
A Kinetic Analysis of Footfall Patterns at Landing in Netball: A Follow-up Study

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INTRODUCTION

Netball is a fast and skilful team game that has attracted one of the largest number of participants of any team game within Australia with close to half a million registered players. It is a game in which players frequently perform short burst of acceleration to "break free" from a defender in combination with sudden, explosive changes in direction or rapid deceleration to receive a pass. The consequence of the majority of these explosive netball movement patterns is the subsequent impact which occurs on landing. Landing actions have received far less attention than the mechanics of the skills themselves, despite the fact landings are more likely to result in both acute and chronic injury as a result of large impact forces (Lees, 1981).

The technique a netball player uses to land on receiving a pass is influenced by several factors including the type of pass, the speed and style of approach to the pass, the position of opposition players, the movements

required following the **landing** action (for example, whether a player is required to pivot or make a straight lead), the court surface, and the footwear worn by the player. One of the main determinants governing landing technique in netball, however, is the limitation imposed on a player's movements by the "footwork rule". After receiving a pass a player is restricted to a maximum of one-and-a-half steps. Therefore, upon landing after receiving the ball, a player must decelerate rapidly and assume a position which affords sufficient stability so that she or he does not infringe the footwork rule.

Previous investigations have demonstrated that netball players achieve this rapid deceleration on landing by applying a large horizontal shear or "braking" force. Braking forces as high as 6.5 times a player's body weight (BW) have been recorded at landing for individual players (Steele and Milburn, 1987a). Numerous studies have indicated that excessive and repeated ground reaction forces, both in the horizontal and vertical **direction**, can place the lower extremity at risk in terms of increasing the **potential** for ligament damage, degeneration of articular cartilage, or chronic musculo-skeletal disorders (Radin et al, 1982; Voloshin and Wosk, 1982; Steele and Milburn, 1987a).

In an attempt to reduce the magnitude of the ground reaction forces which result from abrupt decelerative movement patterns characteristic of netball, several studies examining the mechanics of landing in netball have been conducted (Steele and Milburn, 1987a; 1987b; 1988a; 1988b; in press). One specific area of research has been directed towards **quantifying** the influence of footfall patterns on the ground reaction forces experienced at landing. Steele and Milburn (1987b) examined the footfall patterns demonstrated by skilled netball players at landing following a typical attacking netball movement pattern under different footwear conditions. Regardless of the shoes worn, the most frequent footfall pattern observed was initial ground contact by the heel of the foot (83.6%). Only 6.3% of the subjects impacted the ground with the forefoot, 2.5% with the **midfoot** (flatfooted), and 7.6% of the subjects used a combination of footfall patterns throughout the trials studied (Steele and Milburn, 1987b). Further work by Steele and Milburn (1988b) examined footfall patterns of skilled subjects landing on 12 different synthetic sport surfaces. Of the 357 trials analysed, subjects made initial foot-ground contact with the heel of the foot in 342 trials (**95.8%** of cases). Contact was made with the forefoot in only 11 of the trials (**3.1%**), while contact was made with the **midfoot** in only 4 trials (1.1%). The results of these studies appeared to refute statements appearing in netball coaching manuals where coaches claimed "con-

tact with the ground is initially with the ball of the foot" (Cornwell, 1984, page 16).

Steele and Milburn (in press) continued to examine footfall patterns at landing in **netball**, focusing upon the influence of changes to pass height on landing technique. In contrast to previous studies, the majority of subjects (70%) made initial contact with the forefoot upon landing while only three of the ten subjects (30%) made initial contact with the heel of the foot. These results were obtained in trials in which the subjects received high passes. Similar results were reported by Valiant and Cavanagh (1985) who examined the footfall patterns of ten male university intramural basketball players rebounding a basketball dropped from a random height above their head. Eight of the ten basketball subjects made initial ground contact with the forefoot while the remaining two subjects contacted the ground with a flatfooted landing pattern. It therefore appeared the height at which a pass was caught by a player, either in netball or basketball, was the main factor which influenced the footfall pattern used on landing.

In order to determine the influence of changes to footfall patterns, Steele and Milburn (in press) analysed the ground reaction forces generated at landing when catching a high pass. The results indicated that the seven subjects who landed on the forefoot after catching a high pass demonstrated a significantly lower maximum peak VGRF and as **significantly** lower initial peak VGRF than the value recorded when subjects landed on the heel. A reduction in the vertical ground reaction forces after landing on the forefoot could lessen the potential for injury as a result of a decrease in the stress placed on the musculo-skeletal system during the movement. The mean time to the initial peak VGRF for the forefoot strikers was found to be significantly shorter compared to landing on the **heel**. Therefore, landing on the forefoot did not attenuate the rate of loading of the smaller initial peak VGRF generated at landing (Steele and Milburn, in press).

Subjects who landed on the forefoot demonstrated significantly lower braking forces in comparison to the subjects who landed on the heel of the foot. It thus appeared a forefoot landing pattern could decrease the **magnitude** of the braking forces experienced at landing which may, in turn, decrease the potential for injury (Steele and Milburn, in press). However, there was no significant difference in the time to peak braking forces when comparing those subjects who landed on the heel of the foot to those landing on the forefoot.

Steele (1988) further examined the influence of changes to passing height on the kinematics and kinetics of landing following a standard net-

ball task. The results indicated players tended to demonstrate a variety of footfall patterns when receiving a high pass. That is, on catching a high pass four of the ten subjects (40%) consistently landed on the heel of the foot, three subjects (30%) demonstrated a mixture of both the heel and forefoot landing actions throughout their trials. The purpose of this paper was therefore to compare the ground reaction forces demonstrated in trials in which players landed on the heel of the foot to trials in which players landed on the heel of the foot to trials in which players landed on the forefoot.

PROCEDURES

Subjects

The subjects for this study were 10 skilled netball players selected from the 1987 netball scholarship holders at the Australian Institute of Sport (A.I.S.). The age, height and weight of the subjects are summarised in Table 1. Written informed consent was obtained from each subject prior to testing.

TABLE 1: Age, height and weight characteristics of the subjects.

Variable	Mean	(\pm SD)	Range
Age (yrs)	19.56	(\pm 1.22)	18.4 - 22.2
Height (cm)	172.18	(\pm 5.86)	165.4 - 180.7
Weight (kg)	64.87	(\pm 5.56)	55.0 - 73.6

Experimental Protocol

After warming-up and familiarization with the experimental procedures, the subjects performed a standard netball attacking task catching a high pass. This required them to run forward, "break to the side away from a defender, catch the pass, land on the dominant lower extremity, stabilise their position, and pass the ball back to the thrower. All subjects used a "leap" approach to receive the pass. The subjects were not instructed with respect to the technique they were to use on landing. The passes were consistently directed approximately 20 cm above head level of each subject (confirmation of pass height was later conducted by observation of film records of each trial). All trials were performed in accordance with the rules of netball (All Australia Netball Association, 1983).

Throughout each trial the subjects wore a standard design shoe manufactured specifically for netball. Data collection for the study was conducted in the Biomechanics Laboratory of the Australian Institute of Sport in Canberra

Collection of Kinetic Data

To enable collection of kinetic data the subjects were required to land on a KISTLER type Z 4852/C force platform (60 cm X 90 cm). The force platform was mounted on a concrete pedestal below ground level and covered with granulated rubber sport surface (Rekortan) so that the landing surface was flush with the surrounding floor of the laboratory. The subjects were given as many practice trials as were required to enable them to land consistently on the force platform. This ensured minimal alteration to normal landing technique.

Three orthogonal components of the ground reaction force for at least four trials were recorded over 4000 milliseconds a 500 Hz and stored as a function of time using a DEC LSI 11/23. The data were then transferred to the VAX 11/750 computer for further analysis,

To record body weight, each subject was required to stand motionless at the centre of the force platform prior to their trials while the force was recorded. These data were later utilized to standardized force data relative to the body weight of each subject.

Filming Procedures

During each trial the subjects were filmed from a posterior and lateral view using two phase-locked 16mm Photosonics 500 high speed cine cameras located approximately 12 metres from the force platform. The cameras operated at a nominal framing rate of 200 frames per second in conjunction with a 120 degree shutter, producing an effective shutter speed of 1/600 second.

After processing, the film image was projected using a Vanguard Overhead Motion Analyzer (M16CR series) onto the analysis table. The three representative trials per subject were then examined visually to determine the classification of each subject's footfall pattern as either "heel" or "forefoot". This classification system was determined in conjunction with centre of pressure data and based on the part of the foot which initially impacted the landing surface.

Analysis of Kinetic Variable

The ground reaction forces for three representative trials were selected for analysis for each subject. The following kinetic variables were then calculated:

- a) the magnitude of the maximum peak VGRF at impact (peak VGRF);
- b) the time from the onset of impact until the peak VGRF (time to peak);
- c) the magnitude of the initial peak VGRF at impact (initial peak VGRF);
- d) the time from the onset of impact until the initial peak VGRF (time to initial peak VGRF);
- e) the magnitude of the peak mediolateral and anteroposterior forces at impact (peak braking force);
- f) the time from the onset of impact until the peak braking force (time to peak braking force);
- g) the magnitude of the peak resultant force at impact (peak resultant force);
- h) the time from the onset of impact until the peak resultant force (time to peak resultant); and
- i) the position of the centre of pressure under the foot at contact.

Measurements of peak forces were recorded in Newtons (N) and then normalized to body weight. The temporal variables were measured in milliseconds (ms). The above variables enabled comparisons to be made with similar variables quantified during the impact phase of foot-ground contact in the study by Steele and Milburn (in press). Furthermore, the VGRF has been identified as the component most representative of the forces which the foot, leg, and body are subjected to at impact (Lees and McCullagh, 1984).

Subjects in the present study demonstrated VGRF force-time curves with variations from one to three impact peaks at landing. For this reason the magnitude of both the initial peak VGRF and the maximum peak VGRF were calculated. For subjects who demonstrated a single impact peak, initial and maximum VGRF values were equivalent. Calculation of the time to initial peak VGRF provided a measure of the rate of force loading irrespective of the number of impact peaks present. As preparation to land in netball involved rotation of the body, subjects did not land with the landing foot positioned in a consistent direction or aligned with the long-axis of the force platform. Therefore, the resultant of the peak mediolateral and anteroposterior forces represented the braking forces generated at landing. Location of the centre of pressure under the foot at landing enabled confirmation of each subject's footfall pattern.

Statistical Analysis

Means, standard deviations and range values were calculated for each biomechanical variable under investigation. A One-Way ANOVA was applied to the data to test for any significant differences among the kinetic variables with respect to the trials in which the players landed on the heel of the foot compared to trials in which players landed on the forefoot. The level of confidence for all statistical analysis was set at $p \leq 0.05$.

RESULTS AND DISCUSSION

Vertical Ground Reaction Forces

Statistical analysis of the data for the present study indicated there were no significant differences in the magnitude of the peak VGRF demonstrated in trials in which subjects landed on the heel ($x = 5.2$ BW) compared to landing on the forefoot ($x = 5.7$ BW). Nor were any significant differences found in the magnitude of the initial peak VGRF (heel = 3.9 BW; forefoot = 3.2 BW). Steele and Milburn (in press) reported that subjects who landed on the forefoot after receiving a high pass demonstrated a significantly lower peak VGRF ($x = 3.3$ BW), approximately 1.2 BW lower than the value recorded for when subjects landed on their heel ($x = 14.5$ BW). Furthermore, the subjects who landed on the forefoot generated a significantly lower initial peak VGRF ($x = 1.7$ BW) compared to the three subjects who landed on the heel of the foot ($X = 4.4$ BW). The results of the present study therefore did not reflect the earlier findings of Steele and Milburn (in press); the footfall pattern used at landing did not attenuate the vertical forces experienced at landing.

The mean time to peak VGRF demonstrated in the 17 trials in which subjects landed on the heel of the foot in the present study (31.2 ms) was found to be similar to that recorded for the trials in which the subjects landed on the forefoot (30.6 ms). Furthermore, the initial time to peak for the two conditions were not found to be significantly different (heel = 18.0 ms; forefoot = 16.5 ms). These results are also in conflict with the previous findings of Steele and Milburn (in press) who reported that these seven players who landed on the forefoot demonstrated a significantly longer time to the peak VGRF ($x = 47.4$ ms) than the time demonstrated by the three heel-strike landers ($x = 21.0$ ms). The mean time to the initial peak VGRF recorded by Steele and Milburn (in press) for the forefoot strikers ($x = 11.7$ ms) was found to be significantly shorter compared to landing on the heel ($x = 17.0$ ms). Clarke et al (1983) claimed that a delay in the onset of the peak vertical force was advantageous as it represented a reduction

in the rate at which the vertical forces were applied to the musculo-skeletal system. However, the inclusion of an additional joint (the foot) in the movement pattern during the present study did not lessen the potential for injuries which result from high vertical forces, nor did it influence the rate of loading of either the peak VGRF or the initial peak VGRF generated at landing.

TABLE 2:

Kinetic data obtained at landing on the heel compared to landing on the forefoot.

Variable	HEEL (n = 17)		FOREFOOT (n = 13)	
	Mean (+SD)	Range	Mean (+SD)	Range
Peak VGRF (BW)	5.25 (+0.9)	4.1 - 7.1	5.7 (+1.1)	3.4 - 7.4
Time to Peak VGRF (ms)	31.2 (+6.1)	22.0 - 42.0	30.6 (+6.5)	24.0 - 46.0
Initial Peak VGRF (BW)	3.9 (+1.5)	1.7 - 5.4	3.2 (+1.9)	1.1 - 6.7
Time to Initial Peak VGRF (ms)	18.0 (+3.5)	12.0 - 24.0	16.5 (+9.4)	6.0 - 34.0
Peak Braking Force (BW)	3.3 (+0.6)	2.3 - 4.2	2.0 (+0.3)	1.5 - 2.5
Time to Peak Braking Force (ms)	30.5 (+4.6)	20.0 - 38.0	23.9 (+10.3)	8.0 - 48.0
Peak Resultant Force (BW)	6.0 (+1.0)	4.8 - 8.0	5.9 (+1.2)	3.6 - 7.6
Time to Peak Resultant Force (ms)	31.7 (+4.0)	26.0 - 40.0	30.5 (+6.4)	24.0 - 46.0

*indicates a significant difference at $p < .05$

Braking Forces

The results of the present study indicated that subjects generated significantly lower braking forces ($F(1,28) = 53.45$) when landing on the forefoot ($x = 2.0$ BW) compared to landing on the heel of the foot ($x = 3.3$ BW). This trend was also reflected in the results of the study by Steele and Milburn (in press) where subjects who landed on the forefoot after receiving a high pass demonstrated significantly lower braking forces in comparison to subjects who landed on the heel of the foot. Thus, the results of both studies support the finding that a forefoot footfall pattern can decrease the magnitude of the braking forces experienced at landing which may, in turn, potentially decrease stress placed on the lower extremity.

No significant difference was reported by Steele and Milburn (in press) in the time to the peak braking forces recorded when subjects landed on the heel of the foot as compared to the forefoot. However, there was a trend for the time to peak braking force to be shorter under the forefoot

landing conditions. Statistical analysis of the results of the present study supported the trend noted by Steele and Milburn (in press), indicating the time to peak braking force was significantly shorter ($F(1,28) = 5.69$) when subjects landed on the forefoot ($x = 23.9$ ms) in comparison to when landing on the heel of the foot ($x = 30.5$ ms). Thus, forefoot landing increased the rate of loading of the lower extremities as well as the risk of injuries associated to high loading rates.

Resultant Ground Reaction Forces

Statistical analysis of the data of the present study indicated there was no significant difference in the magnitude of the peak resultant force generated when landing on the heel ($x = 6.0$ BW) compared to the forefoot ($x = 5.9$ BW). Nor was any significant difference found in the time to peak resultant force between the two conditions (heel = 31.7 ms; forefoot = 30.5 ms). Thus, it appeared that the footfall pattern utilized at landing did not influence the total resultant force experienced by the subjects at landing. Results pertaining to the resultant forces were not reported by Steele and Milburn (in press).

On the basis of the above results it would appear that the kinetic variable influenced to the greatest extent by the footfall pattern demonstrated at landing was the braking force. That is, utilization of a forefoot landing pattern decreased the magnitude of the braking forces experienced on a landing which could decrease the stress placed on the ligaments of the articulations of the lower extremity, especially at the knee (Steele and Milburn, 1987a). However, a forefoot landing pattern also resulted in an increased rate of loading of the braking forces which could increase the potential for injuries associated with high loading rates.

CONCLUSIONS

Lees (1981) claimed that reduction of impact force levels during landing was a feature of skilled performance that could be developed through training programmes based on correct teaching or coaching points. However, results of the present study have demonstrated conflicts in the current literature with respect to the influence of footfall patterns on impact loadings experienced at landing in netball. Consequently, the development of "correct teaching points" pertaining to which footfall pattern can best reduce impact forces for the netball coach is shrugged in uncertainty. Those subjects who landed on the forefoot in the present study demonstrated no significant difference in the magnitude or timing of either the peak VGRF or the initial peak VGRF in comparison to subjects who

landed on the heel. However, previous research indicated that a forefoot landing could significantly attenuate the vertical impact forces. One point of agreement between both studies is that subjects who landed on the forefoot **experienced** a reduction in the magnitude of the peak braking force in landing. This reduction **may** reduce the stress placed on the lower extremity. However, the time to **peak** braking forces were significantly shorter when subjects landed on the forefoot in comparison to when landing on the heel of the foot, indicating that the rate of loading of the braking forces were higher during a forefoot landing. Furthermore, previous studies have indicated it is more natural for players to land on the heel of the foot when receiving lower passes.

The **findings** of the present study, in conjunction with previous research, appear to support the comments of Clarke (quoted in Prokop, 1984, page 51):

Landing on the forefoot is less jarring than landing on the heel. It's an interesting old theory, but one not substantiated by research..... And I think you'd be doing people a disservice if you tell them 'You must change over to this technique because it's safer.

It is therefore concluded that prior to altering the footfall patterns of netball players, further research must be conducted. Future research should focus on the biological consequences of landing on the forefoot as compared to landing on the heel. It should also focus on the influence of changes in footfall pattern on total body mechanics and the efficiency of the skill of landing. "Such research would ensure any changes to landing technique are made on an informed basis and players are coached to perform netball skills in an efficient manner with the potential for injury at a minimum" (Steele and Milburn, in press).

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