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The effect of external ankle support on knee and ankle joint movement and loading in netball players

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ABSTRACT

Objectives: External ankle support has been successfully used to prevent ankle sprains. However, some recent studies have indicated that reducing ankle range of motion can place larger loads on the knee. The aim of this study was to investigate the effect of external ankle support (braces and high-top shoes) on the ankle and knee joint loading during a netball specific landing task.
Design: A repeated measure design.
Methods: High performance netball players with no previously diagnosed severe ankle or knee injury ($n = 11$) were recruited from NSW Institute of Sport netball programme. The kinematic and kinetic data were collected simultaneously using a 3-D Motion Analysis System and one Kistler force plate to measure ground reaction forces. Players performed a single leg landing whilst receiving a pass while wearing a standard netball shoe, the same shoe with a lace-up brace and a high-top shoe.
Results: Only the brace condition significantly reduced the ankle range of motion in the frontal plane (in/eversion) by 3.95 ± 3.74 degrees compared to the standard condition. No changes were found for the knee joint loading in the brace condition. The high-top shoes acted to increase the peak knee internal rotation moment by 15%. Both the brace and high-top conditions brought about increases in the peak ankle plantar flexion moment during the landing phase.
Conclusions: Lace-up braces can be used by netball players to restrict ankle range of motion during a single leg landing while receiving a pass without increasing the load on the knee joint.

1. Introduction

About 411,300 Australians aged 15 years and over play netball on a regular basis, making it the most popular team sport in Australia.[1] Netball is a physically demanding sport in which speed, strength, fitness and flexibility are important. The incidence of injury in netballers has been reported to be about 14 injuries per 1000 player hours.[2] The most common site of injury is the lower extremity, with the ankle joint accounting for the majority of the injuries sustained in recreation and elite netball competitions.[3,4] The knee joint is the second most common in terms of injury incidence[3,4] but the most significant in terms of costs and disability.[5]

External ankle support strategies, such as prophylactic braces and high-top shoes, are commonly used in an attempt to protect the ankle or prevent further injury.[6] Several biomechanical investigations have demonstrated that ankle braces are effective in preventing, decreasing, or slowing the motions that may cause injury to the lateral ankle ligaments.[7–9] The use of ankle braces has been shown to significantly reduce the occurrence of ankle sprains, especially in people with previous ankle injuries.[10–12] The stabilizing effect of high-top shoes is less obvious from previous literature with limited biomechanical investigations suggesting a restriction in the ankle inversion range of motion (ROM).[13,14] Other studies have reported that the restrictive effect of high-top shoes is considerably less than the ROM restriction imposed by prophylactic ankle stabilizers or ankle taping.[15] This being said, Hume et al.,[6] have suggested that standard (low-cut) shoes should be discouraged for use in netball, and high-top shoes have been recommended for sports such as basketball[16] or those involving sideways cutting movements.[17]

Although it is suggested that ankle braces and high-top shoes may be effective in reducing the likelihood and severity of ankle sprain-type injuries, restricting ankle movements may increase the risk of injuries to proximal joints such as the knee. Recent studies have reported that restricting the movement of the ankle in the

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frontal plane can act to increase the peak knee internal rotation moments,[18,19] which may contribute to the development of knee injuries.[20,21]

The mechanism of knee injury in netball players has often been described as a sudden stop or an incorrect landing.[4,22,23] One of the suggested mechanisms of knee injury is rapid deceleration, twisting and hyperextension of the knee after landing[24] which may potentially occur during single leg netball landings. This may be because upon receiving a pass a player must rapidly reduce horizontal velocity and maintain a position of balance and stability so that the footwork rule is not violated. As knee injuries are the second most common injury in netball players and braces and high-top shoes are recommended,[6] it is important to investigate the effect of high-top shoes and braces on knee joint loading during a netball specific landing task.

The primary objective of this study was to compare knee joint moments incurred during a single leg landing task whilst wearing a standard netball shoe, a standard netball shoe with an ankle brace, and a high-top shoe. We hypothesized that the brace and the high-top shoe would increase knee joint loading compared to the standard shoe. Our secondary aim was to quantify the effect of the brace and the high-top shoe on the ankle joint movement and loading. We hypothesized that the brace and the high-top shoe would restrict the peak ankle joint angles, ROM and position at landing and increase the knee joint moments.

2. Methods

Forty-four players from the New South Wales Institute of Sport (NSWIS) netball programme completed a self-administered screening questionnaire which sought information about their experiences with knee and ankle problems. Nineteen players were ineligible for the study because they satisfied one or more of the following exclusion criteria: (1) a history of knee or ankle surgery; (2) knee or ankle pain in the previous six months that required consultation with a medical practitioner and/or caused a formal netball training session or game to be missed; or (3) current knee or ankle pain or instability that would have prevented performance of the landing task at the required intensity. Twenty-five players who met the inclusion criteria were invited for a biomechanical assessment of their landing technique but only 12 were able to attend a testing session. Players could not attend a testing session because of study or work commitments, unrelated injuries or commitments with the national team. Data analysis was performed on 11 players because data for the netball shoe condition for one player could not be analyzed due to technical problems. Average age, height and mass of the included players were 18.3 ± 1.8 years, 178.5 ± 4.1 cm and 70.1 ± 8.2 kg respectively. All test procedures were approved by the Human Research Ethics Committee at The University of Sydney, and all participants gave their written informed consent before data collection.

A three-dimensional kinematic analysis was performed to track the position of all segments of the right lower limb (pelvis, thigh, shank, rear foot and fore foot, respectively) in space. The data were collected at 200 Hz using a 14-camera 3-D motion analysis system (Cortex, Motion Analysis Corporation, Santa Rosa, CA, USA). Additionally, one Kistler force plate (Kistler Instrumente AG, Winterhur, Switzerland) sampling at 1000 Hz was used to simultaneously measure ground reaction forces. Each subject had twenty-one reflective surface markers taped to specific anatomical landmarks on the pelvis, thigh, shank and shoe using hypoallergenic tape. Markers were placed on the sacrum, right and left anterior superior iliac spine, right and left greater trochanter, right mid-thigh, medial and lateral femoral epicondyle, upper, lower and lateral tibia, medial and lateral malleoli, lateral, medial and posterior calcaneus, navicular, 1st and 5th metatarsal joint, the hallux, and on the left posterior calcaneus.

Motion of the rear-foot was determined using a device previously described by Attwells and Smith (Fig. 1).[25] It consisted of an array of three markers mounted onto a rigid shaft that attached to the calcaneus via a flexible metal stirrup. The stirrup provided a large contact area around the calcaneus and was secured using double sided adhesive tape and strapping tape. The wand extended posteriorly through a 14 mm hole in the rear of the shoe counter. The brace used in this study had no heel cup so the stirrup could be placed on the calcaneus. All players were provided with a pair of socks with a hole in the area of the heel to provide access to the calcaneus.

The movement pattern assessed was a single leg landing whilst receiving a pass. Each player was instructed to use a 5 m straight line approach to the landing area at a self-selected speed. The player 'leapt' from her left leg and landed on her right leg on the force plate. As the player was about to land she received a chest pass that was distributed with a flat trajectory by a tester who was positioned approximately 3 m from the landing area and at a 5 degrees angle relative to the approach direction. After landing the player was permitted to step forward with her left leg but no further steps were allowed. Players were allowed as many practice trials as necessary to become familiar with the procedures and testing environment. Once data collection commenced players were required to complete 8–10 successful trials. A trial was considered successful if it satisfied the requirements of the task and the right foot landed within the border of the force plate. Players performed this movement with a standard netball shoe (Ignite3, Ascics) (standard condition), the same netball shoe with a lace-up brace (E-Professional) (brace condition) and a high-top shoe (Jordan, Nike) (high-top condition). The order of the conditions was randomized.

Kinematic and kinetic data were processed using Visual3D software (C-motion, Rockville, MD, USA). The lower extremity segments were modelled as a frustra of right cones while the pelvis was modelled as a cylinder. Anthropometric data was based on Dempster. Internal moments were calculated at the proximal end of the distal segment of each joint. The local coordinate systems of the pelvis, thigh, leg, rearfoot and forefoot were derived from the standing calibration trial. Coordinate data were low-pass filtered using a fourth-order Butterworth filter with a 6–15 Hz cut-off frequency. Ground reaction force data were low-pass filtered using a fourth-order Butterworth filter with a 20 Hz cut-off frequency.

Six degrees-of-freedom for each segment were determined from the segment's set of reflective markers. Subsequently, lower extremity 3-D joint angles were calculated using a Xyz Cardan rotation sequence.

All data were time-normalized between ground contact for the right foot and ground contact for the left foot. Ground contact for the right foot was determined using the vertical ground reaction force with a threshold of 20 N while ground contact for the left foot was determined by the lowest point of the left calcaneal marker. Several trials from 2 players needed to be eliminated due to the wand hitting the floor or due to the player landing on the border of the force plate. It was therefore decided to analyze the first four good trials from each subject for each condition Discrete variables were extracted from each individual trial and averaged for each player. The individual mean curves were averaged across conditions to produce ensemble curves.

Histograms of all variables were visually inspected for normality. Comparisons between the brace and the standard shoes and between the high-top shoes and the standard shoes were made using paired *t*-tests for normally distributed continuous data and the Kruskal–Wallace test for non-normally distributed continuous data. Dependent variables for the ankle joint loading were the ankle

Fig. 1. Image of the markers on the shoe and the device to measure the in-shoe motion of the calcaneus: an array of three markers mounted onto a rigid shaft that attached to the calcaneus via a flexible metal stirrup.

moments in the sagittal and the frontal plane and for the knee joint loading the knee joint moments in the sagittal, frontal and transversal plane. Dependent variables for the ankle joint movement were ankle range of motion in the sagittal, frontal and transversal plane and ankle inversion velocity. Data were expressed as mean and standard deviation of changes compared to standard shoes, as appropriate. SPSS (Release 20.0 for Windows, 2011, Chicago: IBM corporation) was used for all data analysis. Effect sizes were computed using partial eta square values. The Holm's procedure was used to account for the possibility of a Type 1 error occurring with multiple dependent variables. These adjusted *p*-values were calculated using *R* (version 2.15.1, 2012, Vienna: The *R* Foundation for Statistical Testing).

3. Results

There were no differences in the peak vertical ground reaction forces between the brace or the high-top condition and the standard condition (24.4 ± 4.5 N/kg, 23.3 ± 4.2 N/kg vs 24.0 ± 4.1 N/kg, $p > 0.3$). There was a significant increase in the ankle plantar flexion moment for the high-top conditions compared to the standard condition and a clear trend for the brace condition (Table 1). There was no significant effect of the brace on any of the peak knee joint moments. Peak knee internal rotation moment was increased in the high-top condition compared to the standard condition (Table 1).

During single leg landing, the ankle ROM in the frontal plane (in/eversion) was significantly reduced for the brace condition compared to the standard condition (14.36 ± 3.44 degrees vs 10.41 ± 1.40 degrees, $p = 0.020$, partial eta^2 = 0.553, power = 0.842). This was due to both a significantly larger peak inversion and eversion angle in the standard condition compared to the brace condition (4.40 ± 5.60 degrees vs 2.82 ± 4.42 degrees, $p = 0.05$, partial eta^2 = 0.359, observed power = 0.517; 9.96 ± 4.36 degrees vs 7.59 ± 4.96 degrees, $p = 0.035$, partial eta^2 = 0.405, observed power = 0.598). Peak ankle eversion angular velocity was significantly reduced in the brace condition compared to the standard condition (−249.77 ± 71.84 degrees/s vs −349.03 ± 92.11 degrees/s, $p = 0.05$, partial eta^2 = 0.478, observed power = 0.725). None of the other ranges of motion were significantly different ($p > 0.102$). No significant differences in the ankle range of motion were found between the high-top and the standard conditions ($p > 0.56$).

At ground contact, netball players landed in a significantly less inverted position in the brace condition compared to the standard condition (1.18 ± 4.82 degrees vs 4.05 ± 5.89 degrees, $p = 0.012$, partial eta^2 = 0.524, observed power = 0.8). No significant differences were found between the high-top and the standard condition.

4. Discussion

The current study investigated the effect of external ankle support (a lace-up ankle brace and a high-top shoe) on the ankle and knee joint loading during a netball specific landing task, e.g. a single leg landing while receiving a pass.

Although previous studies[18,19] have indicated that a restriction of the ankle movement could possibly increase the loading at the knee joint, the tasks under investigation were not netball specific. Having said this, any change in knee joint loading that may occur as a result of ankle bracing would be of particular relevance to netballers due to both the widespread use of ankle braces and the already common occurrence of knee injuries in netball.[2] In the current study, the brace restricted the ankle movement in the frontal plane during the single leg landing, without any increases in knee joint loading. Therefore, the lace-up brace may act to stabilize the ankle without increasing the potential for knee injury through altered knee joint mechanics. As previously mentioned, these results are in contrast to those of Venesky et al.,[19] who observed an increased knee internal rotation moment while wearing prophylactic ankle braces. This group measured joint moments during a drop landing onto a 20 degrees slanted board which passively forced the ankle into inversion, and was designed to simulate

Table 1
Mean changes in peak ankle and knee moment during a single leg landing while receiving a pass.

Moments (Nm/kg)		Standard shoe with brace					High-top shoes				
		Mean ± SD	95% CI	*p*	Partial eta^2	Power	Mean ± SD	95% CI	*p*	Partial eta^2	Power
Ankle	Dorsiflexion	0.061 ± 0.175	−0.056; 0.179	0.546	0.119	0.183	−0.063 ± 0.126	−0.147; 0.021	0.254	0.217	0.325
	Plantarflexion	0.132 ± 0.157	0.027; 0.237	0.057	0.438	0.711	−0.133 ± 0.147	−0.232; −0.034	0.039	0.474	0.772
	Inversion	−0.011 ± 0.076	−0.062; 0.040	0.648	0.022	0.071	−0.013 ± 0.115	−0.091; 0.064	0.709	0.015	0.064
Knee	Extensor	−0.078 ± 0.195	−0.209; 0.053	0.864	0.149	0.223	0.106 ± 0.1094	−0.025; 0.236	0.303	0.246	0.373
	Varus	−0.008 ± 0.061	−0.049; 0.033	0.999	0.020	0.069	0.021 ± 0.074	−0.028; 0.071	0.514	0.083	0.139
	Valgus	0.005 ± 0.162	−0.105; 0.114	0.999	0.001	0.051	−0.047 ± 0.130	−0.134; 0.040	0.514	0.126	0.139
	Internal rotation	−0.029 ± 0.094	−0.092; 0.034	0.993	0.095	0.153	0.083 ± 0.085	0.026; 0.140	0.036	0.512	0.831

Data are mean changes ± standard deviation (std) for 11 netball players. CI, confidence interval. *P*-values are adjusted for multiple comparisons.

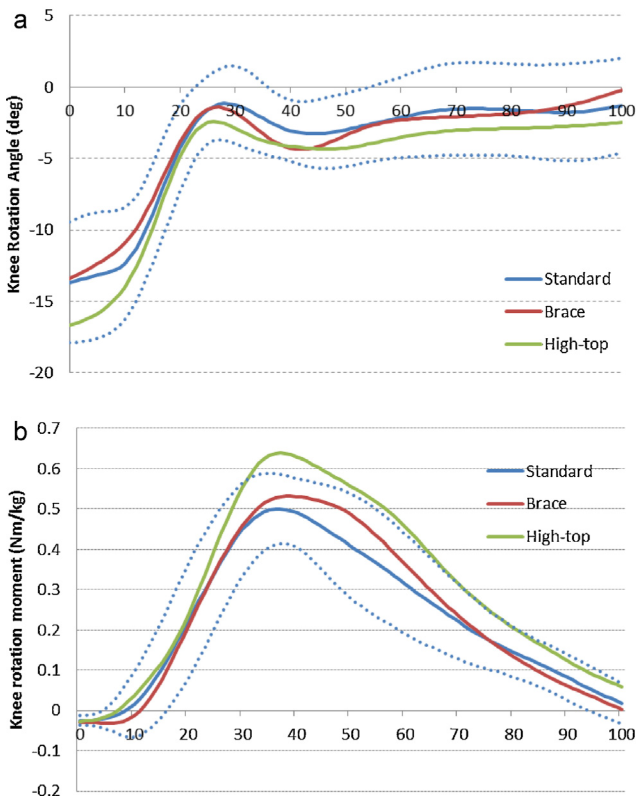

Fig. 2. Mean ensemble curves for (a) the transversal plane knee angular displacement during the landing phase, and (b) the transversal plane knee internal moment during the landing phase. Dotted lines are 95% confidence interval for the standard condition.

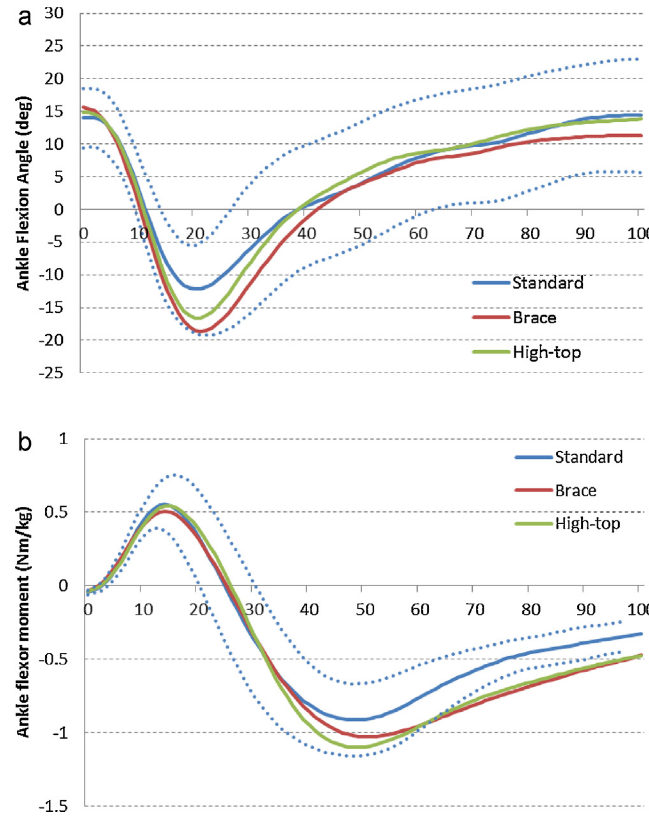

Fig. 3. Mean ensemble curves for (a) the sagittal plane ankle angular displacement during the landing phase, and (b) the sagittal plane ankle internal moment during the landing phase. Dotted lines are 95% confidence interval for the standard condition.

landing on someone's foot. The single leg landing in the current study involved a smaller inversion angle at landing (4 degrees) and predominantly brought about ankle eversion as the landing progressed.

Hume et al.,[6] have suggested that high-top shoes should be encouraged for use in netball. Results from the current study indicated that ankle motion was not restricted in the high-top condition and that the peak knee internal rotation moment increased by 15% (Fig. 2). Players landed in more internally rotated knee in the high-top condition and demonstrated an increased knee ROM in the transverse plane as a result. The knee joint rotation was defined as the rotation of the tibia on the femur. As the knee subsequently external rotated, a larger activation of the knee internal rotators was required in order to control the greater external rotation and angular velocity acting at the knee (Fig. 2). Joint motion and muscle activity are important in decreasing the impact forces associated with landing.[26] Given that taping and braces have been shown to limit motion, they could induce increases in the magnitude of the impact forces.[27] However, similar to previous studies,[27,28] no changes were observed in either the vertical or braking ground reaction forces between conditions. Both the brace and the high-top shoe conditions increased the ankle plantar flexion moment during dorsiflexion (Fig. 3). During landing, players had significantly higher plantarflexion and demonstrated an increased ROM in the sagittal plane. As the ankle moves from plantarflexion to dorsiflexion during the landing phase, a plantar flexion moment was part of the mechanism required to reduce the horizontal velocity of the player. This increased plantar flexion moment is a combination of the moment produced by the plantar flexor muscles and the moment caused by the brace. Therefore the increased moment could be due to the brace itself which is stretched during dorsiflexion or due to a higher activation of the plantar flexor muscles that are working eccentrically to slow down the forward acceleration of the tibia. To be able to distinguish between the two, electromyography needs to be measured.

This study is the first to measure the rear foot motion inside the shoe during single leg landing in netball players. Although our task did not force the ankle into extreme inversion/eversion similar results to previous literature were observed.[7–9] The ankle ROM in the frontal plane was significantly restricted in the brace condition during single leg landing. While wearing a brace, the netball players landed with the ankle in a more neutral alignment (less inversion and adduction) which could suggest that the ankle was in a better position to resist lateral ankle injury.[29] This is in accordance with the suggestion by Eils and Rosenbaum[30] that the most important function of ankle braces is to ensure the necessary stability just before landing to avoid inversion injuries. An increased inversion angle at landing would lead to an increased moment arm at the subtalar joint resulting in a higher external inversion moment. This higher moment places larger strains on the lateral ligaments of the ankle increasing the risk for a lateral ankle sprain. Hopper et al.,[27] found no restriction in the frontal plane using a lace-up brace, however they had the netball players wearing the brace without any shoes on. The netball players also performed a less dynamic forward jump that did not involve a run-up.

The current study is the first to investigate the effect of high-top shoes on the ankle frontal plane ROM during a sport activity. No restriction of the ankle ROM in the frontal plane was found. Ricard et al.,[14] reported a restriction in ankle inversion using an inversion platform when wearing high-top shoes. In this study, the foot frontal plane was recorded using markers on the outside of the shoe which does not account for movement inside the shoe and the foot was passively forced into an inversion angle of 35 degrees which was a lot more than in our study.

Limitations of this study were the small sample size which might have restricted the power of our results. We restricted our cohort to high performance netball players in order to get a homogenous sample. For the high-top shoes the malleolus markers had to be placed on the shoe rather than on the anatomical landmarks. Although the shoe laces were tightly closed to reduce the amount of ankle movement in the shoe, this might have affected the calculation of the ankle joint centre for this shoe condition. Similar techniques have been used in previous studies,[14,17] where the middle of the heel cup was used to estimate the joint centre. Elite netball players mainly play with standard shoes[3] in combination with tape or braces. Only one of the players had previously worn high-top shoes during sporting activities. Although the players were given sufficient time to become accustomed to each external ankle support condition, it is possible that their unfamiliarity with high-top shoes may have influenced the way they performed the landing task.

5. Conclusion

The ankle brace restricted the ankle movement in the frontal plane but no effects on the ankle kinematics were found for the high-top shoes. Wearing an ankle brace did increase the ankle plantar flexion moment but there were no changes in knee joint loading. High-top shoes increased both the ankle plantar flexion moment and knee internal rotation moment.

6. Practical implication

- Lace-up braces can be used by netball players to restrict ankle range of motion during a single leg landing while receiving a pass without increasing the load on the knee joint.
- High-top shoes do not restrict the ankle range of motion during a single leg landing while receiving a pass.
- High-top shoes did increase the loading on the knee joint during a single leg landing while receiving a pass.

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