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Muscle activation and knee biomechanics during squatting and lunging after lower extremity fatigue in healthy young women

Heather S. Longpré [a], Stacey M. Acker [b], Monica R. Maly [a,*]

[a] School of Rehabilitation Science, McMaster University, Hamilton, Ontario, Canada
[b] Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada

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ABSTRACT

Muscle activations and knee joint loads were compared during squatting and lunging before and after lower extremity neuromuscular fatigue. Electromyographic activations of the rectus femoris, vastus lateralis and biceps femoris, and the external knee adduction and flexion moments were collected on 25 healthy women (mean age 23.5 years, BMI of 23.7 kg/m^2) during squatting and lunging. Participants were fatigued through sets of 50 isotonic knee extensions and flexions, with resistance set at 50% of the peak torque achieved during a maximum voluntary isometric contraction. Fatigue was defined as a decrease in peak isometric knee extension or flexion torque $\geqslant$25% from baseline. Co-activation indices were calculated between rectus femoris and biceps femoris; and between vastus lateralis and biceps femoris. Fatigue decreased peak isometric extension and flexion torques ($p < 0.05$), mean vastus lateralis activation during squatting and lunging ($p < 0.05$), and knee adduction and flexion moments during lunging ($p < 0.05$). Quadriceps activations were greater during lunging than squatting ($p < 0.05$). Thus, fatigue altered the recruitment strategy of the quadriceps during squatting and lunging. Lunging challenges quadriceps activation more than squatting in healthy, young women.

1. Introduction

Squatting and lunging are important components of lower limb muscle training and rehabilitation programs. These exercises are often performed with the goal of increasing the force generating capacity of the lower limb muscles, particularly the quadriceps, reducing the risk for joint injury, and training balance in functional postures (Ebben et al., 2009). However, repetitive occupational exposure to squats and lunges may increase the risk for joint pathology, particularly at the knee (Amin et al., 2008). While moderate knee joint loading contributes to articular cartilage health (Griffin and Guilak, 2005), high intensity or long duration loading such as during occupational tasks that require repetitive knee flexion may be excessive, causing joint breakdown (Richmond et al., 2013). The discrepancy between the use of squats and lunges as rehabilitation exercises, and the potential risks of performing these exercises in an occupational setting may be explained by the duration of exposure. It remains unclear whether prolonged or repetitive demands on the knee flexors and extensors change the muscle activation patterns and knee loads required to remain successful in completing the tasks.

Fatigue, characterized by a reduction in the efficiency and force generating capacity of muscles after prolonged exposure to activity (Gandevia et al., 1995), could alter the motor control and joint loading requirements of certain tasks. Knee loads can be estimated by evaluating the external moments at the knee. The knee adduction moment (KAM) and knee flexion moment (KFM) differ for individuals with knee pathologies and injuries compared to healthy controls and may be important in the initiation and progression of joint degeneration (Andriacchi and Mundermann, 2006; Baliunas et al., 2002; Deluzio and Astephen, 2007; Foroughi et al., 2009; Rudolph et al., 2001; Sharma et al., 1998). These load measures are determined largely by the orientation and magnitude of the vertical ground reaction force relative to the knee center and by the actions of the muscles supporting the joint (Shelburne et al., 2006). The quadriceps, hamstrings, and gastrocnemius muscles provide stability to the knee by resisting external joint excursions (Winby et al., 2009). Thus, an alteration in the activation of muscles of the knee may alter knee loads. Neuromuscular fatigue of the muscles around the knee is associated with a loss of postural control during quiet standing (Gribble and Hertel, 2004; Salavati et al., 2007), altered muscle

* Corresponding author. Address: School of Rehabilitation Science, McMaster University, Rm 435, Institute for Applied Health Sciences, 1400 Main Street W, Hamilton, Ontario L8S 1C7, Canada. Tel.: +1 905 525 9140x27823; fax: +1 905 524 0069.

E-mail address: mmaly@mcmaster.ca (M.R. Maly).

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activation strategies, and altered knee mechanics during dynamic tasks such as jumping (Ortiz et al., 2010; Thomas et al., 2010). It is unclear how knee mechanics are affected by neuromuscular fatigue during isometric exercises such as squatting and lunging, which are recommended for muscle training rehabilitation for those with knee pain (American Geriatrics Society Panel on Exercise and Osteoarthritis, 2001; Bennell et al., 2013).

The purpose of this study was to compare muscle and knee loading measures during static squatting and lunging exercises before and after neuromuscular fatigue of the knee extensor and flexor muscles in healthy, young women. Muscle measures included quadriceps and hamstrings activation and co-activation patterns, and the KAM and KFM. We hypothesized that neuromuscular fatigue around the knee would increase lower-limb muscle activations, co-activations of the quadriceps and hamstrings, and knee moments, and that these variables would be higher for lunging than squatting.

2. Methods

2.1. Participants

A sample of 25 healthy women (age 18–30 years) was recruited from the university population. This study focused on women alone as they are more susceptible to knee injuries than men, particularly anterior cruciate ligament injury (Prodromos et al., 2007). Participants were physically active and had no contraindications to exercise on the Physical Activity Readiness Questionnaire (Thomas et al., 1992). Exclusion criteria included pregnancy and a history of knee pain, injury, or surgery. This study was approved by the McMaster University Faculty of Health Sciences Human Research Ethics Board.

2.2. Design

Participants visited the laboratory twice, one week apart. Written, informed consent was obtained at each visit. The first visit served to familiarize participants with the equipment and protocol to facilitate maximal performance during the second visit (Fig. 1).

During the second visit, baseline squats and lunges were performed prior to fatigue. These were followed by measures of baseline isometric peak knee extensor and flexor torques, followed by the first round of fatiguing contractions. After fatigue, participants performed the first set of post fatigue squats and lunges (PF1), followed by a second round of fatiguing contractions to ensure that participants had not recovered. Another set of post fatigue squats and lunges (PF2) were performed after fatigue was verified.

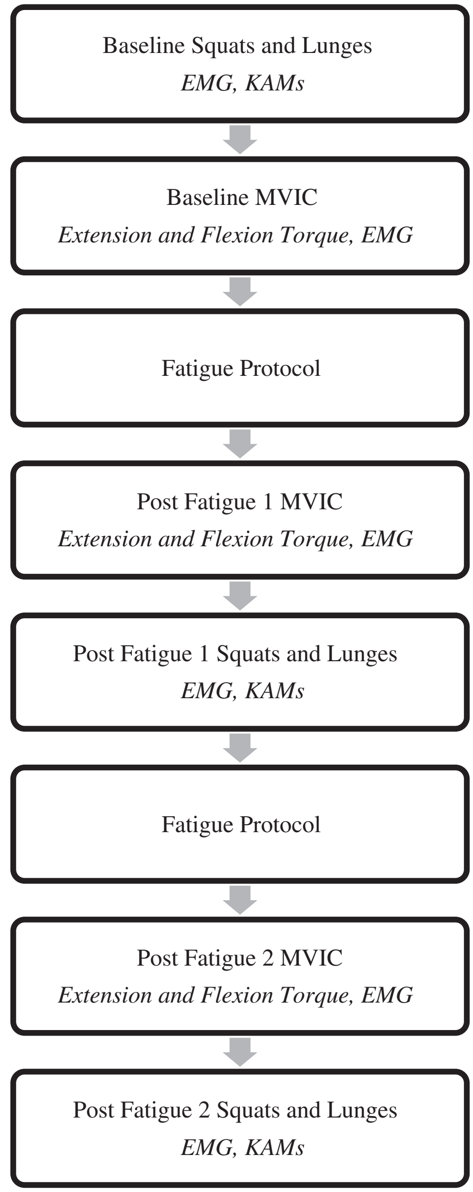

Fig. 1. Study design flow chart for the second laboratory visit. Measures collected at each step are shown in italics. *Note*: External knee adduction moments (KAMs) were collected on a subgroup ($n = 12$).

2.2.1. Squats and lunges

Participants performed three squats and three lunges at baseline, PF1, and PF2. During the squats, feet were approximately hip width apart, toes pointed forward, and the right foot alone was in full contact with a force platform. Participants were encouraged to squat without extending their knees past their toes until their thighs were approximately parallel to the floor while keeping their body mass distributed evenly through the left and right feet. Lunges were performed by stepping forward with the right leg (lead leg) so that the right foot was in full contact with the force platform. Participants were encouraged to lower their torso vertically and bend both knees until the front thigh was approximately parallel to the floor, with the left heel off the ground. Participants were asked to keep their toes pointed forward, their right knee directly above their right ankle. Each was held static for 2 s.

A Vicon MX 8 camera motion capture system sampling at 100 Hz measured marker position during squats and lunges (Vicon Motion Systems, Oxford, UK). Eighteen reflective markers were positioned on the legs as required for Vicon's plug-in-gait lower limb marker set (Vicon Motion Systems, Oxford, UK) for the duration of the protocol. Six additional markers were affixed to the left and right iliac crest, greater trochanters, medial epicondyles, and medial malleoli during static standing calibration trials as digital landmarks but were removed before beginning the squats and lunges. These additional markers were used to define the shank and thigh coordinate systems of the leg in accordance with the models described by Grood and Suntay (1983). Knee flexion/extension and ankle transmalleolar axes were generated between the medial and lateral epicondyles and malleoli, rather than using knee and ankle width measurements and hip joint center estimations as described by the plug-in-gait model. Further, the greater trochanters were palpated and identified during static calibration rather than their locations being estimated based on the location of the anterior superior iliac spinae and the leg length of the participant. The 2 s static portion of each trial was identified as the interval in