Sex Differences and Discriminative Value of Lower Extremity Alignments and Kinematics During Two Functional Tasks

Jennifer M. Medina McKeon, Craig R. Denegar, and Jay Hertel

The purpose of this study was to formulate a predictive equation to discriminate males from females using static and dynamic lower extremity (LE) alignments. Twenty-four healthy adults volunteered to participate. Three-dimensional motion analysis was used to assess the kinematics of the right hip and knee during two functional tasks. Six measures of static LE alignment were also performed. Statistical comparisons were made between males and females for all variables. Static and dynamic variables that were significantly different by sex were entered into separate discriminant analyses for each task. The resulting equations were each able to correctly predict 87% of the subjects by sex. Fifty-eight percent and 55% of the variance was explained by sex for the vertical jump and plant & jump, respectively. The frontal plane hip angle was the best predictor of sex for both tasks. While there were statistically significant differences between the sexes for static measures of LE alignment, kinematic measures were better at discriminating between sexes.

Keywords: Q-angle, alignment, gender, femoral anteversion, functional tasks

Acute and chronic lower extremity (LE) injuries are more prevalent in females compared with males (Arendt & Dick, 1995; Deitch et al., 2006; Hewett, 2000; Powell & Barber-Foss, 2000; Zelisko et al., 1982). Specifically, anterior cruciate ligament (ACL) injuries, patellofemoral pain syndrome (PFPS), and medial tibial stress syndrome are particularly problematic in females. Although several risk factors have been examined to explain this discrepancy in injury rates, no specific sex difference has been identified (Arendt et al., 1999; Davis & Ireland, 2001).

Sex differences in LE static alignments and LE dynamic movements have been studied in the hopes of identifying specific risk factors, or combination of risk factors, that predispose females to more LE injuries. Of the static LE static alignments, females tend to demonstrate observably larger magnitudes in quadriceps angle (Q-angle), genu recurvatum, femoral anteversion, and anterior pelvic tilt as compared with males (Nguyen & Shultz, 2007). The discussion of the relationship between larger magnitudes of certain alignments and LE injury has been considerable (Arendt et al., 1999; Gross, 1995; Hertel et al., 2004; Krivickas, 1997; Loudon et al., 1996; Mizuno et al., 2001; Tomaro, 1995; Trimble et al., 2002; Witvrouw et al., 2005); however consensus to these implications is lacking.

Sex-specific LE dynamics during functional task performance have been demonstrated through kinetic, kinematic, and neuromuscular measures (Decker et al., 2003; Ferber et al., 2003; Ford et al., 2005; Lephart et al., 2002; McLean et al., 2005b). Specifically, females demonstrate greater hip adduction and greater knee abduction. This frontal plane positioning has been theorized to be a factor associated with knee injury (Decker et al., 2003; Ferber et al., 2003; Ford et al., 2003, 2005, 2006; Lephart et al., 2002; McLean et al., 2005a), but the exact relationship between these factors is still unknown. In addition, females have also demonstrated faster time to peak angle during single-leg landings (Schmitz et al., 2007). This indicates that females may have less time to achieve a meaningful protective contraction of the knee stabilizers.

Both LE static and dynamic alignments have been implicated in the search for risk factors that may predispose females to LE injury; however, no consensus exists as to the measure or measures that might be most important to evaluate. A combination of static and dynamic alignments may better explain sex differences in movement patterns during functional tasks. The purpose of this study was to evaluate the effect of sex on LE static and frontal plane dynamic alignment in males and females during two functional movement tasks, and to use this information to develop a predictive equation with which we might find the combination of alignment measures that best discriminates males from females. We hypothesized that there would be significant sex differences for certain static and dynamic measures, and that a predictive model would be formulated to discriminate between males and females. Specifically, we hypothesized females would
demonstrate significantly larger Q-angle, more genu recurvatum, femoral anteversion, and anterior pelvic tilt. We also hypothesized that females would demonstrate more hip adduction and knee abduction compared with males, and that they would reach these peak joint angles in a shorter amount of time than males. We anticipated that measures of static alignment that are typically different by sex and LE kinematics that are believed to increase stress at the knee would be included in the predictive equation.

**Methods**

**Subjects**

Twenty-four healthy, active subjects (12 males; age = 24.8 ± 32 years; height = 177.9 ± 7.5 cm; mass = 83.8 ± 17.6 kg and 12 females; age = 22 ± 0.6 years; height = 165.6 ± 5.7 cm; mass = 61.6 ± 6.3 kg) volunteered for participation. Subjects were between the ages of 18 and 30 years, with at least 1 year of competitive participation (interscholastic or intercollegiate) in basketball. Exclusion included a history of serious knee injury, any acute orthopedic injury to the back or LE for within 1 month of testing, previous participation in any type of ACL injury prevention program, or current participation in plyometric training. Subjects who met the inclusion and exclusion criteria were asked to participate. The subjects who agreed received and signed an informed consent, which was approved by the University's Institutional Review Board for use in this study.

**LE Alignment Data Collection**

Six measures of LE alignment (navicular drop, tibial varum, Q-angle, genu recurvatum, pelvic tilt, and femoral anteversion) were collected by the same investigator (JM) who had extensive experience in performing these measures for both clinical and research purposes. All LE alignments were collected using previously established methods (Brody, 1982; Krawiec et al., 2003; Livingston & Mandigo, 1999; Ruwe et al., 1992; Tomaro, 1995; Trimble et al., 2002) which are described in Table 1. For testing, subjects were clothed in shorts that allowed exposure of all bony landmarks necessary for accurate measurement and were barefoot. For all bony landmarks, the central point was palpated and marked with a fine point marker. To minimize error from skin movement, all landmarks were located while the subject was in the position for measurement. A single measure for each alignment was used in the statistical analysis.

**Kinematic Analysis**

An 8-camera, three-dimensional (3D) VICON motion analysis system (Oxford Metrics Ltd.; Oxford, UK) was used to collect all LE kinematic data. Camera calibration errors were all below 1.3 mm. Each subject was instrumented with 16 retroreflective markers (14-mm diameter) at specific LE bony anatomical locations. Marker trajectories were sampled at 120 Hz and a 30-frame fill gap threshold was set to reconstruct lost markers. Trajectories were filtered through a low-pass Woltering digital filter with predicted MSE value of 30 and a cutoff frequency of 15 Hz. Hip and knee joint centers for the right and left leg were reconstructed using the Plug-in-Gait modeler (VICON Oxford, UK Peak Performance Technologies, Inc., CO). Hip and knee joint angles for the right leg were calculated. Neutral hip and knee alignment was defined as 0°. Relative adduction was subsequently denoted as positive, whereas abduction was negative. Kinematic data were synchronized with one of four imbedded force plates (Kistler Instrument Corp.; Winterthur, Switzerland and AMTI; Watertown MA), which were used to identify the time of initial contact with the ground with respect to task performance.

The frontal plane kinematic variables included peak hip adduction angle and peak knee abduction angle. If the hip never reached a position of adduction (i.e., remained abducted throughout the movement) then the minimal hip abduction angle was used for the analysis, and vice versa for peak knee angle. Frontal plane time-to-peak angle (TTP) for the hip and knee were also variables of interest. Frontal plane motion was chosen as the plane of interest because motions in this plane tend to increase stress at the knee. Peak angle was determined as the largest joint angle reached after initial contact with the force plate. Time-to-peak angle was calculated at the time to reach peak joint angle after initial contact with the force plate. A shorter TTP may indicate a lesser amount of time to stabilize and protect the knee after ground contact. Joint angle at initial contact with the force plate was recorded, however, not included in the analyses.

**Functional tasks**

The two functional tasks were a maximal vertical jump and a plant & jump. These two tasks were designed to mimic common mechanisms of ACL injury. An uncontrolled landing from a vertical jump may result in hyperextension or collapse of the knee joint. The plant & jump task involves significant transitions in momentum, acceleration, and direction in 3 planes of motion and is also commonly associated with ACL rupture. These rapid decelerations and changes in momentum are also a risky dynamic position for knee hyperextension or valgus collapse.

**Maximum Vertical Jump (Figure 1)**

The vertical jump was initiated from a distance that allowed the subject to comfortably use one stride (with the right foot) to reach a spot just in front of the force plate. The plant foot (the right foot) was planted close enough to the force plate so that the subject could perform the jump and land on the force plate with minimal forward progression while in the air. From that right foot plant, the subject performed a 1-footed takeoff, maximal vertical jump with maximal arm reach. The subject was
Table 1  Lower extremity static alignment collection methods

<table>
<thead>
<tr>
<th>Previously Reported Technique</th>
<th>Standardization (If Applicable)</th>
<th>Previously Reported Intratester Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navicular drop (cm)</td>
<td>The difference in height of the navicular tuberosity from the floor during sitting and standing (Brody, 1982).</td>
<td>Subject seated knees over feet. In sitting, both feet in subtalar neutral.</td>
</tr>
<tr>
<td>Tibial varum (°)</td>
<td>Subject in neutral width stance: The angle at which the distal third of the tibia diverges from the perpendicular as measured with a standard goniometer (Tomaro, 1995).</td>
<td>This measurement was taken without controlling for subtalar neutral.</td>
</tr>
<tr>
<td>Q angle (°)</td>
<td>Subject in neutral width stance: The acute angle created by the intersection of the lines from the ASIS to the central point on patella and from the central point of the patella to the tibial tuberosity in the frontal plane (Livingston &amp; Mandigo, 1999).</td>
<td>The subject’s quadriceps were in a relaxed position, as contraction of the quadriceps affects the position of the patella.</td>
</tr>
<tr>
<td>Genu recurvatum (°)</td>
<td>Subject in neutral width stance: The angle created by the femur to the lateral joint line to the lateral malleolus in the sagittal plane with the subject in standing (Trimble et al., 2002).</td>
<td>The subject was asked to fully extend knees for measurement.</td>
</tr>
<tr>
<td>Pelvic tilt (°)</td>
<td>Subject in neutral width stance: The degree of anterior tilt of the pelvis in the sagittal plane with a PALMeter inclinometer (Krawiec et al., 2003; Shultz et al., 2006).</td>
<td>The subject was asked to stand naturally.</td>
</tr>
<tr>
<td>Femoral anteverision (°)</td>
<td>Subject prone: The acute angle formed by the tibia and an imaginary vertical line (Magee, 1987).</td>
<td>Craig’s test was used. A bubble level was attached to the goniometer to ensure that the measurement was performed with respect to the true vertical.</td>
</tr>
</tbody>
</table>

*The PALMeter was manufactured by Performance Attainment Associates, St. Paul, MN.*
instructed to jump as high as possible, and also to reach with both arms up as high as possible, landing on both feet, with the right foot on the force plate and the left foot off. The planting phase of this task was the element of interest for analysis.

**Plant & Jump (Figure 2)**

Each subject started at one end of the runway and sprinted forward to plant the right foot on the force plate (3–5 steps, depending on each individual’s stride length). The approach to the force plate was performed as fast as possible within the constraints of the space being used. The subject planted the right foot at a 30° angle toward the left, as if to perform a cutting maneuver in that direction. Instead, the subject halted abruptly and shifted back to a two-foot stance and jumped straight up in the air, still facing 30° to the left. This task is similar to the motion basketball player would perform after receiving a pass and taking a jump shot. The plant phase of the right limb on the force plate was the variable of interest.

Subjects did not warm up before testing; however, they were allowed to stretch out and practice each task until comfortable with performing tasks in a repeatable fashion. All trials were performed barefoot to better capture motions of the feet rather than motions of the shoe. Kinematics of five successful trials of each task were captured. If performance of any task was overtly altered because of force plate targeting or in the case of technological systems error, the trial was discarded and repeated.

**Data Reduction**

Each variable for each subject represented the average of the peak value identified for five trials. A single measure for each alignment was used in the statistical analysis. The right lower limb only was included in analysis. Dependent variables included the static LE alignment measures (navicular drop, tibial varum, Q-angle, genu recurvatum, pelvic tilt, and femoral anteversion) and frontal plane kinematic variables of the hip and knee (peak angle and TTP). A time-series graph, depicting an averaged representation of frontal plane hip and knee motion during the plant & jump task, is presented in Figure 3. This figure is presented to illustrate the frontal plane motions, not for statistical analysis or as presentation of results.

**Statistical Analysis**

Multiple analysis of variance (MANOVA) was performed to evaluate the effect of sex on LE static variables, LE dynamic variables at the hip and at the knee. Separate analyses were performed to identify sex differences for each task, and a third analysis was performed to identify sex differences.
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Wilks’s Lambda was used to identify significant models. In the event of a significant linear model, individual t tests were performed to identify the specific significant differences. Descriptive statistics including means, standard deviations, effect sizes for the magnitude of the difference between groups, and 95% confidence intervals around the effect sizes were calculated for each variable.

Pooled effect sizes were calculated as the difference between the means divided by the pooled standard deviation and used to evaluate the magnitude of the difference between the means by gender. Effect sizes were interpreted as <.4 is small, .4 to .7 moderate, and >.7 as large (Cohen, 1988).

Static and dynamic variables that were statistically different between sexes were entered into separate discriminant analyses. Stepwise logistic regression was used to formulate the most predictive equation to discriminate males from females using static LE alignment and dynamic LE kinematic variables. Probability of F was set at .05 for a predictor entry into the model, and 1.0 for removal from the model. Separate discriminant analyses were performed for each of the two tasks.

All statistical analyses were conducted in SPSS 14.0 (SPSS for Windows, SPSS Science Inc, Chicago, IL). An alpha level was set a priori at .05 to determine statistical significance in all analyses. Pooled effect sizes were calculated in MATLAB (MATLAB R2007b, The Mathworks, Inc., Natick, MA).

Results

Females demonstrated significantly greater values for Q-angle (p = .009), genu recurvatum (p = .02), and femoral anteversion (p = .005). There was no difference between sexes for navicular drop, tibial varum, or anterior pelvic tilt. Means and standard deviations for each alignment measure are present in Table 2.

For the vertical jump task, males maintained significantly more hip abduction (p = .006) and also an increased TTP knee abduction angle (p = .02) compared with females. There were no other significant kinematic differences between genders for this task.

For the plant & jump task, males maintained the hip in a more abducted position than females (p = .003). There were no other differences between sexes for the kinematics of the plant & jump task. Details of results are presented in Table 3.

Variables that were significantly different by sex for the vertical jump task included three static measures (Q-angle, genu recurvatum, and femoral anteversion) and two dynamic measures during the vertical jump.
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These 5 variables were entered into a discriminant analysis. The resulting equation ($R^2 = .58, p = .03$) revealed peak hip abduction as the best predictor of sex ($R^2 = .31, p = .005$), followed by knee abduction TTP ($R^2Δ = .16, p = .025$) and genu recurvatum ($R^2Δ = .11, p = .03$). From the resulting equation, 81% of the males and 92% of the females were correctly classified by sex (87% of all subjects were correctly classified).

A second discriminant analysis was performed for the plant & jump task. The dynamic variable of peak hip abduction was entered into the discriminant analysis with the 3 static variables already mentioned. The resultant equation ($R^2 = .55, p = .008$) revealed peak hip abduction as the better predictor of sex ($R^2 = .35, p = .003$), followed by femoral anteverision ($R^2Δ = .2, p = .008$). The resulting equation from this analysis correctly classified 91% of the males and 83% of the females by sex. Overall, 87% of the subjects were correctly classified by sex from the use of this equation. The overall model summaries of the discriminant analyses are presented in Table 4.

### Table 2  Sex differences in lower extremity alignments

<table>
<thead>
<tr>
<th>Alignment</th>
<th>Males</th>
<th>Females</th>
<th>P-value</th>
<th>Effect Sizes [95% CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navicular drop (cm)</td>
<td>1.1 ± .3</td>
<td>1.0 ± .3</td>
<td>.43</td>
<td>–0.3 [–0.5, –0.2]</td>
</tr>
<tr>
<td>Tibial varum (°)</td>
<td>5.3 ± 2.8</td>
<td>5.8 ± 2.9</td>
<td>.69</td>
<td>0.2 [–1.0, 1.3]</td>
</tr>
<tr>
<td>Q angle (°)</td>
<td>11.0 ± 2.4</td>
<td>14.8 ± 3.8</td>
<td>.009*</td>
<td>1.2 [–1.0, 2.5]</td>
</tr>
<tr>
<td>Genu recurvatum (°)</td>
<td>3.3 ± 2.0</td>
<td>6.8 ± 4.3</td>
<td>.021*</td>
<td>1.0 [–0.3, 2.4]</td>
</tr>
<tr>
<td>Pelvic tilt (°)</td>
<td>9.0 ± 1.8</td>
<td>10.6 ± 4.2</td>
<td>.25</td>
<td>0.5 [–0.8, 1.8]</td>
</tr>
<tr>
<td>Femoral anteverision (°)</td>
<td>7.5 ± 4.0</td>
<td>13.0 ± 4.6</td>
<td>.005*</td>
<td>1.3 [–0.4, 3]</td>
</tr>
</tbody>
</table>

Means and standard deviations are represented. Effect sizes represent the magnitude of the differences between males and females.

*Denotes statistical significance between groups at $p \leq .05$.

### Table 3  Sex differences in kinematics for the vertical jump and plant & jump

<table>
<thead>
<tr>
<th>Kinematics</th>
<th>Males</th>
<th>Females</th>
<th>P-value</th>
<th>Effect Sizes [95% CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Jump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Hip Angle: Frontal Plane (°)</td>
<td>–6.9 ± 3.2†</td>
<td>–1.79 ± 4.5†</td>
<td>.006*</td>
<td>1.3 [–0.3, 2.9]</td>
</tr>
<tr>
<td>Peak Knee Ankle: Frontal Plane (°)</td>
<td>14.5 ± 9.1</td>
<td>8.7 ± 10.9</td>
<td>.18</td>
<td>–0.6 [–4.6, 3.4]</td>
</tr>
<tr>
<td>Hip Adduction TTP (s)</td>
<td>0.17 ± 0.1</td>
<td>0.16 ± 0.1</td>
<td>.88</td>
<td>–0.1 [–1.4, –0.6]</td>
</tr>
<tr>
<td>Knee Valgus TTP (s)</td>
<td>0.15 ± 0.9</td>
<td>0.07 ± 0.06</td>
<td>.02*</td>
<td>1.05 [1.0, 1.1]</td>
</tr>
<tr>
<td>Plant &amp; Jump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Hip Angle: Frontal Plane (°)</td>
<td>–17.5 ± 5.2†</td>
<td>–10.0 ± 5.0†</td>
<td>.003*</td>
<td>1.5 [–0.6, 3.5]</td>
</tr>
<tr>
<td>Peak Knee Ankle: Frontal Plane (°)</td>
<td>12.8 ± 11.0</td>
<td>7.4 ± 11.3</td>
<td>.25</td>
<td>–0.5 [–4.9, 4.0]</td>
</tr>
<tr>
<td>Hip Adduction TTP (s)</td>
<td>0.13 ± 0.08</td>
<td>0.17 ± 0.06</td>
<td>.20</td>
<td>0.6 [0.5, 0.6]</td>
</tr>
<tr>
<td>Knee Valgus TTP (s)</td>
<td>0.15 ± 0.09</td>
<td>0.14 ± 0.1</td>
<td>.87</td>
<td>–0.1 [–1.4, –0.07]</td>
</tr>
</tbody>
</table>

Means and standard deviations are presented. Effect sizes represent the magnitude of the differences between males and females. TTP: time-to-peak (s).

*Denotes statistical significance between groups at $p \leq .05$.

†Negative values represent abduction, positive values represent adduction.

### Discussion

The purpose of this study was to evaluate LE static and frontal plane dynamic alignment in healthy males and females during two functional movement tasks, and to use this information to develop a predictive equation with which we might find the combination of alignment measures that best discriminates males from females. The initial analyses were used to evaluate sex differences for LE static and dynamic measures. The subsequent analyses were used to develop a discriminative model using static and dynamic LE measures to explain the variance associated with sex.

As anticipated, our initial analysis revealed that females demonstrated greater magnitudes of Q-angle, genu recurvatum, and femoral anteverision compared with males. Based on previous evidence (Medina McKeon & Hertel, 2009; Nguyen & Shultz, 2007), we also expected that females would demonstrate significantly larger measures of anterior pelvic tilt; however this was not the case in our study. All LE alignments fell...
into ranges that have been previously reported as within normal limits and it can be concluded that the static alignments presented in our sample did not abnormally influence the LE kinematics of either sex.

Static alignment has been implicated as a risk factor for injury. Specifically, increased knee joint laxity has been identified as a potential risk factor for knee injury (Kramer et al., 2007; Loudon et al., 1996; Myer et al., 2008; Uhorschak et al., 2003; Woodford-Rogers et al., 1994). In addition, larger values of Q-angle and femoral anteversion have been identified in patients with overuse knee injuries (Cowan et al., 1996; Eckhoff et al., 1994; Waryasz & McDermott, 2008). These three LE alignment measures are believed to increase the risk of LE injuries such as PFPS, iliotibial band syndrome, and increase strain on the ACL. These alignments also tend to be higher in females compared with males, which also was observed in the current study.

We observed an effect of sex on LE dynamic measures at the hip and knee during the two functional tasks. For both the vertical jump and the plant-jump tasks, a sex difference existed for peak hip frontal plane angle. Based on previous evidence (Ferber et al., 2003), we expected that females would be in a position of hip abduction while males would exhibit abduction, or that females would be in a greater position of adduction compared with males. However, in our study, both sexes were in a position of abduction. In this position of abduction, females were in a significantly lesser degree of abduction compared with males, which has been previously reported during similar functional tasks (Pollard et al., 2004). It is believed that a diminished position of hip abduction may increase frontal and transverse plane stresses at the knee, as hip position in the frontal plane is believed to influence moments at the knee in the frontal plane, with greater hip abduction correlating to an increase in knee valgus forces (McLean et al., 2005a).

Although it was expected, we did not see any positional differences between the sexes for knee abduction angle during either task. During functional task performance, females have demonstrated greater knee abduction angles at initial contact (Ford et al., 2003; McLean et al., 1999, 2005a; Noyes et al., 2005) and at maximum joint angle (Ford et al., 2003; Ford et al., 2006; Malinzak et al., 2001; McLean et al., 1999). Others have not reported sex differences in knee abduction during performance of a stop jump task (Chappell et al., 2007), a sidestep cutting task (Sigward & Powers, 2006), or a landing task (Noyes et al., 2005). Based on these previous studies, we propose that a positional difference between sexes for knee abduction is not consistent and therefore, not the behavior of interest. In contrast, the moments that are sustained at the knee may be altered by sex in the absence of kinematic differences (Sigward & Powers, 2006), and that frontal plane knee kinematic analysis alone is not useful for detecting potential risk factors for injury. We also speculate that spatial measures (joint angle) may not be sensitive enough to detect small degrees of variation with 3D motion analysis.

We did identify a sex difference for knee abduction time-to-peak angle, a spatiotemporal measure. TTP knee abduction was significantly less in the female participants, and while the difference between sexes was, on average, 0.08 s, there was a strong effect for the magnitude of the difference between males and females with a narrow confidence interval that did not encompass zero (effect size = 1.3, 95% confidence interval = [1.0, 1.1]). From this we conclude that this is a meaningful difference in TTP, with females demonstrating a far shorter time to reach a stabilizing contraction of the knee musculature. In addition, we also speculate that a combination of spatial and temporal measures is more sensitive to detect small variations in dynamic performance that may be meaningful.

As part of a post hoc analysis, we calculated average angular velocity. Females achieved a faster average angular velocity than males. This faster joint motion in the frontal plane may be a predisposing factor for injury by increasing the joint forces on the knee and by also decreasing the amount of time the dynamic stabilizers around the knee have to contract and protect the joint. The preparatory contraction of periarticular muscles in response to perturbation provides stability and control of

### Table 4 Model summaries for each discriminant analysis

<table>
<thead>
<tr>
<th>Variables Entered</th>
<th>Vertical Jump</th>
<th>Plant &amp; Jump</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R$</td>
<td>$R^2$</td>
</tr>
<tr>
<td>Final Model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Genu Recurvatum ($^\circ$)</td>
<td>.764</td>
<td>.584</td>
</tr>
<tr>
<td>2nd Knee Valgus TTP (s)</td>
<td>.685</td>
<td>.469</td>
</tr>
<tr>
<td>1st Peak Hip Abduction ($^\circ$)</td>
<td>.561</td>
<td>.314</td>
</tr>
<tr>
<td>Final Model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Femoral Anteversion ($^\circ$)</td>
<td>.740</td>
<td>.547</td>
</tr>
<tr>
<td>1st Peak Hip Abduction ($^\circ$)</td>
<td>.592</td>
<td>.351</td>
</tr>
</tbody>
</table>

TTP = time-to-peak.
joint moments to prevent collapse. Faster angular velocities may be detrimental to the joint because of the shorter time to reach a meaningful and protective contraction of the periarticular musculature before the joint reaches its peak angle. Without meaningful contraction of the muscles around the joint, the forces of the perturbation are absorbed fully in the static structures (ligaments, joint capsule, or articular cartilage) of the joint.

Frontal plane dynamic variables and a static measure of knee joint laxity (genu recurvatum) were capable of discriminating males from females, and explained 58% of variance associated with sex for a vertical jump. With the vertical jump, we identified that the model to discriminate between males and females included spatiotemporal measure, coupled with a joint laxity measure. During the vertical jump task only two planes of motion are performed, and we speculate that it is this combination of spatial, temporal, and joint laxity measures that best describes the variations between groups when the differences are subtle. With the plant & jump, the model explained 55% of the variance associated with sex, but did not include both spatial and temporal measures. We conclude that the movements performed during the plant & jump task were less subtle than the vertical jump, incorporating 3 planes of motion, and therefore, spatial measures alone were capable of discriminating between the sexes.

While there were statistically significant differences between the sexes for static measures of LE alignment, dynamic measures were better at discriminating between sexes. From the discriminant analysis, we can conclude that frontal plane dynamic motion appears to be better at discriminating between sexes than static measures. In particular, the degree to which females lacked hip abduction contributed significantly to the differences in measures between the sexes for both the vertical jump and stop jump. This may have significant clinical implications in regards to risk factor identification and risk factor modification.

Limitations

Though the tasks designed for this study are functional in nature, they were described to the subject in full before performance of the task, and therefore, fully anticipated and not spontaneous. There is a conflict between constraining the task to make it reproducible between subjects and allowing the subject to perform the task unimpeded. Predesigned functional tasks are good for capturing motions similar to sport-related performance; however, the anticipated performance of functional tasks may not entirely represent the true performance of these tasks in a real-life situation (Besier et al., 2001). In addition, we chose to have the subjects perform the task barefoot. While this allowed us to better visualize the foot motion, there is the chance that subjects may limit the task performance speed to minimize impact of the feet on the floor.

A final limitation with the current study is that all subjects were healthy. While females may have performed the tasks differently than males, they may not be doing the task in a way that may be considered at risk for injury.

Conclusions

There tend to be normal variations between males and females for certain LE alignments. In the current study, QA, genu recurvatum, and femoral anteversion were all higher in females. These normal, sex-related variations in structure are all thought to potentially increase precarious forces at the knee. In addition to these observed structural differences, frontal plane motion at the hip and knee was also different between males and females. In particular, females were less abducted during the performance of both tasks. This may place abnormal stresses at the knee. While there were statistically significant differences between the sexes for 3 of the 6 measures of static LE alignment, dynamic measures were better at discriminating between sexes. There still exists the possibly that movement patterns inherent to females may be a factor for LE injury.

This study highlights the fact that neither static nor dynamic alignments alone describe potentially risky positions of the lower extremity. The results of this study indicate that the combination of static and dynamic alignments was able to discriminate between healthy males and females. Combinations of static and dynamic alignments may be useful in predicting who may be at risk for injury, independent of sex. Clinicians and researchers will need to continue to study and address both together to truly understand the nature of human movement. Further evaluation of these measures as sex-specific risk factors to LE injury is warranted.

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