# THE INFLUENCE OF PATELLOFEMORAL PAIN ON COORDINATION VARIABILITY OVER A PROLONGED TREADMILL RUN

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The purpose of this study was to understand the influence of patellofemoral pain on lower extremity segment coordination variability throughout a 21-minute treadmill run. Couplings between the pelvis, thigh, and shank were compared at the beginning and end of the run between healthy and injured runners. Average coordination variability in weight acceptance and mid-stance was increased in healthy runners over the course of the run and decreased in those experiencing pain. These results support the hypothesis that injured runners experiencing pain may not be as flexible to internal and external perturbations compared to their healthy counterparts. Thus, in the presence of pain, these runners may place greater stress on specific lower extremity tissues leading to greater risk for injury at these sites.

**KEYWORDS:** running, knee pain, injury.

**INTRODUCTION:** As many as 85 percent of the 30 million runners in the United States get injured each year (Bovens et al., 1989). The most common lower limb injury in runners is patellofemoral pain syndrome (PFPS) (Taunton et al., 2002). PFPS has both poor short and long term outcomes as over 70% of those suffering from PFPS still have pain one year after initial onset (Stathopulu & Baildam, 2003). Chronic PFPS can lead to cartilage damage and osteoarthritis, contributing to disability in older age (Utting et al., 2005). Despite our current depth of knowledge about factors predisposing individuals to PFPS and the resulting impairments in gait mechanics, PFPS treatment is often ineffective, leaving runners in continued pain that worsens with activity. The role of pain and the motor system’s acute or chronic response to pain in the persistence and reoccurrence of PFPS is not well characterized. This information may be critical for improving treatment efficacy and patient outcomes.

Complex movements like running require the neuromuscular system to coordinate multiple degrees of freedom (joints, segments) to produce resultant lower extremity postures. A hypothesis based on dynamical systems theory posits that with injury, there may be an uncoupling of lower limb segment motion and a reduction in the stride-to-stride variability of segment coordination (Hamill et al., 2012). Previous work has found that current or resolved overuse injuries are tied to decreases in movement variability. (Cunningham, 2014; Heiderscheit et al., 2002; Seay et al., 2011). A reduction in the number of available movement patterns may lead to repeated tissue stresses and the inability to adapt to changing conditions. However, much remains unknown about the acute effects of pain on coordinative variability in runners with patellofemoral pain.

Responses and adaptations to increasing pain are believed to alter muscle and movement coordination, potentially through increased demand placed on the motor cortex and other processing resources in the brain (Hodges & Mosely, 2003). To better understand how pain influences the flexibility of movement, we propose to study segment coordination variability during a moderate, self-paced prolonged treadmill run. The aim of the this was to quantify the differences in segment coordination variability of runners with symptomatic PFPS compared to healthy runners. We hypothesized that 1) coordination variability would be lower at baseline in runners with PFPS compared to healthy and 2) coordination variability would decrease by the end of the run in runners with PFPS while healthy runners would show no change.

**METHODS:** Twenty healthy (10 male, 10 female) and 15 PFPS (10 female, 5 male) recreationally active runners between the ages of 18-35 were asked to complete a 21-minute moderate, self-paced treadmill run on an instrumented treadmill (Treadmetrix, Park City, UT). All participants completed the informed consent process as approved by the University Institutional Review Board. Prior to the run, retro-reflective markers were placed on anatomical landmarks of each participant to define 3 segments: pelvis, thigh, and shank. The pelvis was defined by markers placed on the right and left ASIS, PSIS, iliac crests, and greater trochanters. The thigh segment was defined proximally by the greater trochanters and distally by the medial and lateral femoral condyles, which also defined the proximal end of the shank. The medial and lateral malleoli defined the distal end of the shank. These segments were tracked using rigid cluster markers placed on the thigh and shank.

After all markers were placed, participants were given five minutes to warm up as necessary on the treadmill, during which their preferred running speed was determined. The instructions given were to select “a pace that you would choose to comfortably run for twenty minutes on an easy-to-moderate training run”. Once that speed was determined for each participant, speed was increased and decreased around that speed to ensure the appropriate speed was selected. A short rest was then provided prior to the start of the prolonged run. Once the run began, a one minute acclimatization period was given. Immediately following this, kinematic and kinetic data were collected for 30 seconds, sampling at 200 and 2000 Hz, respectively. At the end of the run, data were again collected for 30 seconds. Pain was assessed every two minutes of the run using a verbal numeric rating scale (vNRS) with 0 being “no pain” and 10 being “the most severe pain you’ve experienced” in either the participants’ right leg (healthy) or the affected leg (injured). In addition, heart rate and Rating of Perceived Exertion (RPE) on a 6-20 Borg scale (Borg, 1981) were recorded at these same time intervals.

Data were collected, tracked and labelled in Qualisys Track Manager (Qualisys, Inc, Gothenberg, Sweden). Data processing was performed using Visual 3D software (C-motion, Inc., Rockville, MD). All marker position data were low pass filtered using a dual-pass, $4^{th}$ order Butterworth filter at 8 Hz . Ground reaction force data were filtered at 25 Hz and were used for gait event detection (foot strike, toe off). Global segment angles for the pelvis, thigh and shank for 10 steps for each participant were exported from Visual3D for each participant at the beginning and end of the run (right leg for healthy, affected leg for injured).

Segment coordination variability for each participant was calculated for 10 steps at the beginning and end of the run using a modified vector coding technique (Chang et al., 2008). With the modified vector coding technique, angle-angle plots were created for motion between adjacent segments (pelvis, thigh, shank) over stance. Coordination variability was calculated as the standard deviation of the vector connecting corresponding consecutive time points of the angle-angle plots across trials using circular statistics (Silvernail et al., 2015). Based on the prior findings of injury mechanisms of PFPS, the following intra-limb couplings from the stance limb were examined: frontal pelvis-transverse thigh, frontal pelvis-frontal thigh, sagittal thigh-sagittal shank, and frontal thigh-frontal shank.

Coordination variability was averaged over each third of stance (i.e. weight acceptance, mid-stance, push off). To determine the effect of time and group on average coordination variability for each phase of stance, 2-way repeated measures ANOVAs were performed in SPSS (IBM SPSS Statistics 22, SPSS Inc., Chicago, IL) with $\alpha$ = 0.05. Paired and independent samples t-tests were performed *post-hoc* to test for differences when significant main effects were found.

## RESULTS:

All participants had end of run RPEs of 12 ≤ RPE ≤16 and corresponding peak heart rates between 140-160 bpm. Twelve out of 15 participants in the pain group had a clinically significant pain increase (≥2 points). The average pain increase was 3.13±2.17 points.

Significant effects of time and group* time interaction effects were found for the average coordination variability in the gait cycle phases. For the frontal thigh-frontal shank, there was a main effect of time ($p$=0.018, $\eta_p^2$=0.158) in mid-stance indicating coordination variability decreased significantly over time (Beginning: 23.06±10.53, End: 17.96±9.20) for both healthy and PFPS groups. For the sagittal thigh-sagittal shank coupling, there was a significant group*time interaction ($p$=0.027, $\eta_p^2$=0.139) during weight acceptance. For the frontal pelvis-frontal thigh coupling, there was a significant group*time interaction (p=0.002, $\eta_p^2$=0.260) during mid-stance. No differences were found for the frontal pelvis- transverse thigh coupling. *Post hoc* t-tests were performed where significant interaction effects were found. For the sagittal thigh-sagittal shank coupling, the pain group had significantly higher coordination variability at the beginning of the run than the healthy group during weight acceptance (p = 0.002, healthy: 2.01±0.63, pain: 3.45±1.88). However, the healthy group significantly increased coordination variability in this coupling by the end of the run (p=0.048, Beginning: 2.01±0.63, End: 2.41±1.12) while there was no change in the pain group (p=0.076, Beginning: 3.45±1.88; End: 2.92±1.02) (Figure 1). For the frontal pelvis-frontal thigh coupling, the pain group showed a significant decrease in coordination variability during mid-stance over time (p=0.039, Beginning: 17.14±10.60, End: 13.33±7.61) while the healthy group showed a significant increase over time (p=0.003, Beginning: 12.50±6.96, End: 16.42±8.43) (Figure 1).

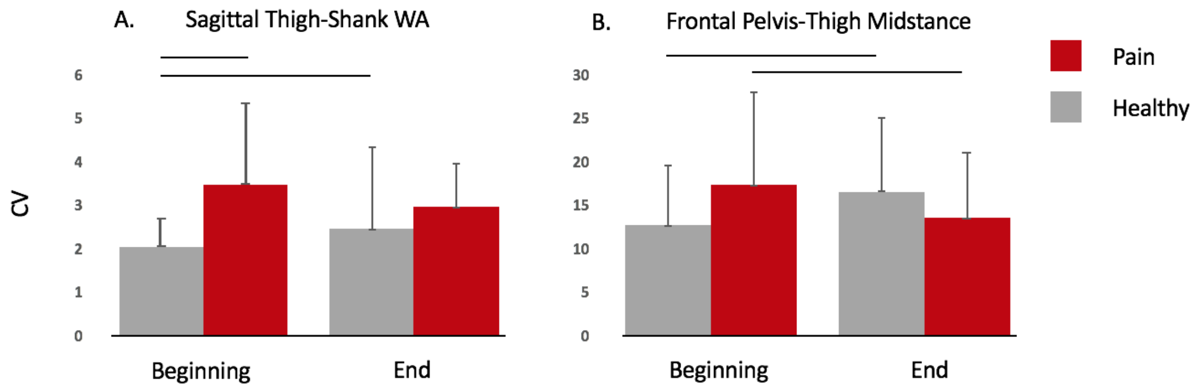


**Figure 1. Beginning and end of run coordination variability (CV; mean with SD bar) for the sagittal thigh-shank coupling during weight acceptance (WA) and frontal pelvis-thigh during midstance. Red indicates the pain group and gray indicates the healthy group. Horizontal lines above bars indicate significant differences at p < 0.05.**

**DISCUSSION:** The findings of this study are not in support of the first hypothesis that coordination variability would be lower in those with PFPS compared to healthy at baseline. The results are in partial support of the hypothesis that coordination variability would be decrease in runners experiencing an acute increase in pain associated with PFPS and, in addition, suggest that this pain response differs by coupling and plane of action.

In contrast to the study hypothesis, coordination variability was higher at baseline in the pain group for the sagittal thigh-sagittal shank coupling during weight acceptance; however, the coordination variability increased to the end of the run in the healthy runners with no change in the pain group. Given that the runners with PFPS were not in significant pain (<2 points) at the beginning of the run, it is possible that those with PFPS were exploring their lower extremity “solution space” in an effort to find a pattern that was more protective and would prevent pain. However, as the run was completed, the majority of these runners experienced pain that may have pushed them towards limiting solutions for gait, “locking” their degrees of freedom, decreasing their coordination variability and potentially causing further increases in pain. This is especially important in the sagittal thigh-sagittal shank coupling, as this is closely tied to knee flexion which has been shown to decrease in the presence of pain (Salsich et al., 2001). These adaptations may initially serve to decrease pain but over time they likely place increased stress on specific sites and tissues, leading to the progression of the injury and further pain (Hodges & Tucker, 2011).

A differential response to the prolonged run was also found for the frontal pelvis-frontal thigh coupling, and the pain group showed a 25% reduction in coordination variability of the frontal pelvis-frontal thigh coupling from the beginning to end of the run, while the healthy counterparts showed a 27.1% increase in coordination variability over the course of the run.

This coupling was chosen for analysis as frontal plane control of the femur is an important factor in development and progression of knee pain. This reduction in coordination variability may be related to weakness or fatigue of the gluteus medius muscle, preventing adequate control and movement of the femur during running.
There are contradictory results in the literature with respect to changes in joint and segment coordination variability with PFPS. Our results suggest that that chronic adaptations to PFPS may not be enough to elicit long-lasting changes in coordination variability from healthy runners at baseline. However, movement evoked pain, a characteristic trait of PFPS, may have been enough to alter coordination variability differentially from healthy runners. This suggests that changes in coordination variability occur in response to symptoms rather than permanent adaptations in gait mechanics.
Given that this was a relatively short run at a moderate effort level, these results may be compounded at greater training volumes and loads. In addition, given a higher effort and longer run time, more significant changes may arise. It is possible that some potential sources of change in coordination variability may have been mitigated due to the fact that this study was performed a constant speed treadmill belt, which constrains the movement task from natural, overground distance running.

**CONCLUSION** According to the findings of this study, runners with PFPS have greater coordination variability for select couplings at baseline compared to their healthy counterparts. These injured runners showed a decrease in coordination variability as pain increased following a prolonged run. This decrease in coordination variability relative to healthy may place these runners at greater risk for injury progression leading to future debilitating diseases such as osteoarthritis and a greater chance of chronic pain. These findings highlight the importance of studying these runners from a dynamical systems perspective during a run to better understand how pain affects coordinated movement and how the segments of the body are coupled to generate resultant movement patterns.

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