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# Biomechanical Factors in the Etiology of Tibial Stress Fractures

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**Abstract:**
The overall aim of this research is to gain insight into the etiology of tibial stress fractures. Three-dimensional motion analysis data along with structural data will be collected from 400 subjects (200 at each site) over a 3-year period. 30 of the subjects will have sustained a tibial stress fracture prior to the study and the other 370 will have not. Subjects will be recruited primarily from track teams, running clubs, and physicians local to the University of Delaware and University of Massachusetts. Within this Annual Report, information concerning adherence to work objectives, preliminary results with respect to the proposed hypotheses, and reportable outcomes are presented for the second year of the investigation. Overall, we have adhered to most work objectives and have proposed plans for rectifying any discrepancies. The preliminary analysis of the data demonstrates encouraging results and support of most hypotheses.

**Subject Terms:**
tibial stress fractures, bone structure, running, etiology

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INTRODUCTION

Stress fractures can be extremely costly to the military in terms of both time and medical expenses. The tibia is a common site for such injuries and has been most often associated with running, an activity common to all military training. Stress fractures are among the top 5 cited lower extremity injuries sustained by runners (Clement et al., 1981; Kowal, 1980; James et al., 1978; Jones et al., 1983; Pagliano et al., 1980; Reinker et al., 1979). They are among the most serious of running-related overuse injuries as they take long to heal and if untreated, can progress to a macrofracture. Females are a growing military contingency and appear to be particularly susceptible, as it has been noted that they are twice as likely to experience a stress fracture as their male counterparts (Brudvig et al, 1983; Pester & Smith, 1992; Reinker et al, 1979).

Structural and biomechanical factors have been suggested in the cause of stress fractures. However, these mechanisms are not well understood. Therefore, the purposes of this study are 1) to compare the structure and mechanics of runners who have sustained a tibial stress fracture to those who have not, 2) to gain an understanding of which combination of factors (structural and/or biomechanical) are predictive of tibial stress fractures, and 3) to assess whether mechanics are altered following a tibial stress fracture. Once the factors associated with stress fractures are identified, future work will focus on formation and testing of a simple screening tool to facilitate identification of those at risk.

This is a dual-site investigation (University of Delaware & University of Massachusetts, Amherst) which began on September 1, 2001 and has been under investigation for 2 years. This Annual Report will focus on preliminary results after the second year of the study.

BODY

Summary of Methodology

The overall aim of this research is to gain insight into the etiology of tibial stress fractures. Three dimensional motion analysis data along with structural data will be collected from 400 subjects (200 at each site) over a 3-year period. A minimum of 30 subjects will have sustained a tibial stress fracture prior to the study. Subjects will be recruited primarily from track teams, running clubs, and physicians local to the University of Delaware and University of Massachusetts. All subjects will be females between the ages of 18 and 45 and will be free of lower extremity injury at the time of testing. Lower extremity kinematics and kinetics will be collected during running. In addition, radiographs of both tibiae will be taken as well as clinical measures of lower extremity alignment. Subjects will then report their exposure data (mileage, intensity, terrain) as well as any injuries they have sustained each month via a custom developed webpage which will serve as a database for this information. If a subject reports a tibial stress fracture/reaction, the site coordinator will be notified automatically and the subject
will be asked to return for a second running analysis once the fracture has healed and they are cleared to run by their physician. The structural and biomechanical factors leading up to a tibial stress fracture will be assessed. In addition, comparisons will be made of mechanics before and after the stress fracture to determine whether subjects revert back to their pre-injury mechanics.

**Statement of Work**

Between the two data collection sites, the following objectives were outlined in the approved Statement of Work for the second year. These objectives included:

1. Recruitment of an additional 75 subjects per site for a sub-total of 125 subjects per site.
2. Data recollected on those who have sustained a tibial stress fracture since the onset of the study.
3. Abstracts submitted to national meetings regarding structural and biomechanical data in subjects who have previously sustained a tibial stress fracture.
4. Continue with follow-up procedures on subjects.

**Adherence to Work Objectives**

1) Recruitment of Subjects

To date, data on 95 subjects have been collected at the University of Delaware and 50 subjects have been collected at the University of Massachusetts. Several local coaches and track teams have been contacted to recruit subjects and establish relationships for injury tracking. Additional contacts are continuing to be made to recruit the necessary subjects.

Of the 95 subjects collected at the University of Delaware, 75 have been collected in the past year which meets the requirement for this year. However, as of the end of year 1, the University of Delaware was 30 subjects short of meeting the objective of 50 subjects. Since the number of subjects for year 2 has already been met, we are confident that the remaining 30 subjects will be collected by December 2002 putting the University of Delaware back on schedule at that time.

The University of Massachusetts has had a difficult time recruiting subjects from the surrounding area of Amherst, MA. As such, the number of subjects collected does not reflect what was proposed and several circumstances exist to explain the discrepancy. First, one of the students intimately involved in recruiting and collecting data graduated in April of 2002 and thus a change of personal was necessary. With a new student involved in recruitment and data collection, time was lost to orient and train them. In addition, the new student who was recruited and trained decided to leave the PhD program only a few months after training. Thus, another student is will begin training at the end of the summer. In the mean time, summer students are working diligently to recruit and collect data. Second, the level of participation from surrounding colleges has been less than predicted. The status of local college recruitment is as follows:
• **Springfield College and Smith College:** The women’s track and field and cross-country teams have been unavailable for the first 2 years of the study due to involvement in another research study. However, these teams will be able to participate in this study for the 2002/2003 school year.

• **Amherst College:** The coach was willing to include several of his runners in this study this past year but only during the fall. We expect to recruit several more subjects from this program in this coming fall.

• **Elms College:** This is a small program that is about 45 minutes away. We have had several subjects from this program and expect several more this coming fall.

• **Mt. Holyoke College:** We have had several subjects from this program and expect several more this coming fall.

• **Hampshire College:** This college does not have a cross-country team.

• **University of Massachusetts:** We have had ongoing data collections from incoming University of Massachusetts cross-country and track and field athletes.

Several actions have been implemented to increase University of Massachusetts recruitment. These actions include the following:

• Subject recruitment booths have been set up at local races. Brochures are given out and interested subjects are signed up at the event. A copy of the advertisements has been included in Appendix B.

• Presentations at several women’s running groups have been given.

• Subject recruitment signs have been posted at local (Amherst, Northampton and Springfield) health clubs and running stores.

• Subject recruitment announcements have been printed in campus newspapers and in local running club bulletins.

• Subject recruitment announcements have been posted on local running club websites.

With these recent implementations, the University of Massachusetts has scheduled 28 subjects over the next two months. In addition, fall semester data collections of the surrounding colleges will begin with the return of the athletes. We believe that we will have the remaining subjects at each site collected by December 2002 putting each site on schedule.

2) **Collection of Data on those who have sustained a tibial stress fracture**

To date, 2 subjects have sustained lower extremity stress fractures since data was first collected on them. Data have been recollected on 1 of these subjects and we are waiting for the second subject to completely heal from the stress fracture before recollection. A summary of their pre-injury findings is included in the Reportable Outcomes section.

Unfortunately, 5 University of Delaware track athletes experienced stress fractures very early in the fall season and we were unable to collect their pre-injury data due to their scheduling conflicts. We have contacted the coach and are planning on collecting data on the new track team recruits prior to fall semester and the cross-country season in an effort to increase the number of prospective stress fracture injuries in our
study. In addition, Delaware State, Widener University, West Chester University, and Lincoln University have all been contacted and a limited number of athletes have participated in the study to date. These Universities have shown limited involvement in the study most likely since they are 30-40 miles away from the University of Delaware. We will be contacting these teams early in the season in hopes of increasing the number of participants and thus the number of prospective stress fractures.

3) Abstract Submission

To date, three additional abstracts have been submitted and were accepted for presentation. These abstracts were presented at the American College of Sports Medicine National Meeting in St. Louis, Missouri and at the World Congress of Biomechanics in Calgary, Alberta, Canada. The references and a summary of the findings are provided in the Reportable Outcomes section and the complete abstracts are included in Appendix A.

4) Follow-up procedures

All subjects have been tracking their monthly running exposure and injuries since their initial visit and these data have been input into the database. The database continues to function properly and all subjects have been logging in on a monthly basis to record their mileage and injuries. A summary of the injuries reported has been summarized in the Reportable Outcomes section.

**KEY RESEARCH ACCOMPLISHMENTS**

Data collection and analysis of this 5-year project is still in the early stages. As defined by the Technical Reporting Requirements guidelines, there are no Key Research Accomplishments to report, nor were any expected at this stage of the project.

**REPORTABLE OUTCOMES**

This section contains a summary of the 3 abstracts presented on retrospective stress fractures, a summary of the data from the 2 prospective tibial stress fractures, a list of abstract publications, a summary degrees obtained that are supported from this award, and a summary of the information from the database.

1) Summary of the 3 abstracts presented on retrospective stress fractures

Subjects consisted of 10 females with a history of at least one lower extremity stress fracture (SF) and 10 females with no SF history who served as a control group. All subjects were between ages 18-35 and ran between 30-80 miles per week. Ground reaction force (GRF), kinematic data, and tibial acceleration data were recorded from 5
running trials. Three radiographs of the distal lower extremity were used to calculate the tibial area moment of inertia (Milgrom et al., 1989). Each subject underwent a structural evaluation by an experienced physical therapist.

1.1 It was hypothesized that runners who had sustained a previous SF would exhibit greater vertical loading rates (LR), vertical ground reaction forces (vGRF), and peak positive tibial acceleration (PPA).

Based on the results of these studies, subjects who had previously sustained a lower extremity stress fracture exhibited significantly greater vGRF, PPA, and LR values compared to non-injured subjects (Fig. 1-3). These results support those of Grimston et al. (1991) who also reported that higher vGRF values were associated with stress fractures in women runners. However, these results are in contrast to Crossley et al. (1999) who reported no differences in kinetic variables between SF and healthy runners. However, these authors used male runners who may exhibit different running mechanics compared to women runners.

Figure 1: Vertical Ground Reaction Force for subjects who had previously experienced a stress fracture versus healthy controls. (* = significantly greater than controls)
Figure 2: Instantaneous and average loading rates for subjects who had previously experienced a stress fracture versus controls. (* = significantly greater than controls)

Figure 3: Peak positive acceleration for subjects who had previously experienced a stress fracture versus healthy controls. (* = significantly greater than controls)
1.2 It was hypothesized that runners who had sustained a previous SF would exhibit greater stiffness, and reduced knee flexion excursion compared to controls.

Although not significant, a trend towards greater stiffness and reduced knee flexion excursion in the SF group was also observed compared to controls (Fig. 4 & 5). The stiffness of elastic structures will control the kinematics of the runner. A “stiff” runner will spend less time in contact with the ground (Farley and Gonzalez, 1996) and will attenuate less shock between the leg and the head (McMahon, Valiant and Frederick, 1987). The results of these subjects who had previously experienced a SF are in agreement with Farley and Gonzalez (1996) and suggest that lower extremity stiffness and knee kinematics are highly correlated and may lead to SF.

![Figure 4: Lower extremity stiffness for subjects who had previously experienced a stress fracture versus healthy controls](image_url)
1.3 It was hypothesized that runners who had sustained a previous SF would exhibit greater tibial varum and reduced tibial area moment of inertia compared to healthy controls.

Although specific structural characteristics have been associated with stress fracture injuries (Crossley, 1999; Milgrom, 1989), these groups of female distance runners did not demonstrate this relationship. However, the SF group exhibited 30% less tibial area moment of inertia (M/L level 2) values compared with the control group (Fig. 6). No differences in tibial varum were observed between the two groups (Fig. 7). A small subject population may account for discrepancies between previous studies and the results of this investigation.
Figure 6: Tibial area moment of inertia (M/L level 2) for subjects who had previously experienced a stress fracture versus healthy controls.

Figure 7: Tibial varum measurement for subjects who had previously experienced a stress fracture versus healthy controls.
In conclusion, there may be numerous underlying mechanisms associated with these stress fracture injuries that are difficult to account for in a retrospective study. Potential underlying mechanisms could have included training mileage, training surface, nutrition and history of amenorrhea. In addition, prospective studies are essential to determine whether the observed increases in these kinetic variables were present prior to the stress injury. However, based on the summary of these 3 abstracts, several of the hypotheses were supported.

2) Summary of the 2 prospective tibial stress fractures

With the relatively small number of participants who have experienced tibial stress fractures (TSF), statistical analyses of the preliminary results have not been performed. Results for each of these variables will be discussed for each individual with respect to trends observed in the data. It was hypothesized that runners who had sustained a TSF would exhibit greater average and instantaneous loading rates (ALR/ILR), vertical ground reaction forces (vGRF), peak positive tibial acceleration (PPA), stiffness, and tibial varum. In addition, it was hypothesized that these subjects would also exhibit reduced knee flexion excursion and tibial area moment of inertia.

A summary of results for the respective hypotheses for the two TSF subjects and for a group of non-injured control subjects are presented in Table 1. Overall, the two TSF subjects collectively supported the majority of the hypotheses. For example, while Subject 1 exhibited only slightly greater ALR, ILR, vGRF, and tibial varum (Figs. 8, 9, & 12; Table 1), she demonstrated very high PPA and stiffness values compared to the control group (Figs. 10 & 11; Table 1). In addition, her tibial area moment of inertia was 31% less than controls (Fig.13; Table 1). On the other hand, while Subject 2 exhibited similar vGRF and stiffness values compared to controls (Figs. 9 & 11; Table 1), her ALR, ILR, and PPA were much higher compared to controls (Figs. 8 & 10; Table 1). In addition, Subject 2 demonstrated greater tibial varum alignment and 37% less tibial area moment of inertia (M/L level 2) compared to controls (Figs. 12 & 13; Table 1).

While only a slightly higher PPA and a lower tibial area moment of inertia were common between the 2 TSF subjects, several other variables were in support of the hypotheses. The etiology of a TSF is multifactorial in nature but is related, in part, to some combination of bone structure, peak forces, loading rates, as well as lower extremity running mechanics. These results suggest that each subject exhibited unique structural measures and running mechanics that may have predisposed them to a tibial stress fracture. Overall, these are encouraging results. As more subjects experience stress fractures, we are confident that a simple screening tool to facilitate identification of those at risk can be developed.
TABLE 1: Summary of variables for the 2 prospective tibial stress fracture subjects in comparison with healthy controls.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Loading Rates (ALR)</td>
<td>80.49</td>
<td>126.38</td>
<td>77.52 (17.03)</td>
</tr>
<tr>
<td>Vertical Loading Rates (ILR)</td>
<td>111.50</td>
<td>142.35</td>
<td>108.89 (26.44)</td>
</tr>
<tr>
<td>Peak vertical GRF (vGRF)</td>
<td>2.66</td>
<td>2.55</td>
<td>2.52 (0.23)</td>
</tr>
<tr>
<td>Peak Positive Tibial Acceleration (PPA)</td>
<td>10.68</td>
<td>9.80</td>
<td>7.52 (2.96)</td>
</tr>
<tr>
<td>Stiffness</td>
<td>9.78</td>
<td>7.93</td>
<td>8.7 (1.13)</td>
</tr>
<tr>
<td>Tibia Varum</td>
<td>6.00</td>
<td>8.00</td>
<td>5.25 (2.05)</td>
</tr>
<tr>
<td>Knee Flexion Excursion</td>
<td>36.03</td>
<td>35.12</td>
<td>33.40 (3.91)</td>
</tr>
<tr>
<td>Moment of Inertia (M/L level 2)</td>
<td>13991.14</td>
<td>12782.46</td>
<td>20322.50 (7819.56)</td>
</tr>
</tbody>
</table>

Figure 8: Instantaneous loading rate for the 2 prospective tibial stress fracture subjects and healthy controls.
Figure 9: Peak vertical ground reaction force for the 2 prospective tibial stress fracture subjects and healthy controls

Figure 10: Peak positive acceleration for the 2 prospective tibial stress fracture subjects and healthy controls
Figure 11: Lower extremity stiffness for the 2 prospective tibial stress fracture subjects and healthy controls

Figure 12: Tibial varum alignment for the 2 prospective tibial stress fracture subjects and healthy controls
Figure 13: Tibial area moment of inertia (M/L level 2) for the 2 prospective tibial stress fracture subjects and healthy controls
3) List of Publications

From the data collected during year 1, one abstract was submitted and presented at the American Physical Therapists’ Association Combined Sections Meeting in Boston, Massachusetts. In addition, information from this abstract is currently being used to prepare a manuscript for the Journal of Orthopaedic and Sports Physical Therapy journal. The reference is provided below.


From the data collected during years 1 and 2, three additional abstracts have been submitted and presented at the American College of Sports Medicine National Meeting in St Louis, Missouri and at the World Congress of Biomechanics in Calgary Alberta, Canada. These abstracts are included in Appendix A and the references are provided below.


4) Degrees obtained that are supported by this award

Kelly Anne McKeown was funded on this award and graduated from the University of Massachusetts with a Masters of Science from the Department of Exercise Science in April of 2002.

5) Summary of information from the database

To date, a total of 473 entries have been recorded and there is a 96% compliance rate for subjects logging into the database on a monthly basis and recording their mileage and any injuries they may have sustained. Any subjects who do not log in on a monthly basis are contacted by telephone. Overall, we are very pleased with the compliance of the subjects involved in the study, the performance of the database program, and with the information we are continuing to collect. It is important to note that 2 subjects have dropped out of the study. One subject was in a near-fatal bicycle accident and is currently in a coma, and the other subject has decided to go on an extended vacation.

Table 2 and 3 are a summary of all retrospective and Table 4 is a summary of all prospective injuries we have collected. It is interesting to note the relatively large number of retrospective stress fractures compared to the other lower extremity injuries. We feel this is because we have been advertising this study as a stress fracture study and not as a running injury study.

<table>
<thead>
<tr>
<th>Injury Category</th>
<th>Incidence of Injury</th>
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<tbody>
<tr>
<td><strong>Retrospective Injuries</strong></td>
<td></td>
</tr>
<tr>
<td>Tibial Stress Syndrome</td>
<td>6</td>
</tr>
<tr>
<td>Previous Tibial Stress Fracture</td>
<td>21</td>
</tr>
<tr>
<td>Plantar Fasciitis</td>
<td>21</td>
</tr>
<tr>
<td>Patellofemoral Pain Syndrome</td>
<td>7</td>
</tr>
<tr>
<td>Other stress fractures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pelvic 2</td>
</tr>
<tr>
<td></td>
<td>femur 2</td>
</tr>
<tr>
<td></td>
<td>fibula 4</td>
</tr>
<tr>
<td></td>
<td>metatarsal 1</td>
</tr>
<tr>
<td>Patellar Tendinitis</td>
<td>6</td>
</tr>
<tr>
<td>Metatarsal Stress Syndrome</td>
<td>10</td>
</tr>
<tr>
<td>Lateral Ankle Sprain</td>
<td>14</td>
</tr>
<tr>
<td>Iliotibial Band Syndrome</td>
<td>23</td>
</tr>
<tr>
<td>Anterior Compartment Syndrome</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>121</strong></td>
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### TABLE 3: Summary of Prospective Injury Information Collected from the Website Database

<table>
<thead>
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</thead>
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<tr>
<td><strong>Prospective Injuries</strong></td>
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<tr>
<td>Tibial Stress Fracture</td>
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</tr>
<tr>
<td>Femoral Stress Fracture</td>
<td>1</td>
</tr>
<tr>
<td>Pelvic Stress Fracture</td>
<td>1</td>
</tr>
<tr>
<td>Metatarsal Stress Fracture</td>
<td>1</td>
</tr>
<tr>
<td>Gastrocnemius/Soleus strain</td>
<td>7</td>
</tr>
<tr>
<td>Anterior Compartment Syndrome</td>
<td>5</td>
</tr>
<tr>
<td>Achilles tendonitis</td>
<td>4</td>
</tr>
<tr>
<td>Back Strain</td>
<td>5</td>
</tr>
<tr>
<td>Iliotibial Band Syndrome</td>
<td>6</td>
</tr>
<tr>
<td>Hamstring Strain</td>
<td>2</td>
</tr>
<tr>
<td>Quadriceps Strain</td>
<td>2</td>
</tr>
<tr>
<td>Plantar Fasciitis</td>
<td>3</td>
</tr>
<tr>
<td>Patellofemoral Pain Syndrome</td>
<td>2</td>
</tr>
<tr>
<td>Ankle Sprain</td>
<td>3</td>
</tr>
<tr>
<td>Foot/Ankle Muscle Strain</td>
<td>4</td>
</tr>
<tr>
<td>Hip/Groin Muscle Strain</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>
CONCLUSIONS

The overall aim of this research is to gain insight into the etiology of tibial stress fractures using 3-D motion analysis and structural data. Data from 400 subjects will be collected at the University of Delaware and University of Massachusetts (200 at each site) over a 3-year period. 30 of the subjects will have sustained a tibial stress fracture prior to the study and the other 370 will have not. The structural and biomechanical factors leading up to a tibial stress fracture will be assessed. In addition, comparisons will be made of mechanics before and after the stress fracture to determine whether subjects revert back to their pre-injury mechanics.

This Annual Report focused on the second-year status of this investigation. Four specific work objectives were outlined and discussed with respect to adherence and methods used to meet all objectives in a timely manner. While the University of Massachusetts is still behind in the number of subjects, measures have been taken to increase recruitment efforts. We are confident that by December of 2002, we will be very close to achieving all work objectives.

To date, data on 143 subjects were collected and an analysis was performed on 2 subjects who had experienced a tibial stress fracture. In addition, 3 additional abstracts were presented at two conferences on subjects who had previously experienced a lower extremity stress fracture. Overall, the primary hypotheses were supported by the data after analysis. These are encouraging results. We are confident that additional data will provide valuable information regarding mechanics and etiology of tibial stress fractures.
REFERENCES


APPENDICES

Appendix A: Abstracts

1) Presented at the American College of Sports Medicine National Meeting

KINETIC VARIABLES IN SUBJECTS WITH PREVIOUS LOWER EXTREMITY STRESS FRACTURES

R. Ferber, I. McClay Davis, FACSM, J. Hamill, FACSM, C.D. Pollard, K.A. McKeown

University of Delaware, Newark, DE, Joyner Sportsmedicine Institute, University of Massachusetts, Amherst, MA e-mail: reedferb@udel.edu

Overuse injuries are common among competitive runners with stress fractures being one of the most serious injuries runners sustain. Females are twice as likely to experience a stress fracture as their male counterparts. The etiology of stress fractures is multifactorial in nature but is related, in part, to some combination of peak forces and loading rate as well as shock experienced by the lower extremity. However, few studies have quantified these factors in competitive female distance runners. PURPOSE: To examine differences in ground reaction force (GRF) variables and tibial acceleration between competitive female distance runners who had sustained a previous lower extremity stress fracture (SF) and uninjured control subjects (CON). METHODS: Ten CON and 10 SF subjects ran along a 25m runway at a speed of 3.7 (±0.2) m/s. GRF and tibial acceleration data were recorded from 5 trials. Peak positive tibial acceleration (PPA), peak to peak acceleration (PTP), peak vertical GRF (VGRF), stiffness, and instantaneous and average loading rate (ILR/ALR) were determined. RESULTS: SF subjects exhibited 22% greater PPA (9.24g vs 7.16g; p=0.05), 26% greater PTP (13.43g vs 9.97g; p=0.03), 36% greater VGRF (3.87BW vs 2.48BW; p=0.01), 32% greater ILR (158.61BW/s vs 108.89BW/s; p=0.03), and 34% greater ALR (117.93BW/s vs 77.52BW/s; p=0.03) as compared to CON. No differences in stiffness (8.67kN/m vs 8.74kN/m; p=0.62) were observed between the two groups. CONCLUSION: Based on the results of this study, subjects who had previously sustained a lower extremity stress fracture exhibited significantly greater GRF values and tibial acceleration. Repetitive exposure to these forces may have predisposed these subjects to overuse-related stress fracture injuries. However, prospective studies are essential to determine whether the observed increases in these kinetic variables were present prior to the stress injury.

This study was funded by the Department of the Army (#17-00-1-0515)
SELECTED STRUCTURAL CHARACTERISTICS OF FEMALE RUNNERS WITH AND WITHOUT LOWER EXTREMITY STRESS FRACTURES

C. D. Pollard, K.A. McKeown, R. Ferber, I. McClay Davis FACSM, J. Hamill FACSM, University of Massachusetts, Amherst, MA

Lower extremity stress fractures are a common injury among female distance runners. Stress fractures are thought to occur when tissues adapt abnormally to repetitive stress and may be a result of this abnormal adaptation. Selected static anthropometric measures have been implicated as a predictor of lower extremity stress fractures. PURPOSE: The aim of this investigation was to examine selected structural characteristics of female runners with and without a history of lower extremity stress fractures to gain insight into the etiology of these injuries. METHODS: Subjects consisted of 9 females with a confirmed history of at least one lower extremity stress fracture and 9 females with no stress fracture history. All subjects were between ages 18-35 and ran an average of 20 miles per week. Each subject underwent a structural evaluation by a licensed physical therapist that included measurement of tibial varum, static rearfoot angle, and arch height. Three radiographs of the distal lower extremity were used to calculate the area moments of inertia (Milgrom et al., 1989). RESULTS: There were no significant differences in the selected structural characteristics between the two groups. However, mean area moments of inertia were 30% less for the stress fracture group (p<.10). CONCLUSION: There may be numerous underlying mechanisms associated with these stress fracture injuries that are difficult to account for in a retrospective study. Potential underlying mechanisms could have included training mileage, training surface, nutrition and history of amenorrhea. Although specific structural characteristics have been associated with stress fracture injuries, these groups of female distance runners did not demonstrate this relationship. However, the observed trend towards decreased tibial area moments of inertia in the stress fracture group were consistent with previous investigations that have suggested stress fractures occur where high bending loads are found.

This study was funded by the Department of the Army (#17-00-1-0515).
INTRODUCTION
Overuse injuries are common among competitive runners with stress fractures (SF) being one of the most serious overuse injuries. SF are among the top 5 cited running-related injuries and females are twice as likely to experience a SF as their male counterparts. The etiology of SF is multifactorial in nature but is related, in part, to some combination of bone structure, peak forces, loading rates, as well as lower extremity running mechanics. Therefore, the purpose of this investigation was to examine differences in ground reaction force (GRF), tibial acceleration, bone structure, and kinematic variables between competitive female distance runners who had sustained a previous lower extremity SF and uninjured control subjects. It was hypothesized that peak tibial acceleration, vertical GRF loading rates, and lower extremity stiffness would be greater in the injured runners and area moment of inertia of the tibia and knee flexion excursion would be lower. In addition, those variables which were different would contribute significantly to the prediction of which runners had sustained a SF.

METHODS
Subjects consisted of 8 females with a history of at least one lower extremity SF and 8 females with no SF history who served as a control group (CON). All subjects were between ages 18-35 and ran between 30-80 miles per week. These subjects are part of a larger ongoing study investigating factors associated with SF in women runners. GRF and tibial acceleration data were recorded from 5 running trials. Three radiographs of the distal lower extremity were used to calculate the tibial area moment of inertia (Milgrom et al., 1989). Variables of interest included peak positive tibial acceleration (PPA), peak vertical GRF (VGRF), instantaneous loading rate (ILR), stiffness (STF), knee flexion excursion (KFlex) and tibial area moment of inertia in the anterior/posterior plane (Iap). Independent t-tests were used to assess differences between groups. A backward, stepwise statistical regression analysis was used to determine the factors that best predicted which subjects had previously suffered a SF.

RESULTS AND DISCUSSION
Of the 8 total SF, 5 were tibial, 2 were fibular and 1 was metatarsal. Results indicated that both PPA and ILR were significantly (p<0.05) greater in the SF group (Table 1). Although not significant (p>0.05), a trend towards greater stiffness and reduced knee flexion excursion in the SF group was also observed (Table 1). Williams et al. (2001) also reported a significantly higher load rate and great stiffness in a group of runners with high arch feet and a greater incidence of stress injuries. However, Crossley et al. (1999) reported no significant differences in GRF variables between SF and control subjects. Other investigations have reported that bone geometry was significantly different between SF and control groups (Crossley, 1999; Milgrom, 1989). However, in the present investigation, the SF group exhibited similar tibial Iap values as compared with the control group (Table 1). A small subject population may account for discrepancies between previous studies and the results of this investigation.

The results indicate that PPA and ILR explained 46% of the variance (p=0.01) in predicting subjects who had previously suffered a SF. (y = 3.50 + 0.12PPA + 0.01ILR). None of the remaining variables entered into the regression equation. However, it is possible that these results may change as more subjects are analyzed during this ongoing study.

SUMMARY
These data suggest that 1) subjects who had previously suffered a lower extremity SF demonstrated greater GRF loading rates, shock, and stiffness and reduced knee flexion excursion as compared with noninjured controls and 2) kinetic measures can be used to predict which subjects had previously sustained a SF.

ACKNOWLEDGEMENTS
This study was funded by the Department of the Army (#17-00-1-0515).

REFERENCES
Crossey, K. et al. (1999). MSSE, 31(8), 1088-1093
Milgrom, C. et al. (1989). J Biomech, 22(11/12), 1243-1248
Williams D.S. et al. (2001) Clin Biomech, 16(4), 341-347

Table 1: Mean (SD) and p-values of selected variables for SF and CON groups.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>SF Mean (SD)</th>
<th>CON Mean (SD)</th>
<th>p value</th>
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<tr>
<td>PPA (g)</td>
<td>8.23 (1.08)</td>
<td>6.50 (1.56)</td>
<td>0.02</td>
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<tr>
<td>ILR (BW/s)</td>
<td>119.20 (27.97)</td>
<td>90.44 (15.28)</td>
<td>0.04</td>
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<tr>
<td>STF (kN/m)</td>
<td>9.32 (1.53)</td>
<td>8.30 (0.54)</td>
<td>0.09</td>
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<tr>
<td>KFlex (°)</td>
<td>29.76 (5.70)</td>
<td>33.40 (3.91)</td>
<td>0.14</td>
</tr>
<tr>
<td>Iap</td>
<td>11016 (3175)</td>
<td>11457 (4098)</td>
<td>0.81</td>
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</table>
We are looking for Female Distance Runners who meet the criterion below to help better understand the mechanisms involved in Lower Extremity Stress Fractures (we are interested in evaluating both those individuals who have never had a stress fracture as well as those who have had a stress fracture).

As you may know, female runners are at a higher risk of sustaining a lower extremity stress fracture than their male counterparts.

As a subject you will be making a significant contribution to this area of research and will gain better understanding of your own lower extremity structure and mechanics. You will also receive $50.00 upon completion of the study.

Inclusion Criteria:
- Ages 18-45
- Average 20 miles per week

Requirements: One two-hour data collection will occur at the University of Massachusetts, Amherst and will include a lower extremity evaluation by a licensed physical therapist, 3-D motion analysis of your running gait, and an x-ray of your lower extremities.
Appendix C: Curriculum Vitae for Irene S. McClay

Irene McClay Davis
Curriculum Vitae

EDUCATION

<table>
<thead>
<tr>
<th>Degree</th>
<th>Year</th>
<th>Institution</th>
<th>Major</th>
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<tr>
<td>PhD</td>
<td>1990</td>
<td>Pennsylvania State University</td>
<td>Biomechanics</td>
</tr>
<tr>
<td>MEd</td>
<td>1984</td>
<td>University of Virginia</td>
<td>Biomechanics</td>
</tr>
<tr>
<td>BS</td>
<td>1978</td>
<td>University of Florida</td>
<td>Physical</td>
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<tr>
<td>Therapy</td>
<td>1977</td>
<td>University of Mass.</td>
<td>Exercise</td>
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</table>

EMPLOYMENT

Director of Research, Joyner Sportsmedicine Institute, (6/97 - present)
Development of research within the Joyner Sportsmedicine Institute aimed at advancing the science of sportsmedicine and improving prevention, diagnosis and treatment of sports-related injuries.

Associate Professor, Program in Physical Therapy, University of Delaware. (5/97 - present)

Assistant Professor, Program in Physical Therapy, University of Delaware. (9/89 - 5/97)
Instruction of graduate students in physical therapy. Research in clinical biomechanics with specific interest in lower extremity mechanics and injury. Director, Running Injury Clinic.

Research Assistant, Pennsylvania State University, Center for Locomotion Studies. (8/85 - 6/89)
Responsible for the development and coordination of the Running Injury Clinic and Orthopedic Clinic. Research activities in locomotor biomechanics. Consultant to the Distance Runner's Camp at US Olympic Training Center.

Research and Teaching Assistant, University of Virginia, Rehabilitation Engineering Center. (8/82-8/85)
Research activities in wheelchair ergonomics. Instructor of graduate courses in biomechanics and human dissection. Co-coordinator of the Arts and Science of Sports Medicine Conference held annually at the University of Virginia (6/84, 6/85)
Physical Therapist, Blue Ridge Rehabilitation Associates, Charlottesville, VA (1/83 - 7/85)
Part time home health and private practice physical therapy.

Physical Therapist, Woodrow Wilson Rehabilitation Center, Fishersville, VA (2/79 - 6/82)
Patient treatment, supervision of physical therapy students, inservice training and
Coordinator of the Amputee Clinic. Instructor in continuing education course in

GRANTS

The Effect of Wedged Foot Orthoses on Lower Extremity Mechanics and Function in
Patients with Knee Osteoarthritis. Submitted to the National Institutes of Health
(COBRE Grant) $932,815 for 5 years (funded)

A Comparison of Custom and Semicustom Foot Orthotic Devices on Lower Extremity
Mechanics and Comfort. The Pauline Marshall Research and Education Foundation,
$15,000 for one year grant period beginning 9/2001.

Biomechanical Factors Associated with the Etiology of Stress Fractures in Runners. The
Department of the Army. $1.05 million for 5 yr grant period beginning 9/2000.

2 Doctoral Scholarship. $20,000. Joyner Sportsmedicine Institute, 1998, 1999, 2000,
2001

Undergraduate Summer Scholarship. $4,000. Joyner Sportsmedicine Institute, 1997 and

A Comparison of Four Methods to Obtain a Negative Impression of the Foot, $3,250,
Foot Management, Inc, 1998-1999

The Effect of Different Orthotic Devices on Lower Extremity Mechanics of Rearfoot and

The Effect of the Protonics System on Patellar Alignment and Gait in Patients with
Patellofemoral Joint Pain. $18,000. Funded by Inverse Technology, 1998-1999

Clinical Efficacy of the Protonics System in Patients with Patellofemoral Joint Pain.
$3,000. Funded by Inverse Technology, 1998-1999

A Comparison of Strengthening vs. Orthotics on Pronation and Pronation Velocity.
Funded by the Physical Therapy Foundation $60,000, 1993-1995

Lower Extremity Mechanics and Injury. Funded by the Whitaker Foundation $180,000,
1993-1996.

The Relationship between Subtalar Joint Axis Orientation, Joint Motion and Injuries in
Runners. Funded by the Biomedical Research Support Grant. $2550, 1992

The Relationship between Subtalar Joint and Knee Joint Motion in Runners. Funded by
the University of Delaware Research Foundation. $16,000, 1990.

PUBLICATIONS


In Review

Butler, R, McClay Davis, I, Laughton, C and Hughes, M. Can a dual function orthosis control rearfoot motion and attenuate shock? (in review) Foot and Ankle


Williams, DS, McClay, IS, Scholz, JP, Hamill, J, Buchanan, TS (2001). Lower extremity stiffness in runners with different foot types (in review) *Gait and Posture*

Laughton, CA, McClay, IS, Hamill, J and Richards, J (2001). The Effect of Orthotic Intervention and Strike Pattern on Rearfoot Motion in Runners. (in review) *Clinical Biomechanics*


**ABSTRACTS**


Leetun, DT, Ireland, ML, Ballantyne, BT and McClay, IS. Differences in Core Stability between Male and Female Collegiate Basketball Athletes as Measured by Trunk and Hip Performance. Presented at the ACL Research Retreat, Lexington, KY, April, 2001

Ireland, ML, Ballantyne, BT, Little, K and McClay, IS. A Radiographic Analysis of the Relationship between the Size and Shape of the Intercondylar Notch and Anterior Cruciate Ligament Injury Presented at the ACL Research Retreat, Lexington, KY, April, 2001
Shapiro, R, Yates, J, McClay, I, and Ireland, ML. Male-Female Biomechanical Differences in Selected Landing Maneuvers. Presented at the ACL Research Retreat, Lexington, KY, April, 2001

Laughton, CA, McClay, IS, Hamill, J Effect of Orthotic Intervention and Strike Pattern on Tibial Shock in Runners. Presented at the International Society of Biomechanics, Zurich, Switzerland, July, 2001


Laughton, CA and McClay, IS. Relationship between Loading Rates and Tibial Accelerometry in Forefoot Strike Runners. Presented at the Annual American Society of Biomechanics Mtg, Chicago, IL, July, 2000


Williams, DS and McClay, IS. Injury Patterns in Runners with Pes Cavus and Pes Planus. Presented at the ACSM National Mtg in Indianapolis, IN, 6/00.

Sahte, V, Ireland, ML, Ballantyne BT and McClay, IS. Acute Effect of the Protonics System on Patellofemoral Alignment. Presented at the ACSM National Mtg in Indianapolis, IN, 6/00.

Ott, S, Ireland, ML, Ballantyne, BT and McClay, IS. Gender Differences in Functional Outcomes following ACL Reconstruction. Presented at the ACSM National Mtg in Indianapolis, IN, 6/00.
Williams, DS, McClay, IS & Laughton, CA. A Comparison of between day Reliability of Different Types of Lower Extremity Kinematic Variables in Runners. Presented at the American Society of Biomechanics, 10/99, Pittsburgh, PA.

McClay, IS, Williams, DS & Laughton, CA. Can Gait be Retrained to Prevent Injury in Runners? Presented at the American Society of Biomechanics, 10/99, Pittsburgh, PA.

McClay, IS, Williams, DS and Baitch, S. The Effect of the Inverted Orthotic on Lower Extremity Mechanics. Presented at the International Society of Biomechanics Mtg, 8/99, Calgary, Canada


Laughton, CA, McClay, IS and Williams, DS. A Comparison of Methods of Obtaining a Negative Impression of the Foot. Presented at the National APTA Conference, Washington, DC, 6/99


McClay, IS, Williams, DS, and Manal, KT. Lower Extremity Mechanics of Runners with a Converted Forefoot Strike Pattern. NACOB, Chicago, IL, 1998


McClay, IS The Relationship between Lower Extremity Mechanics and Injury in Runners to be presented at the Whitaker Conference, Utah, August, 1996.


McClay, IS & Manal, KT Lower Extremity Kinematic Comparisons between Forefoot and Rearfoot Strikers. Presented at the American Society of Biomechanics Meeting, Stanford, CA 8/95

McClay, IS & Manal, KT Lower Extremity Kinetic Comparisons between Forefoot and Rearfoot Strikers. Presented at the American Society of Biomechanics Meeting, Stanford, CA 8/95

McClay, IS & Manal, KT Coupling Parameters in Runners who Pronate and Normals. Presented at the American Society of Biomechanics Meeting, Columbus, Ohio, 11/94.

McClay, IS, Cavanagh, PR, Sommer, HJ, & Kalenak, A: "Three-Dimensional Kinematics of the Patellofemoral Joint during Running". Proceedings of the American Society of Biomechanics Meeting, 10/91, Tempe, AZ.


SELECTED INVITED PRESENTATIONS


"The Effect of the Inverted Orthotic on Lower Extremity Mechanics: An Update" 
Presented at the Prescription Foot Orthotic Laboratory Association Annual Meeting, 
Miami, FL, November, 2001

"How Do Foot Orthotic Devices Influence Lower Extremity Mechanics: Evidence from 
the Literature. Presented at the Prescription Foot Orthotic Laboratory Association 
Annual Meeting, Miami, FL, November, 2001

"Selected Case Studies in Running Injuries" Presented at the Combined Sections 
Meeting of the APTA, San Antonio, TX, Feb, 2001.

"Developing Standards in Epidemiological Research" Presented at the National ACSM 
Mtg in Indianapolis, June, 2000

"Lower Extremity Mechanics and Injury Patterns in High and Low Arch Runners". 
Keynote Presented at the Foot and Ankle Research Retreat, Annapolis, MD, 
May, 2000

"Effect of the Inverted Orthotic on Rearfoot and Knee Mechanics" Presented at the 4th 
Annual John Weed Seminar, Palm Springs, CA, March, 2000 and the PFOLA 
meeting in Vancouver, BC, November 2000

"Influence of foot, knee and hip coupling on patellofemoral mechanics" Symposium at 
the Combined Sections Meeting of the APTA, New Orleans, LA, February, 2000 and 
at the National ACSM Mtg in Indianapolis, June, 2000, and the Arts and Science of 
Sports Medicine, Charlottesville, VA, June, 2000.

"Visual Gait Analysis in Runners" Presented at the Arts and Science of Sports Medicine, 

"Injury Mechanisms in Runners" Keynote speaker at the Fifth IOC Congress on Sport 
Sciences, Sydney, Australia, November, 1999

"Clinical Gait Analysis" Keynote speaker at the Fifth IOC Congress on Sport Sciences, 
Sydney, Australia, November, 1999.

"Risk Factors in Anterior Cruciate Ligament Injuries" Clinical Colloquium presented at 
the National ACSM Mtg, in Seattle, WA, 6/99

"Problem Solving the Injured Runner" Clinical Colloquium presented at the National 
ACSM Mtg, in Seattle, WA, 6/99

"Coupling between the Foot and the Knee in Runners" Presented at Joyner 
Sportsmedicine Institute National Conference, Hilton Head, SC, 10/99

"Biomechanics of the Knee" Presented at Joyner Sportsmedicine Institute National 
Conference, Hilton Head, SC, 10/99

"Physical Therapist to Marathoner - A Classical Tale of Overuse." Presented at the Case 
Conference Seminar at the Annual Conference of the American Physical Therapy 
Association, Minneapolis, MN, 6/98.

Eugene Michels Research Forum - “Instrumented versus Visual Gait Analysis in Clinical 
Assessments” Presented at the Combined Sections Meeting in Dallas, TX, 2/97.


"The Use of Motion Analysis in Physical Therapy". University of PA, Philadelphia, 10/95.

"The Patellofemoral Joint - Implications of the study of three-dimensional kinematics". Grand Rounds, Dept. of Orthopedic Surgery, Hershey Medical Center, 1/95.

"What is Clinical Research". Keynote Address at Research Symposium, Shenandoah University, 4/94

"Research in Foot and Ankle Biomechanics". Presented at the Combined Sections Meeting of the American Physical Therapy Association, New Orleans, LA, 2/94

"Biomechanical Assessment of Gait" Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/93

"Closed Kinetic Chain Activities for the Foot and Ankle" Presented at the Foot and Ankle Seminar for HealthSouth in Orlando, FL, 2/93, Phoenix, AZ, 3/93, St. Louis, MO, 4/93 and for Foot Mgt, Inc in Ocean City, MD in 10/94 and 4/96.

"Normal Structure and Gait". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/92, and at the Symposium on the Biomechanics of the Lower Extremity, NATA, Denver, CO, 2/92.


"Biomechanics of the Foot and Ankle". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/91.


"Anatomy and Biomechanics of the Patellofemoral Joint". Presented at the Sports Physical Therapy Meeting, Orlando, Fla. 12/90.


"Biomechanical Perspective of Stress Fractures in Professional Basketball Players". Presented at the Annual Meeting of the NBA Physicians, West Palm Beach, Fl, 11/88.


"Biomechanical Profile of Elite Woman Distance Runners". Presented at the Dogwood Festival Pre-race Conference, Atlanta, GA, 7/88.

HONORS

<table>
<thead>
<tr>
<th>Physical Therapy Foundation Scholar</th>
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<tr>
<td>Recipient of Zipser Scholarship, The Penn State University</td>
<td>1988</td>
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<tr>
<td>Outstanding Masters Student Award, University of Virginia</td>
<td>1984</td>
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<td>Nominee for Mary McMillan Scholarship Award, APTA</td>
<td>1978</td>
</tr>
<tr>
<td>Magna Cum Laude Graduate, University of Florida</td>
<td>1978</td>
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<tr>
<td>Magna Cum Laude Graduate, University of Massachusetts</td>
<td>1977</td>
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PROFESSIONAL ACTIVITIES

Societies

- American Society of Biomechanics
  - Organizing Committee, Annual ASB Mtg, Chicago, IL, July 2000
  - Membership Committee (1997-2001)
- American College of Sports Medicine, Fellow
- American Physical Therapy Association (APTA)
  - Orthopedic and Research Sections Member
  - Chairperson of Research Committee of the Foot and Ankle Special Interest Group (1997-present)
- International Society of Biomechanics

Advisory

- Invited Participant to the “Working Conference on Gait Analysis in Rehabilitation Medicine” National Institutes for Health, September, 1996
- Medical Consultant for Runners World (1995-present)

Ed. Board

- Clinical Biomechanics (1999-present)

Reviewer

- Journal of Biomechanics
- Medicine and Science in Sports and Exercise
- Foot and Ankle, International
- Journal of the American Podiatric Medical Association
- Journal of Applied Biomechanics
| Other | Organizing Chair for Research Retreat - Static and Dynamic Classification of the Foot. Annapolis, MD, May, 2000.  
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<tr>
<td>Licensure</td>
<td>Licensed Physical Therapist, State of Delaware</td>
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Appendix D: Curriculum Vitae for Joseph Hamill

CURRICULUM VITA

Joseph Hamill, Ph.D.

Professor and Chair
Department of Exercise Science
University of Massachusetts Amherst
Director, Biomechanics Laboratory
University of Massachusetts Amherst

BUSINESS ADDRESS: Biomechanics Laboratory
Department of Exercise Science
University of Massachusetts
Amherst, MA 01003
(413) 545-2245
(413) 545-2906 Fax

E-MAIL ADDRESS: jhamill@excsci.umass.edu

EDUCATION

<table>
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<tr>
<th>Year</th>
<th>Degree</th>
<th>Institution</th>
<th>Area of Study</th>
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<tr>
<td>1967</td>
<td>Teaching Certificate</td>
<td>Lakeshore Teacher's College, Toronto, Canada</td>
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<tr>
<td>1972</td>
<td>B.A.</td>
<td>York University, Toronto, Canada</td>
<td>General Science</td>
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<tr>
<td>1977</td>
<td>B.S. (magna cum laude)</td>
<td>Concordia University, Montreal, Canada</td>
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<td>1978</td>
<td>M.S.</td>
<td>University of Oregon, Eugene, Oregon</td>
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<tr>
<td>1981</td>
<td>Ph.D.</td>
<td>University of Oregon, Eugene, Oregon</td>
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Undergraduate Areas of Study: Political Science General Science
Graduate Area of Study: Biomechanics

RESEARCH INTERESTS
Mechanics of lower extremity function
Mechanical Analysis of normal and pathological gait.
Modeling the lower extremity in gait.
Optimality criteria in human locomotion
Dynamical Systems
EMPLOYMENT EXPERIENCE

1977-1979  Graduate Teaching Fellow
           Biomechanics Laboratory, University of Oregon

1979-1981  Graduate Research Fellow
           Biomechanics Laboratory, University of Oregon

1981-1982  Post-doctoral Fellow
           Biomechanics Laboratory, University of Oregon

1982-1985  Assistant Professor (Biomechanics)
           Department of Physical Education, Southern Illinois University

1985-1986  Assistant Professor (Biomechanics) and Graduate Program Director
           Department of Physical Education, Southern Illinois University

1986-1988  Assistant Professor (Biomechanics)
           Department of Exercise Science, University of Massachusetts

1989-1995  Associate Professor (Biomechanics) and Graduate Program Director
           Department of Exercise Science, University of Massachusetts

1990-1995  Adjunct Professor
           Department of Medicine, University of Massachusetts Medical Center

1995-1996  Associate Professor (Biomechanics) and Department Chair
           Department of Exercise Science, University of Massachusetts

1996-present Professor (Biomechanics) and Department Chair
            Department of Exercise Science, University of Massachusetts

RESPONSIBILITIES OF PRESENT POSITION

Department Chair
Director of the Biomechanics Laboratory
Teach graduate and undergraduate courses in Biomechanics
Advise undergraduate and graduate students
Chair graduate theses and dissertations in the Department
Conduct research in the area of Biomechanics
Secure external funding for the Biomechanics Laboratory

TEACHING RESPONSIBILITIES

At Southern Illinois University

Undergraduate
P.E. 302  Kinesiology for Physical Therapy
P.E. 370  Tests and Measurements

Graduate
P.E. 511  Mechanical Analysis
P.E. 512  Biomechanics of Sport
P.E. 505A Biomechanics Instrumentation
P.E. 505B Computer Applications
P.E. 505C Biomechanics of the Musculo-skeletal System
P.E.  561  Doctoral Seminar
At University of Massachusetts

Undergraduate
Ex Sc 300 Writing Seminar for Exercise Science
Ex Sc 305 Kinesiology
Ex Sc 304 Human Anatomy
Ex Sc 311 Anatomy of Human Motion
Ex Sc 474 Tests and Measurements

Graduate
Ex Sc 531 Mechanical Analysis of Human Motion
Ex Sc 611 Introduction to Research
Ex Sc 732 Advanced Biomechanics
Ex Sc 892 Doctoral Seminar
Ex Sc 895 Clinical Biomechanics Seminar

UNIVERSITY SERVICE

Department Committees
Master's Thesis Review Committee, 1982-1983
Comprehensive Examination Review Committee, 1983-1984
Chair, Graduate Faculty, 1982-1986
Chair, Search Committee for Department Chairperson, 1986
Graduate Committee, 1986-
Telecommunications Committee, 1988-1990
Chair, Department Personnel Committee, 1994-1995
Chair, Motor Control Search Committee, 1994-1995

College Committees
College Computer Advisory Committee, 1982-1986
School Personnel Committee, 1994-1995
School Executive Committee, 1995-
Member, School Development Officer Search Committee, 1997.

University Committees
Graduate Council, 1991
Recruitment and Retention Committee, 1991-1992
Research Council, 1992-1995

PROFESSIONAL ORGANIZATIONS

American Alliance for Health, Physical Education, Recreation and Dance
Biomechanics Academy of the Research Consortium
International Society of Biomechanics
Canadian Society of Biomechanics
American Society of Biomechanics
American College of Sports Medicine
New England College of Sports Medicine
International Society of Biomechanics in Sport
ASTM
RESEARCH AFFILIATIONS
Scientific Advisory Board, LifeFitness, Inc., 1993-
Scientific Advisory Board, USA Field Hockey, 1995-1998

ACADEMIC HONORS
Fellow, Research Consortium of the AAHPERD, 1984
Fellow, American College of Sports Medicine, 1986
Fellow, American Academy of Kinesiology and Physical Education, 1997

OFFICES IN PROFESSIONAL ORGANIZATIONS
1. Chair-elect, Kinesiology Academy, 1990-91.
   3. Chair, Biomechanics Interest Group of the American College of Sports Medicine, 1996-97.
4. Member-at-large, Executive Committee of the New England Chapter of the American College of Sports Medicine, 1995-
7. Member, Credentials Committee, American College of Sports Medicine, 2000-
8. Member-at-Large, Executive Board of Canadian Society of Biomechanics, 2000-

PROFESSIONAL SERVICE
Review Committees For Professional Meetings
3)Program Committee, combined meeting of the 9th International Symposium on Biomechanics in Sports
4)and the Kinesiology Academy, June 29 - July 7, 1991.

External Reviewer for Theses and Dissertations

**External Grant Reviewer**
1. External Reviewer for internal grants at University of Texas at Tyler, 1991.

**Committee Member**
12. Continuing Committee for Doctoral Program Review, American Academy of Kinesiology and Physical Education, 2001-
15. Member, Holyoke Community College Department of Health and Fitness Advisory Board, 2001-

**EDITORIAL BOARD OF PROFESSIONAL JOURNALS**
1. Member, Editorial Review Board, Pediatric Exercise Science, 1988-
4. Section Editor, Biomechanics, Research Quarterly for Exercise and Sport, 1993-96
6. Member, Research Quarterly for Exercise and Sport Editorial Board, 1998-2002
7. Chair, Research Quarterly for Exercise and Sport Editorial Board, 2001-2002
8. Associate Editor, Medicine and Science in Sports and Exercise, 2000-2002
9. Member, Editorial Review Board, Sports Biomechanics, 2000-
10. Member, Editorial Board, Journal of Sports Sciences, 2001-

**REVIEWER FOR PROFESSIONAL JOURNALS**
1. Reviewer, Medicine and Science in Sports and Exercise, 1985-
2. Reviewer, International Journal of Sports Biomechanics, 1986-
3. Reviewer, Research Quarterly for Exercise and Sport, 1989-
4. Reviewer, Sports Medicine, 1991-
5. Reviewer, Journal of Gerontology, 1991-
7. Reviewer, Journal of Applied Biomechanics, 1993-
8. Reviewer, Journal of Applied Physiology, 1993-
9. Reviewer, Journal of Biomechanics, 1993-
10. Reviewer, Clinical Journal of Sports Medicine, 1996-
11. Reviewer, British Journal of Sports Medicine, 1996-
12. Reviewer, Clinical Biomechanics, 1999-
13. Reviewer, Exercise and Sports Science Review, 2000-
14. Reviewer, European Journal of Applied Physiology, 2000-

PUBLICATIONS


**MANUSCRIPTS UNDER REVIEW**


**MANUSCRIPTS IN PREPARATION**


*Hamill, J.*, Derrick, T. R. Co-contraction of lower extremity muscles under varying stride frequency conditions.


**PROCEEDINGS**


PUBLISHED ABSTRACTS


BOOKS

BOOK CHAPTERS

NON-REFEREED PUBLICATIONS


PUBLISHED RESEARCH REPORTS


PUBLISHED BOOK REVIEWS


PRESENTATIONS
International:

National:

Regional, State, and Local:


KEYNOTE PRESENTATIONS

**INVITED PRESENTATIONS**

2. Medio-lateral foot function during locomotion. University of Illinois Graduate Faculty and students, Champaign, IL, February, 1983.
8. If the shoe fits: A biomechanical analysis of locomotion. Sigma Xi Society, University of Massachusetts, Amherst, MA, November 16, 1988.
16. Biomechanical considerations for equipment design in children's sports. Seminar on Children's Activities, United Hospital Medical Center, Port Chester, NY, March 28, 1992.
29. If the shoe fits: the biomechanics of running shoes. American Medical Athletic Association, Boston, MA, April 12, 1996.
38. From a Pendulum to a Spring. Department of Kinesiology, Louisiana State University, Baton Rouge, LA, October 24, 2000.
42. Mechanical models and human locomotion. Beijing University, China, October 18, 2001.
45. The role of variability in running injuries. Invited Symposium at the Annual Meeting of the American College of Sports Medicine, St. Louis, MO, June, 2002.

GRANTS AND GIFTS