THE EFFECTS OF SEX AND FATIGUE ON LOWER EXTREMITY BIOMECHANICS DURING A BILATERAL SQUAT

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SUMMARY
Females are at higher risk of developing patellofemoral pain syndrome than males possibly due to differences in the biomechanics of commonly performed athletic activities. The objective of this project was to assess the biomechanics of bilateral squat in 16 male and 16 female recreational athletes before and after following a fatigue protocol while controlling for skeletal alignment differences and knee flexion angle. Females performed squats with increased knee valgus and hip adduction compared to males. Fatigued athletes exhibited increased rectus femoris and medial hamstrings electromyographic activity. Pre-season screening with this simple squat test may allow early identification of female athletes at risk of developing PFPS and enrollment in targeted intervention programs. Female athletes performed bilateral squats with lower ability to control frontal plane motion of the knee and hip than their male counterparts. This lack of control may be a contributing factor to the higher incidence of PFPS among female athletes.

INTRODUCTION
A recent large epidemiological study [1] has demonstrated that females are at higher risk of developing patellofemoral pain syndrome (PFPS) than males. A likely cause of this disparity is that females perform common athletic maneuvers such as squatting with different biomechanics than their male counterparts. However, very limited research exists on this topic. One study [2] investigated sex differences during a unilateral squat but did not account for variation in lower extremity alignment (which is commonly different between males and females), did not control for knee flexion angles and did not assess the effect of fatigue. Therefore, the objective of this study was to assess the effect of sex and fatigue on lower extremity biomechanics during a bilateral squat while controlling for skeletal alignment variation and for knee flexion.

METHODS
Sixteen female [age=28.2 (5.4) years, height=167(5.9) cm, weight=59(5.8) kg] and 16 male [age=28.8 (3.9) years, height=181.7 (7.4) cm, weight= 81(10.4) kg], with no history of serious lower extremity injury participated in the study. Electromyographic (EMG) data were collected with Noraxon EMG at 1200 Hz and kinematic data were collected with eight Eagle cameras (Motion Analysis Corp.) tracking a 22 marker set (Helen Hayes) at 240 Hz. Data of the right leg were analyzed as subjects performed three bilateral squats to 100° of knee flexion before and after a functional fatigue protocol that consisted of 100 jumps over short (5-7cm) obstacles and 50 maximal effort vertical jumps. Data were extracted at discrete points of the squat cycle when knee flexion was at 25° and 40° to allow comparison across subjects. An initial “neutral” standing position of each subject was used to account for skeletal alignment differences. EMG data were normalized to peak activity exhibited by each muscle during a 20cm drop jump to allow comparison across groups.

Repeated-measures ANOVA were used to determine the effect of gender and fatigue on hip adduction and knee valgus kinematics as well as on EMG of the rectus femoris, medial hamstrings and lateral hamstrings. The α level was set a priori at 0.05.

RESULTS AND DISCUSSION
Females performed the bilateral squats with more knee valgus (p=0.004) and hip adduction (p=0.047) compared to males. Fatigued athletes performed squats with higher EMG of the rectus femoris and medial hamstrings (p=0.001). There were no statistically significant interaction effects. Hip adduction angle was decreased and EMG activity of the rectus femoris and medial hamstrings were increased at 40° compared to 25° of knee flexion (p≤0.004).

The findings of the present study demonstrate that female athletes perform bilateral squats with decreased ability to control frontal plane motion of the lower extremities. This may cause lateral tracking of the patella and subsequent PFPS. Excessive knee valgus and hip adduction increase the “dynamic” Q angle and subsequently increase contact pressure on the lateral compartment of the patellofemoral joint [3]. Pre-season screening with this simple squat test may allow early identification of female athletes at risk of developing PFPS and enrollment in targeted intervention programs.

Fatigue caused an increase in EMG activity of the rectus femoris and the medial hamstrings. Although interpretation of EMG changes in the presence of fatigue is difficult, the increases observed may be a response of the neuromuscular system by recruiting additional muscle fibers of the fatigued muscles to successfully complete the squatting task. Fatigue did not have a differential effect on male and female athletes; however, a more intense or longer fatigue protocol may have elicited different results.
Progression of the squat from 25° to 40° of knee flexion increased hip abduction angle and EMG activity of the rectus femoris and the medial hamstrings regardless of sex or level of fatigue. As this is the range that patients with PFPS commonly experience symptoms, the observed changes may suggest that control of hip adduction and earlier activation of the quadriceps and hamstrings may be protective for the patellofemoral joint. However, this theory can only be confirmed with prospective coupled biomechanical-epidemiological studies.

**CONCLUSIONS**
Female athletes performed bilateral squats with lower ability to control frontal plane motion of the knee and hip than their male counterparts. This lack of control may be a contributing factor to the higher incidence of PFPS among female athletes. Fatigue caused increases in EMG activity of the rectus femoris and medial hamstrings.

**REFERENCES**

### Table 1. Kinematic and electromyographic variables (mean and standard errors) in male and female athletes during a bilateral squat.

<table>
<thead>
<tr>
<th></th>
<th>Pre-fatigue</th>
<th>Post-fatigue</th>
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<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td><strong>Hip Adduction (°)</strong></td>
<td>-3.7(0.6)</td>
<td>-2.3(0.6)</td>
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<tr>
<td><strong>Knee valgus (°)</strong></td>
<td>-5.2(1.3)</td>
<td>-0.8(1.3)</td>
</tr>
<tr>
<td><strong>Rectus femoris EMG(%)</strong></td>
<td>10.4(1)</td>
<td>10.0(1)</td>
</tr>
<tr>
<td><strong>Medial hamstrings EMG(%)</strong></td>
<td>7.0(2)</td>
<td>9.6(2)</td>
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<td><strong>Lateral Hamstrings EMG (%)</strong></td>
<td>5.2(2)</td>
<td>1.9(2)</td>
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