FUNCTIONAL VOLLEYBALL BLOCK JUMP LANDING BIOMECHANICS AND INJURY INCIDENCE OF ADOLESCENT FEMALE ATHLETES AT TWO SKILL LEVELS

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By

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Lastly, I would like to thank my family: my mom, my dad, my sister and Patrick. Thank you for always encouraging and supporting me emotionally from far away. I couldn’t have made it through without you guys.
ABSTRACT

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Purpose: To examine the biomechanics of volleyball block-jump landings of adolescent female athletes to determine injury risk factors associated with this age group. The independent variables were skill level, knee injury history, and lower extremity involvement. Dependent variables were lower extremity kinematics and kinetics.

Methods: We used a causal-comparative retrospective research design to identify associated knee injury risk factors. Prior to the start of the competitive club season a retrospective injury questionnaire was administered to all participants to determine injury history status. Participants were 40 highly trained adolescent female club volleyball athletes who were divided into low (U13) and high (U17, U18) skill level groups. Six high-speed three dimensional motion capture cameras and two force plates were used to collect kinematic and kinetic data. Three-way analyses of variance (ANOVA) linear model were used to analyze three independent variables and six dependent variables of right direction and left direction block jumps.

Results: Findings indicated higher maximal vertical ground reaction forces \((F=4.71, P=0.03)\) on the right leg when subjects performed right direction block jump landings, regardless of skill level or previous injury history. No differences were revealed in any of the other independent or dependent variables.

Key Words: LOWER EXTREMITY INJURY, KINEMATICS, KINETICS, MOTION ANALYSIS, JOINT ANGLES, PEAK GROUND FORCE, ADOLESCENT, MOTION CAPTURE
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Youth sports participation in the United States has increased every year with more than 50% of children aged 5-18 years playing on at least one school or community sports team\(^1\). This increase in sports participation has paralleled the increased injury incidence in this age group\(^2\). Approximately 2.6 million emergency room visits occur from sport-related injuries per year in individuals aged 5-24 years\(^3\). Children in this age group are more susceptible to sport-related injuries than their adult counterparts due to environmental, physiological, and anatomical factors and differences in the body’s reaction to these factors. Force transmission and absorption differ at various maturation stages due to open growth plates that are vulnerable to injury stress during the growth process.\(^2\)

According to the National Federation of State High School Association’s Participation Survey, volleyball is the third most popular sport for females with 405,832 participants. High school surveillance reports indicate that gymnastics, basketball, and volleyball have the highest annual injury rates after football\(^2\).

Volleyball involves constant rapid repetitive jumping and landing and forceful multidirectional movement during conditioning, practice, and game situations \(^4,5\). This fundamental repetitive high-intensity jumping and landing sequence is the most common overuse source of patellar tendinitis and lower extremity injuries in volleyball\(^6,7,8,9\).

While acute traumatic knee injuries are less common than ankle injuries, anterior cruciate ligament (ACL) sprains are responsible for the most sport participation time loss\(^10\). Currently, ACL injury incidence is more prevalent in female than in male athletes\(^11-13\). And patellofemoral disorders, meniscal, and cartilaginous tears are significantly higher in adolescent females than in age matched males with similar training levels\(^14\).
The relationship of injury incidence relative to landing kinematics and kinetics are limited to studies involving high level/elite male athletes\textsuperscript{15,16}, non-functional tasks such as "box jumps"\textsuperscript{13}, and non-volleyball, non-sport specific activities\textsuperscript{17}. Previously, landing biomechanics of adolescent females revealed differences in drop jump landing biomechanics between pre and postpubescent groups\textsuperscript{15}. However, the aforementioned study did not involve the relationship of injuries and landing biomechanics\textsuperscript{14}. One prospective study of female athletes during box drop jump landings indicated that knee abduction and moments of force were the primary predictors of ACL injury risk\textsuperscript{13}. Unfortunately, this study was limited to non-functional drop jump landings. To our knowledge only one study involving investigation of functional volleyball landings was located and it identified specific biomechanical factors that significantly predicted patellar tendonitis pain, however the study included elite male volleyball athletes\textsuperscript{15}. Consequently, examination of the fundamental biomechanical characteristics associated with the high incidence of overuse and acute jumping and landing injuries of female adolescent athletes may help to prevent serious negative outcomes which could affect ones lifelong activity level. Therefore, the purpose of this study was to functionally investigate the volleyball block jump landing biomechanics of adolescent female club volleyball players of different skill levels to determine injury risk factors and injury incidence.
Research Questions

(1) What were the kinetic differences between adolescent females of high and low skill levels during functional block jump landings?

(2) What were the kinematic differences between adolescent females of high and low skill levels during functional block jump landings?

(3) What were the kinetic differences between non injured knees and previously injured knees of adolescent females of high and low skill levels during functional block jump landings?

(4) What were the kinematic differences between non injured knees and previously injured knees of adolescent females of high and low skill levels during functional block jump landings?

(5) What were the kinetic differences between right and left legs of adolescent females of high and low skill levels during functional block jump landings?

(6) What were the kinematic differences between right and left legs of adolescent females of high and low skill levels during functional block jump landings?
METHODS

Research Design

We used a causal-comparative retrospective research design. A retrospective injury questionnaire was used to identify knee injury history (see appendix C.4). The volleyball block jump landings of non injured knees (NIK) and previously injured knees (PIK), low and high skill groups, and right and left knees were compared to examine differences in lower extremity kinematics and kinetics during right and left direction block jumps.

Subjects

Forty (n=40) highly trained female adolescent club volleyball players aged 12 to 18 years volunteered to participate in this study. Subjects were grouped in teams according to coach assigned skill level designations. Skill level group ages represented maximum allowable ages for team members; younger and more skilled subjects were eligible to compete on higher aged team designations. The under (U) 13 team represented the low skill level group and U17-18 teams represented the high skill level group. Demographics of skill groups are presented in Table 1. Prior to study participation, the subjects and their parents/legal guardians completed informed written consent and assent forms approved by the University Committee on Human Studies. General medical and injury questionnaires were reviewed by the university team physician to screen for pathologies or physical contraindications to study participation. All subjects were healthy or asymptomatic at the time of data collection and able to properly perform volleyball block jumps.
Table 1. Subject Demographic Means and Standard Deviations, Skill Level (low vs. high), Club team experience, and Previous injury history

<table>
<thead>
<tr>
<th>Skill Level</th>
<th>n</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Club Volleyball Experience (years)</th>
<th>Previous Injury History</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>19</td>
<td>12.31 ± 0.48</td>
<td>52.58 ± 5.43</td>
<td>160.89 ± 6.82</td>
<td>2.52 ± 0.96</td>
<td>1</td>
</tr>
<tr>
<td>High</td>
<td>21</td>
<td>16.52 ± 0.60</td>
<td>67.80 ± 9.55</td>
<td>170.23 ± 6.91</td>
<td>5.20 ± 2.17</td>
<td>8</td>
</tr>
</tbody>
</table>

**Instrumentation**

Injury History Questionnaire was used to classify subjects into previously injured knees (PIK) and non injured knee (NIK). Knee injury history was defined as any injury that resulted in volleyball practice or game participation time loss and/or medical attention. The questionnaire consisted of 14 closed and five open ended questions, and anterior and posterior pictorial identification. (see appendix C.4)

Three-dimensional (3D) infrared motion capture system (Vicon MX, Vicon, Inc., Centennial, Colorado, USA), and Peak Motus software (version 8.0, Vicon, Inc., Centennial, Colorado, USA) was used to capture, reduce, and analyze kinematic block jump landing data. Six 3D cameras were placed on each side of the testing area so that, at least two of the six cameras captured the position of the reflective markers (1.4 cm in diameter) during the block jump landings. Three-dimensional kinematic data were time synchronized and collected at 240 (Hz). Both kinematic and kinetic data were smoothed using the Butterworth filter optimized by Peak Motus software. Knee flexion angles were calculated with Peak Motus software using projected segmental angles.

Full body reflective marker set described previously by Hewett was used for placement of 24 reflective bilateral markers. Bilateral reflective marker placements included: acromioclavicular (AC) joint, posterior superior iliac spine (PSIS), anterior
superior iliac spine (ASIS), greater trochanter (GT), anterior aspect of thigh (10 cm above the superior pole of patella), lateral epicondyle, tibial tuberosity, anterior aspect of distal tibia, lateral malleolus, calcaneus, head of the second metatarsal, and head of the fifth metatarsal.

**Two force plates** (Advanced Mechanical Technology Incorporated, Boston, Massachusetts) embedded parallel to each other and anterior to the volleyball net (representation), and flush with the floor surface were used to collect kinetic data during block jump landings. Ground reaction force data were time synchronized and collected at 480 (Hz) measured in Newtons, and normalized to body mass.

**Volleyball net** created by investigators were used to simulate functional volleyball blocking. The simulated volleyball net was positioned anterior and parallel to the force plates and set at regulation heights for the low skill level (U13) and high skill level (U17-18) at 2 m and 2.24 m, respectively.

**Procedures**

All data were collected in the University, Kinesiology and Leisure Science Human Performance Laboratory by National Athletic Trainers’ Association (NATA), Board of Certification (BOC) certified athletic trainers (ATC). All subjects completed the retrospective injury history questionnaire to establish injury status (i.e. previously injured knee history=PIK and non injured knee history=NIK). Subjects reported for data collection wearing sports bra, spandex volleyball tights, and volleyball shoes regularly worn during practices and games. Prior to biomechanical data collection the same female BOC ATC collected all anthropometric data consisting of height, weight, body composition, and Q angle.
Subject qualification included participation in at least three practices per week for between 5 and 11 consecutive months. Highly competitive club team classification was based on historic and consistent USA Volleyball Junior Olympics showings and win-loss ranking in the upper 25 percent nationally. All subjects were given a 10-minute warm up session on a stationary bike and self-directed stretching session. Biomechanical test familiarization included right or left direction block jump landings (moving to the right or to the left) practice with a one-step approach and a two foot landing. Acceptable trials consisted of two foot block jump landing bouts with individual foot placement on adjacent individual force plates. Upon successful and consistent right or left direction block jump landing bouts reflective markers were firmly attached to the aforementioned marker set anatomical placement sites directly on the subjects’ skin or spandex (ASIS, PSIS, GT) by the same BOC ATC.

Data collection trails were initiated when a researcher standing four meters from the net cued the subject. Each subject performed three block jump landings in each direction (to the right and to the left). Only those trials involving a proper one-step block jump approach, and landing with the entire right and left foot on the adjacent right and left force plates, respectively were used for data reduction and analysis.

**Statistical Analysis**

Two sets (right direction and left direction block jump conditions) of three-way analyses of variance (ANOVA) linear model were used to analyze three independent variables and six dependent variables. Independent variables included subject data grouped according to skill level, U13 vs. U17 and U18; injury history, PIK vs. NIK; and lower extremity, right vs. left leg. Dependent variables consisted of knee flexion angle at
initial ground contact (IC), knee flexion angle at maximal vertical ground reaction force (MVGRF), maximal knee flexion angle, MVGRF, time to MVGRF from IC, and loading rate from IC to MVGRF. Statistical Analysis Software (SAS) version 9.1 (SAS Institute, Inc., North Carolina, USA) was used to analyze the data. Significance level was established at P< 0.05

RESULTS

Analyses of variance results indicated one significant independent variable main effect in the right block jumping direction regardless of injury history or skill level on MVGRFs. No other main effect differences were revealed in any of the other independent or dependent variables. Significant findings indicated higher MVGRF (F=4.71, P=0.03) on the right leg than left leg regardless of skill level or previous injury history when subjects performed right direction block jumps. No interaction effects were revealed among any of the independent or dependent variables. Averaged kinematic and kinetic data are presented in Tables 2 through Table 9.
Table 2. Knee Joint Kinematics (°) Means and Standard Deviations of High and Low Skill Athletes During Left Direction Block Jump Landings

<table>
<thead>
<tr>
<th>Skill Level</th>
<th>Knee</th>
<th>Knee Flexion Angle at IC*</th>
<th>Knee Flexion Angle at MVGR†</th>
<th>Maximum Knee Flexion Angle</th>
<th>Knee Angular Velocity from IC* to Max Knee Flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Right</td>
<td>17.41 ± 4.68</td>
<td>64.54 ± 7.42</td>
<td>83.91 ± 8.22</td>
<td>347.21 ± 141.77</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>19.81 ± 12.60</td>
<td>66.06 ± 6.43</td>
<td>85.08 ± 7.58</td>
<td>346.14 ± 140.91</td>
</tr>
<tr>
<td>Low</td>
<td>Right</td>
<td>14.94 ± 5.57</td>
<td>61.64 ± 6.35</td>
<td>79.67 ± 12.1</td>
<td>285.21 ± 50.52</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>15.83 ± 5.11</td>
<td>63.63 ± 7.94</td>
<td>79.19 ± 12.25</td>
<td>279.15 ± 40.49</td>
</tr>
</tbody>
</table>

*IC: Initial Contact with the Ground
†MVGRF: Maximal Vertical Ground Reaction Force

Table 3. Knee Joint Kinematics (°) Means and Standard Deviations of High and Low Skill Athletes During Right Direction Block Jump Landings

<table>
<thead>
<tr>
<th>Skill Level</th>
<th>Knee</th>
<th>Knee Flexion Angle at IC*</th>
<th>Knee Flexion Angle at MVGR†</th>
<th>Maximum Knee Flexion Angle</th>
<th>Knee Angular Velocity from IC* to Max Knee Flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Right</td>
<td>16.13 ± 5.58</td>
<td>63.22 ± 6.45</td>
<td>83.13 ± 8.96</td>
<td>341.35 ± 137.83</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>17.71 ± 4.72</td>
<td>67.62 ± 7.08</td>
<td>84.29 ± 7.51</td>
<td>340.17 ± 127.21</td>
</tr>
<tr>
<td>Low</td>
<td>Right</td>
<td>13.62 ± 5.75</td>
<td>59.10 ± 8.71</td>
<td>79.38 ± 13.19</td>
<td>282.53 ± 63.21</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>16.27 ± 6.62</td>
<td>64.46 ± 11.18</td>
<td>80.36 ± 13.14</td>
<td>277.37 ± 60.45</td>
</tr>
</tbody>
</table>

*IC: Initial Contact with the Ground
†MVGRF: Maximal Vertical Ground Reaction Force
### Table 4. Maximal Ground Reaction Force Variables Means and Standard Deviations of High and Low Skill Athletes During Left Direction Block Jump Landings

<table>
<thead>
<tr>
<th>Skill Level</th>
<th>Knee</th>
<th>MVGRF* (N/kg)</th>
<th>Time To MVGRF* (N/kg)</th>
<th>Loading Rate to MVGRF* (N/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Right</td>
<td>12.88 ± 1.68</td>
<td>0.11 ± 0.03</td>
<td>132.49 ± 54.23</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>14.00 ± 2.21</td>
<td>0.11 ± 0.03</td>
<td>141.57 ± 58.16</td>
</tr>
<tr>
<td>Low</td>
<td>Right</td>
<td>13.63 ± 2.30</td>
<td>0.12 ± 0.02</td>
<td>117.74 ± 28.19</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>14.09 ± 2.13</td>
<td>0.13 ± 0.02</td>
<td>113.09 ± 26.07</td>
</tr>
</tbody>
</table>

*MVGRF: Maximum Vertical Ground Reaction Force

### Table 5. Maximal Ground Reaction Force Variables Means and Standard Deviations of High and Low Skill Athletes During Right Direction Block Jump Landings

<table>
<thead>
<tr>
<th>Skill Level</th>
<th>Knee</th>
<th>MVGRF† (N/kg)</th>
<th>Time To MVGRF† (N/kg)</th>
<th>Loading Rate to MVGRF† (N/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Right</td>
<td>14.44 ± 2.23*</td>
<td>0.11 ± 0.03</td>
<td>142.50 ± 49.10</td>
</tr>
<tr>
<td></td>
<td>left</td>
<td>12.62 ± 1.98</td>
<td>0.12 ± 0.03</td>
<td>118.27 ± 49.48</td>
</tr>
<tr>
<td>Low</td>
<td>Right</td>
<td>15.39 ± 4.68*</td>
<td>0.12 ± 0.01</td>
<td>140.74 ± 38.65</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>11.66 ± 3.73</td>
<td>0.14 ± 0.04</td>
<td>99.38 ± 38.98</td>
</tr>
</tbody>
</table>

* Right leg GRF was significantly higher than left leg across skill levels (P<.05)
†MVGRF: Maximum Vertical Ground Reaction Force
### Table 6. Knee Joint Kinematics (°) Means and Standard Deviations of Previously Injured Knees and Non Injured Knees During Left Direction Block Jump Landings

<table>
<thead>
<tr>
<th>Injury History</th>
<th>Knee Flexion Angle at IC*</th>
<th>Knee Flexion Angle at MVGRF†</th>
<th>Maximum Knee Flexion Angle</th>
<th>Knee Angular Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIIq</td>
<td>18.17 ± 3.75</td>
<td>65.18 ± 5.95</td>
<td>87.97 ± 9.39</td>
<td>305.92 ± 102.21</td>
</tr>
<tr>
<td>NIK§</td>
<td>16.94 ± 8.08</td>
<td>63.89 ± 7.27</td>
<td>81.34 ± 10.18</td>
<td>317.32 ± 116.69</td>
</tr>
</tbody>
</table>

*IC: Initial Contact with the Ground
†MVGRF: Maximum Vertical Ground Reaction Force
‡PIIq: Previously Injured Knee
§NIK: Non Injured Knee

### Table 7. Knee Joint Kinematics (°) Means and Standard Deviations of Previously Injured Knees and Non Injured Knees During Right Direction Block Jump Landings

<table>
<thead>
<tr>
<th>Injury History</th>
<th>Knee Flexion Angle at IC*</th>
<th>Knee Flexion Angle at MVGRF†</th>
<th>Maximum Knee Flexion Angle</th>
<th>Knee Angular Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIIq</td>
<td>17.42 ± 4.95</td>
<td>66.69 ± 5.64</td>
<td>88.17 ± 10.65</td>
<td>290.70 ± 63.11</td>
</tr>
<tr>
<td>NIK§</td>
<td>15.82 ± 5.85</td>
<td>63.36 ± 9.09</td>
<td>81.09 ± 10.68</td>
<td>315.56 ± 113.03</td>
</tr>
</tbody>
</table>

*IC: Initial Contact with the Ground
†MVGRF: Maximum Vertical Ground Reaction Force
‡PIIq: Previously Injured Knee
§NIK: Non Injured Knee
Table 8. Maximal Ground Reaction Force Variables Means and Standard Deviations of Previously Injured Knees and Non Injured Knees During Left Direction Block Jump Landings

<table>
<thead>
<tr>
<th>Injury History</th>
<th>MVGRF* (N/kg)</th>
<th>Time to MVGRF* (N/kg)</th>
<th>Landing Rate to MVGRF* (N/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIK†</td>
<td>12.68 ± 1.47</td>
<td>0.11 ± 0.03</td>
<td>121.51 ± 39.87</td>
</tr>
<tr>
<td>NIK‡</td>
<td>13.76 ± 2.15</td>
<td>0.12 ± 0.03</td>
<td>127.43 ± 46.35</td>
</tr>
</tbody>
</table>

*MVGRF: Maximum Vertical Ground Reaction Force
†PIK: Previously Injured Knee
‡NIK: Non injured Knee

Table 9. Maximal Ground Reaction Force Variables Means and Standard Deviations of Previously Injured Knees and Non Injured Knees During Right Direction Block Jump Landings

<table>
<thead>
<tr>
<th>Injury History</th>
<th>MVGRF* (N/kg)</th>
<th>Time to MVGRF* (N/kg)</th>
<th>Landing Rate to MVGRF* (N/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIK†</td>
<td>14.08 ± 2.33</td>
<td>0.12 ± 0.02</td>
<td>120.28 ± 34.23</td>
</tr>
<tr>
<td>NIK‡</td>
<td>13.46 ± 3.67</td>
<td>0.12 ± 0.03</td>
<td>126.32 ± 48.86</td>
</tr>
</tbody>
</table>

*MVGRF: Maximum Vertical Ground Reaction Force
†PIK: Previously Injured Knee
‡NIK: Non injured Knee
DISCUSSION

The most notable finding of our study was that significantly higher maximal vertical ground reaction forces were produced on the right leg (29) than on the left leg (11) when subjects performed right direction block jumps. This difference was consistent for subjects at both skill levels, with and without injury histories demonstrating that subjects favored the right leg when landing from right direction block jumps. Landing patterns of female collegiate volleyball players also indicate that a majority of block jump landings are performed on the right leg. Interestingly, this difference was not found during left direction blocks jumps. The preponderance of the left attacking spiker and the subsequent defensive right direction block requires the defense player to cover more area when moving laterally in the right direction block than when moving laterally to the left in a left direction block. Hence, it is possible that the athlete’s center of gravity was displaced farther to the blocker’s right during right block jumps resulting in higher maximal vertical ground reaction forces on the leading leg (right leg). Unilateral limb landings increase the probability of knee ligament damage since a single limb must dissipate and absorb the forces created by the entire body.
Volleyball study results indicate that patellar tendon pain is associated with:
longer time derivatives during spike and block takeoffs on the right leg; high maximal
vertical ground reaction forces (MVGRF); higher vertical ground reaction force loading
rates;13,15,16 larger knee flexion angles15 higher knee angular velocities, faster ankle
planter flexor moment development, and faster knee extensor moment tendency.16
Unfortunately, the aforementioned studies involved elite and non-elite adult male
volleyball athletes. While adolescent female basketball athletes with knee injury histories
produced significantly lower eccentric muscular activity values during box jump landings
than their uninjured counterparts.17 Additionally, adolescent athletes' knee valgus angles
and moments were identified as primary ACL injury risk factors.13

Contrary to previous studies biomechanical studies of injured and non-injured
athletes, we were not able to reveal biomechanical differences between previously injured
knees (PIK) and non-injured knees (NIK). The lack of significant differences between
PIK and NIK may be attributed to small sample size of PIKs (9/80) compared with NIK (71/80). Our injury questionnaire results revealed nine previously injured knees among 80 legs (40 subjects). Within the limitations of our study two, third degree ACL sprains, four patellar tendinitises, and three painful knees were reported. The variability in injury pathologies reported in our study may have influenced the sensitivity of our questionnaire to identify specific injury risk factors or injury severity. The retrospective design of the injury questionnaire may have affected the athlete’s ability to accurately report previous injuries and their severity.

Regardless of the injury diagnosis and/or severity, it should be noted that injury incidence was higher in the high skill level group (U17&18) than in the low skill level group (U13). Eight of the nine previously injured knees occurred in the high skill level group. Unfortunately, no significant differences in knee joint kinematics were revealed between high and low skill level groups in our study. Conversely, significantly greater knee flexion range of motion was indicated in lower skill than in higher skill level intercollegiate soccer players. The lack of significant findings in our study may be attributed to coach selected skill classification based primarily on age (i.e., low mean age 12.31 ± 0.48 years vs. 16.52 ± 0.60) while subject skill classification in the aforementioned study was based on college size and skeletal mature college aged subjects. Additionally, our study involved a functional volleyball specific task (block jump) as opposed to a non-functional, non-sport specific box drop jump task performed by soccer players. However, previous research results indicate that injury risk increases with increased exposures and not skill level.

Future injury risk/incidence vulnerability and injury severity in adolescents
should involve a prospective design and group classifications should be based on specific identifiers such as "Tanner Maturation Stages" or specific skill level accomplishments.

Therefore our conclusion is that injury risk factors were based on the direction of the block jump (right block or left block).

![Maximal Knee Flexion Angle (Smith) vs Maximal Knee Flexion Angle During Right Block (Harada) vs Maximal Knee Flexion Angle During Left Block (Harada)](image)

**Figure 2:** Knee flexion Range of Motion between low (U13) and high (U17 & U18) skill level groups
REFERENCES


Appendices

Appendix A. The Problem

A.1. Problem statement.

The purpose of this study was to functionally investigate the volleyball block jump landing biomechanics of adolescent female club volleyball players of different skill levels to determine injury risk factors and injury incidence.

A.2. Independent variable(s).

The independent variables are two skill levels (higher and lower), history of knee injuries (previously injured knee and non injured knee), and knee (right and left).

A.3. Dependent variable(s).

The dependent variables are lower extremity kinematics and kinetics.

A.4. Dependent measure(s).

The dependent measures are knee flexion angle at initial contact with the ground (IC), knee flexion angle at maximal vertical ground reaction force (MVGRF), maximal knee flexion angle, MVGRF, time to MVGRF from IC, and loading rate from IC to MVGRF.

A.5. Research question.

(1) What were the kinetic differences between adolescent females of high and low skill levels during functional block jump landings?
(2) What were the kinematic differences between adolescent females of high and low skill levels during functional block jump landings?
(3) What were the kinetic differences between non injured knees and previously injured knees of adolescent females of high and low skill levels during functional block jump landings?
(4) What were the kinematic differences between non injured knees and previously injured knees of adolescent females of high and low skill levels during functional block jump landings?
(5) What were the kinetic differences between right and left legs of adolescent females of high and low skill levels during functional block jump landings during
(6) What were the kinematic differences between right and left legs of adolescent females of high and low skill levels during functional block jump landings during functional block jump landings?
A.6. Operational definitions.

The definitions of previously injured knee were injuries that occurred during volleyball participation, needed a medical attention, and as well as required any length of time lost from participation of volleyball activities.

The definitions of successful landings were proper one step approach to perform a block jump, and proper landing with right foot on the right force plate and left foot on the left force plate. Whole feet need to be contacted with each force plate.

A.7. Experimental hypotheses.

The experimental hypotheses were that; (1) there is no biomechanical difference between different skill levels during volleyball block jump landing, (2) there is no biomechanical difference during volleyball block jump between healthy knee and previously injured knee during volleyball block jump landings, and (3) there is no biomechanical differences between right and left legs during volleyball block jump landings.

A.8. Assumptions.

The assumptions of this study are that (1) each subject is equally capable of performing proper volleyball block jump for their age, (2) subjects answered injury questionnaire honestly and correctly.


Delimitations of this study were (1) two different skill levels (U13, U17, and U18) to represent adolescent athletes, and (2) only female subjects as oppose to both gender subjects.

A.10. Limitations.

Limitations of this study were (1) small sample size, (2) different maturation level in the same age groups, and (3) retrospective injury questionnaire.

A.11. Significance of the study.

The number of volleyball landing biomechanics studies is limited when compared to other general landing studies. In most of these landing studies, adults served as subjects. Involvement of adolescents in athletic activities has been increasing. This population is more prone to injuries due to
physical immaturity. Females are more prone to developing lower extremity injuries due to skeletal and physiological differences as compared to males. Volleyball is one of the most popular sports among female adolescent athletes. Determining the biomechanical characteristics associated with injury may help researchers to develop injury prevention program, and therefore, decrease injury incidence in female adolescent volleyball athletes.
Appendix B. Literature Review

Lower extremity injuries are often seen in sports which require repetitive jump landing sequences such as volleyball. The sports-related injuries in volleyball are commonly seen at the lower extremities and the number of those injuries have increased over the past twenty years due to a higher number of participants in sports activities. Injury history, gender difference, and different developmental stages have drawn attention to the importance of understanding the mechanisms of injuries to prevent sports-related injuries.

Volleyball Jump-Landing and Injury Incidence

Tillman conducted a study to quantify the number of jumps performed by elite female volleyball players in competitive matches and to determine the relative frequency of different jumping techniques. Videotape recording of two matches among four NCAA Division IA female volleyball teams were analyzed in this study. Each activity was categorized by jump type (offensive or defensive) and phase (jump or landing). Offensive jumps were primarily spikes and defensive jumps were mostly blocks. During four game matches, 1087 (484 offensive and 603 defensive) jumps and subsequent landings were evaluated. On average, each of the players studied executed nearly 45 jumps and subsequent landings for the two games. The majority of defensive jumps were performed using both feet. Similarly, the bilateral two foot landing from a defensive jump was prevalent followed by right foot landings and left foot landings. In conclusion, nearly half of all landings in elite women's volleyball utilized a unilateral landing technique. The author concluded that the trend found in this study was important because
the relatively high number of unilateral landings could lead to a loss of balance and subsequent injury.

Augustsson\(^7\) investigated the prevalence of injury in elite Swedish volleyball players. The sample population in this survey comprised 225 volleyball players (10 men's teams and nine women's teams) who played in the elite Swedish division during the 2002-2003 seasons. An injury questionnaire was distributed at the end of the season. The questionnaires were collected from all players, as well as those who dropped out because of injuries. The prevalence of injury was 0.77 injuries per player (0.86 injuries per player for women and 0.68 injuries per player for men). The majority of injuries were located in the ankle (23%), followed by the knee (17%) and the back (16%). Forty-seven percent of all injuries occurred during training, and 12% of injuries occurred during the matches. Among all injuries, 41% of them had a gradual onset. The injuries with gradual onset were mostly located to the knee (33%). Forty-five percent of all the injuries noted in this study could be related to a specific court situation and, furthermore, 54% of these injuries occurred during blocking and 30% during spiking.

Verhagen\(^4\) also conducted a one season prospective cohort study to estimate the overall incidence of acute and overuse volleyball injuries. Fifty teams (20 males, 30 female) consisting of 486 players from Dutch second and third division teams participated in this study. At the start of the season (September 2001), all players completed a questionnaire on previous injuries. The questionnaire was repeated in January, and again at the end of the season (May 2002). The players were free from injury at the start of the study. A total exposure of 44,891 hours was reported throughout the 36 week seasons, during which 100 injuries occurred. The overall risk on injuries
was higher for match play than for training. In terms of acute injuries, the lower extremity was the most commonly injured body region, with 65 injuries. Ankle sprains accounted for most of acute injuries. During the season, 25 overuse injuries were reported. Shoulder was the most common location for overuse injury followed by back and knee. In conclusion, the incidence of acute and overuse injuries was 2.0 and 0.6 per 1000 playing hours, respectively. The ankle sprain was clearly the most common injury in volleyball.

In summary, acute and chronic injury prevalence in volleyball is high among elite athletes due to high amount of jump landing sequences performed by players. Studies reported that the most commonly seen acute injury was ankle sprain. Other common finding in these studies was that knee is mostly affected by overuse injuries. Verhagen failed to show relatively high incidence of overuse knee injuries in their study. This might be due to the fact that the injury registration was limited to injuries that caused the player to stop playing.

Knee Injury Risk Factors Associated with Landing

Bisseling biomechanically tested landing strategies in order to find indication of possible risk factors for patellar tendinopathy. Subjects included 89 male volleyball players from The Netherlands, and they were divided into three groups. First group was control group (CON) with no patellar tendon pain. Second group was the asymptomatic previous jumper’s knee group (PJK), and the third group was the symptomatic recent jumper’s knee group (RJK). Subjects performed jumps from three different height boxes and landed on both feet. Kinematic and kinetic data were collected via an Optorak motion analysis system and a Bertec force plate. The study found that that PJK group
seemed to land with a stiffer knee joint than CON group, as appeared from significantly higher knee angular velocities, faster ankle planter flexor moment development, and a tendency of faster knee extensor moment development and higher loading rate of vertical ground reaction force during landing. The author suggested that by performing a stiffer landing strategy, the patellar tendon, as part of the quadriceps extensor mechanism, was subjected to a higher strain. High frequency of landing movements in volleyball and this landing strategy performed by PJK may collectively be seen as a risk factor for patellar tendinopathy. Another finding in this study was that the landing strategy found in RK group was in contrast with the landing characteristics performed by asymptomatic PJK group. RJK mainly differed significantly on biomechanical variables concerning landing stiffness by lower knee velocities, slower ankle planter flexion and knee extensor moment development and lower knee power values. These landing strategies performed by RJK could be interpreted as a consequence of the pain associated with patellar tendinopathy.

Richards conducted biomechanical study to determine if predictive relations exist between volleyball jump dynamics and patellar tendonitis. Subjects included 10 members of the 1994 Canadian Men’s National Volleyball Team. Six of the 10 had a history of patellar tendonitis and 4 of those 6 had a history of bilateral tendonitis. At the time of testing, 3 of the 10 players were diagnosed as having patellar tendon pain associated with patellar tendon tenderness. Kinematic data of lower extremity and ground reaction force during spike and block jumps were collected using high-speed (200 frames/sec) video digitizing system and a force platform. All data were analyzed with a three-way multivariate analysis of variance test (MANOVA) with repeated measures to
assess right versus left limb, takeoff versus landing, and spike versus block jumps. A portable net set at regulation height (2.43 meters) was used, and subjects performed actual spike and block jumps to simulate sport specific movements. The results showed that limited number of dependent variables reliably predicted the presence or absence of pain, which included; maximal vertical ground-reaction force and its time derivative for the right limb during the spike jump, the peak vertical ground-reaction force for the right limb during the block jump takeoff, the maximal angle of left knee flexion during the spike jump landing, the peak time derivative of knee extensor moment during spike jump landing, and lastly, the peak tibial external rotation moment for the right knee during the spike jump takeoff and for the left knee during the block jump takeoff. This study was the first to quantify a significant predictive relationship between volleyball jump dynamics and the presence or absence of patellar tendinitis.

Louw\(^{17}\) examined kinetic and kinematic differences in landing patterns of previously knee injured and uninjured adolescent basketball players. Eleven injured subjects were conveniently selected on the basis of appropriate matching with 11 uninjured players by age, gender, weight, height and years of play, and playing for the same club. They sustained knee injuries during the 2002 basketball season. The injury mechanism included landing badly from a jump, falling after landing, bumping into another player and pain relate to overuse. At the time of testing, none of the injured players had knee range of motion limitations. Their knee injuries had healed from the player’s perspectives, which were indicated by their functional ability to play basketball. Subjects included four fourteen year old boys, four fifteen year old boys, four sixteen year old boys, four fourteen yea old girls, four fifteen year old girls and two sixteen year
old girls. Six high-speed Vicon 370 cameras and biomechanical software were used to analyze landing patterns. A strain gauge 6-channel force plate, synchronized with the Vicon System, was used to measure the ground reaction forces. Subjects were instructed to run forward for three steps to jump as high as possible and simulate shooting a basketball, and then, land on a force plate with one foot of subjects' choice. All trials were performed with barefoot. The key finding of this study was the strong positive correlation between subjective injury score and ground reaction forces. They also found a negative correlation between the degree of knee flexion angle at the time of maximum ground reaction force and peak vertical ground reaction force. Greater knee flexion angle was related to less peak ground reaction force values. Another important finding was that the injured players demonstrated significantly less eccentric activities of knee joint on landing compared with the uninjured players.

Hewett$^{13}$ conducted a study to collect lower limb biomechanical data in female athletes during the execution of sports movements and followed them prospectively to determine those who suffered noncontact ACL injury. There were 205 female adolescent soccer, basketball, and volleyball players who were screened via 3D biomechanical analyses before their seasons. Nine ACL injuries happened in 205 female athletes. Those who suffered and ACL injury were classified in this study as injured, and the rest was classified as uninjured. Knee kinematics and kinetics of these two groups were compared. Knee joint flexion-extension and adduction-abduction were quantified for each subject over a series of drop vertical jump (DVJ) trials. The DVJ consisted of the subject starting on top of a box with her feet positioned apart. Subjects were instructed to drop directly down off the box on both feet and immediately perform a maximum vertical
jump, raising both arms as if they were jumping for a basketball rebound. The result revealed that female athletes suffering an ACL injury during competition demonstrated altered neuromuscular control characteristics compared to uninjured athletes, as evidenced by differences in lower limb biomechanics during jump-landing movement tasks. Knee abduction angles both at initial contact with the ground and maximum angle were significantly greater in ACL injured group compared to those in uninjured group. No significant difference in knee flexion angle at IC was found, however, ACL injured group demonstrated significantly less maximum knee flexion angle than uninjured group. Vertical ground reaction force was also increased in the injured group. Logistic regression analysis demonstrated that knee abduction moments and angles (IC and peak value) were significant predictors of ACL injury status.

In summary, two studies investigated the relationship of patellar tendonitis and biomechanical landing characteristics in volleyball players revealed landing characteristics demonstrated by subjects with patellar tendon pain. Bisseling concluded that the “stiffer landing” may be related to the previous patellar tendinopathy, while Richards reported the deeper knee flexion angle during volleyball spike landing was the strong predictor of having patellar tendon pain. Other study revealed knee abduction angle and moment appropriately predicted the incidence of ACL injuries. Even though Louw’s study was not specific to one type of injury, they reported that the subject with previous knee injury utilized “stiffer landing” technique.

Different Physical Maturity Levels and Landing Biomechanics

Hass compared knee biomechanics during landings between pre- and post pubescent females. Subjects included 16 recreationally active women between 18 to 25
36 years of age, and 16 recreationally active girls between 8 to 11 years of age. Prepubescent athletes were pre onset of menarche and the growth phase associated with it, defined as an increase in height of greater than 5 cm or an increase in body weight of 10% or more during the preceding 3 months. Postpubescent athletes were at least 6 years past the onset of menarche with a normal menstrual cycle. They performed three different landing sequences at the end of a single drop jump: static landing, vertical jump, and lateral landing sequences. The kinematics data found that the postpubescent participants landed with their knee more extended. Despite landing with a more extended lower extremity, the kinetic data showed that the postpubescent athletes produced ground reaction forces on average 11% less than the prepubescent participants. More flexed landing position of the prepubescent participants resulted in a significantly greater first peak vertical ground reaction force related to the toe contact and faster time to the second peak vertical ground reaction force associated with heel contact. These data suggest that the kinematics and GRF differences between the two groups may be related to their differences in muscle activation patterns, as well as training experience and skills. The result also showed that postpubescent athletes exhibited significantly reduced extension moments compared with the prepubescent participants.

Swartz tested prepubescent and postpubescent males and females to identify developmental and sex differences in knee and hip kinematics and vertical ground reaction forces during vertical jump landings. Fifty eight subjects were divided into developmental stage and sex groupings. (Add definition of pre and postpubescent) Subjects were instructed to jump for a suspended target, and bring it down with them as they landed on both feet as if they jumped for a basketball rebound. Successful trails
required that the subjects reached the target, landed and balanced on both feet facing forward, with only the dominant foot on the force plate. For developmental stage, the result showed that the adults had greater flexion angles for the hip at initial contact and greater flexion angles for the hip and knee at the point of peak vertical ground reaction force (VGRF) than the children. The children’s greater knee and hip extension at impact demonstrated a stiffer landing technique than the adults, which likely led to the higher peak VGRF and impulse and shorter time to the peak VGRF, even when considering the difference in mass and impact velocity.

In summary, prepubescent athletes and postpubescent athletes demonstrate different landing biomechanics. However, the results of these two studies were not consistent. Hass reported that prepubescent subjects demonstrated greater knee flexion angle with greater MGRF whereas Swartz reported prepubescent subjects demonstrated “stiffer landing” technique characterized by less knee flexion and greater MGRF. The common outcome of these studies was the peak vertical ground reaction force values. Both studies reported that postpubescent athletes demonstrated less peak vertical ground reaction force than prepubescent athletes did. Both authors suggested that training experience and increased jumping skill in postpubescent athletes might have helped the performer better absorb landing forces.14,27

Landing Biomechanics characteristics in female athletes

Salci25 compared male and female volleyball players’ both spike and block landing characteristics in relation to muscle strength measures. Subjects were eight male and eight female collegiate volleyball players with no severe previous lower leg injuries. They performed drop jumps from 40 and 60 cm boxes to simulate volleyball spike and
block landings respectively. For spike landings, platform was placed 10 cm away from the edge of the force plate, and for block landings, platform was placed 15 cm away from the side of the force plate. Six Ikegami CCD cameras and two Bertec force plates were used to collect kinematic and kinetic data in this study. An isokinetic dynamometer was used to for the quantitative muscle strength measurements. Results indicated that hip and knee flexions of male volleyball players were more prominent than that of female for the all landing tasks. They also revealed that male volleyball players applied significantly less vertical ground reaction force (VGRF) than females in all landing tasks when the data was normalized to body weight. Quantitative muscle strength measurement revealed that male volleyball players generated significantly higher quadriceps and hamstring peak torque normalized to body weight than females.

Lephart evaluated lower extremity kinematic patterns, vertical ground reaction forces, and muscle strength in collegiate female basketball, volleyball, and soccer players compared with matched recreational male athletes. Fifteen female athletes from division I schools and 15 matched, according to age and activity level, male recreational athletes who previously had played organized basketball or soccer participated in this study. Kinematic and kinetic data were collected using the Motion Analysis System and the Bertec force plate. Isokinetic data were recorded with the Biodex System Dynamometer. Subjects performed two landing tasks. Both landing tasks began with subjects standing with their hands on their hips. Subjects, then, performed box drop and forward hop single leg landing tasks and balancing on the dominant leg. The verbal cue of jump signaled the subjects to hop onto the X marked on the force plate. For single-leg landing, subjects hopped off a 20 cm platform that was placed 11 cm from the back edge
of a force plate. During the forward hop task, subjects started at a distance of 45% of their height away from the X marked on the force plate. Results showed that female demonstrated significantly greater hip internal rotation, less knee flexion, and less lower leg internal rotation compared with the male subjects during single-leg landing. The females also had significantly less time to maximum angular displacement of knee flexion and lower leg internal rotation maximum angular displacement than male. During the forward hop landing the females demonstrated significantly less knee flexion, lower leg internal rotation maximum angular displacement, more time to maximum angular displacement for hip internal rotation and less time to maximum angular displacement for knee flexion than males.

Sel12 investigated biomechanical characteristics of several landing tasks in female and male adolescent basketball players. The first purpose of this study was to examine the neuromuscular and biomechanical characteristics during jumping and landing tasks that incorporate both directional changes (horizontal and vertical) and deceleration component similar to those tasks that have been implicated in noncontact ACL injuries. The second purpose of this study was to determine if these same tasks would be performed differently under conditions that prevented the subjects from knowing the specific task to be performed before initiating the movement. The final purpose of this study was to determine if women perform the reactive jumps and the lateral jumps to the left differently from men. A total of 35 healthy high school basketball players (18 male and 17 female) were recruited from local schools. Subjects were excluded from the study if they had a history of serious musculoskeletal injury, any musculoskeletal injury within the past 6 months, or any disorder that interfered with sensory input, musculoskeletal
function, or motor function. Three-dimensional coordinate data of the retroreflective markers during the stop-jumps were collected and calculated using a 3D optical capture system, and ground reaction force data were collected by 2 force plates. The technique for the stop jump task consisted of the following: (1) an initial starting point measured as 40% of the subject’s height distance from the front edge of the force plates, (2) a legged broad jump with a 2-legged landing on the force plates, and (3) immediate jump for maximum vertical height or maximum horizontal distance. To include a reactive component during the stop-jump tasks, a 19-inch flat-screen monitor was set up in front of the subjects to provide the visual cue for the jump direction. All data were analyzed for the right leg only. The significant findings in this study were that jump direction, task (planned or reactive), and gender had significant main effects on the biomechanical characteristics of the knee during the stop-jump movements. Jumps to the medial aspect of the right knee (to the subject’s left) had the greatest vertical and posterior ground reaction forces, greatest proximal anterior tibia shear force, highest valgus and flexion moments, and lowest flexion angles. During the reactive jumps, the subjects used less knee flexion at peak posterior vertical ground reaction force, a greater maximum knee flexion angle, and experienced greater deceleration forces, knee flexion moments, and knee valgus moments when compared with different tasks. The subjects also demonstrated increased knee joint loading characteristic, as observed in the greater knee valgus and flexion moments, and greater deceleration forces during reactive jumps. The author suggested that these increased forces, combined with the increased knee valgus moment and decreased knee flexion angle at the initial contact, could increase the strain in the ACL. Gender comparisons revealed that the female subjects in this study
performed the reactive jumps and jumps to the left with less knee flexion than did their male counterparts. An increased knee valgus angle was also observed in the female subjects performing the reactive jumps and the jumps to the left. In addition to the kinematic differences, female subjects demonstrated greater proximal anterior tibia shear force at the time of peak posterior ground reaction force during reactive jumps.

As female landing characteristics were revealed in studies mentioned above, Smith\textsuperscript{23} conducted a study to reveal biomechanical landing characteristics within female athletes. In his study, the differences between lower extremity biomechanics and maximal vertical jump height as a measurement of performance of whole body power between National Collegiate Athletic Association Division I and Division III female soccer athletes were compared during a drop vertical jump. Thirty-four female collegiate soccer players (19 from Division I, 15 from Division III) volunteered to participate in the study. Maximum vertical height was determined first with a basketball as a target to encourage maximal jump height. This target height was then set for the drop vertical jump (DVJ). The DVJ consisted of dropping off the box and jumping immediately to grab the basketball. The height of the box was 31 cm. Eight digital cameras and two force plates were used to record the DVJ maneuver. First finding in this study was that knee abduction angular range of motion and knee abduction moments were similar between Division I and Division III female soccer players. Another finding was that Division III athletes demonstrated a significantly greater knee flexion range of motion than Division I athletes. In addition, Division I athletes had greater peak external knee flexion moment than in Division III athletes. Significant difference in vertical jump
height was found between divisions. Division I players jumped a mean of 4.5 cm higher than Division III players.

In summary, female and male subjects exhibited different landing strategies as indicated by less knee flexion angle demonstrated by female subjects\textsuperscript{12,25,26}. Within female intercollegiate soccer players, Division III athletes demonstrated significantly greater knee flexion angle compared to Division I athletes\textsuperscript{23}. Lephart\textsuperscript{26} suggested that physicians, athletic trainers, and others who were concerned with the care of athletes need to evaluate the biomechanics of the female athletes to ensure proper technique was being used during landing activities to protect knee structures.

Finally, many studies examined landing biomechanics in various subjects in order to determine injury risk factors of landing movement that are often linked to lower extremity injuries\textsuperscript{6,12-16,23-29}. Two studies focused on injury risk prevalence in volleyball. They reported that acute and overuse lower extremity injuries in volleyball were quite frequent and knee is most commonly affected by overuse type of injuries\textsuperscript{6,7}. Studies that investigated knee joint landing biomechanics discovered that injuries alter landing strategies indicated by different biomechanical characteristics\textsuperscript{15-17}. Physical maturation status plays an important role in determining injury risk factors in adolescent populations. Previous studies revealed that pre and postpubescent athletes demonstrated different landing biomechanical characteristics, however, some of the outcomes of these studies contradicted\textsuperscript{14,27}. In order to determine injury risk factors related to gender, the landing biomechanics has been investigated. These studies suggested that female were more susceptible to knee injury compared to males due to less knee flexion and increased
valgus angle, and emphasized importance of proper landing education to prevent injuries.\textsuperscript{12,25,26}
Appendix C. Additional Methods

C.1. Institutional Review Board Form

CHS 04/04  CHS #15023

Application for New Approval of a Study Involving Human Subjects

University of Hawai'i, Committee on Human Studies (CHS)
Spalding Hall 253, 2540 Maile Way, Honolulu, Hawai'i 96822
Telephone: (808) 956-5007

Date: March 7, 2007

PI (name & title): Iris F. Kimura, PhD, ATC, PT, Professor; Rumi Bumbera, ATC; Rie Harada, ATC; Kaori Tamura, MS, ATC; Christopher Stickley MA, ATC;
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Phone: 956-5162/3797

Department: Kinesiology and Leisure Science

[ x ] Faculty or Staff  [ x ] Student

Name of supervising professor: Iris F. Kimura, PhD, ATC, PT


Project Title: Jumping Biomechanics as Predictors of Injury in Adolescent Female Volleyball Athletes

Proposed Sponsoring Agency: N/A  Start Date: April 1, 2007

Complete Agency address: ____________

1. Summarize your proposed research. Outline objectives and methods.

Upper and lower extremity injuries are common among athletes who participate in jumping activities, particularly skeletally immature athletes training at high intensities for long periods of time. Currently, the research involving the relationship between injuries and jumping biomechanics are limited and primarily involves adult athletes who participate in jumping activities. The purpose of this study is to investigate spike and block “jump LANDING” kinematics and kinetics of adolescent female volleyball players to determine the relationship to upper and lower extremity injuries.

Subjects will be 100 highly trained and well-conditioned female volleyball players 10 to 18 years of age recruited from local volleyball “club” teams from the greater Honolulu community. Club teams and coaches will be contacted through public club web sites and contact information. Interested club teams will be asked to volunteer to participate in the study following a power point presentation to players, parents/legal guardians, and coaches (attachment #1).

All data will be collected in one 45-minute session in the University of Hawaii, Manoa, Kinesiology and Leisure Science Human Performance Laboratory. Testing order will commence with the older competitive levels (i.e. ≤17s, ≤16s, ≤15s, ≤14s, ≤13s, ≤12s) and continue to the youngest competitive level. Demographic data will be collected (e.g. age, competition level, height, weight, vertical jump, Q-angle, and two skinfolds (triceps and calf) prior to biomechanical assessment. Biomechanic
data collection will involve bilateral reflective markers placement on the following anatomical landmarks: head, shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet. The same female National Athletic Trainers’ Association (NATA), Board of Certification (BOC) certified athletic trainer will collect all demographic data and apply all reflective markers. All subjects will undergo a familiarization and instructional session prior to testing. Subjects will be asked to perform three to five spike jumps and three to five block jumps (total jumps = 10). Kinematic data will be captured via Vicon Optical Capture System. Kinetic data will be collected through ground reaction forces measured via two Advanced Mechanical Technology Incorporated (AMTI) force plates.

2. Summarize all involvement of humans in this project (who, how many, age, sex, length of involvement; frequency, etc.) and the procedures they will be exposed to. Attach survey instrument, if applicable.

All data will be collected in one 45-minute session by National Athletic Trainers’ Association (NATA), Board of Certification (BOC) certified athletic trainers. Subjects will be 100 highly trained and well-conditioned female volleyball players 10 to 18 years of age recruited from local volleyball “club” teams from the greater Honolulu community. Club teams and coaches will be contacted through public club web sites and contact information. Interested club teams will be asked to volunteer to participate in the study following a power point presentation to players, parents/legal guardians, and coaches (attachment #1).

Volunteers will complete injury and health history questionnaires (attachment #2 & 3), which will be reviewed by a medical doctor to screen for pathologies or contraindications to subject inclusion. Only non-pregnant subjects free of injuries within the last six months will be included in the study. Signed informed both consents and the assent forms approved by the University of Hawaii Committee on Human Studies will be obtained prior to participation in the study (attachment #4, 5 & 6).

Check whether any subject of your research will be selected from the following categories:

- Minors [X]
- Pregnant Women [ ]
- Mentally Disabled [ ]
- Physically Disabled [ ]
- Fetuses [ ]
- Abortuses [ ]
- Prisoners [ ]

3. Research involving humans often exposes the subjects to risks. For the purpose of this application, “risk” is defined as exposure of any person to the possibility of injury, including physical, psychological, or social injury, as a consequence of participation as a subject in any research, development, or related activity which departs from the application of those established and accepted methods necessary to meet his needs, or which increases the ordinary risks of daily life, including the recognized risks inherent in a chosen occupation or field or service.

a. Check all the risks to human subjects that apply to your project:
[X] Physical trauma or pain  [ ] Deception  [ ] Experimental diagnostic procedures
[ ] Side effects of medications  [X] Loss of privacy  [ ] Experimental treatment procedures
[ ] Contraction of disease  [ ] Worsening of illness  [ ]
Other – explain
[X] Psychological pain  [ ] Loss of legal rights

b. Check procedures that will be used to protect human participants from risks:
[ ] M.D. or other appropriately trained individuals in attendance
[ ] Sterile equipment
[ ] Precautions in use of stressor or emotional material (explain below)
[ ] When deception used, subjects fully informed as to nature of research at feasible time (explain below)
[ ] Procedures to minimize changes in self-concept (explain below)
[X] Confidentiality of subjects maintained via code numbers and protected files
[ ] Anonymity - no personally identifiable information collected
[ ] Others-- explain

c. Has provision been made to assure that Human Subjects will be indemnified for expenses incurred as a direct or indirect result of participating in this research?
[ ] Not applicable
[X] No - The following language should appear in the written consent form:

I understand that if I am injured in the course of this research procedure, I alone may be responsible for the costs of treating my injuries.

[ ] YES, explain:

d. Are there non-therapeutic tests that the research subjects may be required to pay for?
[ ] Not applicable
[X] No

[ ] Yes - explain below. The following language should appear in the written consent form: I understand that I may be responsible for the costs of procedures that are solely part of the research project.

4. Describe mechanism for safety monitoring: How will you detect if greater harm is accruing to your subjects than you anticipated? What will you do if such increased risk is detected?

Due to the level of physical activity involved, there is risk of muscle strains, soreness, and pain. A very remote possibility of cardiac arrest and death also exists. Subjects may also experience discomfort, muscle cramping or shortness of breath while testing. The investigators are National Athletic Trainers’ Association, Board of Certification certified Athletic Trainers, First Aid/CPR certified and trained to use the
portable automated external defibrillator (AED) on site. In the event of any physical injury from the research procedure, only immediate and essential medical treatment is available. First Aid/CPR and referral to a medical emergency room will be provided.

5. Briefly describe the benefits that will accrue to each human subject or to mankind in general, as a result of the individual's participation in this project, so that the committee can access the risk benefit/ratio.

Subjects may not receive direct/immediate benefits. However, subjects will receive information regarding jumping kinematics and kinetics while playing volleyball and learn about how it may affect upper and lower extremity injury incidence. Also, results of this study may assist athletic trainers, coaches and sport biomechanists in preventing volleyball related adolescent injuries.

6. Participation must be voluntary: the participants cannot waive legal Rights, and must be able to withdraw at any time without prejudice. Indicate how you will obtain informed consent:

[X] Subject (or Parent/Guardian) reads complete consent form & signs (‘written’ form)

[ ] Oral briefings by PI or project personnel, with simple consent form (‘oral’ form). Explain below the reason(s) why a written consent form is not used

[ ] Other- explain

7. Are there any other local IRB's reviewing this proposal? [X] No [ ] Yes, Location: 

I affirm:

(i) that the above and any attachments are a true and accurate statement of the proposed research and of any and all risks to human subjects.

Signed: ____________________________ Date: ______________

Principal Investigator

Signed: ____________________________ Date: ______________

Principal Investigator

Signed: ____________________________ Date: ______________

Principal Investigator

Signed: ____________________________ Date: ______________

Principal Investigator
C.2. Institutional Review Board Proposal

Jumping Biomechanics as Predictors of Injury in Adolescent Female Volleyball Athletes

Principal Investigators: Iris F. Kimura, PhD, ATC, PT; Rumi Bumbera, Rie Harada, ATC; Patricia M. McAndrew, MS; Christopher Stickley, MA, ATC

Department of Kinesiology and Leisure Science
1337 Lower Campus Road, University of Hawaii, Manoa, Honolulu, HI 96822

Introduction

Upper and lower extremity injuries are common among athletes who participate in jumping activities, particularly those with high training volume or skeletal immaturity. Currently, the research examining the relationship between injuries and jumping kinematics and kinetics are limited and primarily involves adult athletes who participate in jumping activities. The purpose of this study is to investigate the jumping kinematics and kinetics of adolescent female volleyball players and the relationship to upper and lower extremity injuries.

Methodology

Subjects
Subjects will be 100 highly trained and well-conditioned female volleyball players 10 to 18 years of age recruited from local volleyball “club” teams from the greater Honolulu community. Club teams and coaches will be contacted through public club web sites and contact information. Interested club teams will be asked to volunteer to participate in the study following a power point presentation to players, parents/legal guardians, and coaches (attachment #1).

Volunteers will complete health history and injury questionnaires (attachment #2 & 3), which will be reviewed by a medical doctor to screen for pathologies or physical contraindications to subject inclusion. Only those subjects free of injuries within the last six months will be allowed to volunteer to participate in the study. Signed informed consent and assent forms approved by the University of Hawaii Committee on Human Studies will be obtained prior to participation in the study (attachment #4 & 5).

Procedures
All data will be collected in one 30-minute session by the same female National Athletic Trainers’ Association (NATA), Board of Certification (BOC) certified athletic trainer in the University of Hawaii, Manoa, Kinesiology and Leisure Science Human Performance Laboratory. On the assigned test/data collection day, demographic and physical characteristics will be collected prior to biomechanical assessment (e.g. age, competition level, height, weight, vertical jump, Q-angle, and two skinfold (triceps and calf).
Reflective markers will be placed on the following anatomical landmarks: head, shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet by the aforementioned female NATA/BOC certified athletic trainer (attachment #6 & 7). All subjects will undergo a familiarization and instructional session prior to data collection. Subjects will be asked to perform three to five spike jumps and three to five block jumps (total jumps = 10). Kinematic data will be captured via Vicon Optical Capture System. Kinetic data will be collected through ground reaction forces measured via two Advanced Mechanical Technology Incorporated (AMTI) force plates.

**Research Design:**

Multiple 2 X 7 ANOVA's with repeated measures and interclass correlation analyses will be performed on the kinematic and kinetic data. Independent variables will include subject data grouped according to competition level (i.e. < 10, 11, 12, 13, 14, 15, 16, 17, 18), injury history and skill type (i.e. spike or block jump). Dependent variables will include lower extremity, upper extremity and trunk rotation, angles, velocities, and ground reaction forces. All data will be analyzed using Statistical Analysis Software (SAS) version 9.0 and statistical significance will be established at the < 0.05 probability level.
C.3. Informed consent form

INFORMED CONSENT FOR PARENT/LEGAL GUARDIAN
To Participate in a Research Study

Department of Kinesiology and Leisure Science, University of Hawaii at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606

I. INVESTIGATORS
Principle Investigators: Iris F. Kimura, PhD, ATC, PT; Rumi I. Bumbera, ATC; Rie Harada, ATC, CSCS; Christopher Stickley, MA, ATC; Kaori Tamura, MS, ATC

II. TITLE
Jumping Biomechanics as Predictors of Injury in Adolescent Female Volleyball Athletes

III. INTRODUCTION
The following information is being provided to help you and your child decide if she would like to participate in this study. This form may have words that you do not understand. If you have questions, please ask us. The purpose of this study is to determine how body movements (joint angles) and forces sustained during spike and block jumps affect injuries. Your child is being asked to participate in this study because she is a highly competitive well trained young female volleyball player.

IV. DESCRIPTION OF PROCEDURES
Your child will be asked to fill out health history and injury questionnaires prior to testing to determine if it is safe for your child to participate in this study. If there are no contraindications to study participation she will be asked to report to the University of Hawaii at Manoa, Kinesiology and Leisure Science Laboratory for testing. Your daughter’s height, weight, knee angle, 2 skinfolds (arm & leg), and vertical jump will be measured by a female National Athletic Trainers’ Association (NATA), Board of Certification (BOC) certified athletic trainer. Next, reflective markers will be applied by a female NATA, BOC certified athletic trainer to the following landmarks on both sides of her body (ex. Head, shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet). Your child will be asked to perform 3 to 5 spike and 3 to 5 block jumps, which will be recorded, however only the reflective markers will be visible (no human images). Instructions and practice time will be provided to your child until she is comfortable with the procedure. The entire procedure will take about 45 minutes.

V. RISKS
Due to the level of physical activity involved, there is a risk of injury. Your child may have muscle soreness and/or pain after testing. Your child may also have some discomfort, muscle cramping or shortness of breath while testing. There is also a very remote chance of cardiac arrest and death. The investigators are NATA, BOC certified athletic trainers and First Aid/CPR trained. In the event of any physical injury from the
research, only immediate and essential medical treatment is available. First Aid/CPR and
a referral to a medical emergency room will be provided.
Please note that if your child is pregnant, she is NOT eligible to participate in this study.
You should understand that if your child is injured in the course of this research process
that you alone will be responsible for the costs of treating her injuries.

VI. BENEFITS
You and your child may not receive direct or immediate benefits. However, your
child will obtain information regarding her physical characteristics and how her body
moves during volleyball spike and block jumping. Results of this study may assist
athletic trainers, coaches and sport biomechanists in preventing future injuries to
adolescent female athletes.

VII. CONFIDENTIALITY
Your child's research records will be confidential to the extent permitted by law.
Agencies with research oversight, such as The University of Hawaii Committee on
Human Studies, have the right to review research records.
Your child will be assigned a subject identification number (ID) that will be used instead
of her name and will be known only to your child and the study personnel. In addition,
all data and subject (identity) information will be kept under lock and key in the
Department of Kinesiology and Leisure Science at the University of Hawaii at Manoa.
These materials will be permanently disposed of in a period not longer than 5 years.
Your child will not be personally identified in any publication arising from this study.
Personal information about your child's test results will not be given to anyone without
you and your child's written permission.

VIII. CERTIFICATION
I certify that I have read and I understand the foregoing, that I have been given
satisfactory answers to my inquiries concerning the project procedures and other matters
and that I have been advised that I am free to withdraw my consent for my child's
participation and to discontinue her participation in the project or activity at any time
without prejudice.
I herewith give my consent for my child to participate in this project with the
understanding that such consent does not waive any of our legal rights, nor does it release
the principle investigators or institution or any employee or agent thereof from liability
for negligence.
If you have any questions related to this study, please contact any of the principle
investigators: Dr. Iris F. Kimura at 956-3797, Rumi Bumbera at 956-9455, Rie Harada at
956-8793, Christopher Stickley at 956-3798, or Kaori Tamura at 956-3801 at any time.

ID # ____________________________ ____________________________ ____________
Signature of Parent or Legal Guardian Date

If you cannot obtain satisfactory answers to your questions, or have complaints about your
treatment in this study, please contact: Committee on Human Subjects, University of Hawaii at Manoa,
2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.
INFORMED ASSENT
To Participate in a Research Study

Department of Kinesiology and Leisure Science, University of Hawaii at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606

I. INVESTIGATORS
Principle Investigators: Iris F. Kimura, PhD, ATC, PT; Rumi I. Bumbera, ATC; Rie Harada, ATC, CSCS; Christopher D. Stickley, MA, ATC; Kaori Tamura, MS, ATC

II. TITLE
Jumping Biomechanics as Predictors of Injury in Adolescent Female Volleyball Athletes

III. INTRODUCTION
The following information is being provided to help you decide if you would like to participate in this study. This form may have words that you do not understand. If you have questions, please do not hesitate to ask us. The purpose of this study is to see what body movements during spike and block jump landings affect injuries. You are being asked to participate in this study because you are a highly competitive, well trained young female volleyball player.

IV. DESCRIPTION OF PROCEDURES
You and your parents/legal guardians will be asked to fill out injury and health history questionnaires before the study begins to see if it is safe for you to be in this study. You will then report to the University of Hawaii, Manoa, Kinesiology and Leisure Science Human Performance Laboratory for testing (report to KLUM Gym). Your height, weight, knee angle, 2 skinfolds (arm & leg), and vertical jump will be measured. Next, reflective markers will be applied to your head and both sides of your body on your shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet). All measurements and reflective marker applications will be done by a female athletic trainer. You will be asked to perform 3 to 5 spike and 3 to 5 block jumps that will be recorded, however only the reflective markers will be visible on the computer. You will be given instructions and practice time until you are comfortable with the testing procedure. The entire procedure will take about 45 minutes.

V. RISKS
Due to the level of physical activity involved, there is a risk of injury. You may have muscle soreness and/or pain after testing. You may also have some discomfort, muscle cramping or shortness of breath while testing. There is also a very slim (small) chance of cardiac arrest and death. The investigators are National Athletic Trainers’ Association, Board of Certification certified athletic trainers and First Aid/CPR trained. In the event of any physical injury from the research, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided.
Please note that if you are pregnant, you are not eligible to participate in this study.

VI. BENEFITS
You may not receive direct/immediate benefits. However, you will learn how your body moves during spiking and blocking landings. Results of this study may help athletic trainers, coaches and sport biomechanists prevent future injuries to young female volleyball players.

VII. CONFIDENTIALITY
Your research records will be confidential (private) to the extent permitted by law. Agencies with research oversight, such as The University of Hawaii Committee on Human Studies, have the right to review (look at) research records.
A code number (ID #) will be used instead of your name and that code # will be known only to you and the researchers. All research data and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Leisure Science at the University of Hawaii at Manoa. These materials will be permanently destroyed in a period not longer than 5 years. You will not be personally identified in any publication resulting from this study. Personal information about your test results will not be given to anyone without your written permission.

VIII. CERTIFICATION
I certify that I have read and I understand the above information, that I have been given satisfactory answers to my questions concerning the study and that I am free to withdraw (quit) participation in the study at any time without prejudice or negative consequences.
I give my assent (agree) to be in this study with the understanding that my assent (agreeing) does not waive (eliminate) any of my legal rights, and it does not release the investigators or institution or any employee or agent (involved persons) thereof from liability for negligence.
I understand that a parent or legal guardian must also sign the consent form for me to participate in this study.
If you have any questions related to this study, please contact any of the principle investigators: Rumi Bumbera at 956-9455, Rie Harada at 956-8793, Christopher Stickley at 956-3798, Kaori Tamura at 956-3801, or Dr. Iris F. Kimura at 956-3797 at any time.

ID # ___________________________ Signature of Participant ____________ Date ________

If you cannot obtain satisfactory answers to your questions, nor have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawai‘i at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.
INFORMED CONSENT FOR ADULT PARTICIPANT
To Participate in a Research Study

Department of Kinesiology and Leisure Science, University of Hawaii at Manoa
1337 Lower Campus Road, PE/A Complex Rm. 231, Honolulu, HI 96822
Phone: 808-956-7606

I. INVESTIGATORS
Principal Investigators: Iris F. Kimura, PhD, ATC, PT; Rumi I. Bumbera; Rie Harada, ATC, CSCS; Christopher D. Stickley, MA, ATC; Patricia M. McAndrew, MS

II. TITLE
Jumping Biomechanics as Predictor of Injury in Adolescent Female Volleyball Athletes

III. INTRODUCTION
The following information is being provided to help you decide if you would like to participate in this study. This form may have words that you do not understand. If you have questions, please do not hesitate to ask us.

The purpose of this study is to see how the body moves while performing volleyball spike and block jumps and the relationship to arm and leg related injuries. You are being asked to participate in this study because you are a highly competitive, well trained young female volleyball player.

IV. DESCRIPTION OF PROCEDURES
You and your parents/legal guardians will be asked to fill out injury and health history questionnaires before the study begins. You will then report to the University of Hawaii, Manoa, Kinesiology and Leisure Science Human Performance Laboratory for testing. Your height, weight, knee angle, 2 skinfolds (arm & leg), and vertical jump will be measured. Next, reflective markers will be placed on several landmarks on your body (ex. Head, shoulders, elbows, wrists, hands, lower back, hips, thighs, knees, shins, ankles, and feet). Marker placement will be done by a female athletic trainer. You will be asked to perform 3 to 5 spike and 3 to 5 block jumps that will be filmed. Instructions and practice time will be provided until you are comfortable with the procedure. The entire procedure will take about 30 minutes.
V. RISKS
Due to the level of physical activity involved, there is a risk of injury. You may have muscle soreness and/or pain after testing. You may also have some discomfort, muscle cramping or shortness of breath while testing. There is also a very remote chance of cardiac arrest and death. The investigators are National Athletic Trainers’ Association, Board of Certification certified athletic trainers and First Aid/CPR trained. In the event of any physical injury from the research, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided. You should understand that if you are injured in the course of this research process that you and your will be responsible for the costs of treating your injuries.

Please note that if you are pregnant, you are not eligible to participate in this study. If you fail to inform us that you are pregnant, you will be responsible for any complications that may result from participation in this study.

VI. BENEFITS
You may not receive direct/immediate benefits. However, you will obtain information regarding your physical characteristics and how your body moves during volleyball spike and block jumping. Results of this study may assist athletic trainers, coaches and sport biomechanists in preventing future injuries in adolescent female athletes.

VII. CONFIDENTIALITY
Your research records will be confidential to the extent permitted by law. Agencies with research oversight, such as The University of Hawaii Committee on Human Studies, have the right to review research records.

An identification number will be used to identify you during the study, which will be known only to you and study personnel. In addition, all data and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Leisure Science at the University of Hawaii at Manoa. These materials will be permanently disposed of in a period not longer than 5 years. You will not be personally identified in any publication arising from this study. Personal information about your test results will not be given to anyone without your written permission.
VIII. CERTIFICATION

I certify that I have read and I understand the foregoing, that I have been given satisfactory answers to my inquiries concerning the project procedures and other matters and that I have been advised that I am free to withdraw my consent and to discontinue my participation in the project or activity at any time without prejudice.

I herewith give my assent to be in this project with the understanding that such assent does not waive any of my legal rights, nor does it release the principle investigator or institution or any employee or agent thereof from liability for negligence.

I understand that a parent or legal guardian also must sign the consent form for me to participate in this study.

If you have any questions related to this study, please contact any of the principle investigators: Dr. Iris F. Kimura at 956-3797/277-7586, Rumi Bumbera at 956-9455, Rie Harada at 956-8793, Christopher Stickley at 956-3798, or Kaori Tamura at 956-3798 at any time.

ID # ____________________________ _____________ Date

Signature of Participant

If you cannot obtain satisfactory answers to your questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawai‘i at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.
C.4. Questionnaire(s)

UNIVERSITY OF HAWAII AT MANOA
DEPARTMENT OF KINESIOLOGY AND LEISURE SCIENCE
INJURY QUESTIONNAIRE

Today's Date ___________ Subject ID# _________ Date of Birth ______

GENERAL QUESTIONS (circle the appropriate answer)

1. What position do you play?  OH/RH  MB  S  DS
2. Do you play any other sports?  NO  YES (please specify)
3. Do you play volleyball for your school?  NO  YES
4. Counting this year, how many years have you been on the Jammers or other CLUB team?
   Please circle one below.
   This is my (1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th) season with the
   Jammers or a CLUB team
5. Do you wear any braces, pads, and/or special training equipments when you play volleyball?
   NO
   YES (what is it? ____________ , you use it for which part of your body? ____________ )
6. IF YES, are you required to wear or use these devices?  NO  YES

INJURY QUESTIONS (circle the appropriate answer)

Have you ever hurt yourself while playing sports?
   a. IF NO, you are finished (PAU)!
   b. IF YES, answer questions 1 to 10 on the next page.
   c. IF YES, more than once ASK for another Injury Questionnaire Page
   2
   d. How many times? __________
INJURY QUESTIONNAIRE (page 2)

ID# ________________

ON THE PICTURE BELOW, circle where (location) you have or had the injury or pain.

Please answer 1 to 10 below that describes the injury location you circled.

1. What sport were you injured in? ________________________________

2. How old were you when you got the injury? ______

3. Approximate date of the injury (month/year) ________________________________

4. Write the name of injury (if you know what it is called) ________________________________

5. Have or did you miss practices or games because of this injury? NO YES

6. Did you see a doctor for this injury/pain? NO YES

7. Did the doctor: (circle all that apply)
   a. Give you or prescribe medicine(s)
   b. Give you exercise(s)
   c. Send you to an athletic trainer
   d. Send you to a physical therapist
   e. Recommended surgery
   f. Recommended you stay out of practices/games
   g. OTHER ________________________________

8. Did you have surgery for this injury? NO YES
   a. When was the surgery? ________________________________

9. Is this injury still painful? NO YES
<table>
<thead>
<tr>
<th></th>
<th>Does it hurt when you walk?</th>
<th>NO</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Does it hurt when you run?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>b</td>
<td>Does it hurt when you jump?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>c</td>
<td>Does it hurt at rest?</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>d</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Are you able to participate in volleyball now? NO YES
UNIVERSITY OF HAWAI'I AT MANOA
DEPARTMENT OF KINESIOLOGY AND LEISURE SCIENCE
MEDICAL HISTORY FORM

Today's date __________ Subject ID # __________ Date of Birth __ / __ / __ Age __

Home Address

________________________________________________________________________

________________________________________________________________________

Home Phone __________ Work Phone __________ Cell Phone __________

Emergency Contact Person

Parent/Guardian Information Relationship __________

Home Phone __________ Work Phone __________ Cell Phone __________

Hospital Preference

________________________________________________________________________

Doctor Preference __________ Phone __________

Please identify any condition that you have or had that might restrict your participation in physical activity. If you answer yes to any of the following, please describe the proper aid requirements on the next page.

A. General Conditions
1. Fainting Spells Yes No Past
2. Headaches Yes No Past
3. Convulsions/epilepsy Yes No Past Present
4. Asthma Yes No Past Present
5. High Blood Pressure Yes No Past Present
6. Kidney Problems Yes No Past Present
7. Intestinal Disorder Yes No Past Present
8. Hernia Yes No Past

B. Injuries
1. Toes Yes No Past Present
2. Foot Yes No Past Present
3. Ankles Yes No Past Present
4. Lower Legs Yes No Past Present
5. Knees Yes No Past Present
6. Thighs Yes No Past Present
7. Hips Yes No Past Present
8. Lower Back Yes No Past Present
9. Upper Back Yes No Past Present
10. Ribs Yes No Past Present
11. Abdomen Yes No Past Present
12. Chest Yes No Past Present
13. Neck Yes No Past Present
14. Fingers Yes No Past Present
15. Hands Yes No Past Present
### Present

1. **Diabetes**
   - Yes No Past Present

2. **Heart Disease/Disorder**
   - Yes No Past Present

3. **Dental Plate**
   - Yes No Past Present

4. **Poor Vision**
   - Yes No Past Present

5. **Poor Hearing**
   - Yes No Past Present

6. **Skin Disorder**
   - Yes No Past Present

7. **Allergies**
   - Yes No Past Present

   Specific __________________________

   Past Present

8. **Joint Dislocation or separations**
   - Yes No Past Present

   Specify __________________________

   Past Present

9. **Allergies**
   - Yes No Past Present

   Specific __________________________

   Past Present

10. **Other**
    - ________________________________

    Past Present

### PLEASE ANSWER THE FOLLOWING QUESTIONS TO THE BEST OF YOUR ABILITY

**Are you pregnant?**

No______ Yes______ *(If you are pregnant, you are not eligible to participate in this study)*

**Have you injured either shoulder in the last 6 months?**

No______ Yes______ *(if so, explain)*

**Have you injured either elbow in the last 6 months?**

No______ Yes______ *(if so, explain)*

**Have you injured either wrist in the last 6 months?**

No______ Yes______ *(if so, explain)*

**Have you injured either hand in the last 6 months?**

No______ Yes______ *(if so, explain)*
Do you have any predisposing cardiorespiratory or cardiovascular conditions that the researcher should be aware of?

No_____ Yes_____ (if so, explain)

Do you have any other medical problems that the researcher should be aware of?

No_____ Yes_____ (if so, explain)

Have you ever undergone any type of surgery?

No_____ Yes_____ (if so, explain)

If there are any questions feel free to contact us at the following number and address:

Rumi Bumbera, ATC; Rie Harada, ATC, CSCS; Christopher Stickley, MA, ATC; Kaori Tamura, MS, ATC; or Iris F. Kimura, PhD, ATC, PT

University of Hawaii, College of Education
Department of Kinesiology and Leisure Science
1337 Lower Campus Road, PE/A Complex, Room 231
Honolulu, Hawaii 96822
Phone: (808) 956-5162, (808) 956-7421, or (808) 956-3797
C.5. Data collection forms

Jump Study Data Collection Check List
University of Hawaii at Manoa
Kinesiology and Leisure Science

Participants I.D. #____________________ Name____________________

Age ______ Date __________

☐ Check in / documentation check
☐ Stationary bike / Stretch
☐ Landing trial standard instruction / practice
☐ Reflective marker placement / shoes coverage
☐ Landing trials

Block right 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Block left 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Spike 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

☐ Check out
C.6. Standard instructions

Hello, my name is _________. I am a certified athletic trainer and a graduate student here at the University of Hawaii Manoa. Thank you for your participation in our research. First aid care will be provided in case of emergency by certified athletic trainers here. If you have any questions, please ask at any time.

Today, we will be measuring your block and spike jumps. You are going to perform block and spike jumps until we have 3 successful measurements. You can practice until you feel comfortable with your tasks. First, you are going to perform block jumps. You will stand beside two force plates, and after a researcher gives you a cue to start, you will make a one step approach to your either right or left to jump onto the force plates. Then, you will perform a block jump, landing on both feet so that each foot is on each individual force plate. Your entire right foot needs to be on the right force plate, and your entire left foot needs to be on the left force plate. You will repeat this process to perform 3 block jumps to each side (right and left) for a total of 6 block jumps.

Next, you will perform spike jumps in which you will take an approach from your preferred side (right or left) to hit this suspended volleyball (placed here in this holder). Please do the following things for this process; first, use an approach of 3 or 4 steps. Second, make sure to hit this volleyball across the net. Lastly, land so that your entire foot is placed on this square board. You can practice as much as you want, and we will adjust the height of the holder. Please feel free to ask questions, and tell us what the best setting is for you to do this task.
Appendix D. Additional Results

D.1. Raw data tables

<table>
<thead>
<tr>
<th>Subject</th>
<th>Max GRF (LB) n/kg</th>
<th>Knee Angle at IC (LB)</th>
<th>Knee Angle at MVGRF (LB)</th>
<th>Max Knee Angle (LB)</th>
<th>Time To MVGRF loading Rate (LB) n/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
<td>Right</td>
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</tr>
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D.2. Statistical tables

1. **ANOVA Table for Maximal Vertical Ground Reaction Force (N/kg) During Left Direction Block Jump Landing**

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PIH*: Previous Injury History

2. **ANOVA Table for Maximal Vertical Ground Reaction Force (N/kg) During Right Direction Block Jump Landing**

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PIH*: Previous Injury History

3. **ANOVA Table for Knee Flexion Angle at Initial Contact with the Ground during Left Direction Block Jump Landing**

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PIH*: Previous Injury History
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</tr>
<tr>
<td>PIH*</td>
<td>1</td>
<td>52.18</td>
<td>1.67</td>
<td>0.2</td>
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<tr>
<td>Knee x PIH*</td>
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<td>1.17</td>
<td>0.28</td>
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<tr>
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<td>0.16</td>
</tr>
</tbody>
</table>

PIH*: Previous Injury History

5. ANOVA Table for Knee Flexion Angle at Maximal Vertical Ground Reaction Force during Left Direction Block Jump Landing

<table>
<thead>
<tr>
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<th>P-Value</th>
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<tbody>
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<td>Skill Level</td>
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<td>0.39</td>
<td>0.01</td>
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<td>0.01</td>
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</table>

PIH*: Previous Injury History

6. ANOVA Table for Knee Angle at Maximal Vertical Ground Reaction Force during Right Direction Block Jump Landing

<table>
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<td>PIH*</td>
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<td>0.33</td>
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<tr>
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<td>0.56</td>
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PIH*: Previous Injury History
7. ANOVA Table for Maximal Knee Flexion Angle during Left Direction Block Jump Landing

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<tr>
<td>PIH*</td>
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<td>0.05</td>
<td>0.82</td>
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PIH*: Previous Injury History

8. ANOVA Table for Maximal Knee Flexion Angle during Right Direction Block Jump Landing

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<td>0.91</td>
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</table>

PIH*: Previous Injury History

9. ANOVA Table for Time to Maximal Vertical Ground Reaction Force during Left Direction Block Jump Landing

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<th>P-Value</th>
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</thead>
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<td>0.00004</td>
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<tr>
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<td>Skill Level x PIH*</td>
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<td>0.55</td>
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PIH*: Previous Injury History
10. ANOVA Table for Time to Maximal Vertical Ground Reaction Force during Right Direction Block Jump Landing

<table>
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PIH*: Previous Injury History

11. ANOVA Table for Loading Rate during Left Direction Block Jump Landing

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</table>

PIH*: Previous Injury History

12. ANOVA Table for Loading Rate during Left Direction Block Jump Landing

<table>
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</tr>
</thead>
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<td>0.76</td>
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<td>0.76</td>
</tr>
</tbody>
</table>

PIH*: Previous Injury History
Appendix E. Bibliography