Introduction
Due to the similarity in physical structure, symmetrical coordination patterns are generally expected between interlimb couplings involving homologous joints and limbs. A 1:1 interlimb coordination pattern is predicted, indicating tight phase and frequency synchronization. Such ideal symmetry, however, has not been demonstrated among non-impaired subjects (Öunpuu and Winter, 1986). Thus, a degree of coordination pattern asymmetry is frequently observed among non-impaired individuals. Among individuals with clinical pathology (e.g. cerebral palsy), this level of pattern asymmetry has been observed to increase due to the presence of neuromuscular asymmetries (White et al., 1999). Further, alterations to mechanical characteristics of homologous limbs have produced an increase in the level of coordination asymmetry (Serrien and Swinnen, 1997; Haddad, 2000). Therefore, one would expect an increase in coordination pattern asymmetry among individuals displaying a neuromuscular or mechanical difference bilaterally. However, such an observation has not been documented among individuals with unilateral patellofemoral pain (PFP). The purpose of this investigation was to determine if individuals with unilateral PFP displayed greater interlimb coordination asymmetry of the knee compared to non-impaired individuals.

Methods
Sixteen female volunteer subjects (19-36 yrs), eight with unilateral PFP and eight non-impaired, provided informed consent for this study consistent with University policy. The eight symptomatic subjects with PFP were admitted to the subject if the pain was reproducible with at least two exercises associating with exacerbating PFP symptoms (Powers et al., 1997). The non-impaired group had no history of knee surgery or pathology and was free from any current pain.

Kinematic data (200 Hz) of the bilateral lower extremities were collected using a seven digital camera system. Triads of markers fixed to a rigid base were secured to the thighs and legs of each subject, while individual markers were secured to anatomical landmarks of the feet. Subjects ran on a motorized treadmill (20 s) at a preferred and fixed (2.68 m·s⁻¹) speed. Using a visual analog scale, perceived pain values were recorded by each subject during each running speed.

Reconstructed three-dimensional coordinate data of each marker were low pass filtered at 9Hz. Sagittal (flexion) and transverse (rotation) plane knee angles were calculated using a joint coordinate system analysis (Grood and Suntay, 1983). Relative motion diagrams were constructed for each angle by plotting the right vs. left limb. Interlimb coordination asymmetry and variability were measured using a modification of the vector coding technique described by Sparrow et al. (1987). This method involved calculating the orientation of the resultant vector between two adjacent data points (with respect to time) in a stride. An orientation of 45° indicates symmetry with the level of deviation away from 45° representing asymmetry.

Mean and standard deviation of the vector orientations were calculated across the running strides using circular statistics (Batschelet, 1981). These values were then averaged across the stride cycle, with the mean orientation indicating the level of symmetry and the standard deviation indicating the level of pattern variability. Prior to averaging, 180° was subtracted from vector orientations greater than 180°, producing a range of values from 0-180°. The average values were further adjusted by calculating the absolute difference between the average symmetry value and 45°. Thus, the reported values reflect the level of asymmetry, with 0° indicating perfect symmetry. Interlimb coordination pattern symmetry and variability were compared using a two-factor ANOVA with repeated measures.

Results and Discussion
The non-impaired subjects reported no pain at either running speed, while the PFP group reported average pain values of 2.4 (0-10 scale) at the fixed speed and 1.9 at the preferred. Representative relative motion plots for both knee flexion and rotation are displayed in Figure 1. Interlimb coordination
asymmetry was similar between groups regardless of speed for both knee flexion ($F(1,14)=1.85, p=0.20$) and knee rotation ($F(1,14)=2.07, p=0.66$) (Figure 2). The variability of the interlimb coordination pattern was also similar between groups for knee flexion ($F(1,14)=0.80, p=0.39$) and knee rotation ($F(1,14)=0.96, p=0.34$) (Figure 3).

![Figure 1](image1.png)

**Figure 1.** Relative motion plots of a representative subject from each group for a) knee flexion and b) knee rotation during running at 2.68 m·s$^{-1}$. A single stride is displayed.

![Figure 2](image2.png)

**Figure 2.** Mean interlimb coordination pattern asymmetry of a) knee flexion and b) knee rotation. Values are displayed for both running speeds. A value of 0° indicates perfect symmetry.

![Figure 3](image3.png)

**Figure 3.** Mean interlimb coordination pattern variability of a) knee flexion and b) knee rotation. Values are displayed for both running speeds. The variability reflects the between trial consistency in the level of bilateral coordination asymmetry.
Based on previously documented gait deviations, unilateral PFP was hypothesized to produce an increase in the interlimb coordination asymmetry of the knee. Compared to non-impaired subjects, individuals with unilateral PFP did not display an increase in the asymmetry of the interlimb coordination patterns during running for either knee flexion or rotation. Additionally, the between trial consistency of the interlimb patterns was similar between groups, indicating that the presence of unilateral PFP did not produce a more variable pattern. Based on previous evidence, a neuromuscular or mechanical difference between homologous limbs should produce an asymmetrical coordination pattern (Serrien and Swinnen, 1997; Haddad, 2000). The absence of this observation in the present investigation suggests that the neuromuscular difference was not significant enough to produce the expected asymmetries. The rather low values of pain reported by the PFP group supports this hypothesis.

References