# KNEE INJURIES AND LANDINGS IN NETBALL: AN INJURY PREVENTION SAGA

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## INTRODUCTION

Knee injuries sustained in netball have become an emotional issue both in netball circles and in the general population. This interest is mainly due to sensationalised media reporting based on minimal, if any, factual or scientific evidence. Netball in Australia is mainly played by females, with over 350,000 players registered with Netball Australia (NA). It has been estimated that one in every seven females in Australia has been or is involved in netball in some way.

Many recent studies have identified that knee injuries are second only in frequency to ankle injuries in sports such as soccer, basketball, handball, volleyball, Australian rules, rugby union, rugby league and badminton (Backx, Beijer, Bol, & Erich, 1991; Crawford & Fricker, 1990; Egger, 1990; Ferratti, Papandrea, & Conteduca, 1990; Purdam, 1987). An unpublished study by the Victorian branch of the A.S.M.F. (1992) found that the risk of an anterior cruciate ligament injury in netball was 0.04 per 1000 participations. Although this risk factor is extremely low, given the large number of participants in the sport in Victoria alone, this risk factor would indicate an average of 4.7 ACL injuries per week.

According to Draper (1990), the ACL is the most often seriously injured knee ligament. Mechanisms for rupturing the ACL are numerous, including hyperextension (Andriacchi, 1990; Draper, 1990; McConkey, 1986), cutting or twisting manoeuvres during weight bearing (Draper, 1990; McConkey, 1986), rapid deceleration (Draper, 1990; McConkey, 1986), and valgus or varus forces (Draper, 1990). McNair, Marshall, & Matheson (1990) found that 70% of subjects with isolated tears of the ACL sustained the injury at footstrike during non contact situations. Steele (1990) stated that the factor which influences musculo-skeletal stress to the greatest extent is a player's landing technique. This statement is supported by McNitt-Gray (1991) who claimed that during landing, the human body is exposed to large forces and moments that create the potential for injury.

Netball landing forces have been shown by Steele and Milburn (1988b) to be much higher than those found in distance running. The peak vertical ground reaction force(PVGRF) was 3.9-4.3 times body weight (BW) compared to 2-3 BW in running. Steele and Milburn(1988a) looked at the changes that occurred when two to three steps were permitted on landing. They found that there were no significant differences in VGRF generated under the three conditions of landing (i.e., a normal landing, a normal landing plus pivot, and an illegal stepping manoeuvre) when two types of passes (chest level and high) were used. Steele and Milburn (1988a) also found that the average time to PVGRF after receiving a high pass was significantly longer than

after a chest level pass or altering the footwork rule. They did find a significant difference in the braking force between a chest level pass and both a high pass and the extra steps. The chest pass generated higher braking forces on landing than a high pass or an extra steps landing technique. This finding has great significance in terms of reducing load on the joints. They concluded from these findings that the height of the pass seemed to be more important in decreasing the load than taking an extra step.

Neal and Sydney-Smith (1992) studied 6 elite netball players and examined the effects of footfall pattern and passing height on ground reaction forces(GRF) in landing. They found that the peak VGRF was 4.65 BW over all trials. This figure is similar to those found by Steele and Milburn (1987). The speed of approach to the force plate for either of the chest pass landings was similar, however the high pass approach speed was significantly lower. The corrections for the effect of speed produced results which are in conflict to those of Steele and Milburn (1988b). McNitt-Gray (1991) measured force and kinematic data on subjects jumping from three heights. She found that as impact velocity increased, there were statistically significant increases in joint flexion (except ankle), angular velocities and impact forces. Given the results of these studies it appears that the heights of jumps in netball will greatly affect the loads transmitted through the knee joint.

When investigating knee injuries in netball, a number of questions must be taken into consideration. Firstly, an outcome of an investigation must be to attempt to find out whether there are preventative measures that can be taken to decrease the incidence of knee injuries. deBruijn and Keizers (1991) and Backx et al. (1991) stated that preventative measures cannot be taken before the main causes have been determined. Koplan, Powell, Sikes, Shirley & Campbell (1982) stated that each sport, due to its unique demands, will predispose individuals to a given pattern of injury.

Egger (1990) suggested that a simple rule change to allow one extra step after catching the ball will decrease the incidence of knee injuries although there is no evidence to support his view.

The present study deals with biomechanical parameters derived from studying five methods of landing at two different pass heights. The study focused on lower limb kinematics and kinetics at landing, using five different landing techniques; two of these landings required an additional step and are currently illegal in netball.

**Objectives:**

The objectives of the study were threefold.

1. To investigate whether an extra step landing would decrease forces experienced by the body;

2. To determine the "softest" landing technique and;

3. To investigate the best way to land for the most common pivot landing technique.

## METHODS AND PROCEDURES

**Description of subjects**

Twenty female netball players of State or State Under 21 team standard, were tested in the study. They were actively involved in netball throughout the duration of the data collection period. Subjects with a significant knee injury (Grade II or above) were excluded from the study. The subjects were required to sign an informed consent form after an explanation of the test protocols. All research protocols complied with the NH&MRC standards for human experimentation. The subject means and standard deviations for height, age and mass were 172.82 (7.05)cms, 21.34 (3.62)years and 68.64 (7.85)kg respectively.

**Landing Conditions**

Five landing techniques, listed below, were investigated during the course of this study.

Legal landings.

    (1)   Catch - land - pivot - pass.................................................................coded as LPIV

    (2)   Catch - land - step forward - pass ................................................... coded as LRUN

    (3)   Catch - land on two feet - step - pass.........................................................coded as 2F

One extra step (illegal) landings.

    (4)   Catch - land - step - step - pass .......................................................coded as XSRUN

    (5)   Catch - land - step - pivot - pass.......................................................coded as XSPIV

    **N.B.** The underlining indicates the landing and stepping foot which contacted the force plates.

Landings were chosen to study as an extrinsic factor in knee injuries because the results of a retrospective survey on knee injuries (Otago, 1994) indicated that 72.4% of ACL injured players reported that their injury occurred on landing. The next highest occurrences 10.5%, 5.3% and 5.3%, were for a sharp twist and turn, takeoffs and sudden stopping respectively.

### *Pass heights*

Two pass heights were selected for use in the study. These were (i) Above Head - HIGH PASS and (ii) a combined category of Waist - Head - MEDIUM PASS, with the passers instructed to direct the ball at the shoulder area of the subject. Passes were checked for height using a video camera positioned at 90 degrees to the first force.

### *Testing procedure*

The experimental trials were undertaken at the Department of Human Movement Studies Biomechanics laboratory, University of Queensland.

Subjects were tested in pairs to allow adequate rest between blocks of trials. Height and weight measurements were taken using electronic calibrated scales and a stadiometer. Each subjects' right lower limb lengths were measured to obtain the position of the centre of mass for the thigh, lower leg and foot. The position of each centre of mass was determined using de Leva's (1996) data which were based on Zatsiorsky and Seleyonov's (1983) data set.

A stationary calibration of subjects was performed with the subject standing on the first force plate. Prior to filming the subjects, a calibrated space frame of approximately $1m^3$ was filmed to provide the control coordinates necessary for calculating three dimensional (3D) coordinates using the DLT method. The subjects were then asked to perform a warm-up. This consisted of a five minute run, followed by a stretching routine that would be used before a netball game. The subjects were then allowed to practice the landings to be tested on each day until they felt comfortable with the procedures. All subjects were required to land on their right leg on the first force plate.

Four high speed (200 Hz) video cameras were set up so that at any time during testing each marker would be seen by at least 2 cameras. Two force platforms were positioned so that each foot on which data were to be collected contacted a force plate on landing. The experimental set-up is shown in Figure 1.
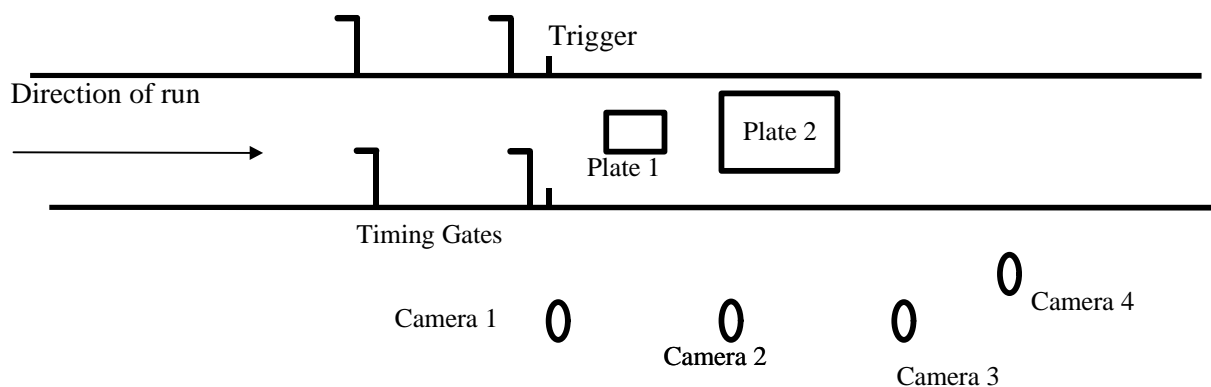
Figure 1  Diagram of experimental setup

Five successful trials at each of the conditions of landing were required for each subject. Subjects ran towards the testing area, received a pass, performed the required landing and then passed the ball to the receiver. As the subjects ran in to receive the pass they broke a beam situated in front of the first force plate which drove a set of relays triggering the data acquisition software both analog (force) and video systems. Thus time synchronisation of all data records was achieved. Approach speed of the subjects immediately prior to landing on the force plates was calculated using electronic timing lights.

During all trials each subject wore the same style of Puma shoes.

### Data analytic techniques

After filming the subjects, the video records were tracked using the Motion Analysis Corporation's Flextrak® software. This software performs the DLT of pairs of digitised coordinates and then orders these in time for each marker. These data were smoothed using a Butterworth digital filter (cut off 5 Hz).

The kinematics of the knee joint were described using a mathematical model (Grood and Suntay, 1983). The JTMOTION software was developed to provide a description of the relative motion, in clinical terms of flexion-extension, abduction-adduction and internal-external axial rotation, between two adjacent segments. The data presented will be described about the 3 axes of movement at the knee joint. The JTMOTION software relies on the development of a clinically relevant anatomical coordinate system for segments under investigation. Local orthogonal Cartesian coordinate systems (dynamic coordinate systems) are used when the subject is moving and are determined for each segment of interest. The stationary shot data were used to calculate a transformation matrix between the anatomical and the dynamic coordinate systems. A joint coordinate system which describes the relative motion between the two adjacent lower limb systems was then calculated using methods devised by Grood and Suntay (1983).

Loading rates were calculated by dividing the peak forces by the times taken to reach the peak for each individual trial.

### Inverse Dynamics

An inverse dynamics approach was used to estimate the intersegmental forces and torques at the ankle and knee joints. This approach relied on the kinematic data of the motion of the three segments of the lower limb, the anthropometric data of de Leva(1996) and the external reaction forces registered at the two force plates. A Newton-Euler formulation of the equations of motion of each segment was used to estimate the intersegmental force and torque at each joint at every point in time.

### Statistical analysis

The statistical design is a randomised blocks design. ANCOVA testing was performed using approach speed as the covariate. Post hoc analysis was performed using Tukey's studentised range test (HSD). Means and least squares mean (LSM) and standard errors of the mean were calculated for all values. A critical probability level  of  0.05 was applied to all tests. All analyses on the first force plate looked at the effects of landing condition and pass on the selected kinetic and kinematic variables.

A discriminant analysis was performed on the legal pivot data for vertical and braking force loading rates. The data for nine subjects was used in this analysis. Vertical and braking force loading rates were examined separately. For both braking force and vertical force loading rates, the highest and lowest rates were determined for each subject. The selected trials were then analysed for the knee joint kinematic variables.

## RESULTS AND DISCUSSION

### *Vertical loading rate*

The least squares means for the vertical loading rates for the five conditions are shown in Figure 2.
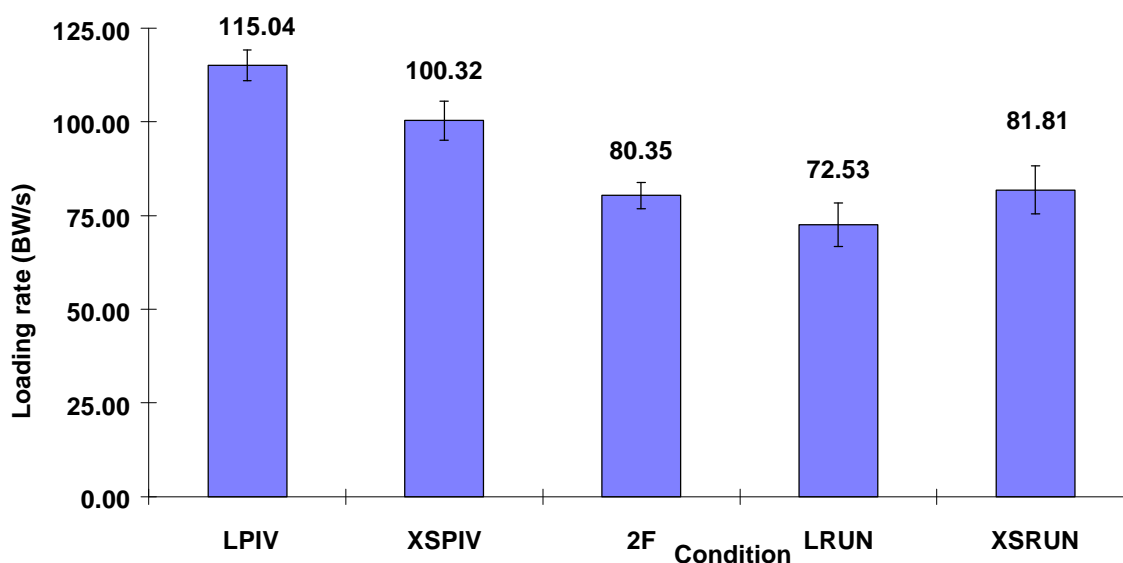


Figure 2  Least squares means and standard errors of the mean for vertical loading rates.

The conditions were significantly different ($F(4,17) = 8.66$, $p < .0001$). The value for the 2F condition has been halved to attempt to compare this method of landing with the other 4 one-legged conditions. The legal and extra step conditions were not significantly different from each other for either the pivot or run-on techniques. The vertical loading rates for the pivot landings were significantly higher than for the other three landing conditions.

Miller (1990) calculated loading rates by computing the time it took to increase VGRF by one BW from initial ground contact (threshold of 50N). This is a different method to that used in this study however the values obtained allows some comparisons to be made. For running speeds found in the present study the loading rates presented by Miller (1990) were 77.4 BW.s$^{-1}$ (3.25m.s$^{-1}$) to 90.5 BW.s$^{-1}$ (3.25m.s$^{-1}$). These values are similar to those calculated for the present study.

The results show that the pivot landings are more stressful then either the run-on or 2F landing techniques, however taking an extra step in a pivot landing does not significantly reduce the vertical loading rate.

### *Braking force loading rates*

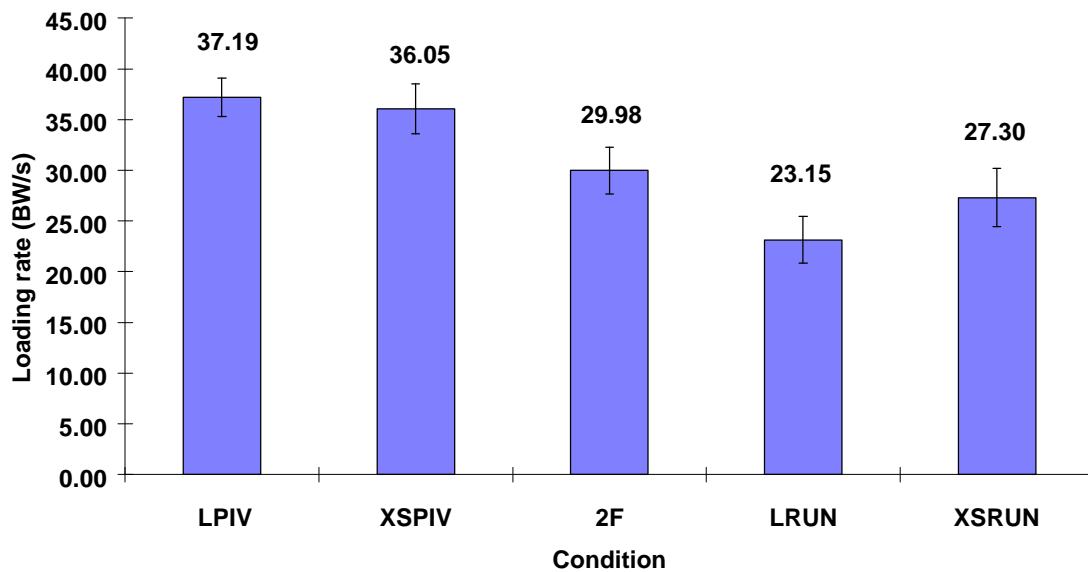The least squares means for the braking force loading rates for the five conditions are shown in Figure 3.

Figure 3   Least squares means and standard errors of the mean for braking force loading rates.

The conditions were significantly different $(F_{(4,17)} = 2.90$, $p < .0304)$. The legal and extra step conditions were not significantly different from each other for either the pivot or run-on techniques. LPIV was significantly higher than LRUN and XSRUN, and XSPIV was significantly higher than LRUN. The similarity of the loading rates for the pivot landings is noteworthy. It is the 2 components of the braking force that are most likely to cause rotations and translations in the knee joint which potentially cause stress in the ACL. Thus the taking of an extra step will not diminish the loads and loading rates of the forces and torques around the knee joint.

**Influence of Pass Height**

The results of the present study for pass height variations and the effects on force and related variables are shown in Table 1.

**Table 1  Means and standard error of the means for loading rates, peak forces and times to peak forces**

| Variable | High Pass  Mean (sem) | Medium Pass Mean (sem) |
|---|---|---|
| VGF loading rate (BW.s$^{-1}$) | 93.76  (3.47) | 85.86  (3.17) |
| BF loading rate (BW.s$^{-1}$)** $(F_{(1,14)} = 8.96$, $p < .0104)$. | 34.06  (1.67) | 27.41  (1.63) |

** denotes a significant difference between conditions existed.

The VGF load rates were not significantly different whilst the BF load rates were significantly higher for the high pass compared to the medium pass. When examining the data (Table 1) it is obvious that in terms of loading rates the high pass places more stress on the body both in the vertical and braking components.

*Knee Angle Data*

The knee flexion angles at land are shown in Figure 4 for the 4 conditions.
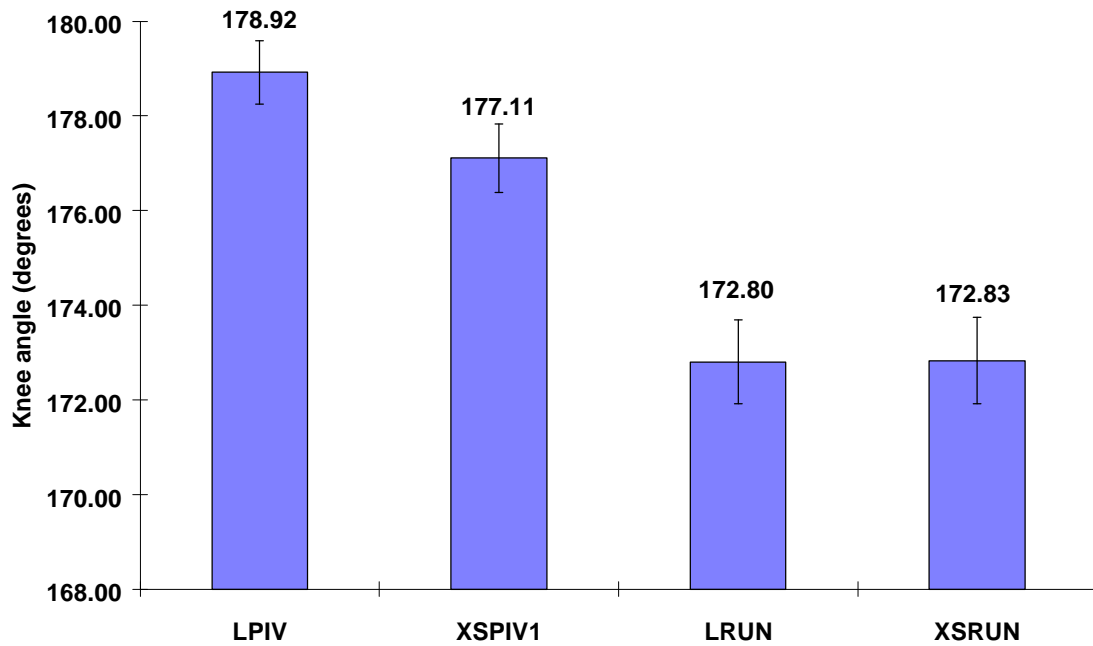
Figure 4  Means and sem's for the knee angle at land

The conditions were not significantly different. There does appear to be greater flexion angles for the run-on techniques compared to the pivot techniques. This trend may suggest, given the obvious lower stress placed on the body for the run-on techniques, that landing with increased knee flexion may assist in decreasing the loads on the body and the knee joint. Nyland et al. (1994) suggested that peak forces decrease as knee flexion at touchdown increases which supports the trends shown in the present study. Devita and Skelly (1992) on investigating females landing from a height also suggested that in "soft" landings the hip, knee and ankle were more flexed. Steele (1986) reported that the knee angle on landing was 163.2 degrees. This is a much deeper angle than found in the present study. McNitt-Gray (1991) found that gymnasts landed with a mean knee angle of 160.6 degrees from a drop height of 72cm.

The near full extension angles exhibited by subjects in this study would be dangerous given the literature on forces and ACL injury mechanisms. A common mechanisms for rupturing the ACL found in the literature were knee hyperextensions. The coaching literature on landing suggests that players should flex their knees on landing. What this message does not get across is that the knee should be flexed at landing and this flexion increased as the landing proceeds.

The other variables analysed - abduction/adduction angles and internal/external rotation angles at land were not significantly different from each other. The results show that for the first foot for all landings the knee is externally rotated (between 7.8 and 10.2 degrees) and abducted to a maximum of three degrees. Thus the leg is in a relatively neutral alignment at landing. The values were very similar for all landing conditions. It appears that these angles do not contribute greatly to altering the forces possible at the knee joint between the landing conditions.

The change in knee joint angles from land to peak VGRF were significantly different amongst conditions $(F(4,12) = 3.30, p < .0226)$. Results can be seen in Table 2. The pivot conditions were not significantly different from each other, nor were the run-on conditions. LPIV was significantly different from LRUN and XSRUN; XSPIV1 was significantly different from LRUN.

**Table 2  Least squares Means and standard errors of the means for the knee flexion angle changes from land to peak braking and vertical forces**

|  | Legal Pivot | Extra step pivot | Legal Run-on | Extra step run-on |
|---|---|---|---|---|
| Land to peak VGRF | 17.61 (0.94) | 20.49 (1.37) | 26.94 (1.27) | 24.97 (1.33) |
| Land to peak braking force | 19.49 (1.25) | 17.45 (1.26) | 27.95 (2.04) | 25.55 (2.23) |

The increased knee flexion change for the run-on landings would suggest that to attenuate the forces at the knee, an increased cushioning provided by increased knee flexion is important.

The results for the change in knee flexion angles from land to peak BF are shown in Table 2. The conditions were not significantly different ($F(4,12) = 2.48$, $p < .064$). The increased angle change for the run-on techniques further enhances the suggestion that an increased "giving" in the knees will decrease the stress on the body and the knee joint.

Lafortune, Hennig and Lake (1996a) found that larger knee angles resulted in lower impact forces, but increased shank shock, however the initial knee impact had no effect upon force loading rates. Using softer surfaces consistently reduced both loading rates and impact forces. Lafortune, Hennig and Lake (1996b) in a later study found that larger initial knee angles offered limited protection against impact loading but that they expose the shank to a more severe shock. All these factors must be taken into account when making suggestions about possible technique changes however Lafortune, Hennig and Lake (1996a) did not test their subjects vertically with the effects of gravity. The ability of the muscles to react to the impacts in their test apparatus was also an unknown, but potentially is an important factor.

No significant differences were found for changes in angles for either internal/external rotation or abduction/adduction amongst the landing conditions.

The only significant difference in the joint angle variables and pass height occurred for the knee angle at land. The knee angle mean at land for a high pass was significantly higher ($F(1,9) = 10.70$, $p < .0114$) at 176.83 degrees compared to 174.66 degrees for a medium pass.

### *Summary of differences*

A summary of the variables which show significant differences between conditions is presented in Table 3.

**Table 3  A summary of the significant differences between conditions**

| Variable | Differences pivots & run-ons | Differences pivots and 2F | Differences run-ons & 2F | Differences LPIV & XSPIV1 | Differences LRUN & XSRUN |
|---|---|---|---|---|---|
| VGR load rate | Yes | Yes | No | No | No |
| BF load rate | Yes | No | No | No | No |
| Knee flexion angle change -land to PVGRF | Yes | N/A | N/A | No | No |
| Approach Speed | Yes | No | Yes | No | No |

The summary shown in Table 3 shows that the following conclusions may be drawn from the data.

1.  Run-on techniques are less stressful on the body compared to either the pivot or 2 foot landing techniques.

2.  The extra step landing in the run-on technique does not reduce any variable selected in this study. Thus there is no advantage to taking an extra step.

3. In pivot landings, the extra step showed no significant difference in the braking or vertical force loading rates.

4. Overall the differences between the 2 landings appear not to warrant a change in rules.

### *Legal pivot landings - Technique considerations*

A discriminant analysis was performed on the data of 9 subjects to see whether it was possible to discriminate between a light and a heavy landing using both vertical and braking force loading rates. For the legal pivot condition (LPIV) for each of the 9 subjects the values for the angle data were taken from trials with the highest and lowest vertical and braking loading rates respectively. The variables and the values found are presented in Table 4.

**Table 4  Means of the six knee angle variables (degrees) for both vertical
and braking force load rates for the LPIV condition.**

| Variables | VG load rate HIGH | VG load rate LOW | | BF load rate HIGH | BF load rate LOW |
|---|---|---|---|---|---|
| Approach Speed | 3.35 | 3.41 | | 3.41 | 3.15 |
| Flexion angle at land | 179.22 | 180.1 | | 178.53 | 177.61 |
| Adduct/Abduct angle at land | 1.37 Abd | 0.57 Add | | 0.66 Add | 1.49 Add |
| Internal Rotation angle at land | 9.71 . | 7.22 | | 8.46 | 5.77 |
| Flexion angle change - land to peak VGRF or BF | 14.62 | 26.08 | | 16.30 | 25.20 |
| Adduct/abduct angle change - land to peak VGRF or BF | 3.54 | 7.72 | | 3.49 | 6.67 |
| Int/Ext rotation angle change - land to peak VGRF or BF | 5.85 | 9.83 | | 5.25 | 11.03 |

### *Effects of variables on braking force loading rates*

The results of the discriminant analysis for the braking force variables showed that only the changes in angles from land to peak BF could discriminate between high and low loads. These variables were changes in abduction/adduction angle ($p=0.0167$) and changes in internal and external rotation ( $p=0.0114$). The flexion angle change approached significance at $p=0.0633$. Thus it appears that more movement at the knee joint results in a lower braking force loading rate.

### *Effects of variables on vertical loading rates*

The results of the discriminant analysis shows that the only variable which could discriminate between high and low loaders was knee flexion angle change from land to peak VGRF ($p=0.0292$). The change in internal/external rotation was the next closest variable in discriminating between loading rates ($p=0.0841$).

Steele (1988) found that increases in times to peak VGRF were associated with increased knee flexion and that higher peak BF was related to less flexion at the knee at foot contact. These findings are similar to those found in the present study.

The results from both vertical and braking loading rates would strongly suggest that increased movement of the knee at and after landing helps to diminish the loading rate acting on the body. This together with the lower knee angles at contact for the less stressful run on techniques would suggest that the following recommendations be made to alter pivoting techniques:

1. Land with the knee flexed not near full extension.

2. The knee should "give" on landing to ensure that increased knee movements helps to attenuate the forces acting through the body.

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