THE EFFECTS OF LOWER-LIMB FATIGUE ON KNEE JOINT MECHANICS DURING GAIT IN YOUNG WOMEN

Heather S. Linley, Stacey M. Acker and Monica R. Maly
School of Rehabilitation Science, McMaster University, Hamilton, ON, Canada, email: mmaly@mcmaster.ca

INTRODUCTION
Fatigue refers to the complex mechanisms that reduce the efficiency of a system after prolonged exposure to activity [1]. Neuromuscular fatigue around the knee occurs when the quadriceps and hamstrings muscles are unable to maintain voluntary force production. Fatigue alters knee joint mechanics during weight-bearing activities and increases risk for injury. In 16 healthy, young participants, neuromuscular fatigue of the knee extensors resulted in reduced knee flexion angle and angular velocity at heel strike, and a reduced the peak knee extensor moment [2].

Fatigue may also be a risk factor for knee osteoarthritis (OA). Quadriceps weakness is strongly associated with knee pain and disability, and is thought to contribute to the incidence and progression of OA by impairing the ability to dampen loads across the knee [3]. Also, it is hypothesized that fatigue alters knee joint kinematics and kinetics to mimic the abnormal patterns observed in knee OA [4]. Knee OA is linked with an elevated knee adduction moment and greater dynamic knee stiffness during gait [5].

It remains unclear whether neuromuscular fatigue induced by repetitive exercise targeting the quadriceps and hamstrings increases the knee adduction moment or dynamic knee stiffness. If true, fatigue may be an important risk factor for the development of OA in the knee.

This study aimed to evaluate the impact of knee extensor and flexor fatigue, induced by repetitive isotonic exercise, on the adduction moment and dynamic stiffness of the knee during gait in healthy, young women. We hypothesized that neuromuscular fatigue of the knee extensors and flexors would increase the knee adduction moment and stiffness during gait.

METHODS
We studied the right knees of 9 active, healthy women (24.6 ± 3.8 years, Body Mass Index: 23.4 ± 3.3 kg/m²). Participants were familiarized with the instruments and protocol one week prior to collection.

This study utilized a repeated measures design. Measures of gait (knee adduction-abduction moment, dynamic knee stiffness) and peak torque were completed at three time points: Baseline (BL) and after two consecutive bouts of fatigue, labeled as Post-Fatigue 1 (PF1) and Post-Fatigue 2 (PF2). Two fatigue bouts enabled collection of additional gait trials while minimizing the risk of recovery from fatigue.

Measures
Gait analysis was conducted with an 8 camera passive motion capture system sampling at 100 Hz (MX40, Oxford Metrics, Oxford, UK). Twenty-four reflective markers were affixed to landmarks based on the Plug-in Gait Lower Extremity Model (Vicon Nexus, Oxford Metrics, Oxford, UK). Motion capture was synchronized with three force platforms sampling at 100 Hz (AMTI, Watertown, MA, USA). Data was exported to Visual3D (C-Motion, Inc., Germantown, MD, USA) for analysis. External joint moments were normalized to body mass, and moments and angles were time normalized to the stance cycle of gait. The mean of 5 gait trials was calculated for each participant. Joint moment and angle data were ensemble averaged across all participants to provide representative curves for each of BL, PF1 and PF2. Discrete parameters, including peaks, maximums and minimums were extracted for the frontal and sagittal plane knee moments and angles. Dynamic knee stiffness was calculated as the change in knee flexion moment divided by the change in knee flexion angle during loading response (6-25% stance) [6]. Dynamic knee stiffness was the slope of a linear regression line fitted to the data points for each set of gait trials separately.

Peak knee extensor and flexor torque (Nm) during a maximum voluntary isometric contraction (MVIC) at 60° were recorded on a dynamometer (Biodex Medical Systems, Shirley, NY, USA). Peak torque for extension and flexion were each represented by a single value over 5 isometric cycles.

Fatiguing Contractions
An isotonic protocol was selected to induce fatigue with repetitive dynamic contractions. Resistance was standardized to 50% MVIC for both knee extension and flexion. Participants repeated sets of 50 concentric knee extensions and flexions until MVIC dropped by 25% in either muscle group.

Protocol
At BL, participants completed gait analysis and MVIC. Then, participants completed sets of 50 isotonic knee extensions and flexions until MVICs dropped by 25%. Once fatigued, participants repeated gait analysis (PF1). Then participants repeated fatiguing contractions. Once fatigued a second time, participants repeated gait analysis (PF2).

Statistical Analysis
A repeated measures analysis of variance and post hoc tests were used to identify differences in measures between BL, PF1 and PF2 (alpha=0.05, adjusted using a Bonferroni correction for multiple comparisons).
RESULTS AND DISCUSSION
The fatigue protocol reduced peak knee extensor and flexor torque from BL to each of PF1 and PF2 (Table 1). Gait speed decreased from PF1 to PF2; and stride length decreased from BL to PF1 and from BL to PF2.

The first and second peak of the knee adduction moment waveform were unaffected by the fatigue protocol (Figure 1).

Dynamic knee stiffness remained unchanged after fatigue (Figure 2). However, the peak knee extension moment decreased from BL to PF1 and again from BL to PF2, suggesting that fatigue of the knee extensors and flexors altered loading across the knee (Table 1).

CONCLUSIONS
Neuromuscular fatigue of knee extensors and flexors did not affect the net medial-lateral loads applied to the knee in a sample of healthy young women. Similarly, fatigue of the knee musculature did not affect dynamic knee stiffness. These findings suggest that neuromuscular fatigue does not incite alterations in gait that mimic knee OA.

Nonetheless, neuromuscular fatigue of knee extensors and flexors did slow gait by reducing stride length. Fatigue reduced the external knee extension moment during late stance. It is possible that co-activation, often caused by fatigue, influenced this alteration in the knee flexion-extension moment [6]. Future work will evaluate the muscle activation patterns during gait before and after fatigue in this sample.

ACKNOWLEDGEMENTS
Natural Science & Engineering Research Council of Canada – Discovery Grant 353715 (MRM).

REFERENCES

Table 1: Mean (standard deviation) of peak torque and gait measures before and after neuromuscular fatigue.

<table>
<thead>
<tr>
<th>Measure</th>
<th>BL</th>
<th>PF1</th>
<th>PF2</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak isometric torque (Nm) – Extension</td>
<td>167.81</td>
<td>120.83</td>
<td>120.95</td>
<td>p = 0.002(^a), p = 0.001(^b)</td>
</tr>
<tr>
<td>Peak isometric torque (Nm) – Flexion</td>
<td>79.96</td>
<td>58.60</td>
<td>56.27</td>
<td>p = 0.003(^a), p = 0.001(^b)</td>
</tr>
<tr>
<td>Gait speed (m/s)</td>
<td>1.34 (0.16)</td>
<td>1.31 (0.20)</td>
<td>1.28 (0.21)</td>
<td>p = 0.026(^c)</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>1.26 (0.14)</td>
<td>1.22 (0.14)</td>
<td>1.20 (0.16)</td>
<td>p = 0.046(^a), p = 0.013(^b)</td>
</tr>
<tr>
<td>Knee Adduction /Abduction Moment (Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First Peak</td>
<td>0.42 (0.14)</td>
<td>0.40 (0.14)</td>
<td>0.42 (0.14)</td>
<td>NS</td>
</tr>
<tr>
<td>Second Peak</td>
<td>0.32 (0.16)</td>
<td>0.29 (0.15)</td>
<td>0.31 (0.13)</td>
<td>NS</td>
</tr>
<tr>
<td>Dynamic Knee Stiffness (Nm/degree)</td>
<td>0.038 (0.006)</td>
<td>0.030 (0.006)</td>
<td>0.033 (0.006)</td>
<td>NS</td>
</tr>
<tr>
<td>Knee Flexion Angle (degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First Peak</td>
<td>14.99 (3.83)</td>
<td>14.42 (4.04)</td>
<td>14.45 (3.32)</td>
<td>NS</td>
</tr>
<tr>
<td>Knee Flexion / Extension Moment (Nm/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>0.35 (0.21)</td>
<td>0.31 (0.23)</td>
<td>0.32 (0.19)</td>
<td>NS</td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.26 (0.18)</td>
<td>-0.21 (0.22)</td>
<td>-0.20 (0.18)</td>
<td>p = 0.018(^a), p = 0.005(^b)</td>
</tr>
</tbody>
</table>

BL = Baseline, PF1 = Post-Fatigue 1, PF2 = Post-Fatigue 2, NS = non-significant, \(^a\)BL-PF1, \(^b\)BL-PF2, \(^c\)PF1-PF2