Fatigue of lower extremity muscles is known to impact balance and increase the risk of falls and injuries. Among muscle groups of the lower extremity, the ankle plantar flexors generally are viewed as the most influential for control of posture, especially when the human body is modeled as an inverted pendulum. On the other hand, both plantar flexors and dorsiflexors of the ankle, and the flexors and extensors of the knee, have similar effects on the control of posture when fatigued.

The specific role of quadriceps muscle group (QU) in control of posture, however, is not completely understood. The function of QU is particularly important during the performance of numerous athletic activities that challenge postural control. Early literature has suggested that because the line of gravity action passes anterior to the knee joint, the resulting external extension moment makes the QU activity unnecessary during static bipedal standing. Recent electromyographic evidence, however, has demonstrated that the QU is active during static bipedal stance, with the vastus lateralis identified as the most active component. Electromyographic data also have demonstrated that the QU helps stabilize the knee during the loading response stage of the gait cycle and that it influences gait speed and stair ambulation. The QU appears to play a significant role in the control of posture and maintenance of balance following a perturbation and during static standing. Fatigue of the QU may adversely affect proprioceptive input to the central nervous system during motion of the knee and may adversely affect postural control to an extent that increases the risk of falling. QU fatigue has been shown to alter patterns of coordinated muscle activity in response to sudden perturbations and appears to slow neuromuscular response time, resulting in a decreased ability to dynamically control displacements of the knee and hip joints. The QU fatigue has been shown to increase the likelihood of a slip or fall, due to an inability to correct postural instability at the moment of contralateral knee extension. Compensatory stepping is vital for maintenance of postural control in a situation that presents potential for disruption of balance.

Studies of the role of the QU in maintenance of postural balance have generally imposed a fatigued state through performance of an isotonic single-leg squat, which simultaneously activates other muscles in the lower extremity. Isometric contractions of the QU have also been used, which produce different fatigue characteristics than isotonic contractions. The procedure used in this study was designed to induce localized QU fatigue through isotonic exercise.

Postural control has been defined as the ability to maintain the body center of gravity.
within its base of support.\textsuperscript{28,29} Postural stability often is quantified by measurement of postural sway, or the movement of the center of pressure (COP) beneath the foot while standing on a force platform.\textsuperscript{30,31} Normal limits of postural sway are about 12 degrees in the sagittal plane and 16 degrees in the frontal plane.\textsuperscript{32} Numerous studies have demonstrated that poor postural stabilization can be identified by an increase in time-distance and area of postural sway.\textsuperscript{33,34} Postural control can also be represented by sway frequency variables, including power.\textsuperscript{35,36} To our knowledge, no previous investigations have addressed the effect of QU fatigue on both time and frequency characteristics of postural sway during standing. The purpose of this study was to examine the effects of QU fatigue on postural stability in healthy young adult subjects. QU fatigue was hypothesized to produce an increase in postural sway.

**Procedure and Findings**

Following approval from the Institutional Review Board of Northern Illinois University, 31 healthy young adults (11 male and 20 female) between the ages of 21 and 28 years of age (mean = 23.7, SD = 1.3) were recruited to participate in the study. Participants were included if they had no physical or cognitive disability that could potentially affect postural balance. Individuals with any visual or vestibular deficits, and those with a history of injury or surgery of the lower extremities in the past 6 months, were excluded from participation.

A Kistler-9287BA force platform (Kistler Co., Winterthur, Switzerland) was used to collect COP data at 100 Hz. During testing, participants stood barefoot on the force platform with double-limb support, with the knees extended and the arms relaxed. Positioning of the feet was determined by a self-selected stance.\textsuperscript{37} For each trial, subjects were instructed to look straight ahead at a 1-inch diameter point on the wall that was 6 feet away at eye-level and to stand as motionless as possible. Data were collected for two 30-second trials prior to performance of fatiguing exercise. To induce fatigue, participants performed isotonic long-arc resisted QU exercise with a 10-lb weight attached to each foot. Participants were verbally encouraged to continue performing the exercise. QU fatigue was operationally defined as the inability to achieve a full range of extension with either extremity. Immediately after fatigue had been induced, a 50-second trial balance trial was performed, followed by another 30-second trial at 60 to 90 seconds after completion of the fatiguing exercise. Results were recorded for the three conditions: prefatigue (PRF), immediately postfatigue (IPF), and late post-fatigue (LPF).

Anteroposterior and mediolateral time series data acquired from the force platform were filtered through a fourth-order zero-phase Butterworth low-pass filter with cut-off frequency of 5 Hz.\textsuperscript{38} The first 10 seconds and the last 2 seconds of each 30-second data acquisition trial were discarded.\textsuperscript{38} A detailed explanation of time and frequency domain variables computed in this study is available in the literature.\textsuperscript{38-42} Matlab and SAS statistical analysis software were used for data processing and analysis. Resultant and directional characteristics of postural sway in time and frequency domains were compared using repeated measures analysis of variance to identify any significant differences (p < 0.05).

Significant differences were observed among trials for resultant postural sway distance from COP, as well as postural sway in both medio-lateral (p = 0.035) and antero-posterior directions (p = 0.014). Mediolateral mean distance increased from PRF to IPF but did not change significantly from IPF to LPF. Antero-posterior mean distance did not change significantly from PRF to IPF but did change significantly from PRF to LPF (Figure 1). The 95% confidence circle area of postural sway also demonstrated significant change immediately following performance of the fatigue protocol (p < 0.001), but there was not a significant difference between the IPF and LPF measurements (Figure 2). The total power of postural sway increased significantly from PRF to IPF (p = 0.005), but change between PRF and LPF was not significant. Similarly, power of postural sway in the medio-lateral direction significantly increased from PRF and IPF, but significantly decreased from IPF to LPF (Figure 3).

**Discussion**

Our findings demonstrate that QU fatigue significantly affects postural control in both time-distance and frequency variables that quantify postural sway. Thus, QU fatigue may contribute to increased risk of falling. Increase in postural sway distance was evident both from resultant mean distances from the COP and 95% confidence circle area. Increased postural sway in the medio-lateral direction may be an indication...