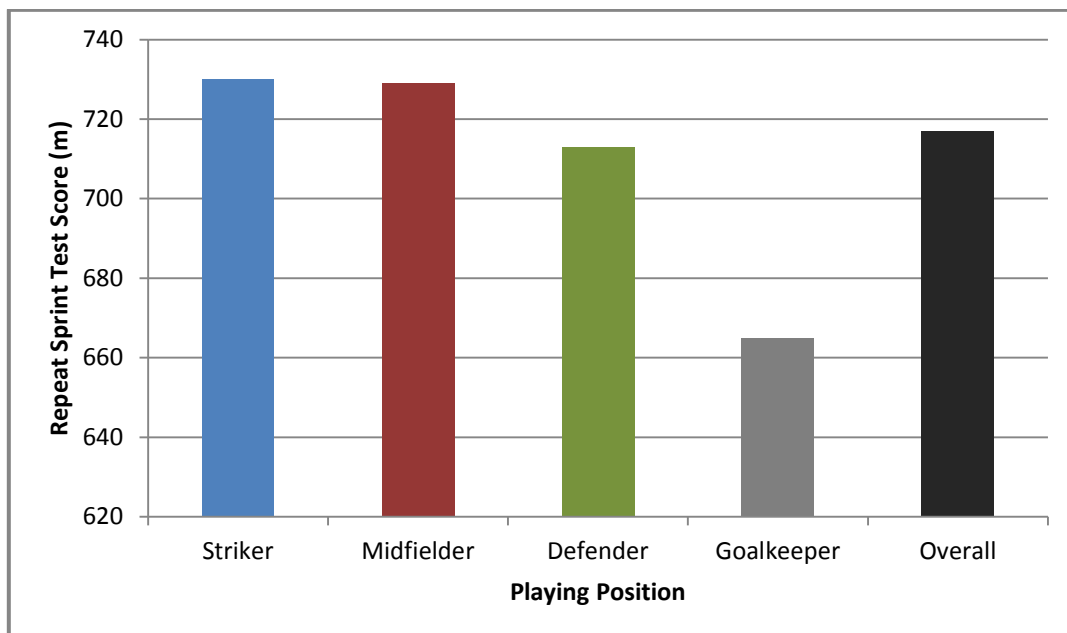


Figure 4.14: Mean repeated sprint test score by playing position

4.2.1.8 Sprint test

4.2.1.8.1 Ten metre (10 m) sprint

Figure 4.15 shows the individual 10 m sprint times for the players tested. No goalkeepers were tested. The overall mean score for the group tested (n=26) was 1.90 seconds. The mean scores for each position were: strikers (n=10) 1.91 seconds, midfielders (n=9) 1.88 seconds and defenders (n=7) at 1.92 seconds. These results are shown in Figure 4.16.

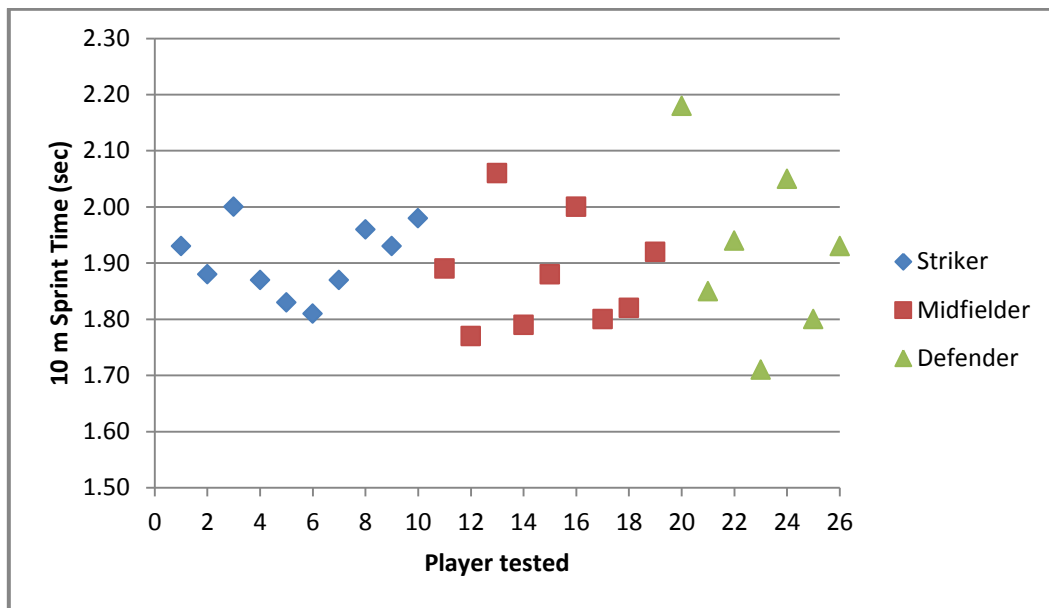


Figure 4.15: Individual 10 m sprint score

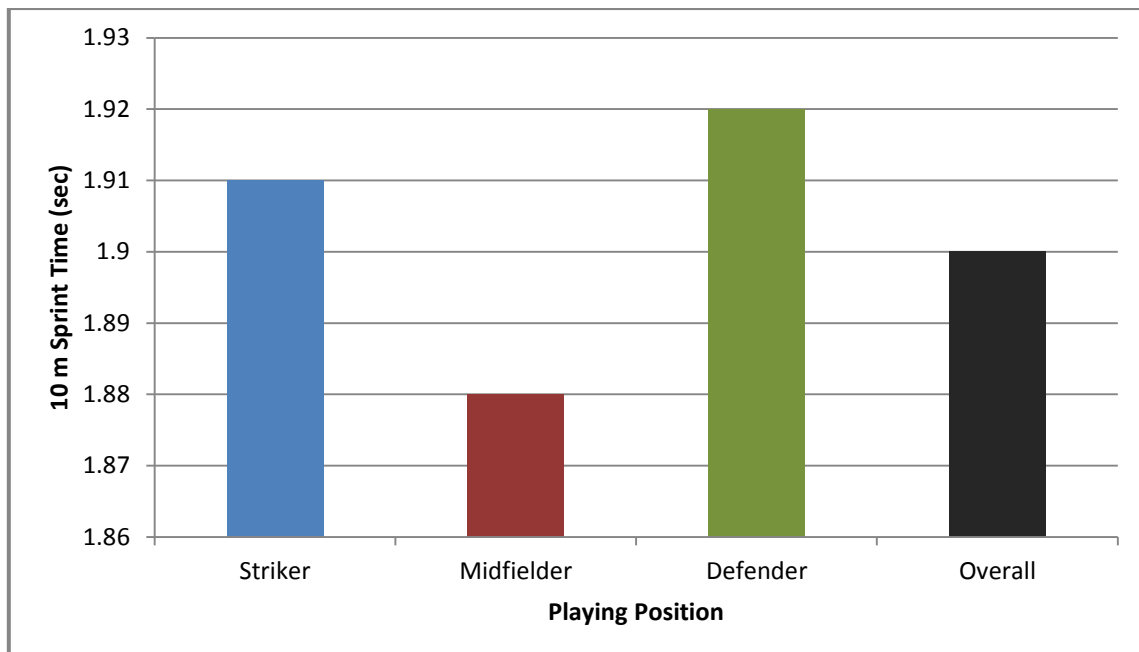


Figure 4.16: Mean 10 m sprint score by playing position

4.2.1.8.2 Forty metre (40 m) sprint

Figure 4.17 shows the individual players' 40 m sprint time. The overall mean for the group (n=26) was 5.94seconds. The positional mean times were: strikers (n=10) 5.91seconds, midfielders (n=9) 5.98seconds and defenders (n=7) 5.92 seconds. The goalkeepers were not tested on the 40 m sprint test.

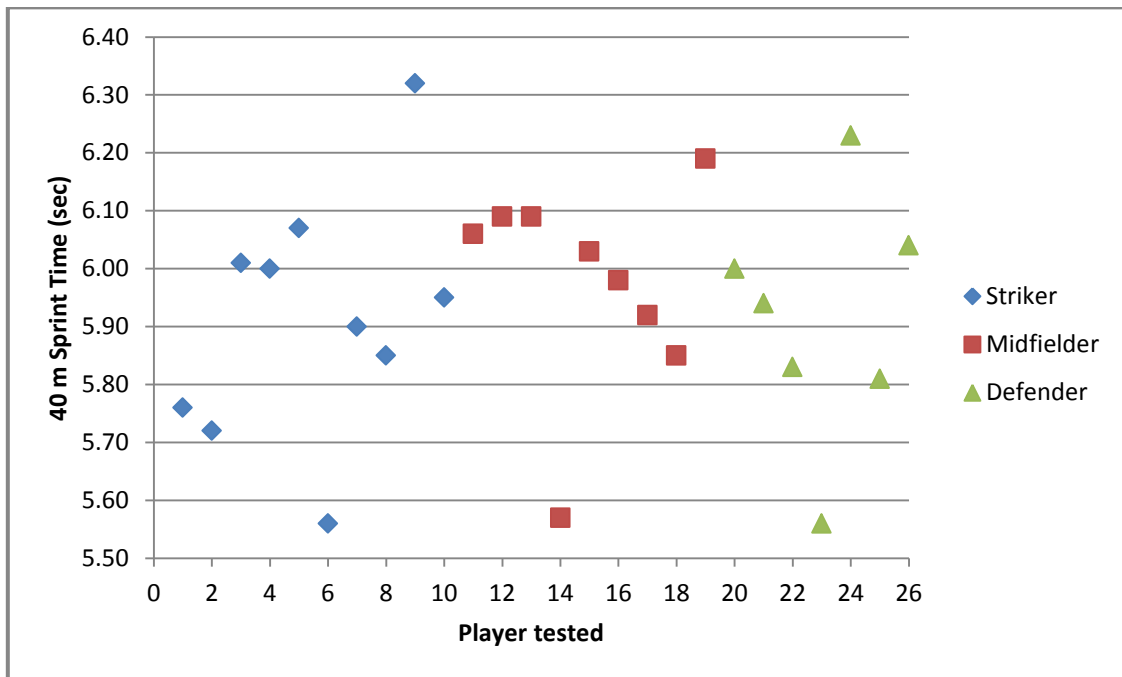


Figure 4.17: Individual 40 m sprint score

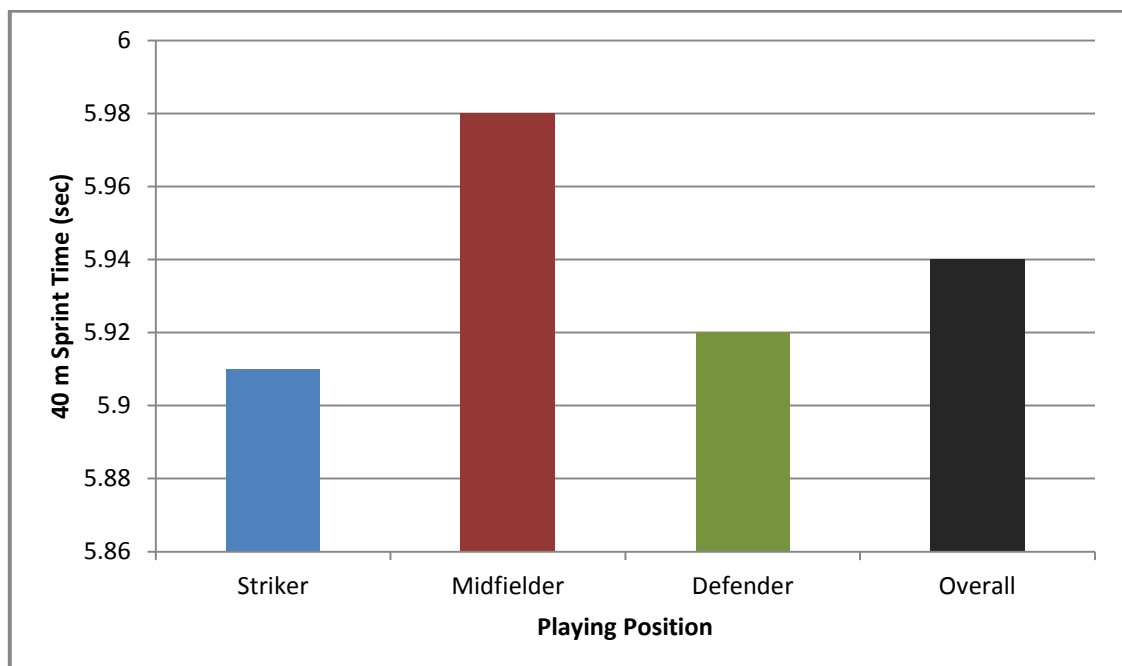


Figure 4.18: Mean 40 m sprint score by playing position

4.2.1.8.3 Forty metre (40 m) sprint time with hockey stick in hand

Figure 4.19 shows the individual players' 40 m sprint time with hockey stick in hand while performing the sprint. The overall mean for the group (n=26) was 6.67seconds. The positional mean times were: strikers (n=10) 6.61seconds, midfielders (n=9) 6.73seconds and defenders (n=6) 6.69seconds. These results are shown in Figure 4.20.

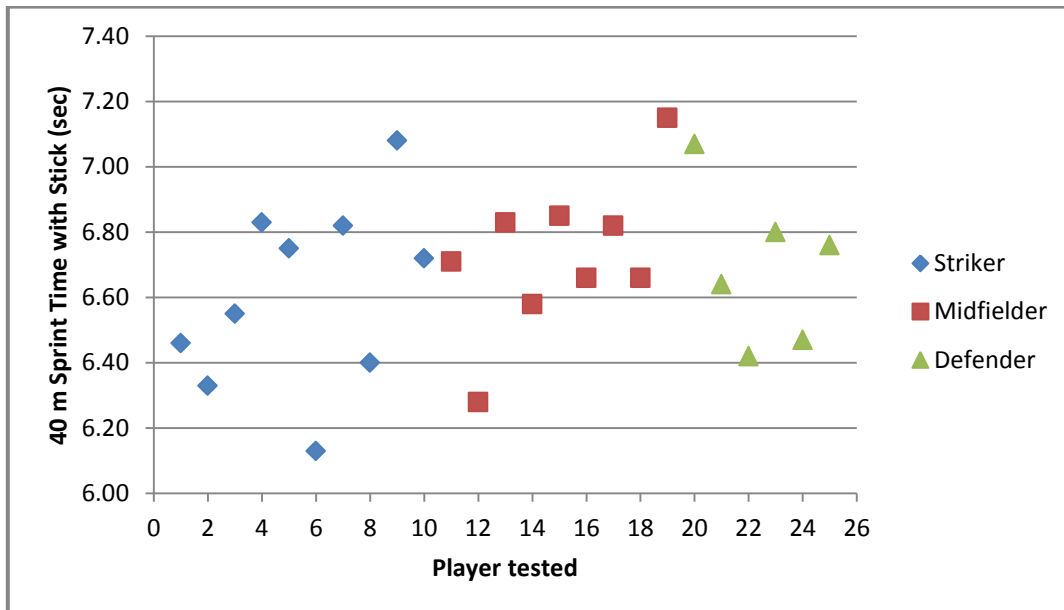


Figure 4.19: Individual 40 m sprint score (with hockey stick in hand)

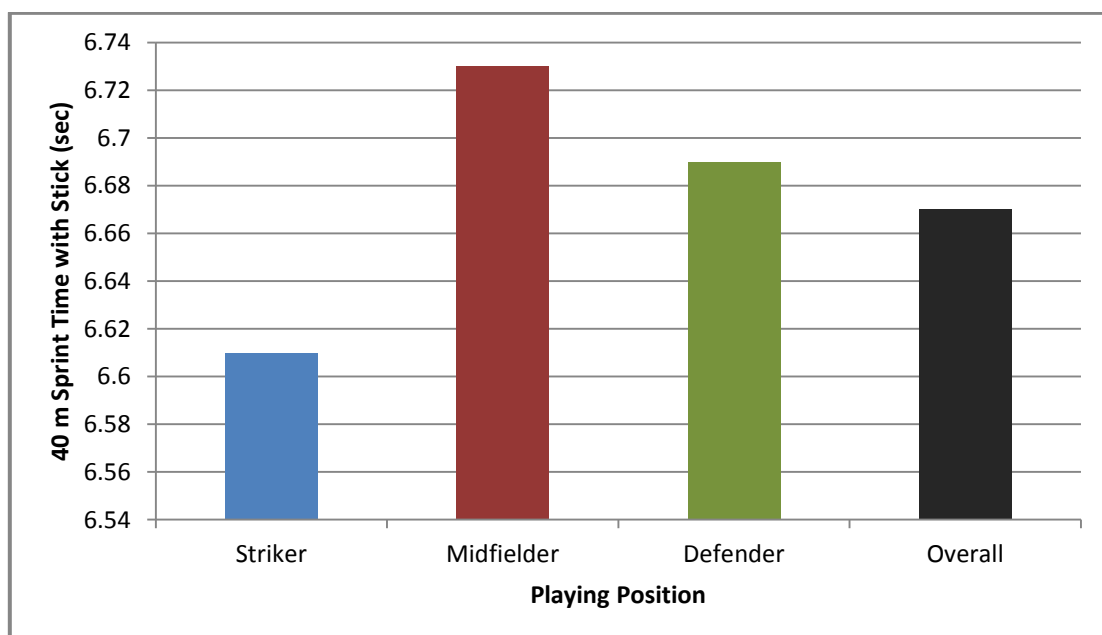


Figure 4.20: Mean 40 m sprint score (with hockey stick in hand) by playing position

4.2.1.9 Agility test

4.2.1.9.1 Illinois Agility Test

Figure 4.21 shows the individual results of the Illinois Agility Test. The overall mean for the group (n=26) was 15.54 seconds. The positional mean scores were: strikers (n=10) 15.46seconds, midfielders (n=9) 15.57seconds and defenders (n=7) 15.62seconds. These results are shown in Figure 4.22.

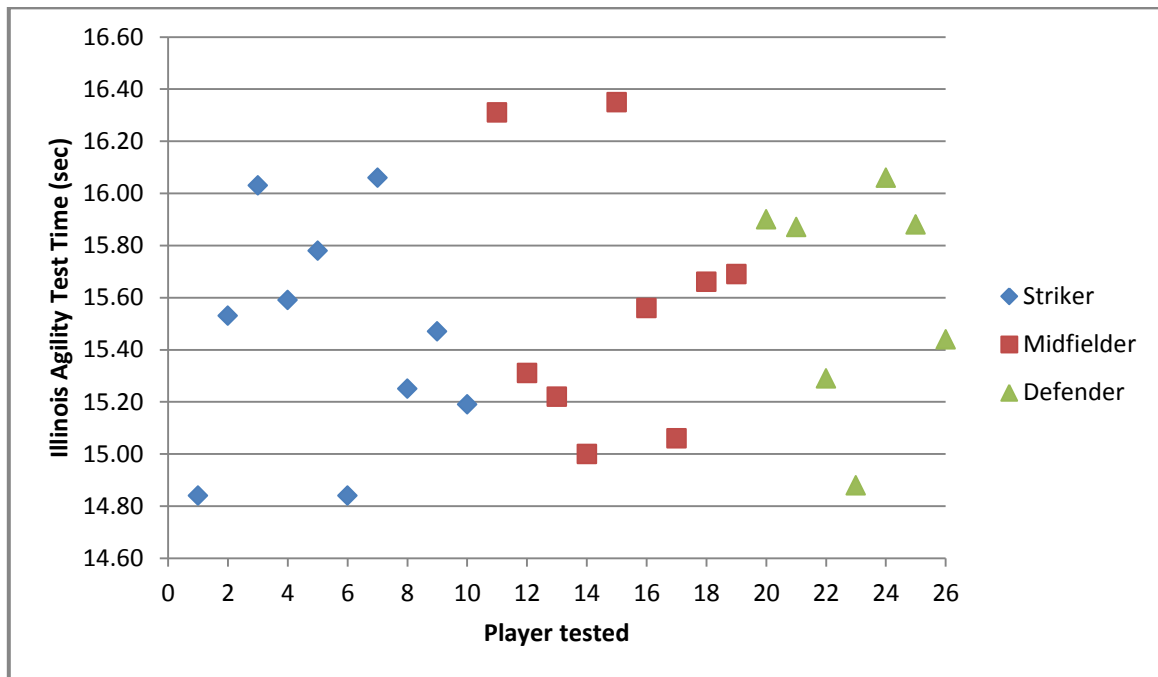


Figure 4.21: Individual Illinois Agility Test score

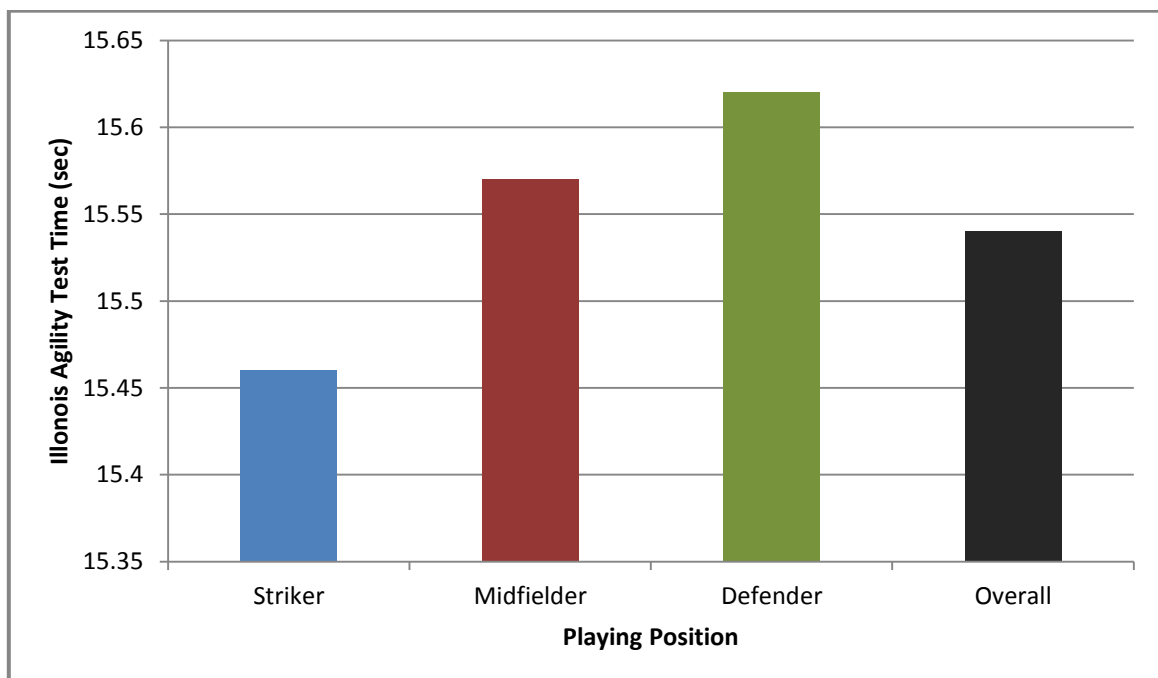


Figure 4.22: Mean Illinois Agility Test score by playing position

4.2.1.9.2 Illinois Agility Test with hockey stick in hand

Figure 4.23 shows the results of the Illinois Agility Test with the hockey stick in hand. The overall mean for the group (n=26) was 17.17seconds. The positional mean scores were: strikers (n=10) 17.01seconds, midfielders (n=9) 17.23seconds and defenders (n=6) 17.33seconds. These are represented in Figure 4.24.

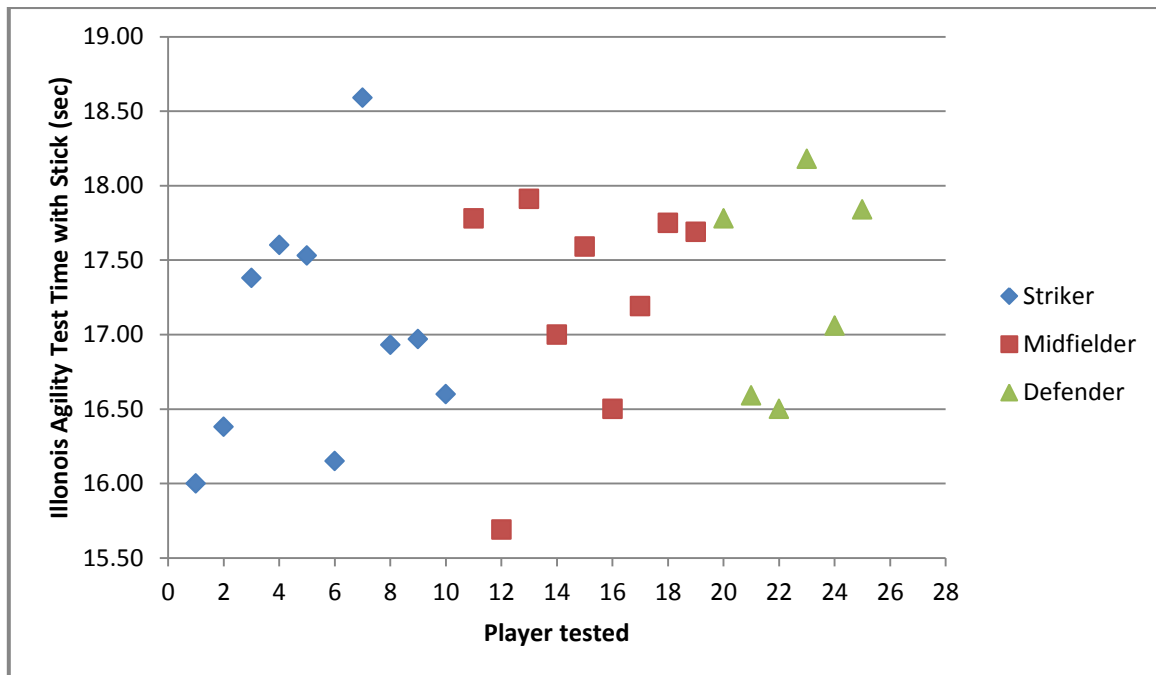


Figure 4.23: Individual Illinois Agility Test score (with hockey stick in hand)

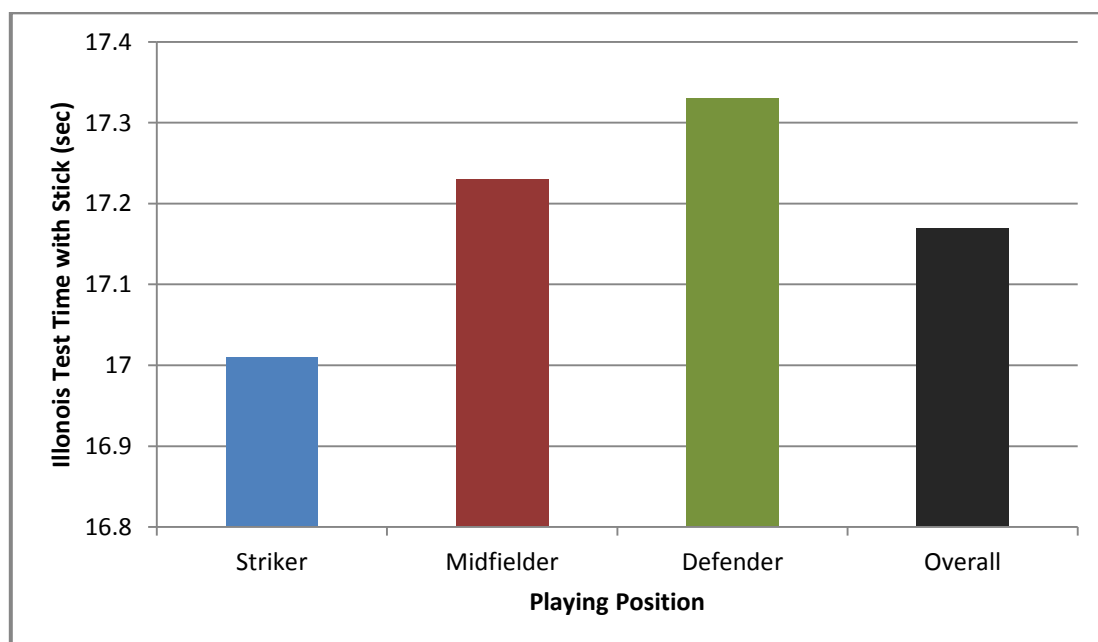


Figure 4.24: Mean Illinois Agility Test score (with hockey stick in hand) by playing position

4.2.1.10 Isokinetic testing of the ankle

Figure 4.25 shows the mean value of strength in the various ankle movements for the whole team. For plantar flexion, the mean score for the right legs of the players was 68.8 Nm, while for their left legs it was 70.3 Nm. For dorsiflexion, the mean score for the right legs of the players was 21.2 Nm while the mean score for their left legs was 17.1. Mean score for eversion of the right leg was 21.2 Nm and 17.7 Nm for the left leg of the players. For inversion, the mean score for the right and left legs was 23.9 Nm and 24.2 Nm respectively.

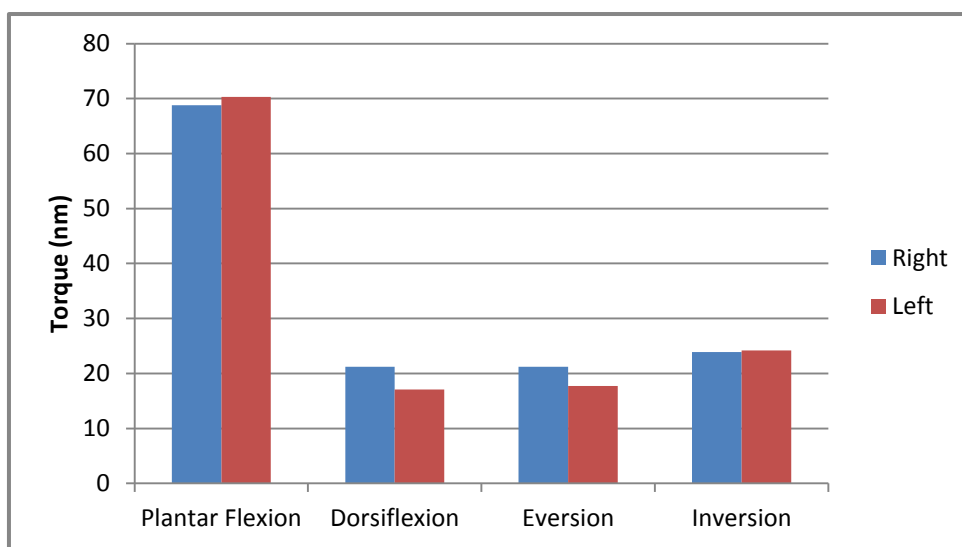


Figure 4.25: Mean ankle isokinetic strength score for various movements

4.2.1.11 Balance tests

Figure 4.26 shows the mean scores for the balance test for all the participants. For the anterior/posterior balance index the mean score obtained by all participants was 4.3. For the medial/lateral balance test, the mean balance index score was 3.3. The overall mean balance index score was 4.3.

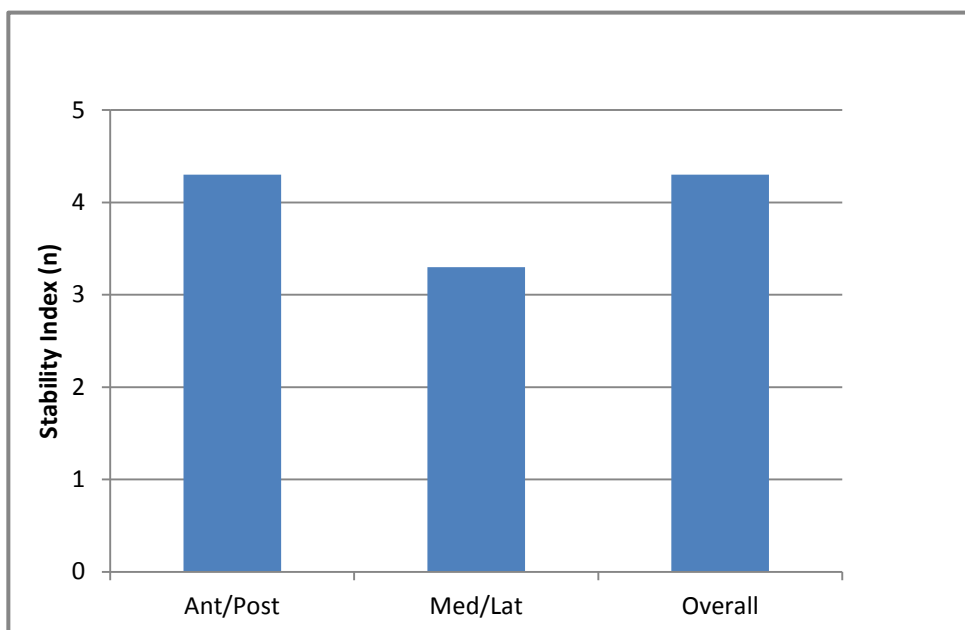


Figure 4.26: Mean balance index scores for all the participants

4.2.1.12 Pre-season variables

Table 4.1: Descriptive statistics for pre-season variables: Overall and by playing position

VARIABLE	SCORE	OVERALL	STRIKERS	MIDFIELDERS	DEFENDERS	GOALKEEPER
Age (yrs)	Mean	23.80	24.50	24.33	22.71	22.75
	STD	3.16	3.06	3.57	2.14	4.27
	Min/Max	20.00/31.00	20.00/31.00	20.00/31.00	20.00/26.00	20.00/ 29.00
Mass (kg)	Mean	62.56	61.10	61.78	62.24	68.53
	STD	8.45	6.14	10.37	5.88	12.79
	Min/Max	46.90/86.65	48.35/70.60	46.90/80.50	51.80/69.80	57.00/ 86.65
Height (cm)	Mean	164.52	164.70	164.28	163.14	167.00
	STD	5.24	4.14	6.46	5.24	5.89
	Min/Max	156.00/175.00	158.00/173.00	156.00/175.00	156.00/169.00	161.00/175.00
Sum of 7 (n)	Mean	83.83	80.35	82.00	84.43	95.63
	STD	18.06	15.07	16.28	13.99	33.71
	Min/Max	60.00/143.50	60.00/105.50	61.00/112.00	66.00/101.50	67.00/143.50
Body Fat (%)	Mean	15.60	15.12	15.34	15.71	17.23
	STD	2.56	2.15	2.33	1.90	4.80
	Min/Max	12.25/24.09	12.25/18.91	12.56/19.60	13.10/17.74	13.26/24.09
Sit/Reach (cm)	Mean	42.33	40.06	42.89	44.81	42.43
	STD	8.36	8.96	7.33	7.88	11.61
	Min/Max	25.00/54.20	25.00/54.50	31.00/53.00	32.00/ 53.50	26.70/53.00
Vertical Jump (cm)	Mean	43.98	43.90	41.72	48.21	41.88
	STD	2.29	5.79	3.58	5.77	2.43
	Min/Max	36.00/57.00	36.00/54.00	38.00/48.00	42.00/57.00	39.50/45.00
Illinois Run (s)	Mean	15.54	15.46	15.57	15.62	
	STD	0.44	0.43	0.49	0.43	
	Min/Max	14.84/16.35	14.84/16.06	15.00/ 16.35	14.88/16.06	
Illinois Run with Stick(s)	Mean	17.17	17.01	17.23	17.33	
	STD	0.73	0.79	0.74	0.71	
	Min/Max	15.69/18.59	16.00/18.95	15.69/17.91	16.50/18.18	
T Test (sec)	Mean	11.89				11.89
	STD	0.63				0.63
	Min/Max	11.31/12.65				11.31/12.65
Speed 10m (sec)	Mean	1.90	1.91	1.88	1.92	
	STD	0.10	0.06	0.10	0.16	
	Min/Max	1.71/2.18	1.81/2.00	1.77/2.06	1.71/2.18	
Speed 40m (sec)	Mean	5.94	5.91	5.98	5.92	
	STD	0.20	0.21	0.18	0.21	
	Min/Max	5.56/6.32	5.56/6.32	5.57/6.19	5.56/6.23	

VARIABLE		OVERALL	STRIKERS	MIDFIELDERS	DEFENDERS	GOALKEEPER
Speed 40m w/Stick (s)	Mean	6.67	6.61	6.73	6.69	
	STD	0.25	0.28	0.24	0.24	
	Min/Max	6.13/7.15	6.13/7.08	6.28/7.15	6.42/7.07	
Speed 2m (s)	Mean	0.48				0.48
	STD	0.03				0.03
	Min/Max	0.43/0.50				0.43/0.50
Speed 5m (s)	Mean	1.10				1.10
	STD	0.06				0.06
	Min/Max	1.01/1.16				1.01/1.16
Speed 10m (s)	Mean	1.88				1.88
	STD	0.10				0.10
	Min/Max	1.79/1.97				1.79/1.97
Strength Bench (%)	Mean	0.77	0.77	0.73	0.82	0.78
	STD	0.08	0.07	0.07	0.07	0.13
	Min/Max	0.63/0.95	0.66/0.93	0.63/0.81	0.72/0.92	0.63/0.95
Strength Leg Press (%)	Mean	3.98	4.00	4.15	4.07	3.36
	STD	0.62	0.54	0.64	0.65	0.49
	Min/Max	2.88/5.23	3.27/4.78	3.20/5.23	3.22/5.04	2.88/3.87
Repeat Sprint (m)	Mean	717.28	730.40	728.89	713.17	664.50
	STD	47.43	16.73	18.49	67.47	83.25
	Min/Max	540.00/773.00	709.00/763.00	706.00/753.00	582.00/773.00	540.00/715.00
Plantar flexion R (Nm)	Mean	68.83	71.06	64.32	71.13	69.93
	STD	20.64	25.54	16.28	21.90	20.52
	Min/Max	32.80/109.30	32.80/109.30	42.70/89.30	37.60/96.90	42.90/86.90
Plantar flexion L (Nm)	Mean	70.33	72.25	65.74	73.10	71.68
	STD	22.27	26.57	24.27	19.10	15.41
	Min/Max	28.90/119.70	28.90/119.70	35.70/101.70	51.20/98.40	55.30/88.10
Plantar Deficit (%)	Mean	10.84	8.53	15.86	4.78	14.40
	STD	9.52	5.65	11.57	2.64	14.04
	Min/Max	0.70/42.50	0.70/17.20	5.00/42.50	1.20/8.30	6.50/35.40
Dorsi flexion R (Nm)	Mean	21.22	22.09	19.98	18.37	26.10
	STD	9.72	15.03	4.34	3.43	8.90
	Min/Max	10.30/63.80	10.30/63.80	14.80/26.70	14.10/23.10	19.90/39.30
Dorsi flexion L (Nm)	Mean	17.13	15.36	16.91	17.55	21.45
	STD	5.12	4.08	4.95	6.77	4.11
	Min/Max	8.20/29.50	8.20/21.30	12.40/25.30	10.70/29.50	17.20/26.60
Dorsi flexion Deficit (%)	Mean	11.92	12.99	10.99	7.53	17.90
	STD	9.10	9.40	5.80	4.79	16.94
	Min/Max	0.20/42.40	2.50/33.20	1.80/18.20	0.20/14.80	5.60/42.40

VARIABLE		OVERALL	STRIKERS	MIDFIELDERS	DEFENDERS	GOALKEEPER
Ankle eversion R (Nm)	Mean	21.17	19.83	22.31	22.15	20.48
	STD	5.14	5.18	6.23	3.33	5.65
	Min/Max	14.00/31.60	14.00/31.20	15.20/31.60	18.10/25.90	14.50/26.50
Ankle eversion L (Nm)	Mean	17.65	16.28	17.54	20.98	16.33
	STD	4.27	3.14	4.61	4.07	5.00
	Min/Max	11.10/28.20	12.30/22.10	12.10/28.20	15.30/25.50	11.10/22.90
Ankle eversion Deficit (%)	Mean	10.73	13.86	14.38	2.72	6.73
	STD	12.06	11.56	14.09	10.30	5.23
	Min/Max	-0.32	0.90/34.20	2.20/45.70	-0.86	1.70/13.90
Ankle inversion R (Nm)	Mean	23.89	21.49	24.72	28.03	21.78
	STD	7.92	6.48	10.73	6.53	4.46
	Min/Max	12.10/49.50	12.10/32.90	14.40/49.50	19.90/36.00	18.20/28.30
Ankle inversion L (Nm)	Mean	24.23	23.85	23.78	27.95	20.65
	STD	7.64	8.48	9.88	2.49	3.63
	Min/Max	5.20/41.80	5.20/37.10	12.20/41.80	25.30/31.30	18.20/26.00
Ankle inversion Deficit (%)	Mean	9.59	8.74	11.30	10.97	5.80
	STD	6.81	6.57	7.62	7.44	4.75
	Min/Max	-0.23	-0.27	2.00/23.00	4.40/22.80	1.40/11.30
Balance Ant/Post (n)	Mean	4.26	4.27	4.13	4.10	4.80
	STD	1.74	2.12	1.80	1.63	1.10
	Min/Max	1.30/9.10	2.60/9.10	2.20/8.10	1.30/ 5.80	3.80/5.90
Balance Med/Lat (n)	Mean	3.35	3.00	2.96	3.46	4.90
	STD	1.43	1.70	0.51	1.59	1.09
	Min/Max	1.10/7.20	1.10/7.20	2.40/4.20	1.20/5.30	3.90/6.20
Balance Overall (n)	Mean	4.33	4.37	3.54	4.51	5.68
	STD	2.06	2.87	1.26	1.82	1.02
	Min/Max	1.70/11.40	2.60/11.40	2.20/5.70	1.70/6.60	4.40/6.90

*The blank cells indicate positions and variables for which there were no data

Table 4.1 shows that there were no notable differences when comparing between the playing positions.

4.3 Injury incidence in different anatomical locations

In total, 87 injuries were reported by the 30 players during the 2011-2012 field hockey season, which is an incidence of 2.9 injuries per player per season. The number of injuries during this season, classified by anatomical region injured, is presented in Figure 4.27. The highest overall incidence of injury (16.1%) occurred in the ankle (n=14), followed by the back of the thigh 12.6% (n=11), and the lower back 10.3% (n=9) respectively. Besides injuries to the anatomical regions specified in Figure 4.27, three facial injuries (two of the nose and one of the eye) were also reported. No concussion injuries were reported during this field hockey season.

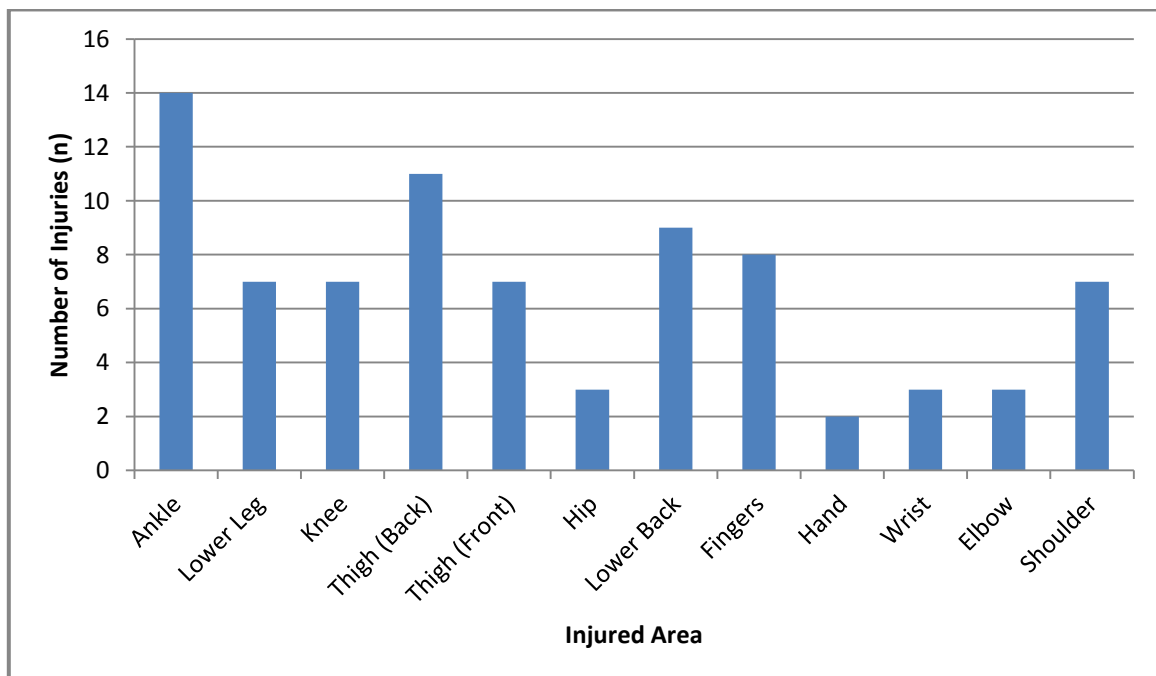


Figure 4.27: Number of injuries and anatomical location in national female field hockey players (n=30) during the 2011-2012 field hockey season

4.3.1 Injury incidence and playing position

An indication of the incidence of injuries for each region of the body by playing position is presented in Figure 4.28. Figure 4.29 shows the incidence of injuries sustained by the different playing positions. Overall, the midfielders had the highest incidence of injury (3.4 injuries/athlete/year), including the highest percentage of back thigh (hamstring) injuries (45%), and the second highest percentage of ankle injuries (36%). The strikers accounted for the second highest incidence of injuries (2.8 injuries/athlete/year) including the highest percentage of ankle injuries (50%), and the highest percentage of front thigh (quadriceps) injuries 57% (n=4). This was followed by the defenders who produced an injury incidence rate of 2.4 injuries/athlete/year and, finally, the goalkeepers with 1.3 injuries/athlete/year.

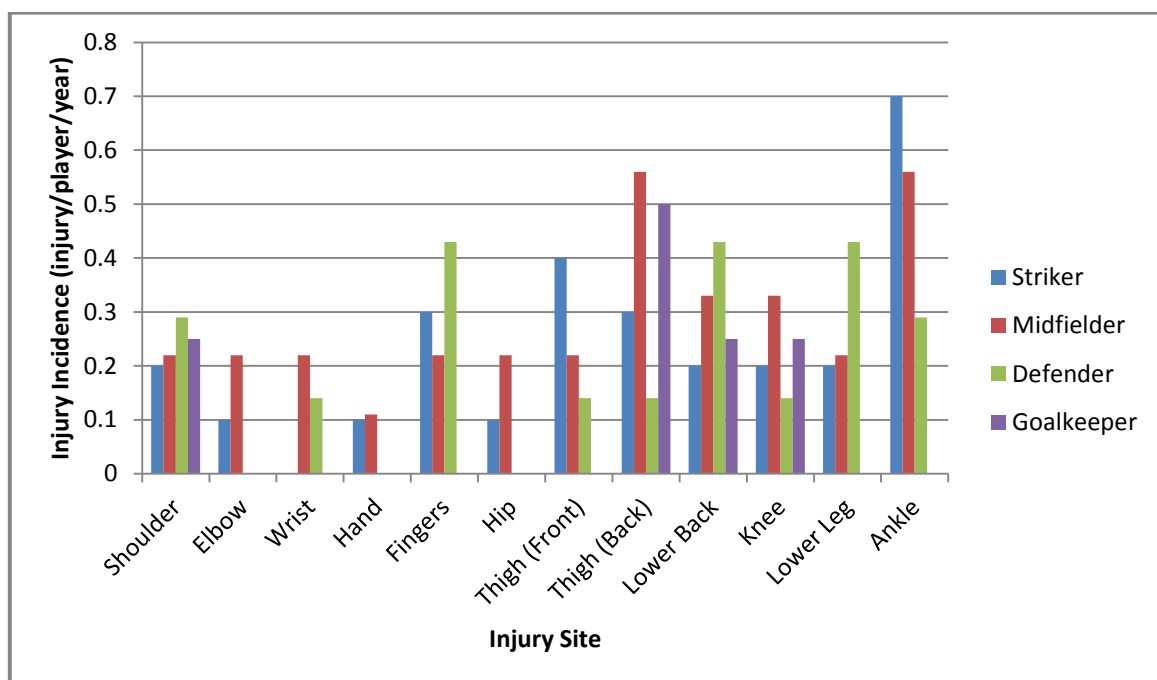


Figure 4.28: Incidence of injury by anatomical location and playing position

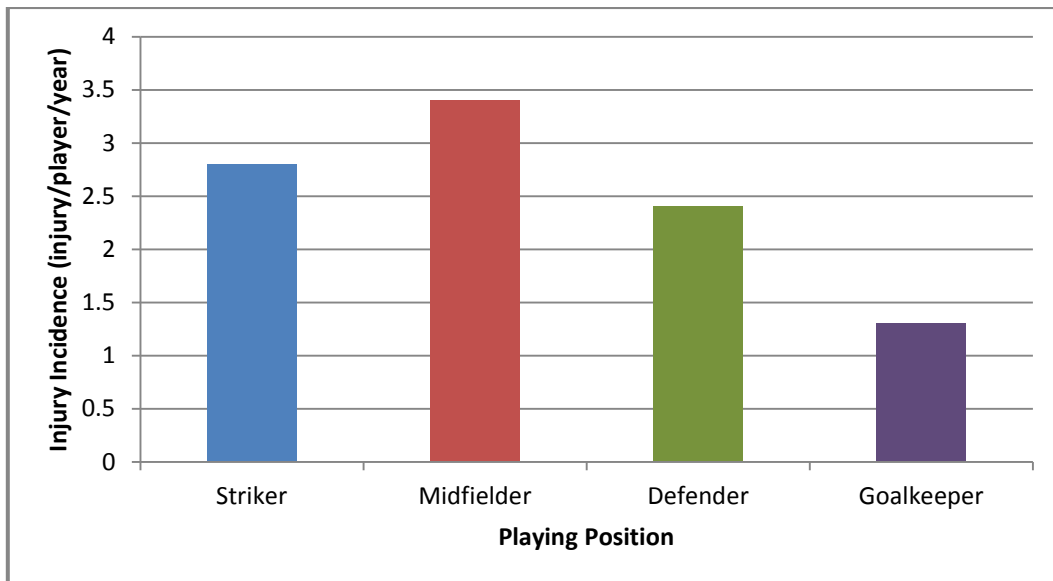


Figure 4.29: Overall incidence of injury by playing position

4.3.2 Time of injury occurrence

Figure 4.30 displays when the injuries sustained in the 2011-2012 season occurred. Of these injuries, 33% (n=29) were reported to have occurred during a training session, while 67% (n=58) occurred during a match. In terms of injuries occurring during a match, 35% (n=20) were reported to have occurred in the first half of the match, while 65% (n=38) occurred in the second half.

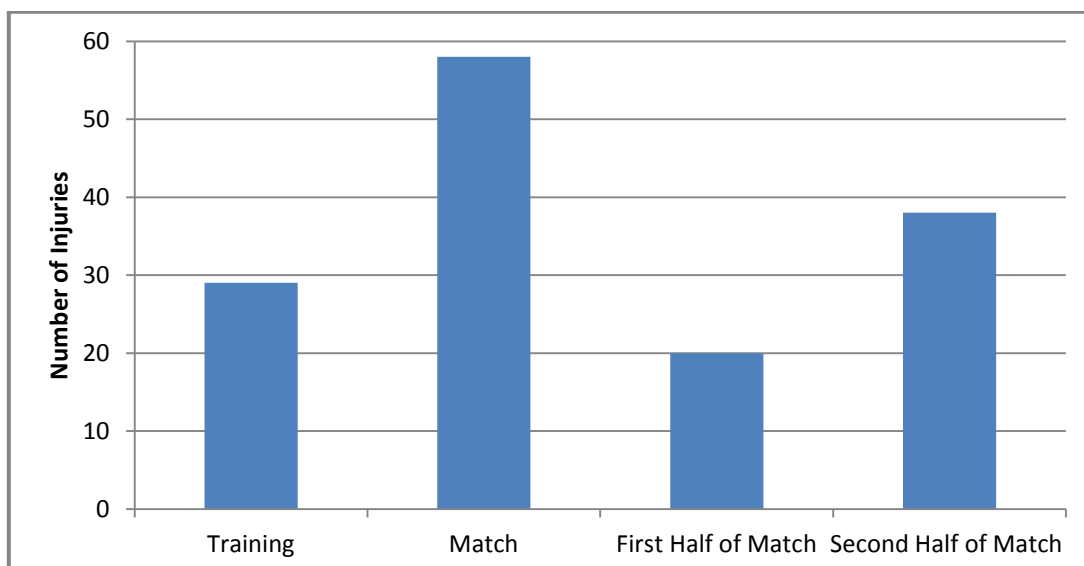


Figure 4.30: Time of play that injury was sustained.

4.3.3 Mechanism of injury

The mechanisms of injury, as described by the players, were classified into falls, struck by ball, struck by stick, player contact, and overuse injuries. The percentage of injuries sustained due to each of these mechanisms is presented in Figure 4.31. The highest percentage of injuries (29.89%) was due to a fall, while overuse injuries were described by seven players (8.05% of all injuries).

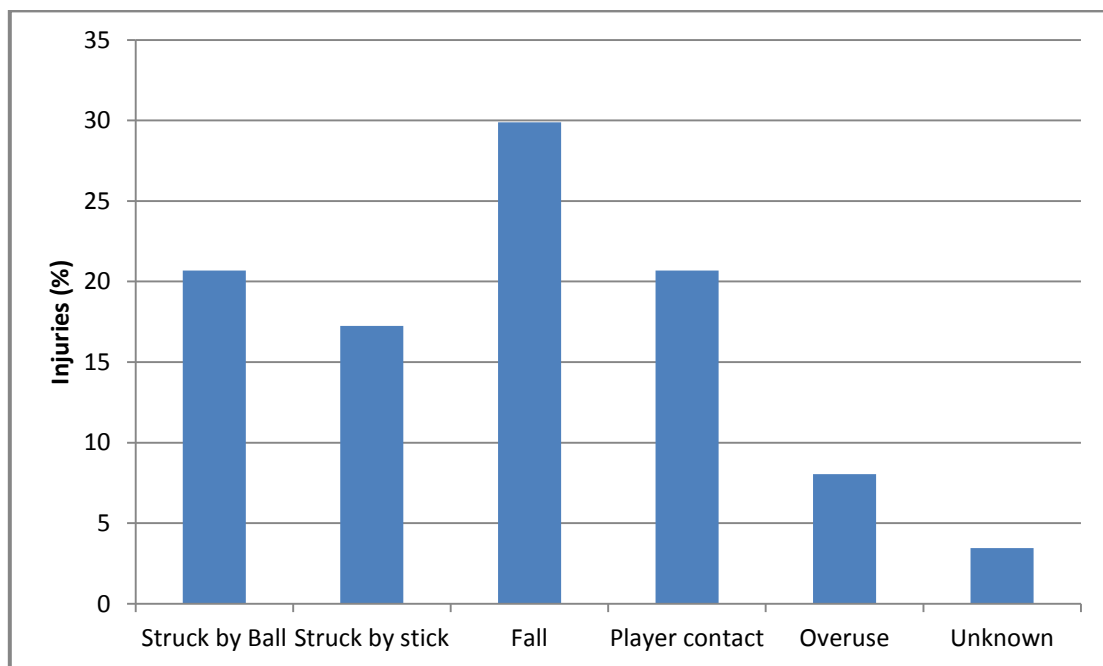


Figure 4.31: Mechanism of injuries sustained during the 2011-2012 season

4.3.4 Severity of injury

Severity of the injury was related to time lost from playing the game and is presented in Figure 4.32. Mild injuries (RTP within 7 days of injury) accounted for 45% (n=39) of the injuries, while transient injuries (RTP within 3 days of injury) accounted for 35% (n=31) of the injuries, moderate injuries (RTP within 10 days of injury) for 13% (n=11) and only 7% (n=6) sustained severe injuries (RTP within longer than 10 days).

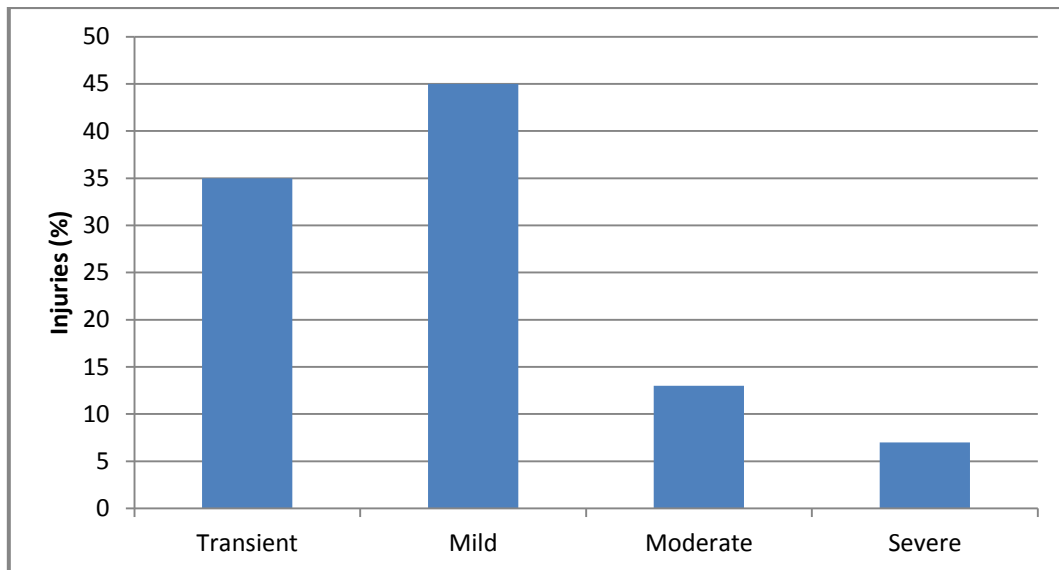


Figure 4.32: Severity of injuries sustained during the 2011-2012 season

4.3.5 Type of injury sustained

The type of injuries sustained is presented in Figure 4.33. The most common type of injury was a ligament sprain accounting for 40% (n=35) of total injuries, followed by strains at 32% (n=28) and lacerations at 20% (n=18). Most sprains occurred to the ankle and knees, while most strains involved the hamstring, quadriceps and lower back muscles. Most lacerations were to the face, hand and fingers. Of the remaining 7% of the injuries, 2% (n=2) were fractures, 1% (n=1) were dislocations, 1% (n=1) were subluxations and 2% (n=2) were ruptures.

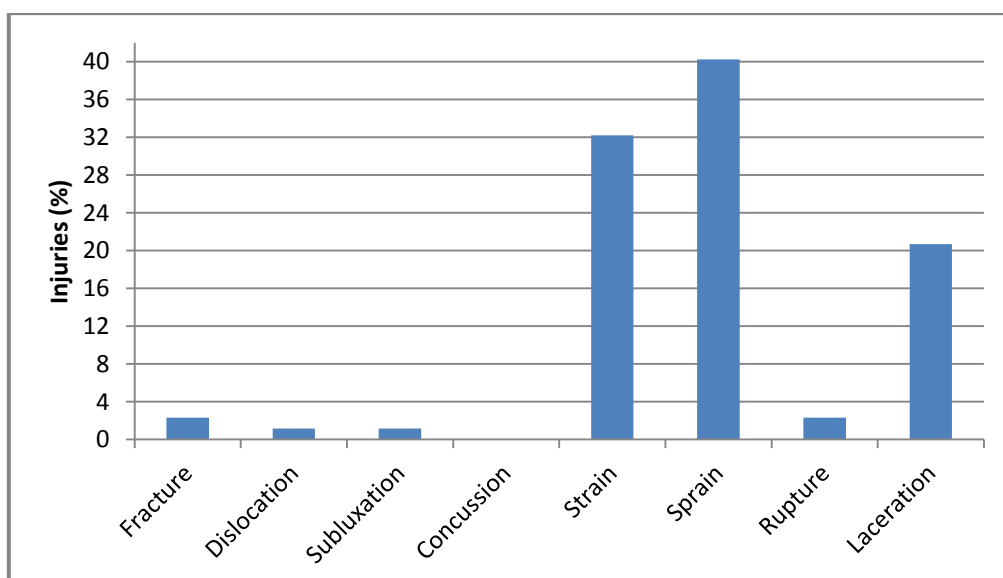


Figure 4.33: Types of injury sustained during the 2011-2012 field hockey season

4.3.6 Injury management

Most of the injuries required some attention from the medical personnel. Figure 4.34 shows that 64% of the injuries required physiotherapy treatment, 23% needed medical attention from the doctor, 11% needed rehabilitation for their injuries and 2% required surgical intervention.

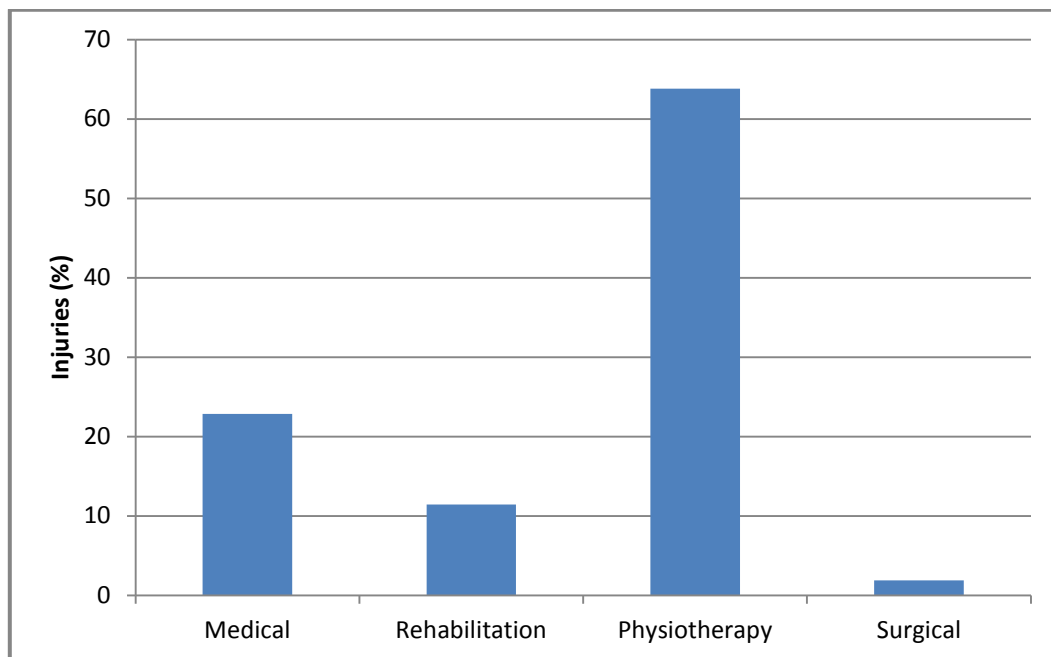


Figure 4.34: Injury management during the 2011-2012 Field hockey seasons.

4.4 Predictors of injury

One of the main goals of the study was to investigate if variables measured in the pre-season can predict injuries during the playing in-season. Both univariate and multivariate logistic regression were used to identify potential predictors of injury.

4.4.1 Univariate logistic regression: Potential predictors of injury

4.4.1.1 Ankle injuries

Table 4.2: Association of variables tested in pre-season with ankle injuries

Variable	Likelihood ratio statistic (DF=1)	P-value	Odds ratio	95% CI
Mass (kg)	0.0173	0.8954	1.006	0.920 to 1.101
Height (m)	0.2302	0.6314	0.966	0.833 to 1.112
Sum of 7 Skinfolds (n)	0.2317	0.6302	1.010	0.969 to 1.056
Fat Percentage (%)	0.1972	0.6570	1.067	0.797 to 1.458
Sit and Reach (cm)	1.3293	0.2489	1.054	0.964 to 1.165
Vertical Jump (cm)	0.4790	0.4889	0.952	0.816 to 1.094
Illinois Run (s)	1.7093	0.1911	0.292	0.036 to 1.820
Illinois Run w/Stick (s)	2.0322	0.1540	0.430	0.110 to 1.356
Strength Bench (%)	1.3914	0.2382	0.004	<0.001 to 34.389
StrengthLeg Press (%)	0.1995	0.6551	0.763	0.219 to 2.512
Repeat Sprint (m)	0.0983	0.7539	1.003	0.986 to 1.022
Plantar flexion R (Nm)	1.6987	0.1925	1.025	0.988 to 1.069
Plantar flexion L (Nm)	2.4446	0.1179	1.028	0.993 to 1.072
Plantar Deficit (%)	1.6555	0.1982	1.056	0.973 to 1.181
Dorsiflexion R (Nm)	0.4129	0.5205	1.026	0.947 to 1.140
Dorsiflexion L (Nm)	13.9506	0.0002	0.663	0.465 to 0.848
Dorsiflexion Deficit (%)	4.9087	0.0267	1.124	1.012 to 1.316
Ankle inversion R (Nm)	0.959	0.3274	1.049	0.953 to 1.174
Ankle inversion L (Nm)	2.3707	0.1236	1.086	0.979 to 1.232
InversionDeficit (%)	2.0689	0.1503	1.088	0.971 to 1.245
Ankle eversion R (Nm)	1.9607	0.1614	1.112	0.959 to 1.316
Ankle eversion L (Nm)	1.7299	0.1884	0.884	0.712 to 1.060
Eversion Deficit (%)	8.5153	0.0035	1.133	1.035 to 1.291
Ant/PostBalance (n)	3.9644	0.0465	0.611	0.322 to 0.993
Med/LatBalance (n)	29.3391	<.0001	0.004	<0.001 to 0.114
OverallBalance (n)	41.4169	<.0001	<0.001	0.0 to 0.078

($p < 0.05$) is statistically significant

Table 4.2 indicates that for ankle muscle strength, dorsiflexion of the left foot was a significant predictor of injury ($p=0.0002$) together with dorsiflexion deficit ($p=0.0267$) and ankle eversion deficit ($p=0.0035$). All movements of balance i.e. anterior/posterior ($p=0.0465$), medial/lateral ($p<0.0001$) and overall ($p<0.0001$) were also highly significant predictors of injury.

Figure 4.35 shows the mean values for ankle movements of players (who sustained ankle injuries) comparing the injured and uninjured legs. The injured ankles were weaker with the movements of ankle eversion and ankle dorsiflexion. Figure 4.36

shows the mean values of balance scores for the players that sustained ankle injuries and those that did not sustain ankle injuries. The players that sustained ankle injuries were weaker on balance scores for both anterior/posterior movements as well as medial/lateral movements, when compared to those that did not have ankle injuries.

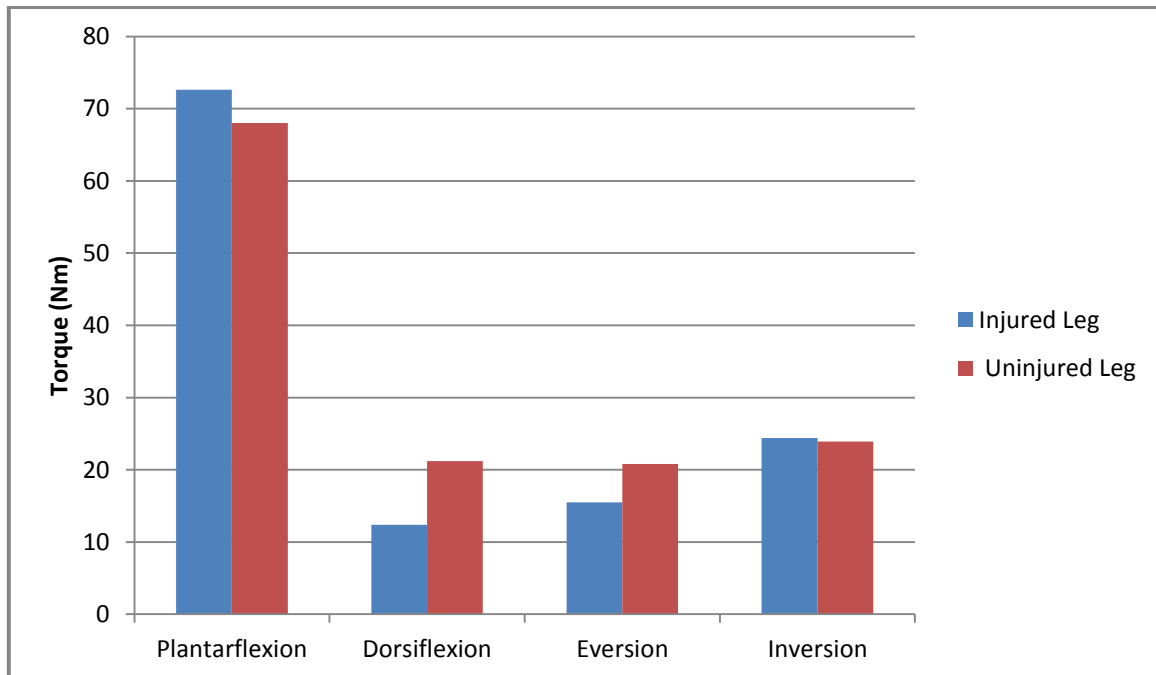


Figure 4.35: Mean values of injured and uninjured legs of players with ankle injuries

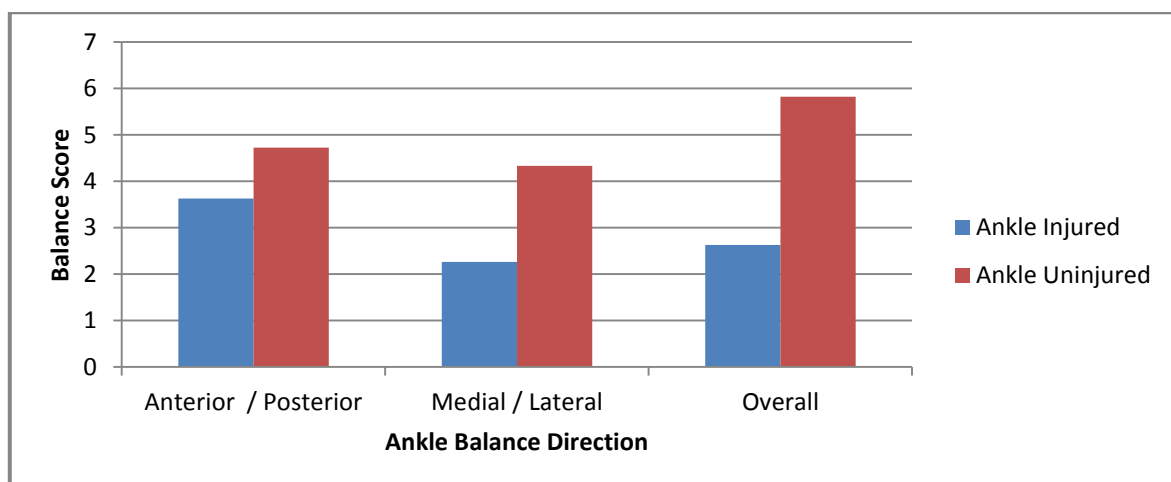


Figure 4.36: Mean balance scores of players with and without ankle injuries

4.4.1.2 Lower leg injuries

Lower leg injuries comprise all injuries to the knee and lower leg area.

Table 4.3: Association of variables tested in pre-season with lower leg injuries

Variable	Likelihood ratio statistic (DF=1)	P-value	Odds ratio	95% CI
Mass (kg)	0.0537	0.8167	0.990	0.900 to 1.082
Height (cm)	2.3567	0.1247	0.888	0.741 to 1.032
Sum of 7 Skinfolds (n)	0.3307	0.5652	1.012	0.971 to 1.058
Fat percentage (%)	0.2866	0.5924	1.082	0.804 to 1.481
Sit and Reach (cm)	0.7008	0.4025	1.040	0.950 to 1.149
Vertical Jump (cm)	0.0167	0.8971	0.991	0.853 to 1.142
Illinois Run (s)	2.6787	0.1017	4.892	0.740 to 46.150
Illinois Run with Stick (s)	2.4980	0.1140	2.580	0.850 to 10.515
Strength Bench Press (%)	0.7761	0.3783	59.031	0.007 to >999.999
Strength Leg Press (%)	0.0632	0.8015	1.167	0.343 to 4.025
Repeat Sprint (m)	0.0002	0.9891	1.000	0.984 to 1.019
Plantar flexion R (Nm)	0.0889	0.7655	0.994	0.958 to 1.032
Plantar flexion L (Nm)	0.1305	0.7180	0.994	0.959 to 1.028
Plantar Deficit (%)	1.8342	0.1756	1.059	0.976 to 1.182
Dorsiflexion R (Nm)	0.2801	0.5966	0.978	0.868 to 1.060
Dorsiflexion L (Nm)	0.2263	0.6343	0.965	0.822 to 1.119
Dorsiflexion Deficit (%)	0.0065	0.9358	0.997	0.909 to 1.085
Ankle inversion R (Nm)	1.4582	0.2274	1.062	0.964 to 1.194
Ankle inversion L (Nm)	2.7583	0.0967	1.095	0.985 to 1.249
Inversion Deficit (%)	5.0035	0.0253	1.152	1.016 to 1.357
Ankle eversion R (Nm)	0.3183	0.5726	1.043	0.900 to 1.215
Ankle eversion L (Nm)	0.1477	0.7007	1.035	0.865 to 1.243
Eversion Deficit (Nm)	4.3105	0.0379	1.078	1.004 to 1.185
Ant/Post Balance (n)	4.0524	0.0441	0.590	0.292 to 0.988
Med/Lat Balance (n)	0.7239	0.3949	0.791	0.426 to 1.345
Overall Balance (n)	1.8089	0.1785	0.756	0.457 to 1.124

p < 0.05 is statistically significant

Table 4.3 shows that ankle inversion deficit (p=0.0253), ankle eversion deficit (p=0.0379) and anterior/posterior balance (p=0.0441) were found to be significant predictors of lower leg injuries. Inversion of the left ankle (p=0.0967) was found to be a borderline predictor of lower leg injuries. Since the odds ratios for inversion deficit, ankle eversion deficit, and ankle inversion are larger than one, increasing values of these variables are associated with increased odds (or risk) of injury; in contrast, the odds ratio for anterior/posterior balance is smaller than one, which implies that decreasing values of this variable are associated with increased odds of injury.

4.4.1.3 Thigh injuries

Thigh injuries comprise all injuries to the front and back of the thigh.

Table 4.4: Association of variables tested in pre-season with thigh injuries

Variable	Likelihood ratio statistic (DF=1)	P-value	Odds ratio	95% CI
Mass (kg)	0.0970	0.7554	1.014	0.928 to 1.112
Height (cm)	0.0003	0.9859	0.999	0.866 to 1.152
Sum of 7 Skinfolds (n)	0.0513	0.8209	0.995	0.953 to 1.038
Fat Percentage (%)	0.0249	0.8747	0.977	0.721 to 1.312
Sit and Reach (cm)	0.1428	0.7055	0.983	0.898 to 1.074
Vertical Jump (cm)	0.9482	0.3302	0.932	0.796 to 1.072
Illinois Run (s)	0.0267	0.8702	0.862	0.137 to 5.268
Illinois Run with Stick (s)	0.0074	0.9316	0.953	0.307 to 2.920
Strength Bench (%)	0.0080	0.9285	1.495	<0.001 to >999.999
Strength Leg Press (%)	0.1904	0.6626	1.301	0.396 to 4.500
Repeat Sprint (m)	0.0746	0.7847	0.998	0.979 to 1.014
Plantar flexion R (Nm)	0.0552	0.8143	0.996	0.959 to 1.033
Plantar flexion L (Nm)	0.1626	0.6868	0.993	0.959 to 1.027
Plantar Deficit (%)	1.6745	0.1957	1.059	0.973 to 1.196
Dorsiflexion R (Nm)	1.5114	0.2189	1.062	0.970 to 1.246
Dorsiflexion L (Nm)	0.0180	0.8931	0.990	0.852 to 1.148
Dorsiflexion Deficit (Nm)	1.1187	0.2902	1.048	0.963 to 1.171
Ankle inversion R (Nm)	0.0059	0.9388	1.004	0.911 to 1.109
Ankle inversion L (Nm)	0.2828	0.5949	0.974	0.876 to 1.074
Inversion Deficit (%)	1.1060	0.2929	1.062	0.950 to 1.207
Ankle eversion R (Nm)	0.0029	0.9569	0.996	0.859 to 1.154
Ankle eversion L (Nm)	3.5417	0.0598	0.834	0.660 to 1.007
Eversion Deficit (%)	2.1817	0.1397	0.951	0.875 to 1.016
Anter/Post Balance (n)	0.0554	0.8139	1.052	0.685 to 1.640
Med/Lat Balance (n)	0.0547	0.8151	0.941	0.550 to 1.583
Overall Balance (n)	0.0594	0.8074	1.045	0.726 to 1.532

p < 0.05 is statistically significant

Table 4.4 shows that eversion of the left ankle (p=0.0598) was found to be a significant predictor of thigh injuries.

4.4.1.4 Hand injuries

Hand injuries comprise the total number of injuries sustained to the wrist, hand and fingers.

Table 4.5: Association of variables tested in pre-season with hand injuries

Variable	Likelihood ratio statistic (DF=1)	P-value	Odds ratio	95% CI
Mass (kg)	1.5709	0.2101	0.941	0.840 to 1.033
Height (cm)	0.9336	0.3339	0.931	0.790 to 1.075
Sum of 7 Skinfolts (n)	0.6637	0.4153	0.982	0.934 to 1.025
Fat Percentage (%)	0.7150	0.3978	0.876	0.610 to 1.182
Sit and Reach (cm)	0.0362	0.8491	0.991	0.905 to 1.086
Vertical Jump (cm)	0.1383	0.7099	1.027	0.889 to 1.187
Illinois Run (s)	0.6169	0.4322	0.485	0.069 to 2.934
Illinois Run with Stick (s)	0.6322	0.4265	0.636	0.190 to 1.936
Strength Bench (%)	0.0804	0.7767	3.660	<0.001 to >999.999
Strength Leg Press (%)	0.7605	0.3832	0.579	0.150 to 1.957
Repeat Sprint (m)	0.7257	0.3943	1.008	0.991 to 1.037
Plantar flexion R (Nm)	0.7547	0.3850	1.017	0.979 to 1.059
Plantar flexion L (Nm)	0.3180	0.5728	1.010	0.976 to 1.048
Plantar Deficit (%)	1.1251	0.2888	0.951	0.836 to 1.038
Dorsiflexion R (Nm)	1.5389	0.2148	0.931	0.3769 to 1.032
Dorsiflexion L (Nm)	0.3903	0.5781	1.043	0.897 to 1.220
Dorsiflexion Deficit (%)	1.2625	0.2612	0.947	0.833 to 1.037
Ankle inversion R (Nm)	0.1933	0.6601	0.978	0.875 to 1.078
Ankle inversion L (Nm)	0.7675	0.3810	0.955	0.852 to 1.057
Inversion Deficit (%)	5.1350	0.0234	0.856	0.706 to 0.981
Ankle eversion R (Nm)	0.6042	0.4370	0.941	0.795 to 1.094
Ankle eversion L (Nm)	1.1636	0.2807	1.104	0.922 to 1.346
Eversion Deficit (%)	0.2675	0.6060	0.983	0.913 to 1.048
Ant/Post Balance (n)	0.0220	0.8822	1.033	0.660 to 1.600
Med/Lat Balance (n)	0.3659	0.5452	0.849	0.469 to 1.435
Overall Balance (n)	0.0099	0.9209	1.018	0.693 to 1.478

p < 0.05 is statistically significant

Table 4.5 shows that only ankle inversion deficit (p=0.0234) was found to be a significant predictor of hand injuries.

4.4.1.5 Lower back injuries

Lower back injuries comprise injuries sustained to both the lower back and hip areas.

Table 4.6: Association of variables tested in pre-season with lower back injuries

Variable	Likelihood ratio statistic (DF=1)	P-value	Odds ratio	95% CI
Mass (kg)	3.0477	0.0809	0.912	0.800 to 1.010
Height (cm)	1.4716	0.2251	0.911	0.764 to 1.057
Sum of 7 Skinfolts (n)	1.0633	0.3025	0.976	0.924 to 1.020
Fat Percentage (%)	1.0739	0.3001	0.843	0.671 to 1.152
Sit and Reach (cm)	0.6422	0.4615	1.035	0.945 to 1.146
Vertical Jump (cm)	0.9109	0.3399	0.929	0.780 to 1.077
Illinois Run (s)	0.0392	0.8430	1.203	0.187 to 7.998
Illinois Run with Stick (s)	0.1285	0.7200	1.233	0.390 to 4.180
Strength Bench (%)	0.3254	0.5684	14.275	0.001 to >999.999
Strength Leg Press (%)	2.0442	0.1528	0.389	0.085 to 1.399
Repeat Sprint (m)	0.6547	0.4184	0.993	0.974 to 1.010
Plantar flexion R (Nm)	0.0592	0.8077	1.005	0.967 to 1.045
Plantar flexion L (Nm)	0.0011	0.9733	0.999	0.964 to 1.036
Plantar Deficit (%)	3.6706	0.0554	1.090	0.998 to 1.214
Dorsiflexion R (Nm)	0.0080	0.9288	0.966	0.896 to 1.081
Dorsiflexion L (Nm)	0.1617	0.6876	0.969	0.820 to 1.129
Dorsiflexion Deficit (%)	1.3039	0.2535	1.051	0.965 to 1.163
Ankle inversion R (Nm)	0.0040	0.9494	0.997	0.895 to 1.101
Ankle inversion L (Nm)	1.1305	0.2877	0.945	0.837 to 1.048
Inversion Deficit (%)	0.8086	0.3685	0.947	0.827 to 1.064
Ankle eversion R (Nm)	0.7055	0.4009	1.067	0.916 to 1.252
Ankle eversion L (Nm)	0.0450	0.8319	1.020	0.844 to 1.227
Eversion Deficit (%)	0.3434	0.5579	1.019	0.954 to 1.091
Ant/Post Balance (n)	0.0033	0.9539	0.987	0.618 to 1.530
Med/Lat Balance (n)	0.0025	0.9599	1.014	0.580 to 1.730
Overall Balance (n)	0.8378	0.3600	0.831	0.516 to 1.219

p < 0.05 is statistically significant

Table 4.6 shows that ankle plantar flexion deficit (p=0.0554) was found to be a significant predictor of lower back injuries, while mass (p=0.0809) was found to be a borderline predictor of lower back injuries.

4.4.1.6 Upper arm injuries

Upper arm injuries include all injuries sustained to the elbow and shoulder areas.

Table 4.7: Association of variables tested in pre-season with upper arm injuries

Variable	Likelihood ratio statistic (DF=1)	P-value	Odds ratio	95% CI
Mass (kg)	0.7790	0.3774	1.043	0.946 to 1.157
Height (cm)	0.7671	0.3811	1.070	0.919 to 1.259
Sum of 7 Skinfolts (n)	0.1040	0.7470	1.007	0.962 to 1.053
Fat Percentage (%)	0.1147	0.7349	1.054	0.761 to 1.443
Sit and Reach (cm)	0.8224	0.3645	0.957	0.866 to 1.053
Vertical Jump (cm)	0.0043	0.9480	0.995	0.845 to 1.155
Illinois Run (s)	1.3775	0.2405	3.276	0.459 to 30.997
Illinois Run with Stick (s)	0.0170	0.8963	1.085	0.315 to 3.939
Strength Bench (%)	0.5204	0.4707	0.027	<0.001 to 441.864
Strength Leg Press (%)	2.7721	0.0959	0.302	0.053 to 1.220
Repeat Sprint (m)	0.7577	0.3840	0.993	0.974 to 1.010
Plantar flexion R (Nm)	3.4352	0.0638	1.041	0.998 to 1.096
Plantar flexion L (Nm)	4.8263	0.0280	1.046	1.005 to 1.102
Plantar Deficit (%)	0.0014	0.9706	1.002	0.908 to 1.008
Dorsiflexion R (Nm)	2.4613	0.1167	1.074	0.984 to 1.246
Dorsiflexion L (Nm)	0.0582	0.8093	0.981	0.827 to 1.147
Dorsiflexion Deficit (%)	0.2211	0.6382	1.021	0.931 to 1.116
Ankle inversion R (Nm)	4.2730	0.0387	1.123	1.006 to 1.302
Ankle inversion L (Nm)	1.2936	0.2554	1.065	0.957 to 1.208
Inversion Deficit (%)	3.5157	0.0608	0.878	0.731 to 1.005
Ankle eversion R (Nm)	1.9770	0.1597	1.119	0.957 to 1.332
Ankle eversion L (Nm)	0.2674	0.6051	1.050	0.867 to 1.273
Eversion Deficit (%)	0.0443	0.8333	0.993	0.921 to 1.061
Ant/Post Balance (n)	4.6441	0.0312	1.696	1.046 to 3.134
Med/Lat Balance (n)	0.4841	0.4866	1.214	0.693 to 2.158
Overall Balance (n)	0.4158	0.5191	1.132	0.764 to 1.695

p < 0.05 is statistically significant

Table 4.7 shows that plantar flexion of the left ankle (p=0.0280), inversion of the right ankle (p=0.0387), and anterior/posterior balance (p=0.0312) were found to be significant predictors of upper arm injuries. Ankle plantar flexion of the right ankle (p=0.0638), and ankle inversion deficit (p=0.0608) were found to be borderline predictors of upper arm injuries.

4.4.2 Multivariate logistic regression: Potential predictors of injury

4.4.2.1 Ankle injuries

Table 4.8: Association of variables tested in pre-season with ankle injuries

Variable	Chi-square statistic (df=1)	P-value	Odds Ratio	95% CI
Strength Bench (%)	3.2397	0.0719	<0.001	<0.001 to 0.024
Dorsi L (Nm)	4.0029	0.0454	0.398	0.108 to 0.735
Eversion deficit (%)	3.5678	0.0589	1.177	1.032 to 1.500

4.4.2.2 Lower leg injuries

Lower leg injuries comprise all injuries to the knee and lower leg areas.

Table 4.9: Association of variables tested in pre-season with lower leg injuries

Variable	Chi-square statistic (df=1)	P-value	Odds Ratio	95% CI
Eversion Deficit (%)	2.8242	0.0929	1.072	0.993 to 1.174
Inversion Deficit (%)	3.3010	0.0692	1.148	1.001 to 1.361

4.4.2.3 Thigh injuries

Thigh injuries comprise the total injuries to both the front and back of the thigh.

Table 4.10: Association of variables tested in pre-season with thigh injuries

Variable	Chi-square statistic (df=1)	P-value	Odds Ratio	95% CI
Plantar Deficit (%)	2.9223	0.0874	1.273	1.058 to 1.833
Eversion L (Nm)	5.6049	0.0179	0.673	0.435 to 0.882
Eversion Deficit (%)	6.4843	0.0109	0.803	0.651 to 0.923
Ant/Post Balance (n)	2.9864	0.0840	0.501	0.189 to 0.997

4.4.2.4 Hand injuries

Hand injuries comprise all injuries to the wrist, hand and fingers.

Table 4.11: Association of variables tested in pre-season with hand injuries

Variable	Chi-square statistic (df=1)	P-value	Odds Ratio	95% CI
Inversion Deficit (%)	3.6896	0.0548	0.856	0.706 to 0.981

4.4.2.5 Lower back injuries

Lower back injuries comprise all injuries to both the lower back and hip areas.

Table 4.12: Association of variables tested in pre-season with lower back injuries

Variable	Chi-square statistic(df=1)	P-value	Odds Ratio	95% CI
Plantar Deficit (%)	2.7390	0.979	1.090	0.998 to 1.241

4.4.2.6 Upper arm injuries

Upper arm injuries comprise all injuries to both the elbow and shoulder areas.

Table 4.13: Association of variables tested in pre-season with upper arm injuries

Variable	Chi-square statistic (df=1)	P-value	Odds Ratio	95% CI
Sit/Reach (cm)	3.2776	0.0702	0.855	0.689 to 0.991
Inversion R (Nm)	5.7603	0.0164	1.478	1.158 to 2.252
Inversion Deficit (%)	5.8216	0.0158	0.711	0.502 to 0.893

The selected variables listed in the tables above (Tables 4.8 to 4.13) can form part of a predictive model for their respective injuries.

The sets of variables selected in the multivariate analyses do not necessarily comprise those variables which in the univariate analysis were found to be the most significant predictors of injury. Furthermore, there is not necessarily a causal relationship between the selected variables and the injury in question. Rather, the selected variables represent a subset of the independent variables which, within the context of stepwise logistic variable selection, emerged as the best subset of variables to include in a prediction model for the injury in question.

4.5 Summary of results

From the results obtained in this study, Table 4.14 was formulated as a summary of the athletic profile found in this group of players.

Table 4.14: Summary of athletic profile of national female field hockey players 2011-12 season.

Variable	Median (IQR range)
Age (yrs)	23.0 (21.0 - 26.0)
Mass (kg)	62.3(56.8 - 67.2)
Height (cm)	163.5 (161.0 - 168.0)
Body Fat (%)	15.3 (13.6 - 17.1)
Sit and Reach (cm)	43.3 (38.0 - 49.0)
Vertical Jump (cm)	42.8(39.5 - 46.0)
Illinois Run (s)	15.5 (15.2 - 15.9)
Illinois Run with Stick (s)	17.2 (16.6 - 17.8)
10m Sprint (s)	1.9(1.8 - 2.0)
40m Sprint (s)	6.0 (5.8 - 6.1)
40m Sprint with Stick (s)	6.7 (6.5 - 6.8)
Strength Bench Press (%)	0.8 (0.7 - 0.8)
Strength Leg press (%)	3.9 (3.5 - 4.4)
Repeat Sprint (m)	722.0 (711.0 - 740.0)
Core grade (n)	1.5 (0.0 - 2.0)

CHAPTER 5

DISCUSSION OF RESULTS

There is a paucity of scientific research that has been undertaken in field hockey, particularly research that is focused on elite female field hockey. Furthermore, in a game that has developed into a professional sport, little data exists regarding the physical requirements and injury risk factors for the elite female field hockey player.

Prevention of injuries is an important aspect of athletic training. However, very little research is available to guide coaches and medical personnel regarding specific injury prevention practices in field hockey. Our current understanding of injury causation is limited and must be improved in order to develop effective interventions for modifying injury risk. The conditioning of field hockey athletes has focused on general risk factors, rather than developing protective neuromuscular adaptations that are specific to an individual athlete's characteristics. This study sought to develop a predictive model for injury in elite female field hockey players using pre-season performance measures.

5.1 Anthropometry

The analysis of body composition is an essential component to improve sport performance in elite athletes. It provides reliable information for accurately evaluating the efficiency of the team's nutritional and training programme with relation to physical performance. Despite the fact that field hockey is quite popular, very few data are available on the anthropometric features of elite female field hockey players.

With regards to the anthropometric profile established in this study, the results for mean mass (62.5 kg) and height (164.5 cm) were similar to the 61.3 kg and 164 cm reported for elite hockey players by Murtaugh (2001), the 63.06 kg and 164.26 cm by Wassmer & Mookerjee (2002) and the 60.70 kg and 164 cm reported by Astorino *et al.* (2004) for mass and height respectively. The total mean body fat percentage in this study was 15.6%. This result is similar to the 15.7% reported for female members of the Italian field hockey national team (Calò *et al.*, 2009) but lower than the 16.9% reported for the USA 1996 Olympic women's field hockey team (Sparling

et al., 1998). These differences in physical characteristics likely reflect the rapid development of the game and increase in the physical demands and athleticism that has occurred over the years in international hockey.

When compared to studies involving lower level representative teams, the mean body fat percentage in this study was also much lower (Wassmer & Mookerjee, 2002; Keogh *et al.*, 2003). Wassmer and Mookerjee (2002) reported a mean body fat percentage of 17.3% when they examined 37 female collegiate field hockey players, while Keogh *et al.* (2003) recorded a mean body fat percentage of 24.8% and 27.4% for representative and club players respectively. This study therefore concurs with Keogh *et al.* (2003) that the level of the game seems to also determine and influence the body fat percentage whereby the higher the level of play, the lower the body fat percentage. As this study involved national-level players, the decrease in body fat percentage when compared to the other studies could be attributed, as described in Chapter 2, to the higher physical demands at higher levels with more stringent conditioning programmes and possibly stricter endurance training.

When playing position was considered, goalkeepers had the highest body fat percentage in this study, which was also found in the study by Wassmer and Mookerjee (2002) as well as Calò *et al.* (2009). Strikers produced the lowest body fat percentage in this study as was also reported by Calò *et al.* (2009). The increased running and sprinting of strikers when compared to goalkeepers could be attributed to the lower body fat percentage found in the strikers. Therefore, a measure of body fat percentage is a useful tool for describing, in part, the anthropometric characteristics of hockey players of higher capability. Furthermore, such a measure may even be used to identify the playing position that might best suit a player.

5.2 Explosive power - Vertical jump test

High intensity, short bursts of sprinting are required in the game of field hockey and demands high anaerobic capacity. The overall mean vertical jump score in this study was 44 cm. Although this was higher than the 35 cm and 29 cm recorded by Keogh *et al.* (2003) for representative and club players respectively, the score in this study would be considered to be low by Amusa and Toriola (2003) in terms of athletes required to do sprints when they described a mean vertical jump score of 51.9 cm to

be a low score for their sprint athletes. It would be expected of the strikers, who are often involved in high bursts of sprints, to make goal scoring opportunities to produce the highest score. However, the defenders produced the highest scores for vertical jump in this study. While Wassmer and Mookerjee (2002) found no differences in player position and the physical parameters they tested, this study found that goalkeepers and midfielders produced low scores for vertical jump. Although goalkeepers do not require large amounts of sprinting in a game, explosive strength is imperative for diving, jumping and quick reactions around the goal area with the explosive power assisting to cover more of the net. Explosive power perhaps is an area to improve in this sample of players.

5.3 Flexibility -Sit and reach test

Flexibility has been described as an important aspect of injury prevention (Gleim & McHugh, 1997; Wathan *et al.*, 2000). Increasing one's flexibility helps to maintain stability and balance which assists in injury prevention. Improved flexibility also assures that muscles and tendons work coherently, making muscles more elastic for increased lower body explosiveness. With the explosive power being less than that recommended for athletes requiring sprinting above, perhaps flexibility is also an area that can be improved on in the players of this study.

The mean score of flexibility for the sit and reach test in this study was 42.3 cm. The scores were very similar, with the defenders producing only slightly higher scores than the other field hockey playing positions. While there are different ranges of flexibility for different sports (Wathan *et al.*, 2000), there is unfortunately not enough literature to establish an optimal range of flexibility for elite female field hockey players. Therefore, more studies need to be conducted on elite female field hockey players to establish an optimal range of flexibility to avoid injuries and improve overall sports performance.

5.4 Upper body strength -Bench press test

Upper body strength is important in field hockey, whether a player is powering through an opponent, driving the ball, or simply pushing the ball out from another player's stick. The upper body plays an important role while running. It helps to propel the body forward and maintain balance, increasing overall speed. Neglecting

upperbody strength and power can have negative effects on one's overall development as a field hockey player, decreasing the ability to reach maximum velocity and change direction quickly. This should be another main goal of training for most field hockey players. Increased upper body strength also allows players to shoot more powerfully and pass over a greater range of distances. This could explain the defenders in this study producing the highest score for upper body strength, demonstrating their robust role in the game as defenders facing physical challenges from the opposition players and perhaps from making a greater number of longer range passes. When the maximum bench press score was expressed as a percentage of their own body weight, the overall mean for this group of 30 players was 0.77 kg/body weight.

Astorino *et al.* (2004) confirmed the superior levels of muscular strength and leanness in female field hockey players compared with age-matched peers. They reported, however, that muscular strength (upper and lower body) decreased during a competitive field hockey in-season compared to pre-season tests results, and suggested that coaches incorporate more rigorous in-season resistance training to prevent strength decrements. Interestingly though, Hrysomallis (2010) reported that upper body strength could be maintained or even increased past the mid-season point when he reviewed studies involving American football players and rugby players. Although dependent on age, football code, and level of play, Hrysomallis (2010) also suggested that an in-season periodised programme that includes high-intensity resistance training be done to optimise strength and power ability during the in-season.

Unfortunately, this study did not conduct tests during the in-season and further studies should be done to confirm the findings in female field hockey players.

5.5 Lower body strength – Leg press

Field hockey players need incredible lower body strength to maintain the low body position on both offense and defense. The game of field hockey also demands that players must be able to run at high speed whilst also being able to decelerate, stop or change direction sharply. Lower body muscular strength capacity is very influential in the performance of these powerful, speed-related activities (Peterson *et al.*, 2006).

In order to run faster, there must be an increase in force production to the ground which can only be achieved through improving lower body strength. Comfort *et al.* (2014) were able to illustrate the importance of developing high levels of lower body strength to enhance sprint and jump performance in youth soccer players while Spiteri *et al.* (2014) found that change of direction ability was significantly correlated to maximal dynamic, isometric, concentric, and eccentric strength of elite female basketball players, with eccentric strength identified as the sole predictor of change of direction performance. In a game like field hockey where sprinting ability and change of direction ability are crucial to the game, it will therefore be beneficial for a field hockey player to have a high lower body muscular strength and perhaps as indicated, eccentric strength training to be included in the conditioning programmes of elite female field hockey players.

A higher muscular strength also diminishes the risk of injury (Reilly & Borrie, 1992; Gorger *et al.*, 2001). It has been proposed that strength imbalances or specific muscle weaknesses might be a factor predisposing players to muscle strain (Safran *et al.*, 1989). A stronger muscle will absorb more energy than a weak muscle prior to failure, therefore reducing the likelihood of muscle strain. According to Safran *et al.* (1989), strength must also be balanced between antagonistic muscle groups. If quadricep muscles, for example, are over 10% stronger than the hamstrings, there is an increased risk of hamstring muscle strain under maximal load. Muscle imbalance and decreased muscle strength have also been associated with an increase in muscle injury (Safran *et al.*, 1989; Reilly & Borrie, 1992). It is therefore imperative to test and monitor the strength of elite athletes to formulate a baseline for strength performance and to determine the effectiveness of their training programmes.

The leg press machine used in this study is an accepted and reliable means of determining lower body strength (Seo *et al.*, 2012). The mean leg press strength for the overall group of players tested was 3.98 kg/body weight. One would expect to find the strikers who perform high frequencies of sprint speed and planned agility drills at greater levels than other positions on the field, to have the highest scores. Leg press scores in this study revealed little difference among player positions, with the midfielders producing the slightly higher score. While this demonstrates the hard work of midfielders alternating between assisting strikers and defenders, it also

perhaps highlights a weakness in this group of strikers. A sound weight-training programme will allow for these developments and reduce the risk of injury during competition.

5.6 Core strength

Core strength is essential for proper posture, balance and stabilisation of the body, all of which are imperative for the game of field hockey. All movements are generated from the core and translated to the extremities while the core works to stabilise the body and spine (Brukner & Khan, 2001). The core muscles lie deep within the trunk of the body and act like a corset, taking pressure off the lower back. Core stability is responsible for the muscular control required around the lumbopelvic hip region and the production, transfer, and control of force through the extremities (Kibler *et al.*, 2006). Without adequate core strength and stability, the athlete will not be able to apply extremity strength. Greater core stability therefore may benefit sports performance by providing a foundation for greater force production in the upper and lower extremities and a reduced injury risk (Willardson, 2007).

Field hockey players are constantly in a semi-upright, crouched or low body position while engaged in dynamic or static movement requirements of the game. In field hockey, players are to bend forward to the ground for the maximum groundwork and to cover a wider range all round during the game (Sodhi, 1991) and maximum strain comes over the back muscles as well as abdominal muscles during the entire duration of the game (Sharm *et al.*, 2012). A large amount of strain is also placed on the intervertebral discs when players assume a semi-crouched posture while dribbling the ball (Reilly & Borrie, 1992). Sharm *et al.* (2012) found an increased risk for incidence of chronic lower back pain in the general public exposed to awkward postures in daily activities. The awkward postures in a high-intensity, fast-paced game like field hockey will certainly increase the strain on the lower back of these players. Execution of most field hockey ball handling skills, whether dribbling, hitting, flicking or tackling, requires players not only to maintain these semi-low positions but also at the same time execute the required skills with power.

The overall mean for the group was 1, with midfielders producing the highest scores for core strength tests with little difference between the core strengths of the other

playing positions. Perhaps the large amount of work done by midfielders and the large area covered by them (Holmes, 2010) has helped them develop stronger core muscles. Midfielders it seems need to focus more on conditioning compared to other positions for optimal performance. The overall mean of 1 for the group, however, is low for this sample of elite athletes. To meet the demands of the game and its unique biomechanics, a strong core is required and developing core strength and stability should be a priority in the conditioning programme of field hockey players. Good core stability will assist to stabilise the body centre against dynamic movements of the extremities and absorb repetitive loading forces in the trunk. There is therefore a need for a standard test to be used in calculating core muscle strength and to test hockey players for core strength to be able to profile them and prevent lower back injuries.

5.7 Speed and agility

Being a fast-paced sport, field hockey players need to develop superior speed, agility and quickness in order to excel at the highest levels. Enhanced sprinting technique and ability to react to changes is important for open field running together with cutting ability as players will often accelerate from a stationary stance or a slow jog up to full speed immediately. In terms of speed, the players in this study recorded a mean time of 1.9 6.0 seconds when they ran a 10 m and 40 m sprint respectively. These were similar findings to Keogh *et al.* (2003) who reported that elite female players ran a 10 m and 40 m sprint in a time of 2.0 seconds and 6.5seconds respectively. In the study by Keogh *et al.* (2003) representative players were also significantly faster over 10 m and 40 m compared to club players. Their greater sprinting speed is consistent with Jennings *et al.* (2012) who reported higher level players having 13.9% and 42.0% more total distance covered and high-speed running respectively. These findings suggest that sprinting speed is an important characteristic of field hockey. Consequently, tests that assess short-duration sprinting speed are required for the monitoring of elite female field hockey players.

Both the 40 m sprint and the Illinois Agility Test in this study reported slower results with the player holding the hockey stick in hand than without. Holding a stick alters the mechanics of the upper body and these findings confirm that this unique aspect of the game, when compared to other team-based sports, does indeed place an

additional strain on the players and their lower back (Reilly & Borrie, 1992) demanding extra time and energy from the players who have to assume a stooped posture (Sodhi, 1991) to be ready to receive the ball.

With regards to speed, agility and positional differences, defenders in this study produced the slowest times for the 10 m sprint test and the Illinois Agility Test, with and without the hockey stick in hand. These results seem to confirm the findings of Holmes (2010) who reported that defenders spend a significantly greater percentage of time walking, less time striding and less time sprinting while covering significantly less distance over the game period by almost 1500 m compared to both midfield and forward players.

Midfielders produced the fastest times for the 10 m sprint but the slowest times for the 40 m sprint test with and without the hockey stick in hand. Midfielders, although covering a large area, seem to only be able to sprint over a short distance. Strikers however, produced the fastest times for the 40 m sprint test with hockey stick in hand, and the fastest times for the Illinois Agility Tests with and without a hockey stick in hand. A primary role of strikers is to create opportunities to score goals by making themselves available to receive a pass from a team member usually requiring great speed to outrun opposition players. This could explain the faster times demonstrated by strikers in both the present study and those reported previously (Johnston *et al.*, 2004; Spencer *et al.*, 2004).

5.8 Balance

Field hockey is a game where a player's centre of gravity and body control are incredibly important. Field hockey players perform a series of balance-specific exercises to strengthen their stabilising muscles and allow for better muscular synergy and joint control. Training routines include unstable and stable lifts, dynamic balance movements with the Bosu ball, and a variety of off-balance training aids.

Mean balance index scores for all the participants were similar except for the goalkeepers who produced higher scores than their counterparts for all anterior/posterior-, medial/lateral and overall balance score indices. Balance is essentially one's ability to control and stabilise one's own body mass and centre of

gravity in various activities. For field hockey, this is an important trait in a goalkeeper as they have to maintain balance whilst reacting quickly to get to a ball and to also recover just as quickly to be ready to repeat quick and agile actions in preventing goals from the opposition. As the goalkeepers in this study had a higher body fat percentage, perhaps this assists in grounding the goalkeeper and stabilising the body's centre of gravity.

Although some of the literature sources have indicated the importance of some of the variables of field hockey tested in this study, such as core strength (Sharma *et al.*, 2012), flexibility (Ellenbecker & Roetert, 2003) muscle strength and explosive power (Reilly & Borrie, 1992), as well as balance (Anders & Myers, 2008), more research needs to be conducted to establish an optimal range of the variables for elite female field hockey players. The general profile of the elite players established in this study, however, is evident in Chapter 4's Table 4.1. and can be used to compare when further research is conducted.

5.9 Isokinetic testing of the ankle

For plantar flexion, the mean score for the right legs of the players was less than that of their left legs, while dorsiflexion, the mean score for the right legs of the players was higher than their left legs. Although there was no significant difference between inversion of the right and left legs, mean scores for eversion of the right leg were higher than the left leg. Muscle imbalance with the contra-lateral leg has been associated with ankle injury (Baumhauer *et al.*, 1995) and perhaps, as discussed later under predictors of injury, muscle strength and the balance thereof is constitute a factor to be considered when planning an injury prevention programme.

5.10 Incidence of injury

The overall mean incidence of injury reported by this sample of players (2.8 per player in the 2011-2012 season) was much higher than (0.6 per player per season) previously reported by Eggers-Stroder and Hermann (1994), the 0.36–0.37 per player per season reported by Murtaugh (2001) and the 0.48 per player per year reported by Petrick *et al.* (1992; 1993). In addition to the fact that this study focused on a small sample of hockey players who were in the “elite” category and hence exposed to a high level of play and very competitive playing milieu, the relatively high

incidence obtained in this sample of elite female field hockey players could possibly be attributed to the greater use of synthetic playing surfaces (Reilly & Borrie, 1992), recent rule changes (Tully, 2003) and advances in stick construction (Murtaugh, 2001) which have increased the pace of the game and potential for injury.

In terms of injury incidence and anatomical site of injury, this study supports the findings of other authors that the ankle joint was the most frequently injured joint in the body in field hockey players (Rose, 1981; Murtaugh, 2001; Dick *et al.*, 2007; Naicker *et al.*, 2007; Rishiraj *et al.*, 2009). In the study by Murtaugh (2001), the most common type of injury was a ligament sprain (39.7%), where ankle sprains accounted for most of the ligament sprains reported. Ankle sprains were also the most common of the 81 injuries reported by Rose (1981) and from their 15-year surveillance (1988-2003) of collegiate female field hockey players, Dick *et al.* (2007), reported ankle injuries to be the most frequent in game injuries (13.7%, n=118) and second most frequently injured area in practices (15%, n=209). These findings were confirmed by Naicker *et al.* (2007) who reported an incidence of ankle injury, over one field hockey season, of 25.5% (n=12) when they investigated the first teams for provincial senior, under-21 and school teams (n=47). The incidence of ankle injury of the current study was 46.7% (n=14), which is much higher than the above studies. The higher incidence of ankle injury in this study may again possibly be related to the higher level of play of these players where the demands are greater.

The high incidence of ankle injuries in field hockey could be attributed to the rapid changes in speed and direction that the game entails, which place high amounts of stress to the ankle joint. This result is not unique to field hockey as the lateral ankle is the most frequently injured area in the body, and ankle sprain is generally the most common injury in sport (Garrick, 1977; Torg, 1982). Whether the mechanism of injury in field hockey is the same as in other field sports, such as soccer, has yet to be determined. The synthetic surface "Astroturf", on which international hockey is exclusively played, is a fast-paced surface placing greater demands on the lower body compared to play on grass where the speed of players is slower and the external torque on the lower limb is less. It has been reported that injury rates are higher on synthetic surfaces compared to grass for field hockey (Jamison & Lee, 1989) and elite soccer players (Arnason *et al.*, 1996). ACL injuries in particular have

been identified as being 1.39 times higher on artificial surfaces than on grass surfaces in NFL players (Dragoo *et al.*, 2013). Fox (1981) also suggests that the stooped position used when dribbling the ball may be an unsound position for fast locomotion and could contribute to lower limb injury. All of the above could explain the high reports of lower limb injury by Murtaugh (2001) of 51%, Rose (1981) of 79% and by Dick *et al.* (2007) of 43.2% during matches and 60.2% during practices. It could also explain the highest amount of ankle injuries occurring in the fastest players on the field in this study, i.e. the strikers. The high rate of injury to the ankle region indicates that the potential for such injury still exists.

The high incidence of ankle injuries was followed by injuries to the hamstring muscle at 36.6% (n=11) and the lower back at 30% (n=9) respectively. Although muscle strains have accounted for injuries in previous research (Merrett, 2003), they have not particularly identified a high incidence in the hamstring muscle. The 12 muscle strain injuries, reported by Merrett (2003) and sustained by the twenty-two (22) female field hockey players over the one season, included injuries to the hamstring, quadriceps and adductor muscle groups. The high incidence of hamstring injuries reported in this study, sustained mostly by the midfielders (71%), might be related to the greater distances covered by this group of players with a higher work rate (Holmes, 2010).

The high incidence of lower back injuries in this study supports the findings of previous studies (Reilly & Borrie, 1992; Murtaugh, 2001; Rishirajet *et al.*, 2009, Dick *et al.*, 2007). Murtaugh (2001) reported that 59% of the sample of female field hockey players had low back pain during a season, while Dick *et al.* (2007) concluded that the lower back was the second most commonly injured area that mainly occurred during practices (16.2%). The biomechanics of bending over and rotating the upper body at the same time, places strain on the structures of the lower back. With shooting posture often combining these two movements, building core stability in all three planes of motion becomes critical to minimising pain in this region. Awkward postures are associated with chronic lower back pain (V2012) and, in field hockey, the lower back is placed under stress due to the semi-crouched position of the players and the need to maintain this position throughout the game (Sodhi, 1991). It has been shown that seven minutes of dribbling a field hockey ball can cause an

average spinal shrinkage of 2.73 mm (Reilly & Seaton, 1990). Low back pain is common in field hockey players and athletic movements such as twisting, lunging, running in a bent over position and physical contact all create strenuous forces on the back, which are required during a match or practice sessions, and which predisposes the player to low back pain. If the back and trunk have not been trained to function optimally, this can lead to weakness and reduced movement capabilities. Over time, this can lead to impaired athletic performance, injury and pain (Hedrick, 2000). No research has been done to examine the effect of muscle training on symptomatic field hockey players. Trunk strength is critical because all movements either originate in, or are 5 coupled, through the trunk, and a well developed core stability allows for improved force output, increased neuromuscular efficiency and a decrease in the incidence of overuse injuries (Hedrick, 2000). By strengthening the core stability system and trunk extensor muscles, one enhances the ability to better utilise the musculature of the upper and lower body to perform certain tasks. This results in more efficient, accurate and powerful movements.

There was a much lower incidence of head and facial injuries in this study (10%) compared to the 19% reported by Hendriks *et al.* (2008), the 34% reported by Murtaugh (2001) and the 54% reported by Bolhuis *et al.* (1987). Murtaugh (2001) found that being struck by a ball accounted for most of these injuries. The low incidence of facial injuries in this current study could be attributed to the mandatory use of a mouthguard which is said to lower the incidence of facial injuries. It has also become popular now to wear protective eyewear which is said to lower the incidence of head and facial injuries (Kriz *et al.*, 2012). Strict adherence to the rules at international level also prevents such injuries from occurring.

5.11 Injury incidence and playing position

Contrary to the findings of Murtaugh (2001) and Verow (1989), who found that goalkeepers sustained the highest amount of injuries, the goalkeepers in this study had the least amount of injuries (1.3 injuries/athlete/year). In the study by Murtaugh (2001), the goalkeepers had the overall highest risk of injury (0.58 injuries/athlete-year), including the highest rate of upperlimb (0.12 injuries/athlete-year) and back/torso injury (0.03 injuries/athlete-year). The author went on to report that the goalkeepers had a rate of back and torso injury 16.7 times higher than the rate

calculated for field players. The most common injuries to goalkeepers constituted concussions, wrist fractures, ankle sprains, thigh muscle strains, and knee ligament tears. The majority of these injuries occurred due to contact with other players, the playing surface, or the goal itself. The current study supports, however, the findings of Merrett (2003) who also reported that goalkeepers produced the lowest amount of injuries (18%). Perhaps with the development of the game, increased education about injuries and with modern technologies available to meet the requirements of this high performance sport (e.g. hi-tech goalkeeper protective equipment and specialised training for flexibility and preconception), the incidence of goalkeeper injuries is lower than that reported by Murtaugh (2001) and have indeed decreased risk of injury to goalkeepers. The now exclusive use of the artificial Astroturf surface for practice and matches has been identified as being especially dangerous (Eggers-Stroder & Hermann, 1994), while the new improved stick constructions which allow players to manipulate the ball at higher velocities, has increased the pace of the game and the potential for injuries of the field players.

Midfielders had the highest rate of injury including the highest rate of injury to the hamstring muscle and the second highest rate of ankle injuries. It is possible that these injuries were due to a higher physical intensity than other positions, a greater distance covered by these players and perhaps greater fatigue which can lead to errors in play and possible injury. Midfielders also execute most defensive skills in a recovery mode, making a chase tackle from the rear of a player about to strike a ball, where great care is needed to avoid the backward swing of the stick. In fact, up to 20% of field hockey injuries have been attributed to tackling for the ball (Graham & Bruce, 1977).

The second highest rate of injury was the strikers, including the highest rate of ankle injuries 50% (n=7) and the highest incidence of quadricep injuries 57% (n=4). The high incidence of ankle injuries among the strikers in this study could be attributed to these players spending more time near the goal area with the competitive, offensive and attacking atmosphere in the circle area with defenders also crowding the area possibly giving rise to potential for injury. In addition, these players are constantly required to make high sprinting plays in a game, which may well have predisposed them to a greater risk of injury than the players in the defensive positions. The

elimination of the offside rule has perhaps also increased the pace of the game and the potential for injury.

5.12 Time of injury occurrence

In this study, there seems to be a higher risk of injury occurring during a match than during a practice session, with 33% (n=29) of the injuries reported to have occurred during a practice session while 66% (n=58) occurred during a match. This confirms the findings of Naicker *et al.* (2007) who found that 75% (n=9) of the reported ankle injuries sustained by provincial female field hockey players occurred during matches as well as Ekstrand *et al.* (1983) who reported one injury every third game and every ninth practice session sustained by senior division male soccer players.

For field hockey, Eggers-Stroder and Hermann (1994) reported that injury risk during matches exceeded the risk during practice by 10.4%. This could be due to the increased intensity of play and more competitive atmosphere during matches as opposed to practice sessions. Perhaps during matches, the demand on the player to get results and win the game increases the physical output of the player, increasing the potential for injury. Players are also playing against a clock which creates added pressure for performance. Opposition team members are also perhaps not as considerate as fellow team members during practice sessions.

There was a higher risk of injury resulting during the second half of a match (66%) compared to injuries occurring during the first half of the match (34%). This supports the findings of Rishiraj *et al.* (2009), Gabbett (2010) as well as Ostenberg and Roos (2000), all of whom reported that most injuries occurred during the second half of a match. Gabbett found that most injuries (70.8%) were sustained in the second half of amateur rugby league matches. It is interesting to note that the results of the study by Rishiraj *et al.* (2009) were based on subjects under the age of 21 years, suggesting that age does not play a factor when it comes to fatigue. The high incidence of injury during the second half of a match is no doubt related to fatigue when decreases in both physical and mental performance are frequently observed towards the end of a match (Mohr *et al.*, 2003; Krstrup *et al.*, 2006). As muscular fatigue increases, muscular force output drops, and the muscles and associated connective tissues, including tendons and ligaments, struggle to protect themselves

from injury. Coordination is also lost as fatigue mounts, leading to poorly controlled tackles and thus a greater risk of injury. Players can reduce second-half muscular and mental fatigue, of course, by upgrading their overall aerobic fitness. In addition to working on their strength and quickness during training, they should also be concerned about variables such as VO_{2max} , lactate threshold, and movement efficiency.

Fatigue may also be caused by low muscle glycogen concentrations and/or dehydration, where the depletion of carbohydrate stores is a limiting factor in the ability to perform long-term exercise (Noakes, 2000). Pre-exercise muscle glycogen supercompensation (carbohydrate-loading) or carbohydrate ingestion during exercise, or both, delays the onset of fatigue and improves exercise performance (Noakes, 2000). Perhaps the dietary intake of this group of participants also needs to be considered and modified to accommodate the energy requirements of the full duration of a match.

5.13 Mechanism of injury

Most of the injuries sustained in this study occurred from a fall, followed by player contact, being struck by a ball and finally from being struck by a stick. However, Rishiraj *et al.* (2009) reported that the highest number of injuries resulted from no contact. Not only did they report on under-21 female field hockey players but the difference perhaps also relates to the more physical game that is now being played. The high incidence of injuries occurring from a fall could be related to the increased pace of the game and the increased high-speed running that occurs at international level (Jennings *et al.*, 2012). Identifying less than optimal physical characteristics becomes even more imperative to reduce the amount of injuries or perhaps the severity of the injuries that may be sustained from a fall.

5.14 Severity of injury

Severity of the injury was related to time lost from playing the game. The majority of the injuries in this study (45%) fell under the mild category (RTP within 7 days of injury). No play for seven days, however, can be quite detrimental to a national team where test matches can run for a few days only. This can impact on player and team performance where it is imperative for all players to be match fit. Transient injuries

(RTP within 3 days of injury) accounted for 35% of the injuries, moderate injuries (RTP within 10 days of injury) for 13% and only 7% sustained severe injuries (RTP within longer than 10 days). The low percentage of severe injuries in this study compared to the high incidence reported by Rose (1981) could be attributed to the development of the game and the improved conditioning of players over the years. Ankle injuries have also been reported to account for most of the serious injuries sustained (Rose, 1981; Dick *et al.*, 2007). Although the incidence of ankle injuries was high in this study, only two injuries were reported to be severe. It seems that the ankle joint is still vulnerable to injury in field hockey but the degree of the injury has in fact lessened with players returning to play much sooner. This could not only be attributed to better conditioning of players, but also to a better medical support structure that is in place to immediately diagnose and treat and then to provide proper rehabilitation.

5.15 Type of injury sustained

The injuries in this study consisted mainly of muscle strains to the hamstring, quadriceps and lower back muscles, while ligament sprains were predominantly of the ankle and knee. The most common injury was ligament sprains which accounted for 40% of all injuries, followed by muscle strains which accounted for 32% of all injuries. These findings are consistent with other studies reporting muscle sprain/strain as the most prevalent injury (Rose, 1981; Murtagh, 2001; Järvinen *et al.*, 2005). This was very similar data to that showed in the study by Rishiraj *et al.* (2009). However, in the study by Murtagh (2001), muscle strains accounted for only 8.1% of the injuries. This could be attributed to how much more physical the game has become and the increase in muscle work done by the players.

5.16 Injury management

Most national teams travel with a physiotherapist and doctor at least and a high percentage of players reported to have received treatment (77%) with good improvement with non-invasive treatment and without expensive investigations. Initiating treatment within 24 hours also reduces the risk of the injury becoming chronic, which is harder to resolve (Verow, 1989), and the early and guided rehabilitation of injuries allows for optimal conditioning and prevention of these

injuries recurring. Only two players required surgery and were not able to return to the hockey season.

5.17 Predictors of injury

In contrast to the findings of Murtaugh (2001), Ostenberg and Roos (2000), as well as Le Gall *et al.* (2006), age did not appear to be a predisposing factor in the present study. The moderate relation ($p=0.0809$) found in this study between mass and incidence of lower back injuries lends support to the findings of Heuch *et al.* (2010). This study, however, did not include elite athletes while Bakker *et al.* (2009) found no evidence of an association between sporting on a professional level and lower back pain. They suggested that the most common reasons for lower back ache would be a combination of overloading the lumbar spine, muscle imbalances, and movement compensations. Perhaps this is the case in this group of elite female field hockey players.

The results indicated that decreased ankle dorsiflexion strength was a very strong predictor of ankle injuries. This supported the findings of Willems *et al.* (2005) who found that decreased dorsiflexion muscle strength in male physical education students had a greater risk of ankle sprains but was contrary to the findings of Wang *et al.* (2006) who found no association with isokinetic ankle strength and ankle injuries when they examined players in the pre-season for the prediction of ankle injuries in men's high school basketball.

Univariate associations suggested that the weaker dorsiflexion strength of the left ankle, as demonstrated by the majority of players who sustained ankle injuries to the left ankle (79%), posed a significantly higher risk of ankle injury ($p=0.0002$). It is interesting to note that those players sustaining injuries to the right ankle (21%) also produced weaker dorsiflexion strength of their right ankles. In a previous study (Naicker *et al.*, 2007), an association between ankle injury and weak dorsiflexion torque seemed to exist but due to the retrospective nature of this study, it was not able to conclude whether the poor dorsiflexor torque was the cause of the injury, the result of the injury or perhaps the result of inadequate rehabilitation of the injured ankles.

The most common ankle injury is a lateral ankle sprain and is sustained in the inverted and plantar-flexed ankle. A possible explanation for our findings in this study is that, during these movements, the evertor and dorsiflexor muscles of the ankle are lengthened and act eccentrically. Weak dorsiflexors in the ankle joint that cannot act with sufficient eccentric strength will therefore allow for excessive plantar flexion and inversion, placing additional stress on the lateral ligaments of the ankle joint, thereby predisposing the ankle to injury. This study not only confirms the association between poor dorsiflexion torque and ankle injury, but has confirmed that poor dorsiflexion torque can in fact predict new ankle injuries and highlights the possibility that strong dorsiflexors assist the ankle in preventing excessive plantar flexion and inversion injury responsible for most lateral ankle sprains.

Ankle dorsiflexion and eversion deficit refers to the difference in muscle strength of these movements between right and left ankles. The results indicated that ankle dorsiflexion deficit ($p=0.0267$) and eversion deficit ($p=0.0035$) were significantly good predictors of ankle injury. This confirms the findings of Fousekis *et al.* (2012) who reported ankle joint asymmetries (right-left) in isokinetic muscle strength in professional soccer players posed a significantly higher risk of a non-contact ankle sprain.

Although evertor muscle weakness and decreased evertor to invertor torque have been implicated as a risk factor to ankle injury in previous studies (Willems T, Witvrouw F, Verstuyft J, Vaes P & De Clercq D, 2002; Amaral De Noronha & Borges, 2004), less is known of the relationship between the incidence of ankle injury and the peak dorsiflexion to plantar flexion torque of the injured ankle and that of the uninjured ankle. Baumhauer *et al.* (1995) were the first to show that the plantar flexion strength and the ratio of dorsiflexion to plantar flexion strength was significantly different for the injured ankle compared with the contralateral uninjured ankles when they studied 145 college-aged athletes before the athletic season.

In a later study, Witchalls *et al.* (2012) found higher concentric plantar flexion strength at faster speeds and lower eccentric eversion strength at slower speeds posed increased risk of ankle injury when they performed a systematic review and meta-analysis of journal articles from selected electronic databases for ankle injury

prediction. In a sport like field hockey, where there are constant intermittent changes in speed, perhaps this is also associated with the high incidence of ankle injuries. In another systematic review by Amaral de Noronha *et al.* (2006), however, ankle muscle strength was found not to be associated with an increase in ankle injuries but instead dorsiflexion range was reported to strongly predict risk of ankle sprain. Although this study did not find an association with flexibility and ankle injury incidence, perhaps an isolated test of range for dorsiflexion of the ankle is required to compare results instead of the generalised sit and reach test of flexibility used in this study. Due to the lack of consistency in these findings, particularly when applied to sportspersons, this is an important direction for future research. A possible explanation for the association found in this study is that muscle imbalances in right and left ankles can cause abnormal movement in the direction of the strongest muscle which can lead to the structures of the ankle joint to be put under pressure. Furthermore, if the musculature responsible for everting the foot is weak, there is a possibility that the ankle could be too weak to keep the foot in a neutral position, especially during heel strike. The athlete therefore could have a higher chance of 'rolling the ankle' causing lateral ligament damage. The strength of the musculature will also influence the power and agility, and therefore an increase in strength could increase the ability of the body to accelerate and decelerate in multiple directions, as is required in field hockey. This study concluded that muscle imbalance around the ankle joint is indeed a consideration when developing conditioning programmes of field hockey players.

All balance indices i.e. anterior/posterior ($p=0.0465$), medial/lateral ($p<0001$) and overall ($p<0001$), showed significant potential to predict ankle injury. This finding confirms the findings of Tropp *et al.* (1984), Watson (1999), Wang *et al.* (2006) as well as McQuine *et al.* (2000) who showed that reduced ability to balance is associated with increased risk of ankle injuries. Tropp *et al.* (1984) measured the change in the athlete's centre of gravity (postural sway) as an indicator of proprioceptive ability during pre-season in soccer players who were then monitored for a complete season and showed that an elevated postural sway value identified the athletes at increased risk of ankle sprain. McQuine *et al.* (2000) confirmed this when they assessed the balance or postural sway of 210 basketball players from five high schools during the pre-season to determine if balance was a predictor of ankle

injury. They found that higher postural sway scores corresponded to increased ankle sprain rates and subjects who demonstrated poor balance (high sway scores) had nearly seven times as many ankle sprains as subjects who had good balance and therefore concluded that pre-season balance measurement served as a predictor of ankle injury susceptibility. Similar to the findings in this study, Wang *et al.* (2006) found high variation of postural sway in both anteroposterior and mediolateral directions corresponded to occurrences of ankle injuries. While Tropp *et al.* (1984) studied soccer players and McQuine *et al.* (2000) and Wang *et al.* (2006) basketball players, this study has identified balance as an ankle injury risk factor in female field hockey players. Their reduced ability to balance on the Biodex Balance, may be indicative of poor sensory input from joint mechanoreceptors (Lephart, 1993), and proprioceptive ability (Tropp *et al.*, 1984), and may also reduce dynamic balance or active position sense (Willems *et al.*, 2002) during the game of hockey. Extremely high forces pass through the ankle joint especially during a game such as hockey with changes in running speed and direction. If the ability to efficiently accelerate and decelerate in multiple directions is lost, there is the likelihood that when trying to change direction during game play, the body will be unable to control the movement, thus allowing unnatural forces to pass through the ankle joint as well as place the foot in abnormal positions. This dynamic balance is required in a fast game of field hockey where players need to transfer their body weight rapidly, move and control their low centre of gravity during squatting and lunging while co-ordinating speed and power. An impairment in this ability may therefore have predisposed these athletes to ankle injury.

Several studies have suggested that proprioceptive or balance training should be an important component of rehabilitation (Mattacola & Dwyer, 2002; Verhagen *et al.*, 2004; Fu & Hui-Chan, 2005) but perhaps this should in fact be incorporated into pre-season conditioning programmes in an attempt to decrease the incidence of ankle injury.

For lower leg injuries, univariate associations were found with ankle inversion deficit ($p=0.0253$), eversion deficit ($p=0.0379$) and anterior/posterior balance index ($p=0.0441$). This is contrary to the findings of Nilstad *et al.* (2014) who found no association with lower extremity injuries in elite female soccer players when they

examined maximal lower extremity strength, dynamic balance and foot pronation of these players. They showed that a greater body mass index was the only factor significantly associated with new lower extremity injuries. Perhaps, although similar to soccer, field hockey poses different physical demands as well as the unique feature of holding a stick while performing the various tasks of the game. The positive association with ankle inversion and eversion deficits and lower limb injuries indicates that muscle imbalance and weakness in the stabilising muscles of the foot and ankle does indeed place an increased strain on the lower limb. Weakness in these stabilising muscles can also lead to a dropped medial arch of the foot, which can cause excessive internal rotation of the tibia and thus could cause abnormal forces produced around the entire lower limb causing it to be vulnerable to injury.

Balance has been established as an important factor in field hockey. A less than optimal balance score, as with the ankle, means that an increased amount of pressure is placed on the structures of the lower limb during the fast-paced changes of direction and intermittent short bursts of acceleration required in field hockey, predisposing the lower limb to injury. It was interesting to note that a significant association was also found between left plantar flexion and upper arm injury ($p=0.0280$) as well as right inversion and upper arm injury (0.0387). Athletes who had higher plantar deficit showed a trend toward a higher risk of lower back injuries ($p=0.0554$), while those with a lower eversion torque of the left ankle showed a trend toward a higher risk of thigh injuries ($p=0.0598$). This finding may confirm that the body does not operate in isolated segments but rather as a dynamic unit, a phenomenon referred to as the kinetic chain. The kinetic chain is a collective effort of two or more sequential joints to create movement where, during sport activity, joints are not used in isolation but rather work in concert with the adjacent joints and surrounding musculature (Baechle & Earle, 2000). Perhaps a weakness in any one of the joints associated with the specific movements of field hockey can make other related joints and structures vulnerable to injury. The weakness of ankle joint eversion and the plantar flexion deficit could have changed the biomechanics of the body during dynamic movements, causing increased stress on the coping mechanisms of the body to maintain movement and posture. Poor ankle eversion strength can result in abnormal mechanics of the lower limb system especially during lateral movement patterns. If the ankle joint is unable to decelerate the body

sufficiently when required to, coping mechanisms must be adopted by the body to avoid acute injury or falling. The knee and hip joints will have to overcompensate for the lack of strength of the ankle, and therefore the quadriceps and hip flexors will have to assist more than normal to decelerate. Through repetition, this could lead to overuse injury of these mentioned muscles. Also, any abnormal force going through the ankle joint can affect any joint above it due to the concept of the kinetic chain. Furthermore, if the foot is excessively inverted due to a lack of strength of the ankle everters then the tibia will externally rotate, which can change the force direction at the knee and hip joints which can cause injury to the ankle, knee, hip or back.

This study confirms that field hockey is indeed a physically demanding sport requiring players to reach and maintain supreme physical fitness in order to successfully negotiate the fast changes in pace and sharp changes of direction in the game whilst maintaining balance and power with hockey stick in hand. A comprehensive rehabilitation or injury prevention programme is only possible if a thorough understanding of the physical demands and biomechanics, specifically as it is applied to field hockey, is established. However, more research is needed to identify and treat the structures involved.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions can be drawn from findings of this study in relation to the stated aim and objectives.

Objective 1: To profile each national female hockey player in their pre-season in terms of morphological factors of: age; height; weight; body fat percentage; player position; number of playing years; playing surface; and footwear.

The morphological profile includes similar results previously reported for age, height and mass. In terms of fat percentage, however, the 15.3% reported in this study is less than that previously reported for a national team, suggesting that the game of female field hockey has indeed become more competitive and the physical demands greater. There were no noticeable differences between the morphological factors and player position. Seventy percent (70%; n=21) of the players reported having more than twenty caps for South Africa. All matches and practices were conducted on the artificial Astroturf, and players reported using the same shoe for matches and practices.

Objective 2: To profile each national female hockey player in their pre-season in terms of skill-related factors of: muscle strength; balance; flexibility; speed; and agility.

In terms of skill-related factors, there was very little data in the literature to compare this to. The profile established in this study therefore provides a platform for further research. In terms of player position, while not statistically significant, the defenders in this small sample of players had the highest scores for flexibility, explosive power, and bench press, perhaps reflecting the physicality of this position. For lower body strength (leg press) and core strength, the midfielders produced the highest scores which might be attributed to the increased workload of these players who have to cover a larger area on the field.

The results for the 10 m and 40 m speed tests were similar to results previously reported (Keogh *et al.*, 2003) and decreased when the player conducted the tests with the hockey stick in hand. This confirms the unique aspect and extra workload of field hockey players. Defenders produced the lowest scores, confirming the findings of Holmes (2010). Strikers, however, produced the fastest times for the 40 m sprint test with hockey stick in hand, and the fastest times for the Illinois Agility Test with and without hockey stick in hand, confirming their high speed coverage on the field in order to make goal opportunities successful. With regards to balance, goalkeepers produced the slightly higher score, perhaps related to the higher body mass of these players. Isokinetic testing of the ankle joint produced no significant differences between right and left legs. When analysing the morphological and skill-related factors it was found that there were no significant differences between players' positions.

Objective 3: To conduct an analysis of injuries sustained during the subsequent in-season by the national female hockey team and to determine the incidence, severity and mechanism of these injuries.

This study found a high incidence of injury in the 2011-2012 season (2.8 per player) with the prevalence of injury types and locations similar to those found in other studies. In this study the ankle joint was the most frequently injured joint in the body, followed by the hamstring muscles and the lower back. Midfielders had the highest rate of injury, possibly related to the higher workload placed on these players. Strikers produced the highest incidence of ankle injuries which could be attributed to

the higher speed of these players. Matches produced more injuries than practice sessions and there was a higher risk of injury resulting during the second half of a match as opposed to the first half. Most of the injuries sustained in this study occurred from a fall, followed by player contact, being struck by a ball and finally from being struck by a stick. The majority of the injuries in this study (45%) fell under the mild category (RTP within 7 days of injury). The most common injury comprised ligament sprains which accounted for 40% of all injuries, followed by muscle strains which accounted for 32% of all injuries.

Objective 4: To conduct an analysis of injuries sustained during the in-season by the national female hockey team and to establish the morphological and skill-related factors, measured in the pre-season, that best predict injury.

In terms of predictors of injury, there was a moderate relation ($p=0.0809$) found in this study between mass and incidence of lower back injuries. Decreased ankle dorsiflexion strength was a very strong predictor of ankle injuries ($p=0.0002$), while dorsiflexion deficit ($p=0.0267$), eversion deficit ($p=0.0035$), all balance indices (i.e. anterior/posterior ($p=0.0465$), medial/lateral ($p<0.0001$) and overall balance ($p<0.0001$) were also significantly good predictors of ankle injury. For lower leg injuries, univariate associations were found with inversion deficit ($p=0.0253$), eversion deficit ($p=0.0379$) and the anterior/posterior balance index ($p=0.0441$). Furthermore, athletes who had higher plantar deficit showed a trend toward a higher risk of lower back injuries ($p=0.0554$), while a lower eversion torque of the left ankle showed a trend toward a higher risk of thigh injuries ($p=0.0598$).

This thesis, therefore, has satisfied its aims in establishing a platform for the morphological and skill-related profile of the elite female field hockey player, and has determined the incidence and nature of injury as well as detected significant predictors of injury in these players.

Recommendations

The findings of this study have created a platform for a number of future research studies that could be used to further enhance knowledge and understanding of the demands of women's field hockey and the potential injury risk factors. Improvements

to this study, presented in this thesis, and further investigation of the validity and reliability of the potential predictors of injury found, could include:

- Using a larger sample of elite athletes for greater statistical power to help confirm if pre-season performance measures are significant predictors of a specific injury in multivariate models;
- Conducting performance measure tests throughout the season to determine if and how these factors change, and to introduce training accordingly;
- Comparing findings of different national teams and how these relate to the performance of these teams;
- Formulating a possible injury prevention programme based on the findings of this study and to monitor the effectiveness of this programme and henceforth provide vital information for coaches and medical personnel; and
- Monitoring the national team under investigation in the present study over a few seasons to provide enough information to validate the findings of this study and perhaps identify further trends as the game and the way it is played continue to change.

As there has been only a relatively small amount of published literature on elite female field hockey, it is likely that there is still much to learn and significant benefit to be gained from performance analysis research. It is important that basic notational analysis of hockey continues so as to thoroughly document the physical demands of the game at all levels and including men, women and youth. Increased knowledge on risk factors for injuries enables more targeted prevention strategies with the aim of reducing injury rates in elite female field hockey players.

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APPENDIX A



SOUTH AFRICAN HOCKEY ASSOCIATION

Room No. 8, 2nd Floor, Southern Stand, Loftus Versveld Stadium, Lynnwood Road, Sunnyside. P O Box 11573, Hatfield, Pretoria 0028
Tel: (27) 012 343 1226 Fax: (27) 012 343 1234. E- Mail: sahockey@icon.co.za

22 October 2010

TO WHOM IT MAY CONCERN

This is to confirm that the South African Hockey Association gives Marlene Naicker permission to continue her study of the South African Women's Hockey Team.

Regards

Dave Carr

Dave Carr

President



Affiliated to: Federation Internationale De Hockey and African Hockey Federation.

APPENDIX B

QUESTIONNAIRE

To be completed by all national female field hockey players in the 2011 field hockey pre-season. Please tick where appropriate.

1. Name: _____ 2. Age _____

3. Weight: _____ 4. Height _____

5. Are you left-or right-hand dominant?

Left Right

6. Are you left or right leg dominant?

Left Right

7. Number of years playing field hockey:

a) < 2yrs b) 2 – 3.9 yrs c) 4 – 6 yrs d) > 6 yrs

8. How many caps for the South African squad do you have?

a) < 5 b) 5-10 c) 11 -20 d) >20

9. Position played. Please tick if you play more than one position.

a) forward b) back c) midfielder e) goalkeeper

10. Have you sustained an injury before? Yes No

If yes, please complete the attached injury profile sheet.

11. How many hockey training sessions do you have a week?

a) 1 b) 2 c) 3 d) 4 e) >4

12. What playing surface is used for training?

a) grass b) astroturf

13. What playing surface is used for matches?

a) grass b) astroturf

14. Do you use special footwear for playing hockey? Yes No

15. Do you use the same shoe for games and practices? Yes No

16. What brand of footwear do you use?

a) Hi-tech b) Nike c) Adidas d) Other

17. Do you use any braces or special orthotics in your shoe? Yes No

18. What type of orthotic do you use?

a) ankle b) knee c) wrist d) arch support e) other

Thank you very much for your participation in this study.

Marlene Naicker

APPENDIX C

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study:

MORPHOLOGICAL AND SKILL- RELATED FITNESS COMPONENTS AS POSSIBLE PREDICTORS OF INJURIES IN ELITE FEMALE FIELD HOCKEY PLAYERS

You are asked to participate in a research study conducted by Marlene Naicker, from the Sports Science Department Stellenbosch University, the results of which will form part of the dissertation for her PhD. You were selected as a possible participant in this study because you are a senior national female field hockey player and this thesis is based on elite female field hockey players.

1. PURPOSE OF THE STUDY

The purpose of this research project is to determine possible injury risk factors in elite female field hockey players and to determine the effectiveness of an intervention programme in reducing or even preventing the occurrence of an injury in female field hockey players. If injuries are to be prevented, it is imperative to identify risk factors before an intervention programme is implemented.

2. PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:

2.1. To complete a questionnaire in the pre-season regarding age, height, weight, player position, number of years of playing, playing surface, footwear and previous injury.

2.2. To undergo isokinetic testing of the ankle, assessments of posture, balance, speed and agility in the pre-season.

2.2. To complete an injury profile sheet at the end of the competition season.

2.3. To include an injury prevention exercise regime based on the findings of the above, consisting of strengthening, balance and stretching exercises, in the pre-season conditioning programme of the next season.

2.4. To complete an injury profile sheet at the end of the next competition season.

3. POTENTIAL RISKS AND DISCOMFORTS

These tests and exercises will not cause any discomfort or injury and will not affect your performance in a hockey game or training session.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

Research has identified some commonly injured body parts in female field hockey. If we are able to predict factors and identify those female field hockey players that are at risk of sustaining an injury, we can then introduce an intervention programme that can rehabilitate these aspects of the player and prevent injuries from occurring. Decreasing the risk of injury will allow players and coaches the confidence to carry out technical and tactical aspects of the game and maintain consistent participation at an elite level and ultimately improve the team's performance.

5. PAYMENT FOR PARTICIPATION

Unfortunately there is no payment for your participation in this study.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of allocating numbers to different positions of the game e.g. Forward 1, right wing 2 etc. Information will be kept with the investigators only and raw data held under lock and key. All processing of data will be governed by a PC password protector. Only the findings will be published with the strictest of confidentiality to the individual players.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may

also refuse to answer any questions you don't want to answer and still remain in the study. Your position in the SA Women's Hockey Squad will not be affected whether or not you choose to participate in this study.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact Marlene Naicker (Tel:0315633530; Mobile: 0832626795 ; Email: mnaicker8@hotmail.com or Professor JG Barnard (Sports Science Dept. Stellenbosch University).

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Malene Fouche' (mfouche@sun.ac.za; 021-808 4622) at the Division for Research Development.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

The information above was described to me, _____, by Marlene Naicker in *English* and I am in command of this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent to voluntarily participate in this study /I hereby consent that the subject/participant may participate in this study. I have been given a copy of this form.

Name of Subject/Participant

Name of Legal Representative (if applicable)

Signature of Subject/Participant or Legal Representative

Date

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to _____ and her representative _____ was encouraged and given ample time to ask me any questions. This conversation was conducted in English and *no translator was used*.

Signature of Investigator

Date

APPENDIX D

Injury Profile Sheet

To be completed by all players selected for the South African Women's senior team for 2011. Please complete this questionnaire and tick where appropriate.

Name of Player: _____

1. Please tick site of injury in space provided.

Head and neck	<input type="checkbox"/>	Upper limbs	<input type="checkbox"/>	Lower limbs	<input type="checkbox"/>	Trunk	<input type="checkbox"/>
Face	<input type="checkbox"/>	Collar bone	<input type="checkbox"/>	Pelvis	<input type="checkbox"/>	Ribs	<input type="checkbox"/>
Nose	<input type="checkbox"/>	Shoulder	<input type="checkbox"/>	Hip	<input type="checkbox"/>	Sternum	<input type="checkbox"/>
Ear	<input type="checkbox"/>	Upper arm	<input type="checkbox"/>	Thigh(front)	<input type="checkbox"/>	Upper back	<input type="checkbox"/>
Eye	<input type="checkbox"/>	Elbow	<input type="checkbox"/>	Thigh (back)	<input type="checkbox"/>	Lower back	<input type="checkbox"/>
Neck	<input type="checkbox"/>	Fore arm	<input type="checkbox"/>	Knee	<input type="checkbox"/>	Abdomen	<input type="checkbox"/>
Head	<input type="checkbox"/>	Wrist	<input type="checkbox"/>	Lower leg	<input type="checkbox"/>	Groin	<input type="checkbox"/>
Mouth	<input type="checkbox"/>	Hand	<input type="checkbox"/>	Ankle	<input type="checkbox"/>	Buttock	<input type="checkbox"/>
Jaw	<input type="checkbox"/>	Fingers	<input type="checkbox"/>	Foot	<input type="checkbox"/>	Internal	<input type="checkbox"/>

2. What was the date of your injury/injuries (not more than 2 years ago)?

3. When did the injury occur?

a) match b) practice c) first half d) second half

4. Please describe the mechanism of the injury.

a) hit by ball b) hit by stick c) fall d) player contact

5. Severity (how long did it take to return to play?)

Transient (return within 3 days)	<input type="checkbox"/>
Mild (return within 7 days)	<input type="checkbox"/>
Moderate (return within 10 days)	<input type="checkbox"/>
Severe (return more than 10 days)	<input type="checkbox"/>
No return	<input type="checkbox"/>

6. Type of Injury

Fracture	
Dislocation	
Subluxation	
Concussion	
Strain	
Sprain	
Rupture	
Laceration	

7. Management

Medical	
Rehabilitation	
Physiotherapy	
Surgical	

8. Protection

Head gear	
Mouth guard	
Shin guard	
Gloves	
Strapping	
Other	

If you ticked yes for strapping or other please specify. _____
