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

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ABSTRACT

This study investigated whether morphological or skill-related factors measured pre-season can predict injuries sustained in-season by field hockey players. In this cohort-analytical study, 30 female South African national field hockey players underwent pre-season testing including anthropometry, balance, flexibility, explosive power, upper and lower body strength, core strength, speed, agility and isokinetic testing of the ankle. A questionnaire was used to collect demographic data, elite-level experience, playing surface, footwear and injury history. Injuries in training and matches were recorded during the subsequent season using an injury profile sheet completed by injured players. Eighty-seven injuries, mostly involving ligaments and muscles of the ankles, hamstrings and lower back, were recorded. Univariate analyses showed that ankle dorsiflexion strength was a strong predictor of ankle injuries (p=0.0002), while ankle dorsiflexion deficit (p=0.0267) and eversion deficit (p=0.0035) were significant predictors. Balance indices (anterior/posterior, p=0.0465; medial/lateral, p<0.0001; and overall, p<0.0001) were pre-season performance measures significantly predicting potential 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).

Key words**:** Elite female field hockey players; Morphology; Skill-related fitness components; Predictors of injuries.

INTRODUCTION

In South Africa, field hockey is commonly played at primary and high schools, sport clubs and universities. Once an amateur game, it has developed into a professional sport undergoing radical changes. According to Reilly and Borrie (1992), some of these changes have increased the incidence of injuries. Compared to grass pitches, the modern synthetic surface, Astro Turf, is a more consistent playing surface leading to better ball control, higher passing accuracy and higher speed across the turf (Hughes, 1988). These factors contribute to the game being played at a faster pace, which places greater physiological stress on the player, specifically the musculoskeletal system and the lower limb joints, and ultimately increases the risk of injury.

Despite the popularity of this Olympic sport, recent data on the incidence of injuries among female field hockey players are limited, although the head/face (Theilen *et al*., 2016) and ankle (Petrick *et al*., 1992; Murtaugh, 2001; Dick *et al*., 2007; Naicker *et al*., 2007), have been identified as frequently injured sites among female field hockey players. Other common areas of injury among female hockey players are the lower back (Rishiraj *et al*., 2009), knees (Petrick *et al*., 1992; Dick *et al*., 2007), upper leg muscles (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 highlight the use of protective equipment (Hendrick *et al*., 2008; Hendrickson *et al*., 2008; Theilen *et al*., 2016). Theilen *et al*. (2016) argue that although the head or face injuries reported in their study were minor, these injuries need to be addressed because they may reflect the liberalisation to play high balls all over the pitch, especially within the circle.

In terms of playing position on field hockey, goalkeepers have the greatest potential to be injured by direct trauma from sticks and balls (Verow, 1989). This finding was 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 frequently injured field players (0.36 injuries/athlete-year) (Murtaugh, 2001).

Dick *et al.* (2007) found in a 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, in a five-year-long study of 75 under-21 aged female field hockey players, Rishiraj *et al*. (2009) observed a significantly higher risk of injury during the second half of a game or practice.

Neither of these studies (Dick *et al.*, 2007; Rishiraj *et al*., 2009), however, investigated the possible aetiology of injuries or their risk factors. The high incidence of injury reported in field hockey calls for preventative action based on the results of epidemiological research. Preventative strategies and activities are justified on medical, as well as economic grounds. Risk factors that predispose female field hockey players to injury should be understood before implementing an intervention to reduce the incidence of injuries. Identification of risk factors for injuries not only contributes to reduce the risk of injuries, but in a game that is becoming increasingly popular, professional and demanding, knowledge about risk factors will ensure that professionals consistently perform at their peak. Furthermore, a reduction in the incidence of injuries decreases healthcare costs.

PURPOSE OF RESEARCH

The purpose of this study was to identify risk factors for injury in female field hockey players. More specifically, this study investigated the question whether a range of pre-season assessments of morphological and skill-related components can predict injuries sustained in-season.

METHODOLOGY

Ethical clearance and consent

Before the research commenced and the subjects were recruited, the study was approved by the Ethics Committee of the University of Stellenbosch, South Africa (Ethics No. 497/2011). Informed consent forms approved by the Ethics Committee were handed out and signed by all participating players. The study included all players of the South African senior women's field hockey team. The national women's hockey team is selected from the 9 provincial teams in South Africa based on the performance of the players in the inter-provincial tournaments. This group of players, therefore, comprised the elite female field hockey population in South Africa. The group of 30 national-level female hockey players were tested over a 2-day period.

Survey and laboratory testing

A cohort-analytical study where all participants completed a survey and underwent a battery of pre-season fitness tests was conducted. Injury data were obtained using a self-administered injury report survey. After scrutiny of various injury surveillance questionnaires and definitions of injuries, the questionnaire was based on a document drafted by the Rugby Injury Consensus Group to monitor the epidemiology of rugby injuries (Fuller *et al*., 2006; Fuller *et al*., 2007; Pluim *et al*., 2009). The questionnaire was adapted by the researchers to address the aims of this study and to standardise definitions of injury. The study included all players of the South African senior women's field hockey team during the 2011/12 season. All measurements took place under laboratory conditions. Players were instructed to refrain from eating or drinking within 2 hours of the appointment and to empty the bladder before measurements were taken. 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 fitness tests used in this study have been shown to be adequately reliable (Jackson *et al*., 1980; Wisbey-Roth, 2000; Boddington *et al*., 2001; Cachupe *et al*., 2001; ISAK, 2001; Baltaci *et al*., 2003; Durandt *et al*., 2007; Ostojić *et al*., 2010; Evans, 2011; Seo *et al*., 2012; Váczi *et al*., 2013).

Morphological measures

Height, mass, body fat percentage (ISAK 2001) were measured. Body weight and height were measured using a calibrated mechanical scale with height rod (Seca 700; Seca GmbH & Co. Kg., Hamburg Germany). Weight graduation was 50g, and measurement rod graduation was 1mm. Players were weighed wearing shorts and a T-shirt with bare feet. Body fat percentage was then calculated using the Jackson and Pollock method (Jackson *et al*., 1980).

Skill-related fitness

All players performed a 3-minute warm-up and static stretch routine, emphasising the lower body before starting with the flexibility test. Flexibility (sit and reach test) (Baltaci *et al*., 2003), balance (Biodex Balance system single leg test) (Cachupe *et al*., 2001), strength (1 RM leg press, 1 RM bench press) (Seo *et al*., 2012), core strength (Wisbey-Roth, 2000), isokinetic testing of the ankle joint (Biodex System 3) (Evans, 2011), and explosive power (vertical jump test) (Ostojić *et al*., 2010), were measured on the first day of testing. On the second day of testing, on-field tests were performed, namely speed (10m and 40m linear sprints) (Durandt *et al*., 2007), agility (Illinois Agility Test) (Váczi *et al*., 2013), and anaerobic capacity (5m-multishuttle run test) (Boddington *et al*., 2001). Speed and agility tests were run once without the player holding a hockey stick and a second time with the player holding a hockey stick.

Injury report survey

At the end of the season, the self-administered injury report survey was handed out to players to establish incidence, mechanism and severity of the injury/injuries sustained during competition. The principal researcher explained the procedure for the completion of the self-administered injury report to each of the players.

Statistical analyses

Every binary dependent variable (specific injury occurred or did not occur) was analysed using 1-way logistic regression, fitting (1 at a time) the potential predictors of injury. For each independent variable, a point estimate and associated 95% confidence interval (CI) for the odds ratio of injury, as well as the corresponding likelihood ratio chi-square test statistic and P-value were reported. Furthermore, a multivariate analysis was conducted where each binary dependent variable was analysed using multiple logistic regression fitting all potential predictors of injury, followed by stepwise variable selection (P-value for entry and P-value to stay were both set to 0.1). The statistical analysis was done using the SAS statistical software package (version 9.22).

RESULTS

Demographic characteristics of study sample

Thirty (N=30) national female field hockey players completed the general questionnaire, which constituted a 100% response rate. The mean age of the players was 23.8±3.16 years (range=20 to 31yrs). Their mean height was 164.5±5.24cm (range=156 to 175cm), and their mean body mass 62.6±8.45kg (range=46.9 to 86.7kg). All participants reported in this this study were right hand dominant, playing the game at provincial level for more than 6 years, with 6.7% (n=2) of the players having less than 5 caps, 23.3% (n=7) having between 11 and 20 caps, and 70.0% (n=21) having more than 20 caps for South Africa. Ten of the players were strikers, 9 midfielders, 7 defenders and 4 goalkeepers.

Injury profile

In total, 87 injuries were reported by the 30 players during the 2011/12 field hockey season, giving 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 1. Most injuries (n=14; 16.1%) involved the ankle, followed by the back of the thigh (n=11; 12.6%), and the lower back (n=9; 10.3%). Besides injuries to the anatomical regions specified in Figure 2, 3 facial injuries (2 of the nose and 1 of the eye) were also reported. No concussion injuries were reported. The incidence of injuries by body site and playing position was also calculated. Overall, the midfielders had the highest incidence of injury (3.4 injuries/athlete/year), including the highest percentage (45%) of back thigh (hamstring) injuries, and the second highest percentage (36%) of ankle injuries. The strikers experienced the second highest incidence of injuries (2.8 injuries/athlete/year), including the highest percentage (50%) of ankle injuries, and the highest percentage (57%) of front thigh (quadriceps) injuries. This was followed by the defenders who had an injury incidence rate of 2.4 injuries/athlete/year and, finally, the goalkeepers with 1.3 injuries/athlete/year.

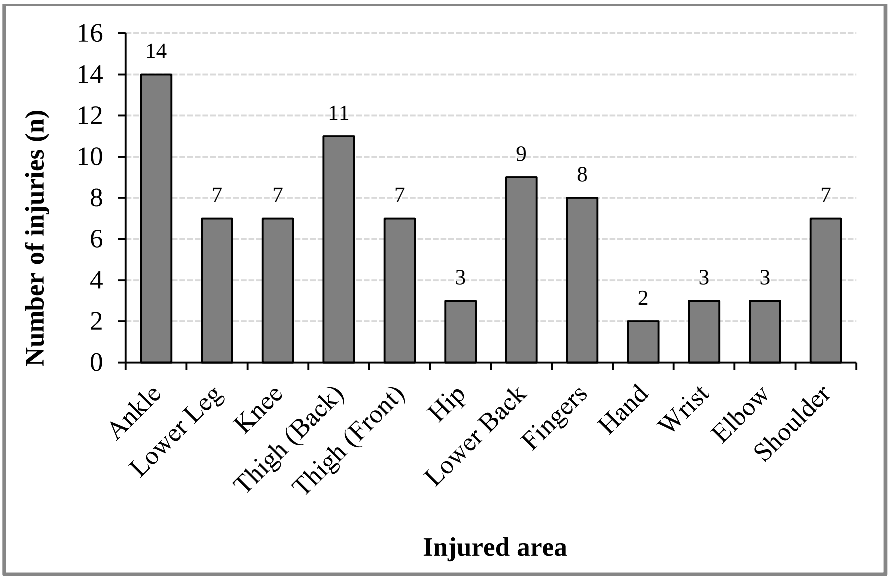

Figure 1. **ANATOMICAL REGION: NUMBER OF INJURIES DURING 2011/12 SEASON**

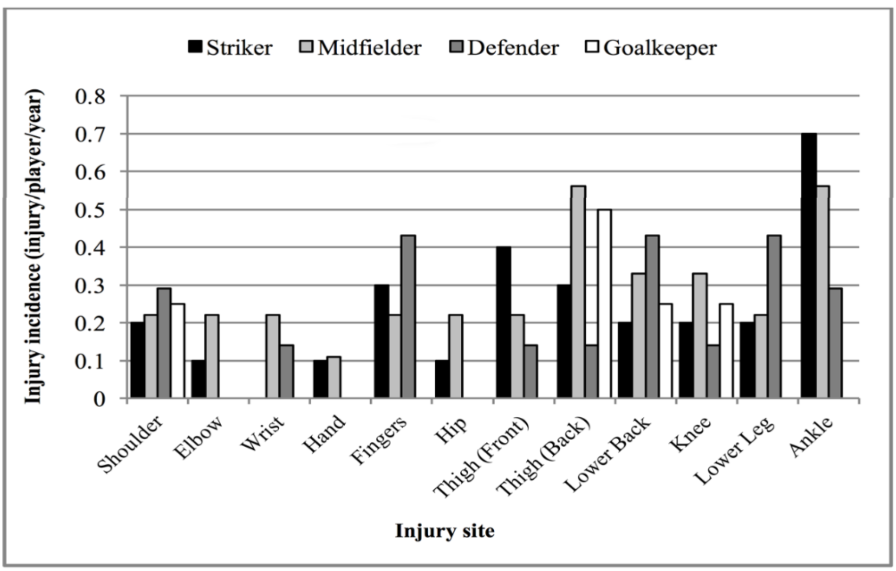

Figure 2. **INCIDENCE OF INJURIES IN ANATOMICAL REGIONS CLASSIFIED BY PLAYER POSITION**

The time of injury occurrence was captured, showing that 33.3% (n=29) of all injuries occurred during a training session, while the remainder (66.7%; n=58) occurred during a match. Among injuries occurring during a match, 34.5% (n=20) occurred in the first half of the match, while the remainder (65.5%; n=38) occurred in the second half.

The mechanisms of injury, as described by the players, were classified into falls, being struck by the ball or a stick, player contact and overuse injuries. The highest percentage of injuries (29.9%) was due to falls, while overuse injuries were reported by 7 players (8.1% of all injuries). Severity of the injury was related to time lost from playing the game. Mild injuries [return to play (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 7% (n=6) sustained severe injuries (RTP within longer than 10 days). 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 injuries, 2% (n=2) were fractures, 1% (n=1) were dislocations, 1% (n=1) were subluxations and 2% (n=2) were ruptures. Most of the injuries required some attention from the medical personnel, of which 64% required physiotherapy treatment, 23% needed medical attention from a doctor, 11% needed rehabilitation for their injuries and 2% required surgical intervention.

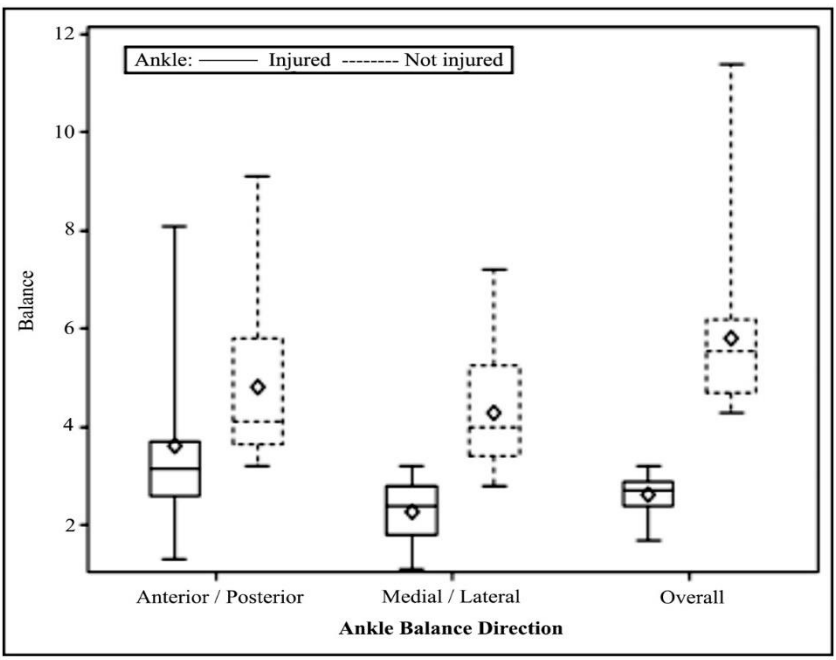

Figure 3. **BALANCE SCORES OF PLAYERS WITH AND WITHOUT ANKLE INJURIES**

Figure 3 shows boxplots of the balance scores for the players that sustained ankle injuries and those not sustaining ankle injuries. The players that sustained ankle injuries were weaker on balance scores for both anterior/posterior movements, as well as medial/lateral movements, and had a lower overall balance score when compared to those that did not have ankle injuries.

Predictors of injury

One of the main aims of the study was to investigate if variables measured in the pre-season could predict injuries during the playing in-season. Both univariate and multivariate (stepwise) logistic regression were used to identify potential predictors of injury. The results of the univariate logistic analyses are summarised in Table 1, where, for the various types of injury, all predictors significant at the $\alpha=0.1$ significance level, are listed. Similarly, Table 2 summarises the results of the multivariate analysis by listing the best set of predictors for the various types of injury, determined through stepwise logistic regression.

Note that in both Table 1 and Table 2, odds ratios larger than 1 imply that the injury risk increased as the value of the predictor variable in question increased; *vice versa*, odds ratios smaller than 1 imply that the injury risk decreased as the value of the predictor variable in question increased.

Table 1. **UNIVARIATE LOGISTIC REGRESSION: SIGNIFICANT (p<0.1) PREDICTORS OF INJURY**

Injury site	**Predictor** (independent variable)	**Likelihood ratio** (df=1)	**p-Value**	**Odds ratio**	**95% CI**
Ankle	Dorsiflexion L (Nm)	13.9506	0.0002	0.663	0.465–0.848
	Dorsiflexion deficit (%)	4.9087	0.0267	1.124	1.012–1.316
	Eversion deficit (%)	8.5153	0.0035	1.133	1.035–1.291
	Ant/Post balance (n)	3.9644	0.0465	0.611	0.322–0.993
	Med/Lat balance (n)	29.3391	<0.0001	0.004	<0.001–0.114
	Overall balance (n)		<0.0001[a]		
Lower leg	Ankle inversion L (Nm)	2.7583	0.0967	1.095	0.985–1.249
	Inversion deficit (%)	5.0035	0.0253	1.152	1.016–1.357
	Eversion deficit (Nm)	4.3105	0.0379	1.078	1.004–1.185
	Ant/Post balance (n)	4.0524	0.0441	0.590	0.292–0.988
Hand	Inversion deficit (%)	5.1350	0.0234	0.856	0.706–0.981
Upper arm	Plantar flexion R (Nm)	3.4352	0.0638	1.041	0.998–1.096
	Plantar flexion L (Nm)	4.8263	0.0280	1.046	1.005–1.102
	Ankle inversion R (Nm)	4.2730	0.0387	1.123	1.006–1.302
	Inversion deficit (%)	3.5157	0.0608	0.878	0.731–1.005
	Ant/Post balance (n)	4.6441	0.0312	1.696	1.046–3.134

[a] p-Value from exact test for effect of overall balance on ankle injuries. CI= Confidence Interval
Odds ratio could not be calculated because of complete data separation (see text).

Table 2. **STEPWISE LOGISTIC REGRESSION: SELECTED SETS OF PREDICTORS OF INJURY**

Injury site	Predictor (independent variable)	Odds ratio	95% CI
Ankle[a]	Strength bench (%)	<0.001	<0.001–0.024
	Dorsi L (Nm)	0.398	0.108–0.735
	Eversion deficit (%)	1.177	1.032–1.500
Lower leg	Eversion deficit (%)	1.072	0.993–1.174
	Inversion deficit (%)	1.148	1.001–1.361
Thigh	Plantar deficit (%)	1.273	1.058–1.833
	Eversion L (Nm)	0.673	0.435–0.882
	Eversion deficit (%)	0.803	0.651–0.923
	Ant/Post balance (n)	0.501	0.189–0.997
Hand	Inversion deficit (%)	0.856	0.706–0.981
Lower back	Plantar deficit (%)	1.090	0.998–1.241
Upper arm	Sit/Reach (cm)	0.855	0.689–0.991
	Inversion R (Nm)	1.478	1.158–2.252
	Inversion deficit (%)	0.711	0.502–0.893

[a] Regarding ankle injuries, the variable overall balance was not fitted in the model for stepwise selection because of complete data separation (see text).

Ankle injuries

Of ankle muscle strength that was tested, dorsiflexion of the left foot was a significant univariate predictor of injury, together with dorsiflexion deficit and ankle eversion deficit (relevant p-values are listed in Table 1). All movements of balance, namely anterior/posterior, medial/lateral and overall, were also highly significant predictors of injury (Table 1; Figure 3). Overall balance was the best observed predictor of ankle injury. All 14 players with overall balance less than or equal to 3.2n had an ankle injury, while all 16 players with overall balance greater than or equal to 4.3n did not have an ankle injury (Figure 3, this is an instance of complete data separation in logistic regression). These results suggest that players with balance scores smaller than 3n are almost certain to sustain an ankle injury.

Lower leg injuries

Lower leg injuries comprise all injuries to the knee and lower leg areas. Table 1 shows that ankle inversion deficit, ankle eversion deficit and anterior/posterior balance were significant univariate predictors of lower leg injuries. Inversion of the left ankle was found to be a borderline predictor of lower leg injuries. Since the odds ratios for inversion deficit, ankle eversion deficit and ankle inversion were larger than 1, increasing values of these variables were associated with increased odds (or risk) of injury. In contrast, the odds ratio for anterior/posterior balance was smaller than 1, implying that decreasing values of this variable were associated with increased odds of injury.

Hand injuries

Hand injuries comprise all injuries to the wrist, hand and fingers. Only ankle inversion deficit was found to be a univariate significant predictor of hand injuries.

Upper arm injuries

Upper arm injuries comprise all injuries to both the elbow and shoulder areas. Plantar flexion of the left ankle, inversion of the right ankle, and anterior/posterior balance were significant univariate predictors of upper arm injuries. Ankle plantar flexion of the right ankle and ankle inversion deficit were borderline predictors of upper arm injuries.

Multivariate analysis

The selected variables listed in Table 2 can form part of a predictive model for the respective injuries. Note that 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.

DISCUSSION

The overall mean incidence of injury reported by this sample of field hockey players (2.8 per player in the 2011/12 season), was much higher than the incidences previously reported respectively by Eggers-Ströder and Hermann (1994) (0.6 per player per season), Murtaugh (2001) (0.36 to 0.37 per player per season), and Petrick *et al*. (1992) (0.48 per player per year). In addition to the fact that the present study focused on elite hockey players exposed to a competitive playing milieu, the relatively high incidence observed in the current sample could possibly be attributed to the greater use of synthetic playing surfaces (Reilly & Borrie, 1992), recent rule changes (Ostenberg & Roos, 2000), and advances in stick construction (Murtaugh, 2001), which have increased the pace of the game and potential for injury.

Regarding anatomical site of injury, the results were similar to the findings of other authors, namely that the ankle joint is the most frequently injured joint in field hockey players (Reilly & Borrie, 1992; Dick *et al*., 2007; Rishiraj *et al*., 2009). The incidence of ankle injuries in the current study was 0.47 injuries per player-year (14 injuries), which is higher than reported in the above cited studies. The higher incidence of ankle injuries in the current study might again be related to the more demanding level of play. After ankle injuries, the hamstring muscle at 0.37 per player-year (11 injuries) and the lower back at 0.30 injuries per player-year (9 injuries), respectively, had the highest incidence.

In contrast to the findings of Ostenberg and Roos (2000), Murtaugh (2001) and Le Gall *et al*. (2006), age did not appear to be a predisposing factor in the present study. The moderately significant association (p=0.0809) between mass and incidence of lower back injuries found in this study, is supported by the findings of Heuch *et al*. (2013). The current results show that decreased ankle dorsiflexion strength is a very strong predictor of ankle injuries. It is similar to findings by Willems *et al*. (2005), who reported that decreased dorsiflexion muscle strength in male physical education students was a risk factor for ankle sprains.

Wang *et al*. (2006) found no association between isokinetic ankle strength and ankle injuries when they examined players in the pre-season in order to predict ankle injuries in men's high school basketball. In this study, the univariate associations suggest 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%), is a significant risk factor for ankle injury (p=0.0002). It is noteworthy that players sustaining injuries to the right ankle (21%) displayed weaker dorsiflexion strength of their right ankles. In a previous study (Naicker *et al*., 2007), an association between ankle injury and weak dorsiflexion torque was observed, but due to the retrospective nature of this study, it was not possible to decide 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 (Naicker *et al*., 2007).

The most common ankle injury is a lateral ankle sprain and is sustained in the inverted and plantar-flexed ankle. A possible explanation for these findings 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. These findings not only confirm the association between poor dorsiflexion torque and ankle injury, but also that poor dorsiflexion torque can in fact predict new ankle injuries. It highlights the possibility that strong dorsiflexors assist the ankle in preventing excessive plantar flexion and inversion injury responsible for most lateral ankle sprains.

Evertor muscle weakness and decreased evertor to invertor torque have been implicated as a risk factor to ankle injury in previous studies (Willems *et al*., 2002; De Noronha & Borges, 2004). However, less is known about 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 systematic review and meta-analysis of journal articles from selected electronic databases for ankle injury prediction (Witchalls *et al*., 2012), it was found that higher concentric plantar flexion strength at faster speeds and lower eccentric eversion strength at slower speeds posed increased risk of ankle injury. In a sport, such as field hockey, the constant intermittent changes in speed could be associated with the high incidence of ankle injuries. In another systematic review (De Noronha *et al*., 2006), however, found that ankle muscle strength was not associated with an increase in ankle injuries, but instead dorsiflexion range was reported to strongly predict risk of ankle sprain. Although the current study did not observe an association between 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 the current study. Due to the lack of consistency in these findings, particularly when applied to sportspersons, this lack of clarity may give constructive direction for future research. From the results, it is concluded that muscle imbalance around the ankle joint is indeed a consideration when developing conditioning programmes of field hockey players.

All balance indices, namely anterior/posterior ($p=0.0465$), medial/lateral ($p<0001$) and overall ($p<0001$), showed significant potential to predict ankle injury, confirming the findings of other researchers (Tropp *et al*., 1984; Watson, 1999; McGuine *et al*., 2000), who showed that reduced ability to balance is associated with increased risk of ankle injuries (Tropp *et al*., 1984). 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. They were then monitored for a complete season and it was found that an elevated postural sway value identified the athletes at increased risk of ankle sprain (Tropp *et al*., 1984). McGuine *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. 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 reported. They, therefore, concluded that pre-season balance measurement served as a predictor of ankle injury susceptibility (McGuine *et al*., 2000). Likewise, Wang *et al*. (2006) found that high variation of postural sway in both anteroposterior and mediolateral directions corresponded to the occurrence of ankle injuries.

While Tropp *et al*. (1984) studied soccer players and McGuine *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. The players' reduced ability to balance on the Biodex Balance might be indicative of poor sensory input from joint mechanoreceptors (Naicker *et al*., 2007) and proprioceptive ability (Tropp *et al*., 1984), and might also reduce dynamic balance or active position sense (De Noronha & Borges, 2004) 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 and 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). Perhaps this should in fact be incorporated into pre-season conditioning programmes in an attempt to decrease the incidence of ankle injury.

CONCLUSION AND PRACTICAL IMPLICATIONS

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 injured structures involved.

Based on the results of this study, the following conclusions and recommendations seem warranted:

- Injury prevention should be an important goal for sport medicine professionals. While most teams rely on medical support for curative and rehabilitative services once injury has occurred, the best approach is to prevent injuries from occurring. An injury prevention model based on the predictive factors highlighted in this study needs to be formulated. However, future research is required to validate this injury prevention model.

- This study has highlighted injury risk factors in elite female field hockey players, which, if known by the medical and coaching team, may prevent injuries from occurring.

- Ankle injuries have been identified as a common injury in female field hockey players and had the highest incidence of injury in this study. Although ankle injuries in this study involved the lateral ankle complex, it will be beneficial for future research to report a standardised classification of ankle injury. While poor dorsiflexion and balance were associated with ankle injury after the ankle injury occurred (Naicker *et al*., 2007), the current study has confirmed that these weaknesses are in fact good predictors of ankle injury, with all balance indices being good predictors of ankle injury.

- Ankle inversion deficit, eversion deficit and anterior/posterior balance were associated with lower leg injuries in elite female field hockey players.

- Conditioning programmes and team preparation need to be adjusted to address these factors which can help prevent serious injuries that keep players out of matches.

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Conflict of interest

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