PREDICTIVE GAIT RELATED RISK FACTORS OF LOWER EXTREMITY OVERUSE INJURY AMONG CADETS IN THE ARMY RESERVE OFFICER TRAINING CORPS

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI‘I AT MĀNOA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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KINESIOLOGY AND REHABILITATION SCIENCE

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By
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To the class of 2013: There is an end to the crazy mess we call graduate school. Stay strong, especially in the biceps area. You’re all wicked smahht.

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PART I:
INTRODUCTION

The purpose of military basic training is to develop soldiers capable of acquiring and maintaining a high level of physical fitness. Soldiers must competently fulfill an appropriate endurance level that will allow their bodies to perform physically demanding duties [0, 1]. Reaching and sustaining this high physical fitness level can be hindered with the development of overuse injuries. Epidemiological surveys of infantry training have attributed 80-90% of limited duty days to training related injuries, and previous research has shown that on average 25% of male and 50% of female enlisted recruits encounter at least one injury during basic training [2, 3]. The majority of injuries sustained during basic training have been lower extremity overuse injuries [2]. These physical training-related injuries are the leading cause of service member hospitalization and outpatient visits, and account for over 25 million limited duty days annually within the Department of Defense [3-5].

Lower extremity overuse injury (LEOI) is a general diagnostic term used to describe any injury of the lower extremity ranging from the hip to the foot, caused by an internal or external factor developed over a long period of time [6]. Common LEOIs studied by researchers include: medial tibial stress syndrome (MTSS), tibial stress fracture, chronic exertional compartment syndrome, Achilles tendinitis, plantar fasciitis, anterior knee pain (AKP), and iliotibial band syndrome (ITBS). Past LEOI studies have focused on the lower leg; this study will focus primarily on the knee joint and specifically consider ITBS and AKP.

Iliotibial band syndrome (ITBS) is the most common injury causing pain to the lateral knee, and is labeled as the second leading cause of knee pain in runners [7]. This condition is defined as an overuse injury brought on by friction of the iliotibial band (ITB), typically causing diffuse pain to the lateral knee just above the lateral knee joint line and at the tendon insertion [7-9]. Despite its prevalence, few biomechanical studies have been published to better understand
the etiology of ITBS. Because the iliotibial band is attached to both the femur and the tibia, it is possible that abnormal hip and foot mechanics could predict the development of ITBS [7].

Anterior knee pain (AKP) has been a common complaint within military and recreational running populations [10-12]. Pathologies such as patellofemoral pain, patellar tendinitis, and chondromalacia patellae are classified as AKP [13]. Like ITBS, the exact etiology of AKP remains obscure. A general agreement exists among risk factors such as biomechanical disorders, anatomical malalignment, neuromuscular dysfunctions, muscle flexibility and strength [14].

Several researchers classify ITBS and AKP under the term LEOI and do not definitively link specific anatomical risk factors with each pathology [2, 11, 15]. Studies conducted on the United States military document a number of potentially modifiable external risk factors for LEOI including running volume and intensity, rapid increases in running distance or intensity, low levels of physical fitness, sedentary lifestyle, and the surface and shoes chosen for training [3, 16-20]. Limited flexibility and excessive flexibility of lower leg musculature have also been reported as a risk factor for LEOI in an active population [21]. Yet contradicting research has been published reporting no difference in range of motion between subjects with LEOI and subjects free of injury [22]. Other anatomical variables such as tibia varum, rearfoot varus, and leg length discrepancies have been categorized as lower extremity alignment abnormalities and have been reported to be associated with LEOI among runners [16, 23, 24], whereas other studies found these abnormalities not to be associated with increased risk of LEOI [25-27]. The etiology of these injuries seems to be multifactorial with contributions from both extrinsic and intrinsic risk factors. In existing studies, the finding of an association between a specific anatomical factor and LEOI is shown to be difficult and without proof of cause and effect [28].

Methods of data collection in available research concerning LEOI varies. Lower extremity overuse injuries (LEOIs) are sustained during training when a body is in motion, suggesting that data should be collected dynamically through such activities as running. Disagreement among the literature may be derived from various methods of data collection in
regards to patient position, as previous data have been collected during non-weight-bearing positions as well as during static stance [29]. Foot arch observed in a static setting will react differently than a running foot due to the impact of the running surface. Because impact during physical training is a leading factor of LEOI, limitations to current research exist with the use of static data collection [30]. Research focusing on dynamic variables in relation to LEOI has accounted for moment variables in the sagittal and frontal planes of the lower extremity such as hip adductor moments and hip flexion moments [31]. Available literature methodologies assessing biomechanical measures also typically use two-dimensional analysis while assessing a motion that is three-dimensional [32-35]. The need remains for three-dimensional kinematic data collection.

Distribution of LEOIs among the active civilian population has been similar to injuries found in the military population [11, 36-38] signifying common etiologies. Millions of Americans engage in recreational and competitive running on a regular basis, and also report injuries caused by overuse. Several studies draw a parallel between military populations and civilian endurance athletes [16, 39], as trainees are expected to report to physical training in optimal condition. Inadequate methodologies are present in research involving civilian populations as data collection has been accomplished by observation, using volunteer recreational runners and questionnaires [15, 40]. Army Reserve Officer Training Corps (ROTC) cadets are a homogenous group of subjects with a strict exercise regimen and remain an ideal population for study and development of preventive strategies, which could be translatable to a civilian population [15].

Prevention of LEOI is a major goal for military personnel. A clear understanding of the biomechanics of the lower extremity and how those biomechanical factors play a role in injury development must be understood in order to achieve this goal. Iliotibial band syndrome and AKP are reported as major LEOIs by researchers tracking injuries during military training and recreational running [2, 7, 11, 15, 19, 41, 42], it is of great importance that prevention strategies
target these specific pathologies. Attempts to decrease the amount of overuse injuries sustained by military personnel have been documented; however these attempts have not been entirely successful. The United States Army continues to recall injury prevention strategies in order to cut costs [3]. Studies fail to provide enough knowledge with regard to the existence of adequate research to support or disapprove prevention strategy implementation [4]. Injury has become a leading health threat to the armed forces; however, many of the LEOIs causing lost time are preventable [4, 43-46].

Based on the large incidence of LEOI in the military population and limited studies using three-dimensional motion capture analysis, this study was designed to assess the kinematics and kinetics of gait and to assess risk factors of LEOI associated with military basic training in Reserve Officer Training Corps (ROTC) cadets prior to the beginning of a physical training cycle, and to track injuries for one academic semester (approximately four months), in order to prospectively determine predictive factors of LEOIs among this population. The purpose of this study was to develop both retrospective and prospective kinetic and kinematic risk factor models for LEOI, specifically ITBS and AKP in members of a single ROTC unit.
METHODS

Research Design

A single cohort, cross-sectional analysis of running gait was performed. Prospective risk of developing lower extremity overuse injury (LEOI) was determined by assessing cadets’ running gait kinetically and kinematically prior to the beginning of a physical training cycle, and tracking cadets’ monthly injury development via questionnaires and care by a Board of Certification certified athletic trainer during physical training sessions. Prospective biomechanical injury risk factors were identified by comparing gait patterns of those cadets who did or did not develop LEOI (ITBS or AKP) over the course of one academic semester (approximately 4 months). Retrospective risk data were collected through an initial injury history questionnaire indicating past physical training habits and previous injury.

Subjects

Sixty-eight cadets (44 males, 24 females) ages 18-34, affiliated with the same Reserve Officer Training Corps (ROTC) physical fitness program volunteered for this study. All subjects completed institutional human subjects committee approved consent forms (Appendix A) prior to data collection. Inclusion criteria consisted of any member of the University of Hawai‘i - Mānoa Army ROTC detachment deemed fit for physical training. Subjects were included in the control group if they reported no current injury at the beginning of the study and reported no development of LEOI during the study. Injury tracking surveys were reviewed for report of ITBS and AKP and subjects who developed other overuse injuries (MTSS, Achilles tendinitis, plantar fasciitis) were excluded from kinematic and kinetic variable analysis. Descriptive data are presented in Table 1.
Table 1. Subject descriptive data (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Overall, n=68</th>
<th>ITBS*, n=5</th>
<th>AKP*, n=5</th>
<th>Control, n=26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>22.6 ± 3.9</td>
<td>26.4 ± 5.2</td>
<td>22.2 ± 2.9</td>
<td>22.3 ± 3.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.5 ± 10.0</td>
<td>173.0 ± 9.7</td>
<td>172.4 ± 11.6</td>
<td>172.4 ± 9.7</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>72.7 ± 13.0</td>
<td>76.1 ± 11.6</td>
<td>71.7 ± 12.6</td>
<td>73.7 ± 14.0</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.6 ± 3.2</td>
<td>25.3 ± 1.8</td>
<td>24.1 ± 3.0</td>
<td>24.7 ± 3.7</td>
</tr>
<tr>
<td>Body Comp. (%)**</td>
<td>13.5 ± 8.4</td>
<td>14.2 ± 7.5</td>
<td>14.5 ± 11.3</td>
<td>12.0 ± 7.8</td>
</tr>
</tbody>
</table>

*Prospective models
**Body density calculated using Jackson and Pollock sum of three sites equation [47]; body composition calculated using Siri body density equation [48]

Instrumentation and Protocol

An injury history form was used to obtain injury history, orthopedic surgery history, and training history. Anthropometric data consisting of height, weight, and skinfold thickness were collected. Height was collected using a stadiometer (Model 67032, Seca Telescopic Stadiometer, Country Technology, Inc., Gays Mills, WI, USA) and weight was obtained using a Befour PS6600-ST digital scale (Befour, Inc., Saukville, Wisconsin, USA). Skinfold measurements were obtained in duplicate with Lange calipers (Cambridge Scientific Industries, Inc., Cambridge, Maryland, USA) using the three site protocol as described by Jackson and Pollock [47]. During data collection, subjects wore Army Improved Physical Fitness Uniforms (IPFU) along with their non-standardized personal running shoes. Previous research has shown that an individual’s adaptive capability exceeds the variability introduced by shoe type [49, 50].

Kinematic data were collected using 27 retroreflective markers placed in accordance with a Vicon plug-in-gait lower leg and thorax marker set (Figure 1). A three-dimensional motion capture system (Vicon, Inc., Centennial, Colorado, USA) including six MX13 cameras situated along an 18-meter concrete runway and Vicon Nexus Software were used to capture, reduce, and analyze kinematic data. Kinetic data were recorded using two force plates (Advanced Mechanical Technology Incorporated, Boston, Massachusetts, USA) adjacent to one another and embedded flush with the runway. Kinematic data were collected at 240 Hz and time
synchronized with kinetic data collected at 480 Hz, and then smoothed using a Woltring filter (10 MSE) [51].

Prior to biomechanical analysis, participants were allowed a self-directed warm-up consisting of jogging and stretching in addition to familiarization running trials conducted on the test track to ensure a consistent running speed (4.0 m·s\(^{-1}\) ± 10%) [32, 49]. Speedtrap II (Brower Timing Systems, Draper, Utah, USA) infrared sensors were placed four meters apart on the middle third of the runway to collect running speed. A running trial was considered successful if the subject ran at the correct running speed and landed with the entire foot on the force plate without apparent targeting. Three successful running trials were recorded for each foot in order to assess running gait, and the mean of these trials was used for analysis. Previous authors have found high reliability when using the mean values of three trials to sufficiently evaluate gait data [52, 53].

Subjects were then assessed via a web-based questionnaire for the development of LEOIs once per month throughout one academic semester of ROTC physical training (approximately four months). Physical training (PT) sessions were conducted three times per week and consisted of the following [54]:

- Situational Training Exercise (STX) lanes involving land navigation
- Sprint workouts on a track
- Long runs over varying terrain
- Organized marches for five to seven miles with full combat gear
- Boat PT using a small fleet of Zodiac boats
- Combat Water Survival Training (CWST) consisting of treading water, freestyle swimming, equipment ditch, and 25-meter high-dive with equipment
- Army Physical Fitness Test (APFT) once per month consisting of sit-ups, push-ups and a timed two-mile run
Assessment of injury tracking questionnaire data and evaluation of injuries, in addition to documentation of medical records provided by the subjects’ personal physicians (Appendix D), were conducted by a Board of Certification (BOC) - certified athletic trainer. Injury definition was based on the Council of Europe stating an injury must have at least one of the following: 1) a reduction in the amount or level of sports activity, 2) a need for medical advice or treatment, or 3) adverse social or economic effects [52]. Lower extremity overuse injuries (LEOIs) were defined as injuries involving the upper leg, knee, lower leg, and foot, with an insidious onset associated with repetitive physical activities [15]. Subjects were instructed to not report any acute injury to the lower extremity on the questionnaire.

Figure 1. Marker Placement
Data Analysis

All statistical procedures were conducted using SPSS (version 20) with an alpha level of p<0.05. Subjects were divided into four injury groups: retrospective ITBS, prospective ITBS, retrospective AKP, and prospective AKP. The retrospective portion of analysis consisted of using multiple one-way analyses of variance (ANOVAs) to assess differences in each kinetic and kinematic gait variable with each retrospective injury group (ITBS and AKP) and with the control group. All moment kinetic variables are reported and discussed as external moments in this study. Prospectively, data were analyzed using the same statistical methods as above for both prospective groups (ITBS and AKP) and for the same control group. Based on the data collected from the injury history questionnaire, cadets’ retrospective fitness levels (determined by initial training volume) were compared with prospective development of LEOI (both ITBS and AKP) using separate one-way ANOVAs to examine initial fitness level and development of LEOI during the physical training cycle. Only one leg from each subject was used in the analysis; right legs were used for the control group and injured legs were used for the LEOI group, similar to the method used by Ferber et al. [7]. The right leg was used for analysis in subjects with bilateral LEOI.
RESULTS

Subjects reported a mean physical training (PT) volume of 5-10 hours per week (mean response 2.07 ± 0.94 – Appendix B) and an average of 5-10 miles per week (mean response 2.50 ± 1.09 - Appendix B) at the beginning of the PT semester. During the PT cycle, subjects reported no change in training duration and mileage (mean 2.46 ± 1.05 and mean 2.43 ± 1.06 responses, respectively – Appendix C). Subjects reported a mean of 3.62 ± 3.57 years in the military including ROTC and prior enlistment in any branch of service.

A total of 68 subjects (44 males, 24 females) completed the initial LEOI injury history questionnaire and biomechanical analysis. Twenty-six subjects (20 males, 6 females) were included in the control group and were injury free with no report of retrospective or prospective LEOIs. Cadets were further divided into injury groups based on prospective and retrospective development of ITBS or AKP. Four subjects (5.88%) reported retrospective ITBS and five subjects (7.35%) reported prospective ITBS with enough pain causing them to seek advice from a medical professional. Nine subjects (13.24%) reported retrospective AKP and five (7.35%) reported prospective development of AKP. A total of 20 subjects (29.41%) developed prospective LEOIs (including ITBS, AKP, and other). The LEOIs recorded were classified as: ITBS, AKP, MTSS, plantar fasciitis, and other. The “other” group consisted of snapping hip syndrome, arthritis, chronic bursitis, and sacroiliac joint pain. Five subjects (7.35%) failed to complete a total of four LEOI monthly surveys due to graduation, pursuing basic training, or dropping out of the ROTC. These subjects were excluded from the prospective injury analysis.

Body composition at the beginning of the study was not significantly different between controls and those who developed LEOI (Table 1). Significant kinematic variables were found at the ankle, knee, hip, pelvis, and thorax (p<0.05). Most significant variables between groups were located at the knee and hip joints. These prospective and retrospective variables are presented in Table 2 and Table 3.
Nine kinetic and kinematic variables were identified as statistically significant in contribution to prospective AKP and six retrospective kinematic and kinetic variables were found to be statistically significant (p<0.05). These variables are presented in Table 4 and Table 5.

Table 2. ANOVA results for significant biomechanical variables of the knee and hip in subjects who prospectively developed ITBS (Mean ± SD).

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>ITBS (n=5)</th>
<th>Control (n=26)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Knee Flexion moment – loading (Nm/kg)</td>
<td>3.24 ± 5.77</td>
<td>2.64 ± 0.34</td>
<td>5.03</td>
<td>.033</td>
</tr>
<tr>
<td>Max Knee Flexion Moment-push-off (Nm/kg)</td>
<td>2.64 ± 3.36</td>
<td>3.24 ± 0.58</td>
<td>5.03</td>
<td>.033</td>
</tr>
<tr>
<td>Max Knee Adduction Moment (Nm/kg)</td>
<td>2.60 ± 4.54</td>
<td>2.06 ± 0.51</td>
<td>4.81</td>
<td>.036</td>
</tr>
<tr>
<td>Max Knee Varus Velocity (%/s)</td>
<td>282.60 ± 123.44</td>
<td>186.12 ± 73.53</td>
<td>5.77</td>
<td>.023</td>
</tr>
<tr>
<td>Mean Knee Varus Velocity (%/s)</td>
<td>131.80 ± 43.60</td>
<td>63.92 ± 40.69</td>
<td>11.44</td>
<td>.002</td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time of Max Hip Extension Velocity (% stance)</td>
<td>77.20 ± 20.67</td>
<td>35.58 ± 30.55</td>
<td>8.42</td>
<td>.007</td>
</tr>
<tr>
<td>Time of Max Hip Adduction (% stance)</td>
<td>39.60 ± 7.06</td>
<td>31.54 ± 6.76</td>
<td>5.89</td>
<td>.022</td>
</tr>
<tr>
<td>Max Hip Internal rotation Moment (Nm/kg)</td>
<td>68.60 ± 31.99</td>
<td>44.96 ± 20.81</td>
<td>4.56</td>
<td>.041</td>
</tr>
<tr>
<td><strong>Ground Reaction Forces</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Vertical GRF (N/kg)</td>
<td>22.60 ± 2.61</td>
<td>25.42 ± 2.37</td>
<td>5.72</td>
<td>.024</td>
</tr>
</tbody>
</table>

Table 3. ANOVA results for significant biomechanical variables of the knee and hip in subjects who retrospectively developed ITBS (Mean ± SD).

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>ITBS (n=4)</th>
<th>Control (n=26)</th>
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<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Max Knee Flexion Velocity (% stance)</td>
<td>20.75 ± 14.89</td>
<td>14.58 ± 1.94</td>
<td>4.87</td>
<td>.036</td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Max Hip Flexion Moment (% stance)</td>
<td>11.75 ± 7.80</td>
<td>18.58 ± 5.72</td>
<td>4.52</td>
<td>.042</td>
</tr>
<tr>
<td>Time Max Hip Extension Moment (% stance)</td>
<td>49.50 ± 9.98</td>
<td>60.19 ± 9.32</td>
<td>4.50</td>
<td>.043</td>
</tr>
<tr>
<td><strong>Ground Reaction Forces</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Max Vertical GRF (% stance)</td>
<td>44.00 ± 7.44</td>
<td>49.84 ± 4.11</td>
<td>5.65</td>
<td>.025</td>
</tr>
</tbody>
</table>
Table 4. ANOVA results for significant biomechanical variables of the knee and hip in subjects who prospectively developed AKP (Mean ± SD).

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>AKP (n=5)</th>
<th>Control (n=26)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time of max knee flex velocity (% stance)</td>
<td>22.40 ± 20.01</td>
<td>14.58 ± 1.94</td>
<td>4.41</td>
<td>.045</td>
</tr>
<tr>
<td>Mean knee flex velocity (°/s)</td>
<td>309.80 ± 38.78</td>
<td>371.35 ± 64.20</td>
<td>4.20</td>
<td>.050</td>
</tr>
<tr>
<td>Max knee varus velocity (°/s)</td>
<td>297.40 ± 175.01</td>
<td>186.12 ± 73.53</td>
<td>5.86</td>
<td>.022</td>
</tr>
<tr>
<td>Knee IR excursion (°)</td>
<td>21.80 ± 5.63</td>
<td>17.54 ± 3.86</td>
<td>4.26</td>
<td>.048</td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max hip ER velocity (°/s)</td>
<td>741.40 ± 673.09</td>
<td>281.54 ± 125.86</td>
<td>11.65</td>
<td>.002</td>
</tr>
<tr>
<td>Max hip ext moment (Nm/kg)</td>
<td>5.08 ± 4.51</td>
<td>3.04 ± 4.93</td>
<td>5.78</td>
<td>.023</td>
</tr>
<tr>
<td>Max hip flex moment (Nm/Kg)</td>
<td>4.57 ± 5.39</td>
<td>1.78 ± 7.21</td>
<td>7.30</td>
<td>.011</td>
</tr>
<tr>
<td>Max hip add moment (Nm/kg)</td>
<td>2.93 ± 1.58</td>
<td>1.76 ± 3.91</td>
<td>12.06</td>
<td>.002</td>
</tr>
</tbody>
</table>

Ground Reaction Forces

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>AKP (n=5)</th>
<th>Control (n=26)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Vertical GRF (N/kg)</td>
<td>22.80 ± 1.79</td>
<td>25.42 ± 2.37</td>
<td>5.39</td>
<td>.027</td>
</tr>
</tbody>
</table>

Table 5. ANOVA results for significant biomechanical variables of the knee and hip in subjects who retrospectively developed AKP (Mean ± SD).

<table>
<thead>
<tr>
<th>Biomechanical Variable</th>
<th>AKP (n=9)</th>
<th>Control (n=26)</th>
<th>F</th>
<th>p</th>
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<tbody>
<tr>
<td><strong>Knee</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee IR excursion (°)</td>
<td>23.43 ± 8.35</td>
<td>17.52 ± 3.93</td>
<td>8.19</td>
<td>.007</td>
</tr>
<tr>
<td>Max IR ER knee velocity (°/s)</td>
<td>564.18 ± 164.90</td>
<td>424.56 ± 139.46</td>
<td>6.11</td>
<td>.019</td>
</tr>
<tr>
<td>Max knee flexion moment-loading (Nm/kg)</td>
<td>2668.11 ± 677.83</td>
<td>3242.63 ± 577.39</td>
<td>6.06</td>
<td>.019</td>
</tr>
<tr>
<td>Max knee flexion moment-pushoff (Nm/kg)</td>
<td>2668.11 ± 677.83</td>
<td>3242.64 ± 577.39</td>
<td>6.06</td>
<td>.019</td>
</tr>
<tr>
<td>Time max knee IR moment (Nm/kg)</td>
<td>50.94 ± 12.94</td>
<td>60.87 ± 9.14</td>
<td>6.34</td>
<td>.017</td>
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</table>

**Hip**

<table>
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<tr>
<th>Biomechanical Variable</th>
<th>AKP (n=9)</th>
<th>Control (n=26)</th>
<th>F</th>
<th>p</th>
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<td>Hip IR ER excursion to max ER (°)</td>
<td>18.42 ± 5.62</td>
<td>13.04 ± 5.75</td>
<td>5.92</td>
<td>.021</td>
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DISCUSSION

The majority of LEOIs reported in this Army ROTC cadet population were ITBS and AKP (62.16%). The term anterior knee pain (AKP) encompassed chondromalacia patellae, patellar tendinitis, and patellofemoral pain. Significant variables related to ITBS included hip internal rotation moment and knee adduction moment. Maximal knee varus velocity was a significant variable in both ITBS and AKP injury groups. Cadets with AKP also experienced significantly greater flexion and adduction moments at the hip. Cadets in this population exhibited degrees of knee flexion at heel strike and through loading response consistent with the ITBS impingement zone as reported in the literature [9, 55-58]. Understanding the etiology of LEOI in relation to these variables is crucial in the development of both rehabilitation protocols and prevention strategies. Results of this study indicate both strength and gait retraining may be beneficial as part of prevention and care in order to minimize LEOI and duty days lost in a military population.

The purpose of the iliotibial band is to serve as a stabilizer to the lateral hip and knee and to resist hip adduction and knee internal rotation [7, 58]. Growing awareness of the concept of proximal factors influencing knee joint kinematics suggests great biomechanical influence of abnormal hip mechanics on knee joint injuries, namely ITBS and AKP [31, 59]. Frontal and sagittal plane motions of the knee joint have been described in this manner by Powers et al. [31]. The frontal plane varus motion is primarily resisted by the ITB and other lateral soft tissue structures of the knee such as the lateral collateral ligament. Hip abductor weakness is a proximal link in the development of knee pain, namely ITBS, due to a compensatory shift in the center of mass during single limb support of running gait [31]. Tension of the gluteus maximus and the tensor fascia lata muscles have been linked to ITB strain due to their insertions on the ITB [56]. Although activity of the hip abductors was not quantified in this study, it is logical to assume that hip abductor weakness plays a role in the development of injury to the ITB during running gait [60]. The contralateral drop of the pelvis away from the stance limb increases the
moment arm from knee joint center to the resultant GRF [31]. This action increases the tensile strain of the ITB on the knee joint, and a combined increase in knee adduction moves the insertion further from the origin causing strain and stretch to the ITB [61]. Max knee adduction moment was significantly greater in subjects who developed ITBS in this study indicating excessive varus force at the knee, which must be resisted by the ITB.

This abrupt onset of varus alignment during early stance has also been defined as varus thrust [62]. Knees with varus thrust have been found to have a greater knee adduction moment [63]. Cadets who developed prospective ITBS had significantly greater maximum knee varus velocity compared to controls (Table 2). This finding supports Chang et al. [62] who reported knees with varus thrust had a higher peak knee varus angular velocity than knees without varus thrust. This suggests that the development of ITBS may be related to the velocity at which the knee moves into varus more so than the magnitude of its angular displacement. Hamill et al. [58] similarly suggested that ITBS may be more related to strain rate as opposed to magnitude of strain. They calculated strain rate as the change in strain or tension of the ITB during touch down to maximum knee flexion of running gait, also accounting for the velocity at which the strain occurred.

Previous research has reported sagittal kinematics of individuals afflicted with ITBS including decreased knee flexion during early stance. Loading following heel strike with the knee positioned between 20-30° of flexion places the stance limb in the “zone of impingement” [9, 31, 56, 58]. The location of this zone has been described as the area in which the ITB passes or lies directly over the lateral femoral condyle [9]. The repetitive contractions of the tensor fascia lata and gluteus maximus cause friction of the ITB at this point [55] and has been reported as a risk factor for ITBS [8, 55, 58, 64]. Cadets who developed ITBS in this study displayed 21.2° of knee flexion at heel strike in the affected leg, mirroring the results recorded by Orchard et al. [9]. Though published normative values of knee flexion at heel strike are greater than 30° and remain above this zone until just prior to push-off [65], the findings of this study are in
accordance with Miller et al. [56] who proposed that impact forces during loading increase immediate stress to the ITB playing an important role in injury development. Their subjects demonstrated loading with the knee positioned in the zone of impingement while nearing exhaustion whereas a control group avoided the zone of impingement completely during loading (the first 10% of stance during running gait) [65]. Control subjects in our study varied in the degree of knee flexion at heel strike, but quickly surpassed the impingement zone and mirrored normative patterns throughout the remainder of stance (Figure 3). Repetitive loading in an extended position has been associated more with distance running than sprinting, contributing to higher incidence of ITBS among distance runners [55, 65]. Results from the present study suggest that ITBS etiology may relate to loading in the zone of impingement as well as the amount of time spent in the 20-30° range of knee flexion.

Figure 3. Graph of Sagittal Plane Knee Joint Kinematics

Maximum GRF was significantly lower in both prospective injury groups (ITBS and AKP) compared to controls. Results are in agreement with previous studies although the reason of this association is unclear and may be related to the degree of knee flexion at heel strike [19, 66, 67]. The association between a greater knee flexion angle during loading in the injured groups (ITBS
and AKP) may indicate greater method of absorption of GRF compared to the control group. Future research should account for stiffness of the knee joint during loading response of subjects diagnosed with LEOI.

Both AKP and ITBS are common injuries in running and military populations [8, 55, 65, 68, 69]. Some factors associated with ITBS have also shown links to AKP. Abnormal patellar tracking has been examined statically and treated by restricting patellar motion with bracing and taping devices [31]. More recently, Powers et al. [31] has described the abnormal tracking of the patella in relation to abnormal hip motions through articulations with the distal femur. Because kinetic variables such as moments about the hip and knee are important to consider during dynamic motions, it is most appropriate to study and examine patellar tracking dynamically. In non-weight bearing positions, the patella has been shown to track laterally on a fixed femur. Conversely, during weight bearing, the patella becomes fixed due to a contraction of the quadriceps femoris muscle and internal rotation of the femur occurs on the fixed patella [31]. Weakness and instability of the hip abductors allows the femur to internally rotate during running (in AKP) and limits the ability to counteract external adduction moment increasing risk for ITBS.

Results from this study also suggest knee internal rotation excursion may be a risk factor for AKP development. Ferber et al. [70] discussed the potential for excessive internal rotation of the femur resulting in malalignment of the patella leading to AKP. They suggested that increased hip internal rotation during running in combination with greater static knee abduction might result in a greater dynamic varus thrust at the knee placing a runner at risk for AKP. Although static measurements were not collected on cadets in the present study, knee internal rotation excursion was significantly higher in those who developed AKP, consistent with studies measuring static anatomical characteristics and prospective development of AKP [70].

An important variable in relation to AKP and ITBS is leg stiffness. The entire lower extremity works as a single spring to absorb and accommodate the impact of the ground during
running. Leg stiffness is the end result when the mechanics of the hip, knee, and ankle comprehensively work together to adjust joint angles and moments to maintain smooth gait [71]. Williams et al. [72] reported subjects with increased leg stiffness were more likely to develop bony injuries such as stress fractures of the lower limb, and subjects with decreased leg stiffness were more likely to develop soft tissue injuries and specifically injuries to the knee. Subjects who developed AKP in our study had significantly greater hip flexion moments accompanied by lower knee and ankle moments, potentially indicating a decreased leg stiffness. The results of this study suggest that the AKP group had decreased leg stiffness and is in agreement with Williams et al. that decreased leg stiffness is a risk factor for AKP.

Only 10% of significant variables were common between retrospective and prospective injury groups. This may be due to the multifactorial origins of LEOI in which injury development is dependent upon the combination of static joint structures, running mechanics, and training dosage [73]. Prospective studies may provide information concerning injury cause by establishing the temporal sequence between biomechanical variables and the onset of symptoms. However, retrospective models are limited to identifying associations between injury and biomechanical abnormalities related to LEOI since it is impossible to determine whether differences in gait parameters are the cause or the effect of the previous injury [7, 31, 58].

The Army Physical Readiness Training (APRT) manual applies to all soldiers, functional branches, units, and operating agencies maintaining consistent PT throughout the Army [74]. Recent amendments to the APRT manual have been implemented to reduce overuse injury during training. Studies correlating training loads with increased injury in the early weeks of basic training have been published [41, 75]. Amendments to decrease injury have consisted of warm-up and cool-down protocols along with progressive PT phases (initial conditioning phase, toughening phase, and sustaining phase). Cadets did not report significant increases in training loads, but intensity increased throughout the training cycle consistent with the APRT guidelines.

Several studies list poor fitness level associations with increased injury in the military
population at basic training [15, 36, 37, 44]. However, in the present study, differences in body composition were not related to development of LEOI. Baseline measurements of body composition categorized participants as physically fit suggesting cadets were adequately prepared for entrance into the Army ROTC program. Although body composition was not reassessed at the end of the training cycle, injury development seems to be more associated with running biomechanics rather than initial fitness level.

Limitations to this study included the potential variability in training load from additional physical activity by cadets outside of structured ROTC PT sessions. However, the sample used in the present study likely allowed for greater control of training load than previous studies of LEOI using nonmilitary populations. Additionally, the military population tends to underreport injuries due to the pressure placed on cadets to remain in the ROTC program or on active duty status. Pain and functional injury limitations were generally underrepresented on the injury survey compared to that seen during physical examination by athletic trainers. A comparison of LEOI physical examinations with injury survey reporting seemed to underscore cadet pain levels and injury severity due to the motivation to remain off of an injury profile status. Variables previously reported as potential risk factors of LEOI that were not addressed in this study included pre-training program status, previous athletic participation, smoking status, alcohol consumption, and menstrual disturbances [49, 76]. Future studies should examine these variables to provide a comprehensive understanding of LEOI prevention strategies.

By identifying gait parameters associated with the development of ITBS and AKP, the results of this study may aid clinicians in selecting the most appropriate targets for intervention. However, the rehabilitation approach should not solely target strength deficits, as these discrepancies may be associated with altered biomechanics. Previous studies have demonstrated that an improvement in hip abductor strength may produce no change in ITBS and AKP symptoms due to habitual running gait patterns [31, 77, 78]. Therefore, rehabilitation protocols should include proper mechanical gait retraining in addition to a strengthening program when
treating individuals afflicted with ITBS or AKP. Previous research has included gait-retraining as a method for rehabilitation of individuals with ITBS and AKP [56, 79] reporting successful results [80].

In conclusion, the combination of altered frontal and sagittal plane motion of the hip and knee plays a role in the development of ITBS and AKP during military training. Though hip strength was not measured directly, the increased hip internal rotation moment, hip adduction, and knee adduction moment among those who developed ITBS or AKP provide evidence for decreased hip abductor strength compared to the control group. Maximal knee varus velocity is suggested to play a role in ITBS friction due to the velocity at which the knee joint is driven through the zone of impingement. Additionally, initial loading in the zone of impingement and the amount of time spent in this range may contribute to ITBS development. The purpose of this study was to identify risk factors of LEOI, specifically ITBS and AKP in order to improve physical training strategies and to reduce injury rate in a military population. Results of this study may contribute to the development of preventative strategies of LEOI and may challenge current rehabilitation techniques. Rehabilitation aimed solely at correcting strength deficiencies may not effectively improve LEOI symptoms and gait retraining exercises may be necessary to improve long-term outcomes.
Several authors concluded that lower extremity injury prevention among military personnel is an area of concern [2, 4, 11, 32, 81, 82]. Recognizing the necessary steps to prevent injury is vital in reducing duty time lost due to injury. Research investigating biomechanical factors correlated to the risks of developing LEOI is sparse within military populations [11]. Examination of risk factors consists of studying the etiology and the epidemiology of overuse injuries, reviewing intrinsic and extrinsic risk factors associated with LEOI, and understanding kinetic and kinematic data. Risk factors of LEOIs can be classified into two categories: intrinsic and extrinsic. The best evaluation of these risk factors would consist of kinematic and kinetic variables as well as injury tracking.

**Etiology and Epidemiology**

Etiology is the study of the cause of a relationship. The etiology of overuse injuries has been previously classified into three categories: anatomical structural deformities, training errors, and interactions between shoes and the running surface [83]. The cause of overuse injuries varies greatly among previous literature and is a necessary aspect in the development of injury prevention programs. Etiology of LEOIs has been known to be multifactorial in nature increasing the difficulty of identifying and tracking the epidemiology of overuse injury would allow one to predict risk factors of those injuries.

Messier et al. [8] agreed with previous literature and suggested that three general factors play a role in the development of overuse syndromes: improper training techniques, poor equipment, and biomechanical/anthropometric abnormalities. This study focused on athletes with iliotibial (IT) band friction syndrome, shin splints, and plantar fasciitis. Iliotibial band friction syndrome was defined as an inflammation of the IT band as it passed over the lateral femoral condyle and/or inflammation at Gerdy’s tubercle. Trends of slightly higher arches were
found in subjects with this disorder. Shin splints were defined as pain along the medial distal two-thirds of the tibia. Both the shin splint group and the IT band group displayed less range of motion in ankle dorsiflexion when compared to the control group. Additionally, training data obtained revealed that 20% more of the injured subjects, including all three injury groups, trained on hills and 20% more of the IT band friction syndrome subjects ran on crowned roads. The percentage of total training time for each subject was not recorded.

Almeida et al. [15] followed male recruits through twelve-weeks of boot camp training and tracked injury rates and incidence of boot camp graduates. Peaks in injury incidence occurred during the weeks with the greatest total volumes of vigorous physical training, being consistent with other studies in civilian distance runners. Physical training consisted of a 12-week standard military instruction divided into three phases: 1) drills and marching and general physical conditioning, 2) weapons firing and field combat skills, 3) water survival training, military marching, and general physical conditioning. This study concluded that volume of physical training may be an etiologic factor for exercise-related injuries, yet no findings from the study suggested that type of training and abrupt increases in training contribute to injury risk.

Linenger et al. [84] described the epidemiology of soft tissue and musculoskeletal injuries of the foot among US Marine recruits during basic training [84]. All subjects were male and consisted of previously screened, healthy, and predominantly Caucasian (age 17 to 28) who visited the podiatry clinic with foot injuries during a three month period of training. Recruits were tracked using a computer system and incidence rates were obtained weekly. Recruits initially visited a corpsman for screening of injury and were referred to the podiatry clinic if deemed necessary. Injuries were tracked resulting in 705 new podiatric injuries, translating into an injury incidence of nine foot injuries for every 100 Marine recruits per month of training. The most common injuries tracked consisted of stress fracture of the foot, ankle sprain, and Achilles tendinitis. Authors concluded that the high foot injury is related to the conditions recruits are exposed to during training, consisting of abrupt increases in running mileage, running on soft
sand, running in boots, and short recovery periods. Identifying risk factors associated with LEOI is needed to reduce attrition among recruits in basic training.

Overuse injuries sustained by military personnel are clearly a concern. Studies have attempted to document etiologic factors of LEOIs; however, these studies have failed to utilize a control group or are strictly based on expert opinion. Previous studies have reported the proportion of injuries by type and without reporting incidence rates. Epidemiological information on the incidence rates is needed as well as the cause of these injuries. There is a need for research establishing a relationship between specific biomechanical, anthropometric, and training variables causing LEOIs.

**Intrinsic Risk Factors**

Structural deformities of the lower extremity result in abnormal foot mechanics and ultimately lead to alterations in the amount of motion, speed of motion, and timing of the lower extremity during physical activity. Adequate biomechanical analysis of these deformities is necessary in determining intrinsic risk factors of LEOIs, or an internal factor that predisposes someone to overuse injury. Within this literature review, exercise related lower leg pain (ERLLP) is used interchangeably with lower extremity overuse injury (LEOI).

Willems et al. [52] examined dynamic biomechanical intrinsic risk factors of exercise related lower leg pain (ERLLP). A group of 400 college physical education students (241 male, 159 female) followed the same sports program for 26 weeks over three academic years and were then divided into an injury group and a control group. Forty-six subjects developed ERLLP. Because 29 of the 46 subjects experienced ERLLP bilaterally, 75 symptomatic lower legs were accounted for. Prior to the sports program, all subjects were tested barefoot for 3D kinematics and plantar pressure measurements in the stance phase of running (3.3 m/s), while goniometric measurements were taken during static lower leg stance. An AMTI-force platform (2 m) was imbedded in a wooden running track (16.5 m) with infrared cameras (collecting at 240 Hz)
monitoring body segment motion by tracking reflective markers placed according to McCla and Manal [85]. Data were collected during three trials with each leg. For each trial, eight anatomical pressure areas (medial calcaneus, lateral calcaneus, the four metatarsal heads, and the hallux) were identified and measured for peak pressure, impulses, and instants on which the regions begin and end contact relative to total foot contact time. The authors recognized five distinct instants of foot contact: 1) first foot contact (FFC), 2) first metatarsal contact (FMC), 3) forefoot flat (FFF), 4) heel-off (HO), and 5) last foot contact. From here, the five categories of measurements were divided into four phases: initial contact phase (ICP), forefoot contact phase (FFCF), foot flat phase (FFP), and forefoot push-off phase (FFPOP).

Similarly to Lieberman et al. (2010), the authors studied plantar pressure variables as well as specific joint angles of the running foot. However, in this article Willems et al. (2007) chose to approach the study prospectively and in a more functional manner combining plantar pressure variables with kinematic data and alignment of the lower leg during the stance phase of running versus the initial contact phase.

The authors concluded that the following altered biomechanics were predisposing risk factors of ERLLP: a significantly central heel strike at initial contact, significantly more pronation accompanied by a higher loading underneath the medial forefoot during the forefoot contact and flat foot phases, and an increased reinversion velocity with an increased lateral roll-off, and increased extension at the first MP joint. The results of this study suggest that altered biomechanics predispose ERLLP and should be considered in prevention and rehabilitation.

Milgrom et al. [81] hypothesized that during fatiguing exercises, bone strains and strain rates reach levels well above those measured previously by researchers in vivo in the non-fatigued state. In order to test this hypothesis, the authors measured in vivo tibial strains and strain rates, maximum gastrocnemius isokinetic torque, and ground reaction forces in four adult male members of the research staff throughout fatiguing exercise protocols. Two fatiguing levels of exercise were performed in this study. Strain-gauged staples (SGS’s) were inserted
surgically in the medial aspect of the mid-tibial diaphysis in order to measure tibial strains and strain rates. Muscle fatigue, defined as the inability of the muscle to do work, was assessed by measuring the right gastrocnemius torque on a Biodex isokinetic machine. Ground reaction forces were measured by having subjects walk over force plates imbedded in a 12 km walkway. Authors found statistically significant changes in all strains and strain rates. Post-march tension strains increased 29%, tension strain rates by 11%, and compression strain rates by 17%. Fatiguing musculature was determined by the gastrocnemius and considered a risk factor of ERLLP in a one-time approach, whereas in the Willems et al.’s [52] study, risk factors were determined by plantar pressure measurements and lower leg alignment characteristics over time. Additionally, this study supplied Nike Air Max shoes for the subjects, whereas in previous studies participants were observed primarily barefoot. Attempting to mimic a military situation, the authors chose a desert march, however more suitable data would be collected if the participants were a younger population, if they wore military boots, and carried combat gear during the experiment.

Jones et al. [37] observed 391 Army trainees over eight weeks of basic training. Participants responded to questionnaires on physical activity in the past six months, were measured for height, weight, and body fat percentage, and were given an initial Army physical training test. From the questionnaires the number of kilocalories expended per week in each participant for the past six months was calculated and were categorized on a four-point scale (1=inactive, 4=very active). The Army physical fitness test consisted of a one-mile run and the number of sit-ups and push-ups performed in a two-minute time period and was used to assess baseline physical fitness level. Injury data were collected by reviewing complete medical records of each participant, in which specific data were considered: date of visit, diagnosis, affected side and body part injured, patient disposition, and the days of limited duty resulting from the injury. The authors concluded that trainees with slower mile-run times (male and female), trainees with histories of inactivity (male and female), trainee males with a higher body
mass index (four-skinfold sites, Durnin & Womersley, [86], and females with a shorter height measurement were at greater risk of training injuries.

Reinking et al. [87] examined the occurrence of exercise related leg pain (ERLP) in collegiate cross-country athletes and compared biomechanical factors in these runners with and without ERLP. A total of 63 athletes participated in the study over the course of one season. Methods consisted of self-reporting ERLP history, the collection of active ankle dorsiflexion data with the knee extended and flexed, navicular drop, and first metatarsal length. Authors reported that 52% of the athletes experienced ERLP consisting of medial leg pain and bilateral symptoms. No differences in structural measures were found between subjects with and without ERLP. Conclusions indicated athletes with ERLP did not have a greater foot pronation measured by navicular drop, nor was there a relationship between limited ankle ROM compared to those without ERLP [87].

The risk of a musculoskeletal injury is an unfavorable consequence in physical training. Within the literature, intrinsic factors in the predisposition to LEOI are found to vary greatly. More evidence of the multifactorial nature of the etiology of LEOIs is needed to fully understand the cause and effect relationship between intrinsic risk factors and injury development.

Extrinsic Risk Factors

Extrinsic risk factors of LEOI are factors not part of the essential nature of an individual. They consist of factors outside of the biomechanical make-up of the human body including but not limited to physical fitness level, shoe type, carrying loads, and physical training routines.

Attwells et al. [88] performed a biomechanical analysis of 20 male soldiers during four different loading conditions: control (rifle, boots, helmet weighing 8 kg), webbing (8 kg), backpack (24 kg), and a light antitank weapon (10 kg). Five trials of a self-paced walk were conducted in each loading condition while a motion analysis system (CODA mpx30) detected 17 active markers were placed on the right side of the subjects’ bodies. Spatiotemporal parameters
(walking speed, stride length & frequency), angular data of the lower limb, and the upper body were analyzed. Conditions were completed in the same order for each participant and mean data from the five trials was calculated. The lower limb, truck, head, and backpack were identified during the stance phase with the markers. To ensure a natural gait pattern, a five meter distance was provided at each end of the testing area.

The authors concluded that the main biomechanical effects of military load carrying included increased range of motion of the knee joint, an increased forward lean, and an increased movement created by the head acting with the trunk to counterbalance the load. These biomechanical alterations with increased load cause increased muscular forces to act on the body amplifying injury potential. The duration of the load carriage was brief in this study making the experiment unlike an actual military situation.

Birrell et al. [89] conducted research to determine the effects that rifle carriage has on ground reaction forces (GRF’s) and to establish factors contributing to the effects. Fifteen males (28.9 yrs ± 5.8) participated in this study. Each participant was either in military service or ex-military, a fit rear-foot striker, and had extensive load carrying experience. Kinetic data were collected using a force plate (Kistler) embedded in an 8.4m walkway in conjunction with a motion analysis system (Coda Mpx30). The force plate was situated halfway along the walkway to allow for adequate distance ensuring a natural gait pattern. Walking speed was measured using infrared photoelectric cells.

The loaded condition depicted a replica of an SA80 assault rifle used by British troops. An actual rifle was not used. A fixed arm position was also implemented with the use of a lightweight wooden rifle mock-up. This restricted the arm swing appropriately without causing additional load. Findings suggested that rifle carriage does not affect gait patterns, however, increases in GRF were found. The restriction in natural arm swing from the rifle carriage was found to be a factor associated with the increases in GRF and ROM.
Jones et al. [36] documented the impact of past physical activity, current physical fitness, and Army physical training along with the incidence of injuries among new recruits. This study included two phases: a baseline evaluation and a follow-up. Past physical fitness was assessed via questionnaire. Present physical fitness was assessed by gathering anthropometric data and calculating average weekly energy expenditures. An Army physical fitness test was used to obtain a baseline fitness level. Injuries were assessed throughout training by physicians. Eighty-six of the 303 subjects in the study experienced LEOIs such as stress fractures, Achilles tendonitis, and patellofemoral pain syndrome. Older participants and participants who were smokers at the time of the study were at a greater risk of injury. Less active individuals at baseline testing were at a significantly higher risk of injury than those with a higher baseline fitness level.

Knapik et al. [21] examined the associations between injuries, physiological measures of physical fitness, and certain lifestyle characteristics. Subjects consisted of 756 men and 474 women during the US Army Basic Combat Training (BCT). Before BCT, physiological measures consisted of a treadmill peak V02max test, dual energy x-ray absorptiometry (for BMI), muscle strength, hamstring flexibility test, and a vertical jump test. A questionnaire was used to collect physical activity training habits and smoking history. All subjects were administered the Army Physical Fitness Test consisting of push-ups, sit-ups, a 3.2 km run. Anthropometric data consisted of gender, age, stature, and body mass and was collected by physical examination records. Injuries tracked during the BCT were recorded from medical records and data consisted of: diagnosis, anatomical location, final outcome of visit, and days of limited duty. Authors concluded that women had over twice as many injuries as men. For men and women, fewer push-ups, slower 3.2 km run time, lower peak V02 max, and cigarette smoking were labeled as risk factors of time-loss injury. Only regarding men, lower levels of physical activity prior to BCT and both high and low levels of flexibility were time-loss injury risk factors. Authors also conducted multivariate analysis revealing lower peak V02 max and
cigarette smoking were independent risk factors of time-loss injury. Further studies are needed to assess relationships between injury and body composition and muscular strength.

Extrinsic risk factors of LEOI have mainly consisted of running volume, low levels of physical fitness, high and low levels of flexibility, sedentary lifestyle, and tobacco use. Further research is needed to clarify extrinsic risk factors associated with LEOI among Army ROTC cadets.

**Kinetic Testing**

With every heel-strike, the runner’s lower extremity absorbs a ground reaction force (GRF) of two to four times his or her body weight [65]. Proper kinetic testing will provide researchers with data to determine how an individual absorbs the GRF and the biomechanical factors that alter the GRFs. Overuse injuries, specifically ITBS and AKP, are studied in relation to lower extremity loading.

Milner et al. [1] looked at a female running athlete population and measured biomechanical factors associated with tibial stress fractures. One group consisted of twenty rear-foot strikers with a history of tibial stress fractures (TSIs) and one group consisted of a mileage-matched rearfoot striking control group. A Bertec platform (Bertec Corporation, Columbus, OH) was used to collect ground reaction force data at 960 Hz during the stance phase of running. Running velocity was monitored with the use of two photocells linked to a timer over a 23 m runway. Standard running shoes were worn during the five running trials. Gait was monitored for any changes with contact with the force plate. Trials were subjectively measured and discarded if running gait was altered. Ground reaction force variables consisted of vertical instantaneous and average loading rate (VILR, VALR), impact peak (IPEAK), and anterior-posterior instantaneous and average loading rates during initial braking (BILR, BALR). Results allowed authors to conclude that VILR and VALR were increased, a higher IPEAK, and an increase in peak tibial shock in the TSF group compared to a control group.
Crossley et al. [90] looked at TSF injuries. Specifically looking at male runners, forty-six male subjects with a history of a healed TSF were compared with a matched control group with no history of stress fracture. Ground reaction force data were collected with the use of a force platform (Advanced Medical Technology Incorporated, Newton, MA, model LG6-4) interfaced to an IBM compatible computer via an analog to digital converter. Data were collected at 500 Hz on a 30 m track with subjects in their “regular” running shoes as human adaption can overcome the variability established by a different shoe type [50, 91]. Results indicated that there were no significant difference between groups in regards to GRF, tibial bone mineral content, and tibial bone mineral density. These findings support the idea that bone geometry plays a role in stress fracture development and that male athletes with small bones in comparison to body size are at greater risk of stress fracture.

Collecting kinetic data is helpful in determining foot strike abnormalities associated with LEOI. Simultaneous kinetic and kinematic data collection has been the most appropriate approach when attempting to analyze dynamic gait patterns.

Kinematic Testing

Kinematic testing can quantify and visually display motion of the human body at exact points in time, proving to be a reliable method of collecting biomechanical abnormalities of the human body in motion. Although static measures of gait exist in the research, dynamic measures should be the focus when evaluating LEOIs because they provide the dynamic interaction of range or motion (ROM) during running. Shod running can measure the same variables as barefoot running, so kinematic measurements are collected easiest with subjects wearing their own running shoes in order for the experimental conditions to be more clinically applicable.

Kaufmann et al. [92] studied overuse injuries of a military population over a two-year time period. Subjects were measured both statically and dynamically during weight-bearing for arch pes planus and pes cavus, ankle dorsiflexion, and hindfoot inversion and eversion. This study
demonstrated an association between foot structure and risk of overuse injury, specifically stress fractures. Kinematic data consisted of arch measurements collected weight-bearing statically by the ratio of navicular height to foot length using the bony arch index and weight-bearing dynamically using a foot-pressure measurement system (TEKSCAN, Boston, MA). This system used a sensor that measures the plantar surface of the foot sensing location, timing, and pressure distribution. The dynamic arch index was collected as the ratio of the area of contact of the midfoot to the total contact area (posterior calcaneus to metatarsal heads). Injuries were tracked most often in phase I (first 9 weeks) of training. Out of the entire 449 subjects, 149 (33.2%) suffered 348 lower extremity overuse injuries during training. The most common overuse injuries were listed as stress fractures, iliotibial band syndrome, patellofemoral syndrome, Achilles tendinitis, and periostitis. The authors found an increased risk of developing a stress fracture for people with either pes planus or pes cavus. No statistically significant relationship was revealed between foot structure and iliotibial band syndrome or patellofemoral syndrome.

Kaufmann et al. [92] claimed that because there was a weak association between the two dynamic arch measurements, a person’s structural characteristics (intrinsic factor) interact with the footwear (extrinsic factor). This interaction altered the inherent structural characteristics of the foot. The results of this study concur with previous reports on military trainees showing that subjects with high arches are at an increased risk of incurring stress fractures. These findings are in contrast, however, with a few previous studies that reported a protective effect of pes planus on the incidence of overuse injury in military trainees.

Cowan et al. [29], like Kaufmann et al. [92], performed a prospective study using a military population. Unlike Kaufmann et al., Cowan et al. reported a protective effect of a pes planus arch on the incidence of overuse injury and concluded that an increased arch height relates to an increase risk of injury in Army infantry trainees. Cowan et al. did not take biomechanical measurements dynamically. Evaluation of subjects consisted of weight-bearing
photographs that involved digitizing of the right foot of 246 US Army infantry trainees. Results of the study indicated that low arches were at lowest risk of injury leaving increased arch height with a significant trend for increasing risk of injury. Musculoskeletal injuries tracked in this study involved the lower back, legs, and feet.

Within the current research, there is a need for three-dimensional kinematics. Also, there are limited studies involving kinematics of the knee joint involving injury tracking as well as biomechanical analysis of the knee in relation to injury.

Iliotibial Band Syndrome

Iliotibial band syndrome has been researched thoroughly and is consistently reported in a similar manner with regard to anatomy and etiology. Slight variations are presented the literature concerning whether ITBS is actually caused by friction [55] or whether the cause has to do more with increased pressure to a highly vascularized and innervated fat structure being impinged between the ITB and the lateral femoral condyle of the femur.

Orchard et al. [9] described ITBFS as an impingement of the IT band occurring during the foot strike phase of gait between the posterior edge of the IT band and the lateral femoral epicondyle. This study involved a kinematic evaluation of nine recreational distance runners with ITBFS and 11 cadaveric subjects that were non-injured. In the cadavers they examined, IT band Length and width was measured and revealed a large variation between the widths of the IT bands, which may play a role in predisposition of ITBFS. The ITBFS group was diagnosed within the past six months with the most prominent symptom of lateral knee pain. Subjects were excluded if they had a history of bilateral ITBFS or any other knee abnormalities. Dynamically, the ITBFS group was assessed via two treadmill runs lasting two minutes each. The pace was chosen by the subject and each subject wore his or her own running shoes without socks. A 0.5-cm heel
lift was placed in the subjects’ shoes for the last treadmill trial in an attempt to increase knee joint angle at heel strike. Subjects were filmed using a 200 frame per second VICON VX 3D Motion Analysis System. Foot strike was determined by a load cell attached to the side of the treadmill. Joint angles were measured by averaging 10 consecutive gait cycles per treadmill run. Authors concluded that downhill running puts an individual as risk for ITBFS because the knee is flexed to a smaller degree compared to flat-surface running at heel-strike. Sprinting and running fast on level ground may cause less aggravation of the IT band because the knee maintains flexion beyond the impingement angles of the IT band. Authors found no significant differences in knee angles between the affected and unaffected legs or the affected leg with and without the heel raise. Authors proposed that there is an “impingement zone” for the IT band in which there is the most friction. This zone is around 30 degrees of flexion and is observed repetitively during downhill running or slow jogging.

Grau et al. [93] studied the effects of participant matching when studying runners with ITBS and healthy runners. Authors examined 52 healthy runners (CO) and 18 runners with ITBS, using three-dimensional kinematics and pressure distribution. The subjects were 18-50 years of age and compared in the following matched situations: ITBS versus CO I (unmatched), ITBS versus CO II (matched to gender) and ITBS versus CO III (matched to gender, height, and weight). Participants ran barefoot in a laboratory setting on a 13-m EVA foam runway (Shore 18 A; Ruckgaber, Se-ebrohn, Germany). Running speed was predetermined at 3.3 m/s (± 5%). A minimum of seven valid trials were recorded for each participant so that five valid trials could be randomly selected for analysis. A pressure platform was located in the middle of the runway flush with the foam mats. Each trial was recorded using a six-camera three-dimensional infrared system. Because differences between runners with ITBS and healthy runners seem to be in the frontal and transverse
planes, not the sagittal plane, two distinct variables (at touch-down and at maximum excursion) were calculated for the angular course of hip adduction, internal tibia rotation, and eversion in the subtalar joint. Authors also assessed rearfoot loading and forefoot loading kinetic variables. The largest statistically significant differences were found between ITBS group and CO III, where the subjects were matched by gender, height, and weight. This study explains the importance of data matching when studying overuse injuries of runners. Considering the variations in lever arms and proportions of taller, shorter, heavier, and lighter individuals and the possible effects these differences could have on running style, the results of this study seem plausible. The differences in plantar pressure measurements between ITBS and CO disappeared when the matching process was refined. Authors questioned the necessity of standardized running speeds during measurement because of the role speed plays in normal running form. Authors claimed that unmatched subjects might be responsible for the meager findings on ITBS development [8, 56].

Ferber et al. [7] retrospectively examined differences in running biomechanics between runners who had previously sustained ITBS and runners with no previous knee-related running injuries. The running mechanics of 35 females with a history of ITBS were compared to 35 healthy age-matched and running distance-matched females. Comparisons of hip, knee, and ankle 3D kinematics and internal moments during the stance phase of running gait were measured. Subjects ran along a 25-m runway at a speed of 3.65 m/s (±5%), striking a force plate at its center. Kinematic data were collected with a 6-camera, 3-D VICON Motion Analysis System. Only the first 60% of stance was analyzed because authors noted, in general, peak joint moments, maximum ground reaction forces, and peak joint angles occur within this time frame. The specific kinematic variables of interest were (1) peak rearfoot eversion angle, (2) peak rearfoot invertor moment, (3) peak knee internal
rotation angle, (4) peak knee external rotator moment, (5) peak hip adduction angle, (6) peak hip abductor moment, and (7) peak knee flexion angle. Data from the previously injured limb of the female runners in the ITBS group were used for analysis and were compared with the right limb of the female runners in the control group. Variables were statistically compared between groups using one way ANOVAs at a confidence level of 0.05. The ITBS group exhibited significantly greater peak rearfoot inverter moment, peak knee internal rotation angle, and peak hip adduction angle compared to controls. No significant differences in peak rearfoot eversion angle, peak knee flexion angle, peak knee external rotator moment, or peak hip abductor moments were observed between groups. Females with a previous history of ITBS demonstrated a kinematic profile that is suggestive of increased stress on the iliotibial band. These results were generally similar to those reported in the literature.

McMahon [94] prospectively studied static anthropometric measures and demographic information and overuse injuries in the lower leg, ankle and foot bilaterally in 204 (ages 17 to 25) US Air Force Academy Cadets. Once a month for six months following the initial assessment, each subject was emailed a follow-up injury tracking form. Type, incidence and cause of injury were documented. Injuries were classified via five digit coding system following guidelines from NAIRS Medical Terminology Codes. Injury was defined as: the injury kept the cadet out of training, exercise or competition on the day following the injury, and/or the injury required medical attention of any kind beyond icing or wrapping. Data were recorded only if it was training, exercise, or sports related. Significant relationships between navicular drop, total talocrural range of motion, total supination, fitness level and injuries to the lower leg, ankle and foot were revealed. This study provides evidence that many lower leg, foot and ankle morphologic characteristics do not place individuals at increased risk for overuse injury, but that formulas may exist which predict potential for injury. The results of this study
suggest that the time consuming screening processes implemented in various athletic and military settings may not be necessary. Particularly when trying to predict injury due to dynamic activity via static measurements.

**Anterior Knee Pain**

Anterior knee pain has been used as an umbrella term by authors studying injuries to the knee. This term has been used by James [13] to encompass chondromalacia patella, excessive lateral pressure syndrome (lateral patellar tracking), patellar instability, patellar/quadriceps tendinopathy, and pathologic plica. The prevalence of AKP is very high among overuse injuries involving military trainees and recreational runners.

Tiggelen et al. [68] explored the role of muscle imbalance and strength as risk factors for the development of AKP. Subjects consisted of 96 male military recruits with no prior history of knee injury or pain. Baseline muscular strength of the knee flexors and extensors was tested. Subjects were tracked for development of AKP during basic training (6 weeks). Independent t-Tests were performed to compare muscle strength in those who did and those who did not develop AKP. Authors concluded that shorter subjects with lower quadriceps strength were more prone to developing AKP. Authors also reported that AKP development is multifactorial and emphasized the importance of incorporating quadriceps strengthening protocols into rehabilitation programs for AKP.

Milgrom et al. [12] conducted a prospective study involving 390 infantry recruits. Results from this study indicated that low strength of the quadriceps was related to incidence of patellofemoral pain caused by activity. Subjects were tracked for injury development throughout basic training. This study reported risk factors for patellofemoral pain were increased medial tibial intercondylar distance and increased quadriceps strength.

Jordaan et al. [11] also tracked overuse injuries of military personnel through basic training (9 weeks). In this study, 1,261 subjects were tracked. The highest incidence of injuries
was reported during weeks 1-3 and week 9. Most injuries consisted of tibial stress fractures, patellofemoral pain, and iliotibial band syndrome. Injuries to the knee, lower leg, and ankle accounted for 80% of injuries. A total of 3.6% of training days were lost due to injury.
APPENDIX A

INFORMED CONSENT FORM
INFORMED CONSENT  
To Participate in a Research Study

Department of Kinesiology and Rehabilitation 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: Christina Bourbeau, ATC; Melanie Presuto, MS; Katherine Perlsweig, MS, ATC; Christopher Stickley, PhD, ATC; Iris F. Kimura, PhD, ATC, PT

II. TITLE
Predictive Gait Related Risk Factors of Lower Extremity Overuse Injury Among Cadets in the Army Reserve Officer Training Corps

III. INTRODUCTION
The following information is being provided to help you decide if you would like to participate in this study. This study is completed as part of a graduate student’s requirements for a Master’s degree. This form may have words that you do not understand. If you have questions, please ask us.

The purpose of this study is to examine the movements and forces experienced during running as they relate to overuse leg pain. You are being asked to participate in this study because you are an active member of the Army ROTC.

IV. DESCRIPTION OF PROCEDURES
You will be asked to report to the University of Hawaii at Manoa, Kinesiology and Rehabilitation Science Laboratory for testing. You will then be asked to fill out an injury history questionnaire. Your height, weight, and skinfold thickness will be measured by a member of the research team who is a certified athletic trainer. Next, reflective markers will be placed on several landmarks on your body (ex. Shoulders, neck, chest, lower back, hips, thighs, knees, shins, ankles, and feet). Measurements and marker application for female subjects will be performed by a female member of the research team. You will be asked to wear your Army PT shorts (or spandex shorts) and a sports bra (for females) and bring your normal running shoes and combat boots. You will be asked to jog at a moderate pace (between 6:00 and 7:30 min/mile pace) down an 18 m runway. You will perform three successful trials for each leg while wearing normal running shoes and three successful trials for each leg while wearing your boots (approximately 12-15 trials total). You will have time prior to running to warm up and stretch, as well as time to get familiar with the procedures. This entire procedure will take approximately 30 minutes.

During the next semester after testing, members of the research team who are certified athletic trainers will evaluate you at the UH Army ROTC facilities once every month for the development of leg pain. This evaluation will include a questionnaire and hands-on injury evaluation.

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 a very remote chance of cardiac arrest and/or death. The investigators are BOC certified athletic trainers and First
Aid/CPR/AED trained. In the event of any physical injury from the research, only immediate and essential medical treatment is available including an AED. First Aid/CPR and a referral to a medical emergency room will be provided. In the event of an emergency outside the lab, as a result of this research, contact your medical doctor and inform the principal investigators (Christina Bourbeau, ATC at 956-7421; Melanie Presuto, MS at 956-8793; Christopher Stickley, PhD, ATC at 956-3798; Iris Kimura, PhD, ATC at 956-3797;).

You should understand that if you are injured in the course of this research process that you alone will be responsible for the costs of treating your injuries.

VI. BENEFITS
You may not receive direct/immediate benefits. However, you will obtain information regarding your running characteristics and body composition. Results of this study may assist athletic trainers, Army physicians and sport biomechanists in preventing future injuries during Army training.

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 Rehabilitation 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 participation and to discontinue participation in the project or activity at any time without prejudice.

I herewith consent to participate in this project with the understanding that such consent 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 attest that I am not currently limited from full participation in my chosen sport due to injury.

I attest that I do not believe that I am currently pregnant and that should I become pregnant during participation in this study that I will voluntarily withdraw from further participation.

If you have any questions related to this study, please contact any of the principle investigators; Christina Bourbeau at 956-7421; Melanie Presuto at 956-8793, Dr. Iris Kimura at 956-3797, or Dr. Christopher Stickley at 956-3798 at any time.

___________________  Subject ID Number

________________________________________
Signature of Participant                      Date

If you cannot obtain satisfactory answers to your questions, or have complaints about your treatment in this study, please contact: Committee on Human Studies, University of Hawai’i at Manoa, 1960 East-West Road, Biomed B-104, Honolulu, Hawaii 96822, Phone (808) 956-5007.
APPENDIX B

LEOI INJURY HISTORY FORM
LEOI HISTORY QUESTIONNAIRE

Date: __________

ID: __________

Name: ______________________________________

Email: ______________________________________

Age: __________ Height: __________ Weight: __________ Years in the Military (Include ROTC, if 1st year: 0): ____

Shoe brand/style: ___________________________ Shoe Size: __________ Shoe Age (months): __________

Orthotics/inserts in Running Shoes: Y   N  Orthotic Type: ___________________________

Boot brand/style: ___________________________ Boot size: __________ Boot Age (months): __________

Boot sole brand/style: ___________________________

Orthotics/inserts in Boots: Y   N  Orthotic type: ___________________________

Training History

I currently train _____ per week  I run an average of _____ per week

_____ 0-5 hours  _____ 0-5 miles

_____ 5-10 hours  _____ 5-10 miles

_____ 10-15 hours  _____ 10-15 miles

_____ 15-20 hours  _____ 15-20 miles

_____ Over 20 hours  _____ Over 20 miles

Injury History

1. YES   NO  I have experienced pain in my left upper leg (above the knee and below the back) resulting from participating in training. (Circle “Yes” or “No” – DO NOT include pain that resulted from a single specific injury episode such as a bruise, sprain or broken bone)

If YES, please answer questions a & b below. IF YOU HAVE EXPERIENCED MORE THAN 1 INJURY, ANSWER QUESTIONS a & b BELOW REGARDING YOUR MOST RECENT INJURY. If NO, skip to question 2 below.

a. The pain in my left upper leg occurred:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>during the last 6 months</td>
</tr>
<tr>
<td></td>
<td>between 6 months and 1 year ago</td>
</tr>
<tr>
<td></td>
<td>between 1 and 2 years ago</td>
</tr>
<tr>
<td></td>
<td>more than 2 years ago</td>
</tr>
</tbody>
</table>

b. The pain in my left upper leg:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>was not serious enough to seek medical care or treatment from a physician or athletic trainer</td>
</tr>
<tr>
<td></td>
<td>was serious enough to get treatment (ice, taping, anti-inflammatory medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training</td>
</tr>
<tr>
<td></td>
<td>required me to decrease my training (amount or intensity) but I did not have to completely miss or “sit-out” any of my training</td>
</tr>
<tr>
<td></td>
<td>required me to completely miss or “sit-out” some of my training</td>
</tr>
</tbody>
</table>

2. YES   NO

(Circle “Yes” or “No” – DO NOT include pain that resulted from a single specific injury episode such as a bruise, sprain or broken bone)
If **YES**, please answer questions **a & b** below. **IF YOU HAVE EXPERIENCED MORE THAN 1 INJURY, ANSWER QUESTIONS a & b BELOW REGARDING YOUR **MOST RECENT** INJURY.**

If **NO**, skip to question **3** below.

<table>
<thead>
<tr>
<th>a. The pain in my <strong>left knee</strong> occurred:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>during the last 6 months</td>
<td></td>
</tr>
<tr>
<td>between 6 months and 1 year ago</td>
<td></td>
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<tr>
<td>between 1 and 2 years ago</td>
<td></td>
</tr>
<tr>
<td>more than 2 years ago</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. The pain in my <strong>left knee</strong> leg:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>was not serious enough to seek medical care or treatment from a physician or athletic trainer</td>
<td></td>
</tr>
<tr>
<td>was serious enough to get treatment (ice, taping, anti-inflammatory medication, etc.) from a physician or athletic trainer but <strong>NOT</strong> serious enough to require any change in training</td>
<td></td>
</tr>
<tr>
<td>required me to decrease my training (amount or intensity) but I did not have to <strong>completely</strong> miss or “sit-out” any of my training</td>
<td></td>
</tr>
<tr>
<td>required me to <strong>completely</strong> miss or “sit-out” some of my training</td>
<td></td>
</tr>
</tbody>
</table>

3. **YES**  **NO**

I have experienced pain in my **left lower leg** resulting from participating in training.

(Circle “Yes” or “No” – **DO NOT** include pain that resulted from a single specific injury episode such as a bruise, sprain or broken bone)

If **YES**, please answer questions **a & b** below. **IF YOU HAVE EXPERIENCED MORE THAN 1 INJURY, ANSWER QUESTIONS a & b BELOW REGARDING YOUR **MOST RECENT** INJURY.**

If **NO**, skip to question **4** below.

<table>
<thead>
<tr>
<th>a. The pain in my <strong>left lower leg</strong> occurred:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>during the last 6 months</td>
<td></td>
</tr>
<tr>
<td>between 6 months and 1 year ago</td>
<td></td>
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<tr>
<td>between 1 and 2 years ago</td>
<td></td>
</tr>
<tr>
<td>more than 2 years ago</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. The pain in my <strong>left lower leg</strong>:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>was not serious enough to seek medical care or treatment from a physician or athletic trainer</td>
<td></td>
</tr>
<tr>
<td>was serious enough to get treatment (ice, taping, anti-inflammatory medication, etc.) from a physician or athletic trainer but <strong>NOT</strong> serious enough to require any change in training</td>
<td></td>
</tr>
<tr>
<td>required me to decrease my training (amount or intensity) but I did not have to <strong>completely</strong> miss or “sit-out” any of my training</td>
<td></td>
</tr>
<tr>
<td>required me to <strong>completely</strong> miss or “sit-out” some of my training</td>
<td></td>
</tr>
</tbody>
</table>

4. **YES**  **NO**

I have experienced pain in my **left foot** resulting from participating in training.

(Circle “Yes” or “No” – **DO NOT** include pain that resulted from a single specific injury episode such as a bruise, sprain or broken bone)

If **YES**, please answer questions **a & b** below. **IF YOU HAVE EXPERIENCED MORE THAN 1 INJURY, ANSWER QUESTIONS a & b BELOW REGARDING YOUR **MOST RECENT** INJURY.**

If **NO**, skip to question **5** below.

<table>
<thead>
<tr>
<th>a. The pain in my <strong>left foot</strong> occurred:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>during the last 6 months</td>
<td></td>
</tr>
<tr>
<td>between 6 months and 1 year ago</td>
<td></td>
</tr>
<tr>
<td>between 1 and 2 years ago</td>
<td></td>
</tr>
</tbody>
</table>
The pain in my **left foot**:  
- was not serious enough to seek medical care or treatment from a physician or athletic trainer  
- was serious enough to get treatment (ice, taping, anti-inflammatory medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training  
- required me to decrease my training (amount or intensity) but I did not have to **completely** miss or “sit-out” any of my training  
- required me to completely miss or “sit-out” some of my training

**5. YES NO**  
I have experienced pain in my **right upper leg** (above the knee and below the back) resulting from participating in training. (Circle “Yes” or “No” – **DO NOT** include pain that resulted from a single specific injury episode such as a bruise, sprain or broken bone)  
If YES, please answer questions a & b below. **IF YOU HAVE EXPERIENCED MORE THAN 1 INJURY, ANSWER QUESTIONS a & b BELOW REGARDING YOUR MOST RECENT INJURY.**  
If **NO**, skip to question **6** below.

**a. The pain in my **right upper leg** occurred:**  
- during the last 6 months  
- between 6 months and 1 year ago  
- between 1 and 2 years ago  
- more than 2 years ago

**b. The pain in my **right upper leg:**  
- was not serious enough to seek medical care or treatment from a physician or athletic trainer  
- was serious enough to get treatment (ice, taping, anti-inflammatory medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training  
- required me to decrease my training (amount or intensity) but I did not have to **completely** miss or “sit-out” any of my training  
- required me to completely miss or “sit-out” some of my training

**6. YES NO**  
I have experienced pain in my **right knee** resulting from participating in training. **(Circle “Yes” or “No” – **DO NOT** include pain that resulted from a single specific injury episode such as a bruise, sprain or broken bone)**  
If **YES**, please answer questions a & b below. **IF YOU HAVE EXPERIENCED MORE THAN 1 INJURY, ANSWER QUESTIONS 5 & 6 BELOW REGARDING YOUR MOST RECENT INJURY.**  
If **NO**, skip to question **7** below.

**a. The pain in my **right knee** occurred:**  
- during the last 6 months  
- between 6 months and 1 year ago  
- between 1 and 2 years ago  
- more than 2 years ago

**b. The pain in my **right knee:**  
- was not serious enough to seek medical care or treatment from a physician or athletic trainer  
- was serious enough to get treatment (ice, taping, anti-inflammatory medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training  
- required me to decrease my training (amount or intensity) but I did not have to **completely** miss or “sit-out” any of my training  
- required me to completely miss or “sit-out” some of my training
7. **YES**  NO  I have experienced pain in my **right lower leg** resulting from participating in training. (Circle “Yes” or “No” – DO NOT include pain that resulted from a single specific injury episode such as a bruise, sprain or broken bone)

If **YES**, please answer questions a & b below. IF YOU HAVE EXPERIENCED MORE THAN 1 INJURY, ANSWER QUESTIONS a & b BELOW REGARDING YOUR **MOST RECENT** INJURY. If **NO**, skip to question 8 below.

a. The pain in my **right lower leg** occurred:
- during the last 6 months
- between 6 months and 1 year ago
- between 1 and 2 years ago
- more than 2 years ago

b. The pain in my **right lower leg**:
- was not serious enough to seek medical care or treatment from a physician or athletic trainer
- was serious enough to get treatment (ice, taping, anti-inflammatory medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training
- required me to decrease my training (amount or intensity) but I did not have to **completely** miss or “sit-out” any of my training
- required me to completely miss or “sit-out” some of my training

8. **YES**  NO  I have experienced pain in my **right foot** resulting from participating in training. (Circle “Yes” or “No” – DO NOT include pain that resulted from a single specific injury episode such as a bruise, sprain or broken bone)

If **YES**, please answer questions a & b below. IF YOU HAVE EXPERIENCED MORE THAN 1 INJURY, ANSWER QUESTIONS a & b BELOW REGARDING YOUR **MOST RECENT** INJURY. If **NO**, you are finished.

a. The pain in my **right foot** occurred:
- during the last 6 months
- between 6 months and 1 year ago
- between 1 and 2 years ago
- more than 2 years ago

b. The pain in my **right foot**:
- was not serious enough to seek medical care or treatment from a physician or athletic trainer
- was serious enough to get treatment (ice, taping, anti-inflammatory medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training
- required me to decrease my training (amount or intensity) but I did not have to **completely** miss or “sit-out” any of my training
- required me to completely miss or “sit-out” some of my training

9. Have you ever had any orthopedic surgery? What body part? When?
10. Have you had any injury to your back, hips, legs, knees, ankles, or feet in the past year that caused you to seek treatment from a physician or athletic trainer? What body part? When?
APPENDIX C

MONTHLY LEOI INJURY HISTORY FORM
MONTHLY LEIO HISTORY QUESTIONNAIRE

Subject ID: ____________  Date: __________

Training

During the past month, I spent about _____ hours per week training

____ 0-5 hours
____ 5-10 hours
____ 10-15 hours
____ 15-20 hours
____ Over 20 hours

During the past month, I ran an average of about _____ per week

____ 0-5 miles
____ 5-10 miles
____ 10-15 miles
____ 15-20 miles
____ Over 20 miles

1. Choose the option that best describes any pain in your LEFT upper leg (below your back and above your knee) resulting from participating in training. DO NOT include pain that resulted from a single specific injury episode, like a bruise, sprain or broken bone.

| I did not have any pain in my LEFT upper leg. |
| The pain was NOT serious enough to seek medical care or treatment from a physician or athletic trainer. |
| The pain was serious enough to get treatment (ice, taping, medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training. |
| The pain required me to decrease my training (amount or intensity) but I did not have to completely miss or "sit-out" any of the activities. |
| The pain required me to completely miss or "sit-out" some of my training. |

2. Choose the option that best describes any pain in your LEFT knee resulting from participating in training. DO NOT include pain that resulted from a single specific injury episode, like a bruise, sprain or broken bone.

| I did not have any pain in my LEFT knee. |
| The pain was NOT serious enough to seek medical care or treatment from a physician or athletic trainer. |
| The pain was serious enough to get treatment (ice, taping, medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training. |
| The pain required me to decrease my training (amount or intensity) but I did not have to completely miss or "sit-out" any of the activities. |
| The pain required me to completely miss or "sit-out" some of my training. |

3. Choose the option that best describes any pain in your LEFT lower leg (below your knee and above your ankle) resulting from participating in training. DO NOT include pain that resulted from a single specific injury episode, like a bruise, sprain or broken bone.

| I did not have any pain in my LEFT lower leg. |
| The pain was NOT serious enough to seek medical care or treatment from a physician or athletic trainer. |
| The pain was serious enough to get treatment (ice, taping, medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training. |
| The pain required me to decrease my training (amount or intensity) but I did not have to completely miss or "sit-out" any of the activities. |
| The pain required me to completely miss or "sit-out" some of my training. |
4. Choose the option that best describes any pain in your LEFT foot (below your ankle) resulting from participating in training. DO NOT include pain that resulted from a single specific injury episode, like a bruise, sprain or broken bone.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I did not have any pain in my LEFT foot.</td>
<td>The pain was NOT serious enough to seek medical care or treatment from a physician or athletic trainer.</td>
</tr>
<tr>
<td></td>
<td>The pain was serious enough to get treatment (ice, taping, medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training.</td>
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<td>The pain required me to decrease my training (amount or intensity) but I did not have to completely miss or &quot;sit-out&quot; any of the activities.</td>
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<td>The pain required me to completely miss or &quot;sit-out&quot; some of my training.</td>
</tr>
</tbody>
</table>

5. Choose the option that best describes any pain in your RIGHT upper leg (below your back and above your knee) resulting from participating in training. DO NOT include pain that resulted from a single specific injury episode, like a bruise, sprain or broken bone.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I did not have any pain in my RIGHT upper leg.</td>
<td>The pain was NOT serious enough to seek medical care or treatment from a physician or athletic trainer.</td>
</tr>
<tr>
<td></td>
<td>The pain was serious enough to get treatment (ice, taping, medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training.</td>
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<td>The pain required me to completely miss or &quot;sit-out&quot; some of my training.</td>
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</table>

6. Choose the option that best describes any pain in your RIGHT knee resulting from participating in training. DO NOT include pain that resulted from a single specific injury episode, like a bruise, sprain or broken bone.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>I did not have any pain in my RIGHT knee.</td>
<td>The pain was NOT serious enough to seek medical care or treatment from a physician or athletic trainer.</td>
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<tr>
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<td>The pain was serious enough to get treatment (ice, taping, medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training.</td>
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<td></td>
<td>The pain required me to completely miss or &quot;sit-out&quot; some of my training.</td>
</tr>
</tbody>
</table>
7. Choose the option that best describes any pain in your RIGHT lower leg (below your knee and above your ankle) resulting from participating in training. DO NOT include pain that resulted from a single specific injury episode, like a bruise, sprain or broken bone.

<table>
<thead>
<tr>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>I did not have any pain in my RIGHT lower leg.</td>
</tr>
<tr>
<td>The pain was NOT serious enough to seek medical care or treatment from a physician or athletic trainer.</td>
</tr>
<tr>
<td>The pain was serious enough to get treatment (ice, taping, medication, etc.) from a physician or athletic trainer but NOT serious enough to require any change in training.</td>
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<tr>
<td>The pain required me to completely miss or &quot;sit-out&quot; some of my training.</td>
</tr>
</tbody>
</table>

8. Choose the option that best describes any pain in your RIGHT foot (below your ankle) resulting from participating in training. DO NOT include pain that resulted from a single specific injury episode, like a bruise, sprain or broken bone.

<table>
<thead>
<tr>
<th>Option</th>
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</thead>
<tbody>
<tr>
<td>I did not have any pain in my RIGHT foot.</td>
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<td>The pain was NOT serious enough to seek medical care or treatment from a physician or athletic trainer.</td>
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</tr>
<tr>
<td>The pain required me to completely miss or &quot;sit-out&quot; some of my training.</td>
</tr>
</tbody>
</table>

9. Do you have any other injuries or pain?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
APPENDIX D

REPORT OF MEDICAL EXAMINATION / PHYSICAL PROFILE
University of Hawaii Army ROTC
**Principal purpose:** To obtain medical data for the determination of medical fitness for participation in ROTC physical training and military exercises.

**Cadet Instructions:** Fill out boxes 1 through 3, and return the completed form to your MS instructor.

**Physician Instructions:** Fill out boxes 4 through 13.

<table>
<thead>
<tr>
<th>1. LAST NAME – FIRST NAME</th>
<th>2. MS LEVEL</th>
<th>3. DATE OF INJURY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. DATE OF EXAMINATION</th>
<th>5. REASON FOR VISIT</th>
<th>6. FOLLOW UP REQUIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INJURY</td>
<td>ILLNESS/DISEASE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7. MEDICAL CONDITION (OR WORKING DIAGNOSIS)</th>
<th>8. ICD-9 CODE (IF AVAILABLE)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>9. DIAGNOSTICS ORDERED / KEY FINDINGS</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>10. CONDITIONING ACTIVITIES ALLOWED</th>
<th>YES</th>
<th>NO</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULTIMITED RUNNING</td>
<td></td>
<td></td>
<td>LIMITED RUN AT OWN PACE &amp; DISTANCE</td>
<td></td>
</tr>
<tr>
<td>UNLIMITED WALKING</td>
<td></td>
<td></td>
<td>LIMITED WALK AT OWN PACE &amp; DISTANCE</td>
<td></td>
</tr>
<tr>
<td>UNLIMITED BIKING</td>
<td></td>
<td></td>
<td>LIMITED BIKE AT OWN PACE &amp; DISTANCE</td>
<td></td>
</tr>
<tr>
<td>UNLIMITED SWIMMING</td>
<td></td>
<td></td>
<td>LIMITED SWIM AT OWN PACE &amp; DISTANCE</td>
<td></td>
</tr>
<tr>
<td>UPPER BODY WEIGHT TRAINING</td>
<td></td>
<td></td>
<td>LOWER BODY WEIGHT TRAINING</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>11. OTHER COMMENTS (e.g. functional limitations and capabilities such as maximum running distance, carrying weight, or impact activities)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>12. PHYSICIAN SIGNATURE</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>13. ISSUING CLINIC, PROVIDER NAME &amp; PHONE NUMBER</th>
</tr>
</thead>
</table>
References


