The purpose of this study was to assess kinematic lower extremity motion patterns (hip flexion, knee flexion, knee valgus, and ankle dorsiflexion) during various foot-landing techniques (self-preferred, forefoot, and rear foot) between genders. 3-D kinematics were collected on 50 (25 male and 25 female) college-age recreational athletes selected from a sample of convenience. Separate repeated-measures ANOVAs were used to analyze each variable at three time instants (initial contact, peak vertical ground reaction force, and maximum knee flexion angle). There were no significant differences found between genders at the three instants for each variable. At initial contact, the forefoot technique (35.79° ± 11.78°) resulted in significantly ($p = .001$) less hip flexion than did the self-preferred (41.25° ± 12.89°) and rear foot (43.15° ± 11.77°) techniques. At peak vertical ground reaction force, the rear foot technique (26.77° ± 9.49°) presented significantly lower ($p = .001$) knee flexion angles as compared with forefoot (58.77° ± 20.00°) and self-preferred (54.21° ± 23.78°) techniques. A significant difference for knee valgus angles ($p = .001$) was also found between landing techniques at peak vertical ground reaction force. The self-preferred (4.12° ± 7.51°) and forefoot (4.97° ± 7.90°) techniques presented greater knee varus angles as compared with the rear foot technique (0.08° ± 6.52°). The rear foot technique created more ankle dorsiflexion and less knee flexion than did the other techniques. The lack of gender differences can mean that lower extremity injuries (e.g., ACL tears) may not be related solely to gender but may instead be associated with the landing technique used and, consequently, the way each individual absorbs jump-landing energy.

**Key Words:** landing, knee, and kinematics

Numerous injuries (e.g., ankle sprains, anterior cruciate ligament tears, and patellofemoral pain syndrome) are theorized to be attributed to the task of landing from a jump (Beynnon et al., 2005; Ferretti, 1986; Ferretti et al., 1990, 1992; Frank & Jackson, 2000; Griffin et al., 2000; Miyasaka et al., 1991). Jump-landing tasks require the body to utilize various movement patterns in order to absorb the body’s energy when landing. Two of the major strategies used when landing from a jump are toe landing first (forefoot) or heel landing (rear foot) first. Athletes often have their own unique landing strategies based on preference and task demands. Any of these strategies has a specific kinematic pattern that will affect the lower extremity angular kinematic intersegmental values. Butler et al. (2003) reported that knee stiffness is related to landing on the toes, whereas ankle stiffness is related to landing on the heels. Schot and Dufek (1993) pointed

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out a major difference between rear foot landing and forefoot landing, whereby they considered forefoot the “real jump-landing,” whereas rear foot landing was associated with locomotor (e.g., walking and jogging) landings. They stated that the difference between those landings changes the motor organization, specifically the neuromusculoskeletal requirements of the subject. Numerous researchers (Dufek & Bates, 1990; Onate et al., 2005; Padua et al., 2005; Pollard et al., 2004; Self & Paine, 2001) have studied various jump-landing factors (e.g., joint angles, shear forces, and jump heights) related to their potential for biomechanical markers as potential differences for lower extremity injury mechanisms (e.g., anterior cruciate ligament [ACL] tears and ankle sprains). The thought is that if evaluation of biomechanical markers can indicate the least dangerous landing technique for the lower extremity, training programs could be implemented to prevent injuries.

As mentioned, research investigating various biomechanical factors that may be associated with increased risk of lower extremity injury (e.g., ACL) can be found in the biomechanics literature (Cowling & Steele, 2001; Fagenbaum & Darling, 2003; Hewett et al., 2005). Poor landing technique has been linked with ACL injuries during dynamic activities (Cowling & Steele, 2001; Hewett et al., 2005). It has been theorized that the risk of collapse on the lower extremity can be minimized if the proper landing technique is used in order to reduce the forces (Hewett et al., 2005). In a gender comparison study of landing technique, Decker et al. (2003) reported that at initial ground contact males had greater knee flexion and ankle dorsiflexion than did females. This means that the females were in a more erect position at ground contact. Also, Lephart et al. (2002) studied gender differences in lower extremity kinematics during two landing tasks: single-leg landing and forward hop landing. Consistent with other studies, they found that females landed in a more erect position following ground contact than did males. Conversely, Habu et al. (2004) conducted a study on the effects of fatigue on landing patterns and reported that there were no statistical differences in hip flexion angles between the conditions of fatigue and between genders.

It has been reported that foot landing style (i.e., forefoot or rear foot) may change both the magnitude and distribution of the power production during the landing (Devita & Skelly, 1992; Kovacs et al., 1999; Lees, 1981; McNitt-Gray, 1993; Mizrahi & Susak, 1982). This power production and distribution of power may be important factors in preventing injuries. Moreover, it has been suggested that it is necessary to understand and evaluate landing biomechanics in female athletes in order to keep providing them the best training practice using the proper landing technique (Lephart et al., 2002). Oggero et al. (1997) emphasized that, as the landing height increases, people should land with higher knee and hip flexion because of the increases in velocity and the resultant increase in the kinetic energy. A forefoot type of landing, the toe–heel landing in particular, seems to reduce vertical ground reaction forces when compared with flat-footed landing (Dufek & Bates, 1990; Schot & Dufek, 1993; Butler et al., 2003). These findings suggest that different landing patterns affect how the body absorbs the energy and the forces.

Most of the current body of knowledge regarding lower extremity movement differences related to knee injury has focused on knee and hip parameters, yet minimal analyses have been conducted on how foot position affects lower extremity kinematics during a drop-jump landing task. The purpose of this study was to analyze lower extremity motion patterns during different foot position aspects (self-preferred, forefoot, and rear foot) while landing from a drop box of 30 cm in height. The study aimed to quantify the kinematic data (knee flexion, knee valgus, ankle dorsiflexion, hip flexion) in order to quantify the lower extremity motion pattern variation between genders and between the foot-landing techniques during the stop-jump phase at three different instants (initial contact, peak vertical ground reaction force, and maximum knee flexion). We hypothesized that the rear foot landing technique would result in decreased hip flexion and knee flexion angles, with a concomitant increase in knee valgus angles as compared with the self-preferred and forefoot landing techniques. Additionally, we hypothesized that females would land in less knee flexion and increased knee valgus angles as compared with their male counterparts.

**Methods**

Twenty-five males (24.40 ± 2.3 years old, 178.58 ± 7.15 cm, 84.09 ± 13.14 kg) and twenty-five females
(23.28 ± 2.5 years old, 167.22 ± 7.38 cm, 62.82 ± 8.48 kg) were recruited from a university student sample of convenience. All participants completed a jump-landing participation questionnaire related to their history of previous jump-landing training, injury, and physical activity levels in order to assess their eligibility to participate in the study. To be eligible, participants must have been exercising at least 30 min per day, three times per week, for the past 6 months. Subjects were free of lower extremity injuries or surgeries (e.g., ankle sprains, knee injuries, fractures) for the past 2 years, and no one was allowed to have participated in a previous jump-landing instructional program. All participants volunteered for participation in the study, and informed consent, previously approved by the Institutional Review Board, was obtained prior to data collection.

Participants reported to the Sports Medicine Research Laboratory to complete all biomechanical testing. The participants wore spandex shorts, T-shirt, and the same sneakers model, Nike Air Max Glide (NIKE USA, Inc, Beaverton, OR), supplied by the investigators of the study. Each participant undertook a 5-min warm-up period consisting of cycling, followed by 5 min of self-directed stretching before participating in the jump-landing trials. After the warm-up period and stretching, electromagnetic sensors (Flock of Birds system; Ascension Technology, Burlington, VT) were placed on the participants’ legs (at the sacrum, thigh, shank, and foot). Weight and height were obtained while standing on the force plates, using the Flock of Bird stylus. The medial-lateral malleolus, the medial-lateral epicondyle, the second phalanx, and both trochanters were digitized in order to obtain the required data. For the study purpose, only the right side was used to maintain biomechanical orientation parameters for data reduction and analysis.

To establish a global reference system, the extended range transmitter was placed on top of a box set beside two Bertec force plates, Model 4060-NC (Bertec Corp., Columbus, OH). The system was defined in such a way that the subjects were facing the negative z-axis, as the z-axis is negative in the anterior direction. This gave the subjects a positive x-axis to their right. In addition, the y-axis was positive superiorly. Motion Monitor (Innovative Sports Training, Inc, Chicago, IL) software was used for data capture, and the sensor sampling rates were set at 100 Hz. The two Bertec force plates were set at a sampling rate of 1,000 Hz and were used to measure vertical ground reaction forces to indicate time phases of initial ground contact and maximum vertical ground reaction force acting as key reference points for kinematic analyses. The instruments were synchronized when the data were exported. Following the recommendations from other investigators (LaScalza et al., 2003; Meskers et al., 1999; Milne et al., 1996; Umberger et al., 1999), pilot testing was performed to validate and calibrate the instruments in the laboratory. During the pilot test, it was determined that the Euler angles method that should be used to export kinematic data, and the sequence for this specific lab was (z, x, y). When the kinematic data in question was flexion, the following sequence was used to export the data: Euler angles (z x y)/z, yet for evaluation of knee valgus, the sequence was (z x y)/x.

Participants underwent a familiarization period during which the investigator explained how to perform the three drop jump techniques. Each participant performed three practice jumps off a 30-cm-high box and landed with both feet on the force plates. The box was placed at a distance of 30 cm from the force plates. The investigator observed and corrected mistakes in technique as necessary (e.g., forefoot landing required toes to touch down first). In order to drop from the box, the participants stood on the box with both feet, extended their arms straight out, and brought them forward to an angle of 30°, with the thumbs pointing upward. The participants were looking straight ahead. To initiate the movement, the participants shifted their weight forward, inclining their trunk, and dropped from the box as vertically as possible to execute each desired landing technique. The participants, after dropping from the box, could use their arms in any manner they desired. Participants were asked to land on the force plates, followed by jumping as high as they could straight up in the air, and finally landing back onto the force plates. At that time, the entire foot needed to be on the force plate, with each foot on a separate force plate. The initial landing from the box was used for the purposes of analyses, with the secondary landing from the maximal vertical jump being discarded. The forefoot landing consisted of initial contact with the toes first on the force plates followed by the rear foot (Figure 1). For the rear foot landing, the initial contact was with the heels first.
on the force plates followed by the forefoot (Figure 2). The self-preferred landing was their normal technique. If the participants lost their balance, either taking an extra step forward or backward, or touching the floor with the hands, the trial was discarded and not analyzed. Participants performed the three different drop-jump landing techniques (self-preferred, forefoot landing, and rear foot landing) five times each. The self-preferred technique was always performed first, with the forefoot and rear foot landing techniques counterbalanced between subjects. There was a 2-min rest period between each jump. Two mini-DV camcorders (DCR-HC40; Sony, New York, NY) were used to record the trials—one on the mediolateral right side of the subject and the other recording the anterior view of the subject. Both cameras recorded the image from the force plate to the umbilicus. The cameras were used in order to analyze the trials and decide whether the correct technique was used as instructed. The self-preferred was considered the “natural” technique, for which the instruction given to the subject was to perform as if they were in a landing situation, without any instruction for how to make the first contact with the force plates.

Data were analyzed from initial contact to maximum knee flexion, with initial contact being defined as the moment at which vertical ground reaction force was higher than 15 N. All data were reduced using Matlab 6.1 (The MathWorks, Inc, Natick, MA), with the creation of Kinematic and Kinetic Data Simplification to export into a Microsoft Excel spreadsheet. Each of the five trials was averaged and exported into SPSS version 12.0 (SPSS Inc, Chicago, IL) for analysis. Separate repeated-measures ANOVAs were used to analyze the kinematic variables (knee flexion, hip flexion, knee valgus, and ankle flexion) at three different

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**Figure 1** — Lateral view of the initial and terminal contact of the forefoot landing.

**Figure 2** — Lateral view of the initial and terminal contact of the rear foot landing.
time frames: initial ground contact, peak vertical ground reaction force, and maximum knee flexion. In all the analyses, gender was the between factor, whereas the number of within and repeated variables were the three landing techniques (self-preferred, forefoot, and rear foot). The alpha level for statistical significance was set at \( p < .05 \) for all data analysis and Tukey post hoc analyses were conducted for further investigation as needed.

**Results**

**Results at Initial Contact**

**Hip Flexion.** There were significant differences at initial contact in hip flexion angles between landing techniques \((p = .001)\). Forefoot landing technique resulted in significantly less hip flexion (35.79° ± 11.78°) than the self-preferred (41.25° ± 12.89°) and rear foot techniques (43.15° ± 11.77°) \((p = .001)\) across gender.

**Knee Flexion.** The subjects presented significant differences in knee flexion angles at initial contact between the three landing techniques \((p = .001)\). There was a significant difference between the forefoot landing technique and the two other techniques \((p = .001)\). The forefoot landing technique resulted in significantly less knee flexion (17.29° ± 9.49°) than did the self-preferred (23.01° ± 9.12°) and the rear foot (23.42° ± 9.36°) landing techniques.

**Knee Valgus.** At initial contact, the participants had a significant difference between landing techniques in knee valgus angles. The self-preferred landing had significantly narrower valgus angles \((0.03° ± 5.74°)\) than the rear foot landing \((p = .027)\) \((1.05° ± 6.50°)\) (Table 1).

**Results at Maximum Vertical Ground Reaction Forces**

**Hip Flexion.** Hip flexion angle at maximum vertical ground reaction force presented significant differences between the three landing techniques \((p = .001)\). During the self-preferred landing technique \((57.74° ± 19.02°)\), the subjects had the highest hip flexion angles at maximum vertical ground reaction force. No significant difference was found in hip flexion angles between self-preferred and forefoot technique \((57.36° ± 20.49°)\) \((p = .815)\), but the rear foot landing technique \((46.57° ± 11.81°)\) was significantly lower than both the self-preferred and forefoot techniques \((p < .001\) and \(p < .001)\).

**Knee Flexion.** Knee flexion angle at maximum vertical ground reaction force revealed significant differences between the three landing techniques \((p < .001)\). Subjects using the rear foot technique presented the lowest knee flexion angle values \((26.77° ± 9.49°)\), whereas subjects using the forefoot technique \((58.77° ± 20.00°)\) had the highest knee flexion angles at maximum vertical ground reaction

<table>
<thead>
<tr>
<th>Kinematic variable</th>
<th>Self-Preferred</th>
<th>Forefoot</th>
<th>Rear foot</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion (^\text{1})</td>
<td>41.25 ± 12.89</td>
<td>35.79 ± 11.78(^\text{a})</td>
<td>43.15 ± 11.77</td>
<td>.001*</td>
</tr>
<tr>
<td>Knee flexion (^\text{2})</td>
<td>23.01 ± 9.12</td>
<td>17.29 ± 9.49(^\text{b})</td>
<td>23.42 ± 9.36</td>
<td>.001*</td>
</tr>
<tr>
<td>Knee valgus (^\text{3})</td>
<td>0.03 ± 5.74</td>
<td>0.86 ± 5.51</td>
<td>1.05 ± 6.50</td>
<td>.059</td>
</tr>
<tr>
<td>Ankle flexion (^\text{4})</td>
<td>−23.06 ± 14.35</td>
<td>−37.76 ± 7.96</td>
<td>17.83 ± 5.95(^\text{c})</td>
<td>.001*</td>
</tr>
</tbody>
</table>

\(^\text{1}\)Positive values indicate hip flexion angles.
\(^\text{2}\)Positive values indicate knee flexion angles.
\(^\text{3}\)Negative values indicate knee valgus angles.
\(^\text{4}\)Positive values indicate dorsiflexion angles.
\(^\text{a}\)Tukey post hoc analysis revealed hip flexion during the forefoot landing technique was significantly lower as compared with both the rear foot and self-preferred landing techniques.
\(^\text{b}\)Tukey post hoc analysis revealed knee flexion during the forefoot landing technique was significantly less as compared with both the rear foot and self-preferred landing techniques.
\(^\text{c}\)Tukey post hoc analysis revealed ankle flexion during the rear foot landing technique was significantly less as compared with both the forefoot and self-preferred landing techniques.

\( * p < .05. \)
force. There were significant differences found in knee flexion angles at maximum vertical ground reaction force between the self-preferred (54.21° ± 23.78°) and rear foot landing techniques ($p < .001$), and between the forefoot and rear foot ($p < .001$).

**Knee Valgus.** The participants had significant differences in knee valgus angles at maximum vertical ground reaction force between landing techniques ($p < .001$). There was a significant difference in knee valgus angles between the self-preferred and rear foot techniques ($p < .001$), whereby the rear foot landing strategy ($−.08° ± 6.52°$) created a narrower knee valgus angle than the self-preferred ($−4.12° ± 7.51°$) landing technique. There was also a significant difference found between the forefoot ($−4.97° ± 7.90°$) and the rear foot landing techniques, with the rear foot technique creating a significantly narrower knee valgus angle ($p < .001$) (Table 2).

**Results at Maximum Knee Flexion**

**Hip Flexion.** There were significant differences in hip flexion angles at maximum knee flexion between landing techniques ($p < .001$). There were significant differences in hip flexion at maximum knee flexion for the self-preferred landing and the forefoot landing ($p = .009$), between the self-preferred and the rear foot landing ($p < .001$), and between the forefoot landing and the rear foot ($p < .001$). The self-preferred technique presented the least degree of hip flexion ($82.09° ± 23.15°$), followed by the forefoot technique ($87.42° ± 23.62°$), and the rear foot technique presented the highest value of hip flexion ($95.81° ± 18.42°$).

**Knee Valgus.** There were no significant differences in knee valgus at maximum knee flexion between techniques ($p = .931$) and in the interaction of techniques with gender ($p = .062$). No significant difference was found between genders ($p = .079$) (Table 3).

**Gender**

There were no significant differences found between genders for each kinematic variable (hip flexion, knee flexion, knee valgus, and ankle flexion) at each

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**Table 2 Lower Extremity Kinematics by Technique at Time of Peak Vertical Ground Reaction Force (in Degrees, $M ± SD$)**

<table>
<thead>
<tr>
<th>Kinematic variable</th>
<th>Self-Preferred</th>
<th>Forefoot</th>
<th>Rear foot</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion(^1)</td>
<td>57.74 ± 19.02</td>
<td>57.36 ± 20.49</td>
<td>46.57 ± 11.81*</td>
<td>.001*</td>
</tr>
<tr>
<td>Knee flexion(^2)</td>
<td>54.21 ± 23.78</td>
<td>58.77 ± 20.00</td>
<td>26.77 ± 9.49*</td>
<td>.001*</td>
</tr>
<tr>
<td>Knee valgus(^3)</td>
<td>−4.21 ± 7.51</td>
<td>−4.97 ± 7.90</td>
<td>−0.08 ± 6.52*</td>
<td>.001*</td>
</tr>
</tbody>
</table>

\(^1\) Positive values indicate hip flexion angles.

\(^2\) Positive values indicate knee flexion angles.

\(^3\) Negative values indicate knee valgus angles.

\(a\) Tukey post hoc analysis revealed hip flexion during the rear foot landing technique was significantly lower as compared with both the forefoot and self-preferred landing techniques.

\(b\) Tukey post hoc analysis revealed knee flexion during the rear foot landing technique was significantly lower as compared with both the forefoot and self-preferred landing techniques.

\(c\) Tukey post hoc analysis revealed knee valgus during the rear foot landing technique was significantly lower as compared with both the forefoot and self-preferred landing techniques.

\(\star p < .05\).
Discussion

Hip angle landing patterns have recently come to the forefront of research investigations (Hewett et al., 1999; Zazulak et al., 2005) aimed at evaluating the kinematic characteristics associated with noncontact ACL injuries due to pivoting or landing from a jump. We found a significant difference in hip flexion angles when performed with different foot landing technique styles. The forefoot landing technique created a significantly lower hip flexion angle at initial ground contact when compared with the rear foot and self-preferred landing styles. It was expected that a difference would occur between rear foot and forefoot landing styles, yet it was not expected for any differences to occur between self-preferred and forefoot techniques because we initially hypothesized that these techniques would result in similar motion patterns. One theory possibly accounting for the significantly low hip flexion angle during forefoot landing style is the lack of shock absorption and range of motion required from the proximal joints during this landing pattern (DeVita & Skelly, 1992). The foot/ankle and knee complexes during the forefoot landing pattern are in an optimal position to allow for center of mass location of the three time instants (initial contact, maximum knee flexion, and maximum vertical ground reaction force) (Table 4).

Table 3  Lower Extremity Kinematics by Technique at Time of Maximum Knee Flexion Angle (in Degrees, $M \pm SD$)

<table>
<thead>
<tr>
<th>Kinematic variable</th>
<th>Self-Preferred</th>
<th>Forefoot</th>
<th>Rear foot</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion$^1$</td>
<td>82.09 ± 23.15$^a$</td>
<td>87.42 ± 23.62</td>
<td>95.81 ± 18.42</td>
<td>.001$^*$</td>
</tr>
<tr>
<td>Knee flexion$^2$</td>
<td>71.32 ± 14.46</td>
<td>77.53 ± 13.11$^b$</td>
<td>72.39 ± 15.77</td>
<td>.002$^*$</td>
</tr>
<tr>
<td>Knee valgus$^3$</td>
<td>−5.39 ± 9.69</td>
<td>−5.55 ± 9.91</td>
<td>−5.40 ± 9.30</td>
<td>.931</td>
</tr>
</tbody>
</table>

$^1$Positive values indicate hip flexion angles.
$^2$Positive values indicate knee flexion angles.
$^3$Negative values indicate knee valgus angles.

Table 4  Lower Extremity Kinematics by Technique and Gender at the Three Different Instants (Initial Contact [IC], Peak Vertical Ground Reaction Force [PKVGRF], and Maximum Knee Flexion [MKF] ($M \pm SD$); $p$ Values for Main Effect of Gender × Technique)

<table>
<thead>
<tr>
<th>Kinematic variable</th>
<th>Instant</th>
<th>Self-Preferred</th>
<th>Forefoot</th>
<th>Rear foot</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion$^1$</td>
<td>IC</td>
<td>42.86 ± 14.98</td>
<td>39.65 ± 10.48</td>
<td>34.61 ± 11.00</td>
<td>44.81 ± 12.77</td>
</tr>
<tr>
<td></td>
<td>PVGRF</td>
<td>58.81 ± 20.71</td>
<td>56.66 ± 17.52</td>
<td>52.95 ± 14.08</td>
<td>48.16 ± 13.00</td>
</tr>
<tr>
<td></td>
<td>MKF</td>
<td>76.62 ± 25.47</td>
<td>85.75 ± 24.12</td>
<td>89.10 ± 23.49</td>
<td>95.23 ± 20.59</td>
</tr>
<tr>
<td>Knee flexion$^2$</td>
<td>IC</td>
<td>24.64 ± 10.36</td>
<td>21.38 ± 7.57</td>
<td>16.99 ± 8.58</td>
<td>23.52 ± 10.07</td>
</tr>
<tr>
<td></td>
<td>PVGRF</td>
<td>55.84 ± 25.73</td>
<td>52.58 ± 22.08</td>
<td>58.77 ± 13.84</td>
<td>27.22 ± 9.98</td>
</tr>
<tr>
<td></td>
<td>MKF</td>
<td>68.02 ± 15.37</td>
<td>74.62 ± 12.97</td>
<td>79.31 ± 12.61</td>
<td>71.71 ± 18.72</td>
</tr>
<tr>
<td>Knee valgus$^3$</td>
<td>IC</td>
<td>−0.53 ± 6.87</td>
<td>0.59 ± 4.40</td>
<td>1.00 ± 5.14</td>
<td>0.65 ± 7.92</td>
</tr>
<tr>
<td></td>
<td>PVGRF</td>
<td>−6.53 ± 6.96</td>
<td>−1.72 ± 7.38</td>
<td>−3.22 ± 8.19</td>
<td>−0.71 ± 7.61</td>
</tr>
<tr>
<td></td>
<td>MKF</td>
<td>−8.20 ± 8.30</td>
<td>−2.57 ± 10.31</td>
<td>−3.04 ± 10.11</td>
<td>−7.09 ± 9.11</td>
</tr>
<tr>
<td>Ankle flexion$^4$</td>
<td>IC</td>
<td>−21.59 ± 14.95</td>
<td>−24.53 ± 13.86</td>
<td>−37.85 ± 8.64</td>
<td>16.89 ± 4.72</td>
</tr>
</tbody>
</table>

$^1$Positive values indicate dorsiflexion angles.
$^2$Positive values indicate flexion angles.
$^3$Positive values indicate flexion angles.
$^4$Negative values indicate knee valgus angles.
deceleration requirements; thus, the amount of hip flexion required during this landing style is minimal as compared with the rear foot technique. The significant difference that occurred in hip flexion between the different techniques may be also due to the task. The forefoot technique required the subjects to have a straighter position at that instant in order to maintain balance and not fall down, which might be why the participants, male and female, had less hip flexion in the forefoot technique.

Another interesting finding was the lack of gender differences in hip flexion angles at initial foot contact. This finding is in direct contrast to the recent findings of Padua et al. (2005), who showed that, during a box drop with no foot landing instructions, females tended to land in significantly less hip flexion angle than did their male counterparts. Hewett et al. (2005) also reported a $10^\circ$ angle difference between hip flexion angles between genders, with females landing in a more erect position. Our findings are in support of the lack of kinematic differences in hip landing strategies as demonstrated by Fagenbaum and Darling (2003) among collegiate basketball players. The lack of difference in hip flexion angles between genders may be due to the aspect of evaluating the hip flexion angle at initial contact as opposed to maximum hip flexion angles.

None of the analyzed kinematic variables presented any difference between genders. These findings were unexpected when compared with the results of other studies (Decker et al., 2003; Fagenbaum & Darling, 2003; Huston et al., 2001; Malinzak et al., 2001; McNitt-Gray, 1993), which have reported kinematic landing pattern differences between genders at initial contact. Conversely, Cowling and Steele (2001) reported that they did not find any significant differences between male and female participants performing a three-step approach and landing on force plates. Padua et al. (2005) also stated that the lack of difference between genders in knee flexion angles during the two-legged hopping activity was a surprise, reasoning that landing is a much more demanding task than hopping. The lack of gender difference in our task may be due to the fact that it was a simple task for normal landing patterns, yet a high demand was presented when using the rear foot technique, and those difficulties were similar for both genders. The notion of evaluating the rear foot technique was devised following the observational analysis of data from a previous study in which subjects conducted a 5-m run-up approach and performed a jump-landing task (Onate et al., 2005). An estimated 75% of the trials of the jump-landing task were performed with a rear foot landing technique pattern, and one of the initial aims of this study was to evaluate the effects with a controlled box-drop approach. The coordination demands of performing a rear foot landing technique when dropping from a box may have limited the gender differences. Future studies should be aimed at comparing the differences between foot-landing techniques across various jump-landing tasks not from a box.

One reason that may explain the findings of lower knee flexion angles at initial contact in the forefoot technique may be due to postural control demands. The participants were not able to flex their knees as much as in the rear-foot landing technique because landing on the toes induces a forward shift of the center of mass, placing them in a straighter lower limb position at initial contact. The rear foot technique showed higher knee flexion angles mostly because the center of mass has a posterior shift owing to the subjects’ requirement to make the initial contact with the heels and therefore needed to have a hip and knee strategy, flexing more joints, in order to maintain postural control and not fall backward. Kovacs et al. (1999) found that in the rear foot technique the subjects presented greater hip flexion than in the forefoot, and that is in accordance with our results, although the authors also found that the hip flexion range of motion was greater for the heel–toe landing, whereas in the present study it was similar across techniques. This finding can be related to the fact that our subjects had to perform a second jump for maximal vertical height as compared with stopping, as Kovacs et al. (1999) had evaluated. Perhaps because our subjects had to acquire more energy to subsequently jump again following the box-drop landing, they required greater flexion angles in the hip joint across all the techniques to perform this task.

We initially hypothesized that females would land differently than their male counterparts (decreased knee flexion angles, decreased hip flexion angles, and increased knee valgus angles), as previously found in other investigations (Decker et al., 2003; Malinzak et al., 2001; Salci et al., 2004). In particular, we expected the behavior of knee valgus
patterns to be the key difference between males and females, with females landing in the theorized at-risk increased knee valgus angles for ACL injury (Hewett et al., 2005; McLean et al., 2004). Most of the foot landing techniques showed that male subjects presented knee valgus angles across time instants, which is contrary to what was previously reported in other investigations (Padua et al., 2004; Hewett et al., 2005). Padua et al. (2004) had contrasting results for knee valgus, in which they found that females landed with more knee valgus than males. Hewett et al. (2005) recently reported that there was a significant difference in knee abduction between genders and stated that this may be the reason why some lower extremity injuries are related to gender. Our results showed that there may be no gender differences noted when controlling for foot landing style techniques. Malinzak et al. (2001) also reported gender differences in selected athletic tasks. One reason that should be noted in that particular study is that Malinzak et al. (2001) used a variety of athletic tasks, whereas in our study a drop jump off a box was used exclusively. The act of jumping from a box in a laboratory setting constitutes a very controlled environment, and that can be one reason why there was no significant difference found between genders for knee valgus motion. On the contrary, Pollard et al. (2004) also did not find significant differences in knee abduction between genders in a study of collegiate soccer players. One reason provided by Pollard et al. (2004) was that their subjects had more than 10 years of specific sport experience in their population of soccer players. Thus, it seems that high levels of experience in activities that have a high demand for landing may play an important role in athletes’ landing patterns and the way they absorb energy.

Knee flexion plays an important role in the energy absorption when landing from a jump. It seems that the difference between rear foot technique and forefoot technique can place subjects at higher risk of injury, especially evident by the fact that the participants had only four more degrees of knee flexion when they achieved the peak vertical ground reaction force than they had at initial contact using the rear foot landing technique. Whereas in the other two techniques, self-preferred and forefoot, the subjects increased their knee flexion from 30° to 40°. This is an important factor because it allows the knee joint to continuously absorb the energy, throughout the 30° to 40° of flexion. Thus, possibly reducing the peak loads across the lower extremity might reduce injury risk. It has been reported that male subjects tend to achieve greater knee flexion angles than do their female counterparts (Malinzak et al., 2001; Decker et al., 2003; Salci et al., 2004). Although in this study no significance difference was found, females presented higher values for knee flexion and range of motion across all the techniques, which is in accordance with the results presented by Fagenbaum and Darling (2003) and Kernozek et al. (2005). Our study did not directly analyze knee angular displacement or range of motion, but essentially these measures are found by analyzing the difference of the angles at maximum knee flexion with knee flexion at initial contact. Thus, our findings of a lack of knee flexion angle differences between genders are also contrary to those of other investigators (Malinzak et al., 2001; Decker et al., 2003; Salci et al., 2004). Lephart et al. (2002) found that female athletes had significantly less knee angular displacement than male athletes, which is in opposition to results presented in this study, where both genders had similar range of motion.

It can be concluded that we found no major kinematic landing differences between genders across each of the foot landing techniques when utilizing a box-drop technique with imposed foot landing style demands. This may mean that lower extremity injuries (e.g., ACL tears) may not be related solely to gender, but may instead be associated with the landing technique used and consequently the way each individual absorbs jump-landing energy. Owing to the contradictory findings of male and female motion analysis pattern differences found between various investigations, our belief is that closer analyses of individual patterns for specific sport movements may provide a better picture for injury risk analyses based on biomechanical movement patterns. Each individual will have different motor organization patterns to adjust to various tasks, which may indicate that strategies might not be related to gender, but to individual landing styles. Each individual, independently of gender, seemed to have a very specific landing pattern that influenced their lower extremity motion patterns. We theorize that it may be that individual patterns are closely related to the individuals’ sport background (e.g., volleyball) and training (e.g., swimming versus plyometrics), and future studies should be aimed at
evaluating individual movement pattern differences to evaluate this hypothesis. Some previous studies (Hewett et al., 1999; Lephart et al., 2005; Onate et al., 2005) have shown promise in altering movement patterns when landing from a jump. Therefore, further studies are recommended to attempt to establish a training program to teach individuals how to land (using a forefoot landing strategy) to minimize the potential dangers that arise from jumping. The self-preferred strategy should also be evaluated in each individual owing to the fact that an individual’s sports background may be a major factor in the self-preferred pattern. An additional recommendation is to analyze the forefoot and rear foot technique landing style effects on lower extremity motion patterns utilizing various types of jump landing tasks, other than from a box.

The major limitation of this study was the use of a controlled laboratory task consisting of a box-drop jump landing task. Even though the task we used was highly constrained, it did provide a foundation for the analysis of future foot landing technique studies to evaluate the effect of foot placement style when landing from a jump and its effects on the lower extremity kinematic chain. Future studies should evaluate the effects of foot landing style effects on kinematic landing patterns while performing real-world tasks such as rebounding a basketball or performing a volleyball block. These simulated real-world tasks should try to encompass as many of the factors that potentially influence jump landing characteristics that occur during sport activity to evaluate the technique that best enhances performance and helps to reduce injury risk.

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References


