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Trunk, Hip and Knee Motions During a Step-Down Test and Running in Patellofemoral Pain Individuals

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**TRUNK, HIP, AND KNEE MOTIONS DURING A STEP-DOWN TEST AND RUNNING
IN PATELLOFEMORAL PAIN INDIVIDUALS**

By

Katie M. Olinger, LAT, ATC

Accepted in Partial Completion
of the Requirements for the Degree
Master of Degree Type

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**TRUNK, HIP AND KNEE MOTIONS DURING A STEP-DOWN TEST AND RUNNING
IN PATELLOFEMORAL PAIN INDIVIDUALS**

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

by
Katie Olinger
April 2019

Abstract

Context: A common knee injury in runners is patellofemoral femoral pain syndrome (PFPS). The step-down test (SDT) is used to analyze lower extremity motions in runners with PFPS because kinematics are similar for the SDT and running. Individuals with PFPS often experience altered kinematics when compared to healthy. However, there are no known studies that examine the relationship in kinematics between the SDT and running.

Objective: Examine the relationship between lower extremity kinematics of the knee, hip and trunk in runners with PFPS and healthy controls, during the midstance of running and during a SDT.

Design: Cross-sectional

Setting: Research laboratory

Patients or Other Participants: Sixteen individuals 8 PFPS, 4 females (mean \pm SD age, 28.5 ± 3.1 years; height, 173.0 ± 6.3 cm), and 8 healthy controls, 4 females (mean \pm SD age, 30.12 ± 6.5 years; height, 171.09 ± 9.7 cm) distance runners.

Intervention(s): A 10-minute treadmill running trial and a bilateral single leg SDT.

Main Outcome Measure(s): Joint angles were recorded with a 3D motion capture system for both tests. Angles included lateral pelvic tilt (LPT), lateral trunk flexion (LTF), knee valgus (KVALGUS).

Results: An excellent to moderate relationship between the SDTmax and midstance of running for LTF ($r < 0.89$), KVALGUS ($r < 0.94$), LPT ($r < 0.68$) were observed. No significant differences in LTL ($p < 0.254$), KVALGUS ($p < 0.069$) and LPT ($p < 0.476$) between groups and condition. There was a significant difference of condition between the run, and SDTmax observed in LTL ($p = 0.034$), but not significant in, KVALGUS ($p = 0.051$), and LPT ($p = 1$).

Conclusions: The midstance phase of running and SDT shows a strong positive relationship and can be useful during clinical evaluation.

Key Words: patellofemoral pain, joint motion, step-down test, running, functional movement

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Chapter 1

Introduction

Over the years, there has been an increase in popularity of running sports in an athletic population, whether it is competitive or recreational¹. This increase in popularity has been followed with an increase in running related injuries that can not only affect training but also activities of daily living¹. Patellofemoral pain syndrome (PFPS) is one of the most common lower extremity injuries observed in runners and commonly present with insidious anterior knee pain that has no known mechanism of injury². Patients experiencing PFPS will generally have no structural damage to ligaments or bones³⁻⁴. Symptoms of PFPS are often increased with prolonged sitting or activities that requires high quadriceps activation or increased stress within the patellofemoral joint^{3, 5-7}. Also, malalignment of the patella during movement caused by anatomical differences or muscle activation will result in increased stress in the patellofemoral joint⁸.

Many intrinsic and extrinsic factors can contribute to the development and symptoms of PFPS. Intrinsic factors include sex, age, previous history of injury whereas extrinsic factors include training surface, training volume and footwear. Lower extremity segments and musculature act together to provide optimal functioning during activity. If a segment proximal or distal to the knee is altered by these intrinsic or extrinsic factors, it can affect the proper alignment and movement of segments both up and down the lower extremity kinetic chain⁹.

Anatomically, a large factor that has been studied in PFPS is the quadriceps angle (Q-angle). This measurement provides information of knee joint alignment and the angle at which the quadriceps muscle group pulls the patella during movement¹⁰⁻¹¹. Quadriceps angle is affected by both static anatomy and dynamic movement. Women have a larger Q-angle due to anatomical

differences and muscle weakness¹¹. An increased angle creates a lateral pull which places a larger stress on the patellofemoral joint¹⁰. This is perhaps why prevalence of PFPS is twice as likely in females^{7, 12}.

Knee joint kinematics become altered during running movement when there is muscle weakness, abnormal muscular activation, and altered rotation of the tibia and femur. These factors lead to increased patellofemoral joint stress and increase pain in the knee¹³. During running, patients with PFPS tend to have a more internally rotated tibia and femur and; increased dynamic Q-angle which could lead to a valgus moment at the knee and a more pronated foot^{2, 5, 7, 12}. These individuals also experience an ipsilateral lateral trunk lean and a contralateral hip drop in order to stabilize the stance leg. These movements can also be used as a compensatory mechanism to reduce pain and external knee movement¹⁴⁻¹⁵.

Clinical evaluations of PFPS primarily include functional movements to identify the location of pain and activities that increase symptoms. This is typically done through variations of squatting movements²²⁻²⁴. Clinically the single-leg step-down test (SDT) is commonly used to determine motions of the hip, knee and trunk in both healthy and injured populations. The SDT mimics everyday activities such as stair descent and midstance phase of running, these two activities have been commonly identified to increase symptoms in PFPS^{2, 18 23, 24-25}.

During a step-down test, patients with PFPS also demonstrate abnormal knee joint kinematics due to muscular weakness and abnormal activation, increased internal rotation of the tibia and femur and increased knee valgus¹⁶⁻¹⁷. These factors lead to an increase in lateral joint stress at the knee due to abnormal pull on the patella causing more joint contact space^{4, 18, 19}. Although many factors affecting running kinematics have been widely studied, but there has been no research to identify a primary source of PFPS. Due to kinematic similarity, peak knee

flexion during the SDT is used to identify the point of highest stress at the patellofemoral joint during the midstance phase of running²⁰⁻²¹. The high stress joint moment will lead to an increase in symptoms seen during movement.

Current research suggests that patients with PFPS exhibit increased range of motion in the frontal and sagittal plane during functional movements when compared to healthy individuals. The SDT is commonly used as a time efficient way to understand the kinematics during running. Recent literature has typically examined two different knee flexion angles during the SDT, either 50-60 degrees, or at the instant of heel tap but not standardized points of knee flexion during a running movement^{23, 25}. These time points could indirectly relate the kinematics of the SDT to running if similar points of flexion are not compared.

This study was designed to examine the kinematic differences of joint angles between a running analysis and step-down test between individuals with and without patellofemoral pain. The purpose of this study was to examine the relationship of the lower extremity kinematic joint angles of the knee, hip and trunk in people with PFPS and healthy controls, during the midstance of running and during a SDT. We hypothesized that there would be no significant interaction between group (PFPS and controls) and condition (running and the SDT). We also hypothesized that there would be a strong relationship between conditions within the PFPS individuals. Lastly, it was hypothesized that individuals with PFPS will exhibit increased lateral pelvic tilt (LPT), lateral trunk lean (LTL), and knee valgus (KVALGUS).

Chapter 2

Methodology

Subjects

The study sample consisted of 16 individuals, 8 with PFPS, 4 females and 4 males (mean \pm SD age, 28.5 ± 3.1 years; height, 173.0 ± 6.3 cm; body mass, 65.2 ± 0.8 kg; run volume, 66.4 ± 12.3 km/week), and 8 healthy controls, 4 females and 4 males (mean \pm SD age, 30.1 ± 6.5 years; height, 171.1 ± 9.7 cm; body mass, 68.7 ± 6.3 kg; run volume, 73.4 ± 28.0 km/week). Control subjects were age and sex matched to PFPS subjects within 4 years of age. Participant demographics information based on sex is presented in Table 1. Participants were recruited from Western Washington University and the surrounding Bellingham community via flyers and word of mouth. The PFPS participants were moderately active, running an average of 16 km per week and experienced anterior or retropatellar knee pain with running activities for past month. The study required participants to be between the ages 18 and 45 years old and have been running regularly for the past 6 months. Inclusion criteria for the PFPS individuals included, knee pain while running, an average of 16 km per week during episodes of pain and 32 km per week while pain-free for the last 6 months, ability to run a 6-minute kilometer pace, or 3 m/s. Exclusion criteria included, any traumatic lower extremity or knee injury or previous reconstructive surgeries of the lower limb (Anterior Cruciate Ligament, Posterior Cruciate Ligament, or meniscus), and any neurological conditions that affect the function of the lower extremity. The inclusion criteria was the same for the healthy controls subjects, with the exception of having no lower extremity injury or pain during activity. Each interested subject underwent a screening process prior to testing to determine eligibility requirements.

Table 1. Subject demographics divided according to group.

	Sex	Age (yrs)	Height (cm)	Body Mass (kg)	Run Volume (km/week)
PFPS	4 male, 4 female	28.5 ± 3.1	173 ± 6.3	65.2 ± 0.8	41.3 ± 7.6
Controls	4 male, 4 female	30.1 ± 6.5	171.1 ± 9.7	68.7 ± 6.3	45.6 ± 17.4
Average		29.3 ± 7.1	172.1 ± 9.3	66.9 ± 6.7	69.9 ± 35.9

Design of the study: The study was a cross-sectional study to determine if the SDT accurately represents the motions of the hip, knee, pelvis, and trunk during running in order to determine if it is an appropriate clinical test for patellofemoral pain.

Instrumentation: Marker position data were collected using a 10-camera Vicon motion capture system (10 v1.3 Vantage, Vicon, Centennial, CO) at 250 Hz. Calibration of the system was done in accordance with manufacture recommendations, with a mean image error less than 1.0 mm in the capture area. Running trials were conducted on an instrumented treadmill (SCIFIT System, Tulsa, Oklahoma, USA). Treadmill data output was recorded into Noraxon Myopressure software (Noraxon M3.14, Scottsdale, Arizona, USA). Twenty-one markers with a diameter of 14 mm were placed on each participant. Five markers placed on the upper body on the following landmarks: clavicle, sternum, 7th cervical vertebrae, 10th thoracic vertebrae, and right scapula. Sixteen markers placed on the lateral side of both the left and right side of the lower body at the following points: anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), left sided placement is the lower 1/3 of the lateral thigh and lateral tibia, placement for the right side is the upper 1/3 of the lateral thigh and lateral tibia, knee joint space, lateral malleolus, posterior

heel, 2nd metatarsal (Figure 1). Marker placement was based on the Vicon template for modified Plug-in Gait²⁶. The SDT was performed from a box set to 10 percent of the subjects' height positioned next to an AMTI inground force platform. Subjects lowered themselves on the ground over the force platform so that the precise time point when the heel contacted the ground could be identified. Heel tap was identified once the vertical ground reaction force exceeded 20 N²⁷.



Experimental Protocol

Experimental testing conditions were randomized prior to testing. Each subject completed both testing protocol to examine within-subject differences for the two conditions: treadmill running and SDT (Figure 2A and 2B). Testing sessions lasted approximately 90

minutes per subject. Each testing session started with an informed consent being signed by each subject. The informed consent form was approved by the Western Washington University Institution Review Board. All testing procedures were within ethical standards of the Western Washington University Institution Review Board.

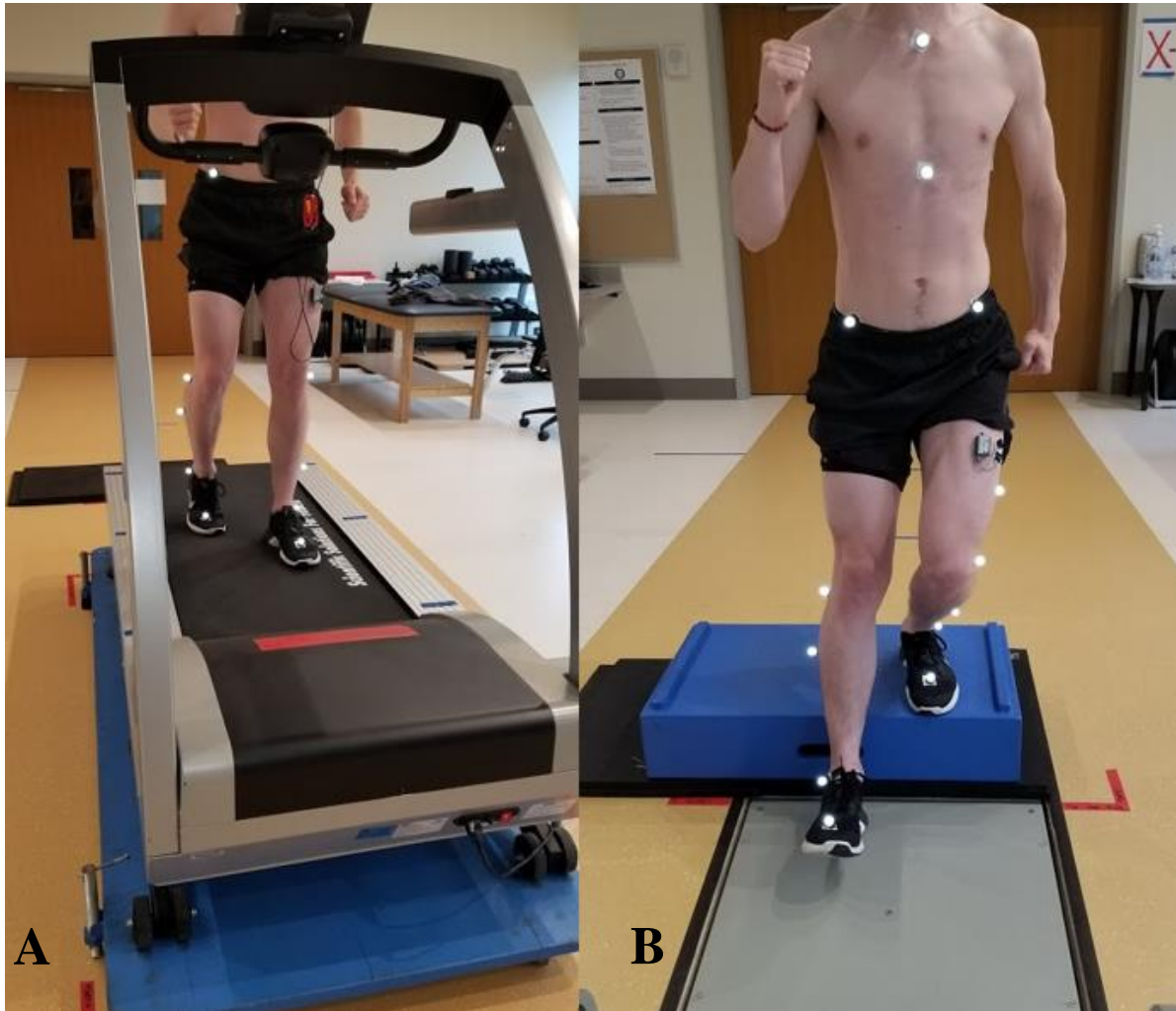


Figure 2. A) Treadmill run and B) Step-Down Test

Testing sessions began with the collection of anthropometric measurements that were used to create subjects' individual skeleton model in the motion capture software. Measurements included bilateral leg length, knee width, ankle width, and inter-ASIS distance as described in the VICON Plug-in Gait Manual²⁶. Sex, height, weight, running volume were also recorded. All

participants completed a standardized warm-up followed by the randomized testing protocol.

Warm-Up protocol: Each participant completed a ten-minute warm up procedure. The warm-up included a five-minute run on the treadmill, specifically 3 minutes at 2.6 m/s and 2 minutes at testing pace of 3.0 m/s, followed by five minutes of dynamic stretching. Initial foot contact pattern was recorded during the warm-up run. Following the running warm-up, five-minutes of lower extremity dynamic stretching was coached. Stretching was done bilaterally and completed down a 40 m runway. Stretching for each subject was led by a lab assistant and completed in the same order for each subject. Stretching included: walking knee grabs for hamstrings, walking foot grabs for quadriceps, walking foot grabs with external rotation for hips, pulsed heel raises for calves, and a forward walking lunge with a forward lean for the groin.

Running protocol: Participants completed a running trial for 10 minutes on a treadmill. Participants ran at 3.0 m/s on the treadmill^{7,28}. This speed was selected as it is the average speed reported in previous literature. Subjects were instructed to run as naturally as possible on the treadmill. Data were recorded during the last 5 minutes of the run. Data collection happened in the last 15 seconds of each of the last 5 minutes. For analysis purposes only the middle 3 trials of 15 seconds were analyzed.

Step-Down protocol: Participants were given three practice trials before data were recorded. Five trials were completed by each participant, while the middle three trials were included in the data set. The box was adjusted to 10% of the individual's height before testing had begun^{15,29}. This height is used so that box height is standardized between subjects. To obtain a box height of 10% of the participant's height, researchers had wooden boxes that were 5cm and 15 cm tall, and rubber mats that measured 2 cm tall. Testing was completed bilaterally. The participants were instructed to stand on top of the box with their toes in line with the front of the

box. They began to slowly lower themselves down on one leg until the non-stance heel touched down on the ground, at which point the subjects returned to standing on top of the box. The test was completed five times, with no rest period between each step-down. Subjects were not instructed on their form throughout the trials. This process was repeated with the subject standing on the other leg.

Data analysis: Kinematic assessments of joint angles were collected for trunk, hip, and knee movements throughout both testing protocols using the Dynamic plug-in gait pipeline.. These joint angle values were used to measure trunk lean in both frontal and sagittal plane, hip drop on the sides of the body, and knee valgus.

For the treadmill run, five running trials were recorded for 15 seconds each during the final 5 minutes of testing. The initial 5 minutes of the treadmill run were used for normalization. The recording began during the fifth minute of the run, and the final 15 seconds of each minute was collected: 5:45, 6:45, 7:45, 8:45, and 9:45. The middle three running trials were used within the data analysis. For the step-down test 5 repetitions were recorded for each leg. Recording began when the subject was instructed to begin and recording ended once the subject returned to the starting position following the 5th heel tap. This test was completed and recorded bilaterally beginning with the right heel being lowered first. The middle three trials were used for data analysis.

The instant of peak knee flexion angles were found within each trial for the SDT and running condition. The instant at which the knee angle during the SDT matched the peak knee angle during running was also identified. At these 3 different time points frontal and sagittal plane angles for the trunk, hip, and knee were identified. During running trials, peak knee flexion is used to determine when the runner has reached the midstance phase according to Gallow and

Heiderscheit²⁰. At the instant of peak knee flexion of the run, the joint angles for hip and knee in the frontal plane and trunk angles in the sagittal plane were taken for analysis.

Peak knee flexion from the three trials during the run were averaged. The average peak knee flexion angle was used to find one time point within the SDT used for analysis. Joint angles at the instant of peak knee flexion during running and identical angle for SDT (SDTmatch) for the trunk, hip and knee during were analyzed to determine the strength and direction of the relationship between the two conditions. A second time point during the step-down test was also analyzed (i.e. a correlation was also computed between these variables for the instant of peak flexion during running trials and the instant of heel tap during the SDT). This point was the lowest or maximum knee flexion angle, when the heel tapped the force plate (SDTmax).

Statistical analysis: All recorded data were input to Microsoft Excel 2016 (Microsoft Inc., Redmond, WA, USA). Kinematic data regarding motion of the trunk, hip, and knee were compared between the SDT and running analysis by a two-way mixed measures analysis of variance (M ANOVA) using SPSS v25.0 (IBM Corp., Armonk, New York, USA). A 2 (group) x 3 (condition) mixed measures ANOVA was used to compare frontal and sagittal plane kinematics. The independent variables were group (control and PFPS patients) and condition (run, SDTmax and SDTmatch). If statistical significance with the two-way ANOVA existed then a simple effects analysis, was performed, and the Bonferroni correction was applied. Partial-eta squared was calculated to determine effect size. Pearson correlation coefficients (r) was used to determine linear relationships for each kinematic variables which include knee abduction, lateral and forward trunk lean, and lateral pelvic tilt. Correlation values were interpreted as; little to no relationship ($r = 0.00 - 0.25$), fair relationship ($r = 0.25 - 0.50$), moderate to good relationship (r

= 0.50 - 0.75), and good to excellent relationship ($r > 0.75$)³⁰. Statistical significance is set to an alpha level of 0.05.

Chapter III

Results

Data for sixteen subjects, eight healthy control and eight PFPS, were analyzed to determine joint angles of the knee, hip and trunk. The average peak knee flexion for the PFPS group was 33.58 ± 11.10 degrees during the run. For the SDT the box was adjusted to 10% of the individual's body height, resulting in 14 subjects performing the test from 17 cm, one subject at 15 cm and one subject at 19 cm. The average knee flexion angle for the SDTmatch of the subjects was 33.69 ± 11.10 degrees and the average for the SDTmax 64.98 ± 17.81 degrees.

For all statistical analysis, Mauchly's test revealed that data violated the assumption of sphericity. Therefore, the Greenhouse-Geisser correction for degrees of freedom was applied for all conditions and groups.

In frontal plane motions, of the hip, knee and trunk, there was no significant interaction observed between the group and conditions for LTL ($F[1.92, 26.89] = 1.44, p < 0.254, \eta_p^2 = 0.09$, observed power = 0.27), KVALGUS ($F[1.40, 19.67] = 3.37, p < 0.069, \eta_p^2 = 0.19$, observed power = 0.48) and LPT ($F[1.97, 27.58] = 0.75, p < 0.476, \eta_p^2 = 0.05$, observed power = 0.16) (Figure 3). However, there was a significant main effect of condition between the run and SDTmax observed. Lateral trunk lean ($F[1.92, 26.89] = 29.56, p < 0.034, \eta_p^2 = 0.67$, observed power = 1.00). There was no significant differences seen for knee valgus ($F[1.40, 19.67] = 6.23, p < 0.051, \eta_p^2 = 0.30$, observed power = 0.71), and lateral pelvic tilt ($F[1.97, 27.58] = 34.30, p = 1.00, \eta_p^2 = 0.71$, observed power = 1.00) between the SDTmax and midstance phase of running (Figure 4). Also, in the frontal plane motion, there was no significant main effect of group between PFPS and healthy controls observed. Lateral trunk lean ($F[1, 14] = 0.271, p < 0.611, \eta_p^2 = 0.19$, observed power = 0.77), knee valgus ($F[1, 14] = 66.71, p < 0.793, \eta_p^2 = 0.01$, observed

power = 0.06), and lateral pelvic tilt ($F[1, 14] = 15.47, p < 0.328, \eta_p^2 = 0.07$, observed power = 0.16).

FIGURE 3. Average frontal plane joint angles between the run and SDTmax.

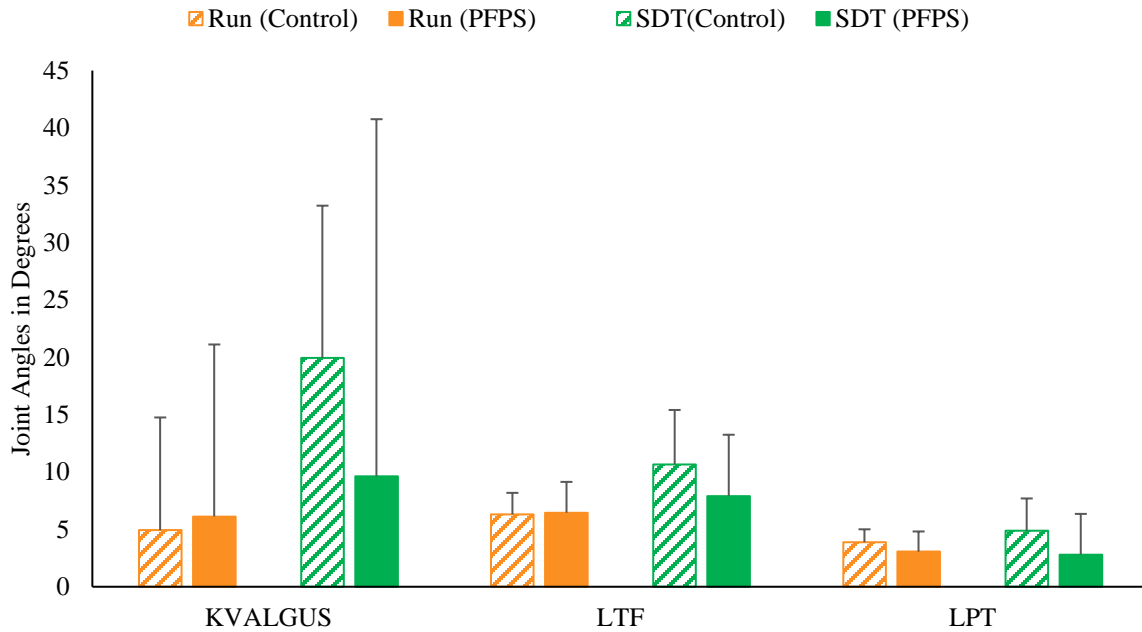
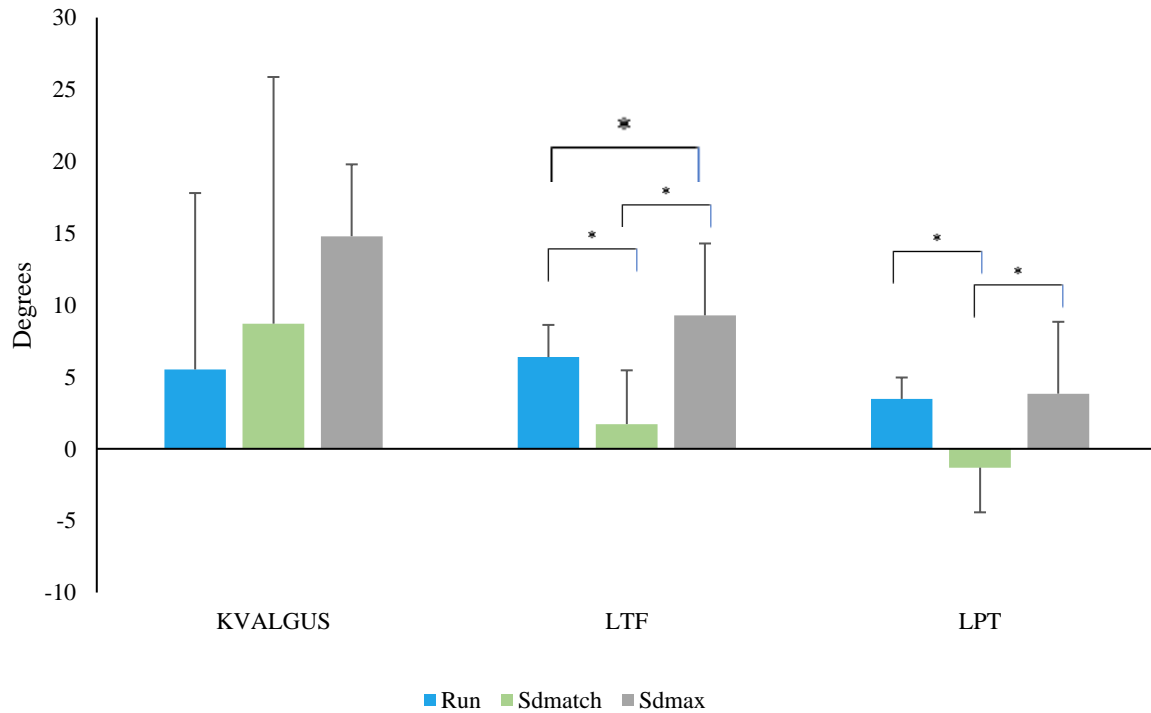


FIGURE 4. Average frontal plane joint angles between conditions.



* $p < 0.05$

In the sagittal plane motion of the trunk, the results showed no interactions between group and condition ($F[1.21, 16.97] = 1.92, p < 0.183 \eta_p^2 = 0.12$, observed power = 0.27) during trunk flexion. Also, there was a non-significant main effect of condition ($F[1.21, 16.97] = 1.50, p < 0.242, \eta_p^2 = 0.09$, observed power = 0.22) and group in the trunk sagittal plane motion ($F[1, 14] = 7.19, p < 0.76, \eta_p^2 = 0.007$, observed power = 0.06).

Two-tailed bivariate Pearson correlation coefficients suggested that there were fair to excellent relationships seen within the frontal plane movements when conditions were compared within the PFPS group. Lateral trunk flexion showed an excellent relationship during the run and SDTmax ($r = 0.898, p < 0.002$) (Figure 5), a moderate relationship during the run and SDTmatch ($r = 0.605, p < 0.112$) (appendix C1), and a fair relationship of the SDTmatch and SDTmax ($r = 0.333, p < 0.421$). Knee valgus showed an excellent relationship the run and SDTmax ($r = 0.945, p < 0.001$) (Figure 6), run and SDTmatch ($r = 0.929, p < 0.001$) (appendix C2), and the SDTmatch and SDTmax ($r = 0.960, p < 0.001$). Lateral pelvic tilt showed a moderate relationship during the run and SDTmax ($r = 0.685, p < 0.061$) (Figure 6), run and SDTmatch ($r = 0.567, p < 0.143$) (appendix C3), and a fair relationship of the SDTmatch and SDTmax ($r = 0.494, p < 0.214$).

Two-tailed bivariate Pearson correlation coefficients suggest that there were fair to moderate relationships seen within sagittal plane movement when conditions were compared within the PFPS group. Trunk flexion showed a moderate relationship during the run and SDTmatch ($r = 0.545, p < 0.162$), and during the SDTmatch and SDTmax ($r = 0.702, p < 0.052$), and a fair relationship during the run and SDTmax ($r = 0.444, p < 0.2.70$).

Figure 5. Relationship between the frontal plane trunk and pelvis angles for the run and the SDTmax.

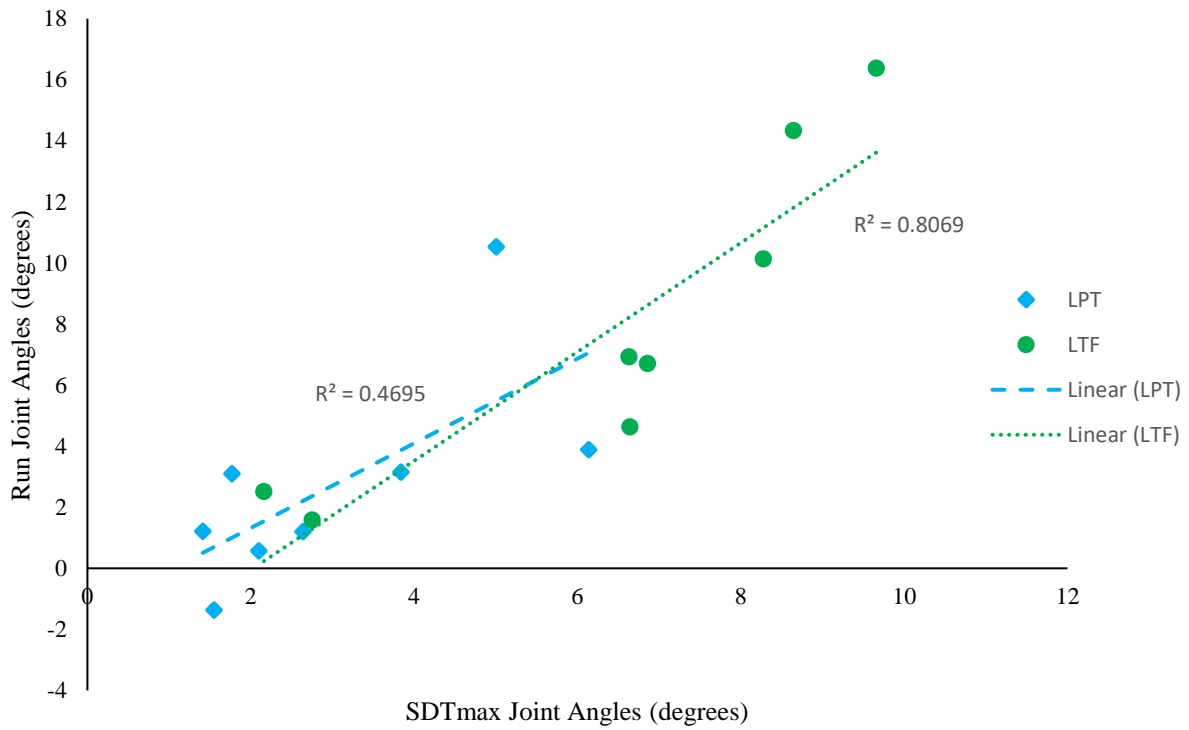
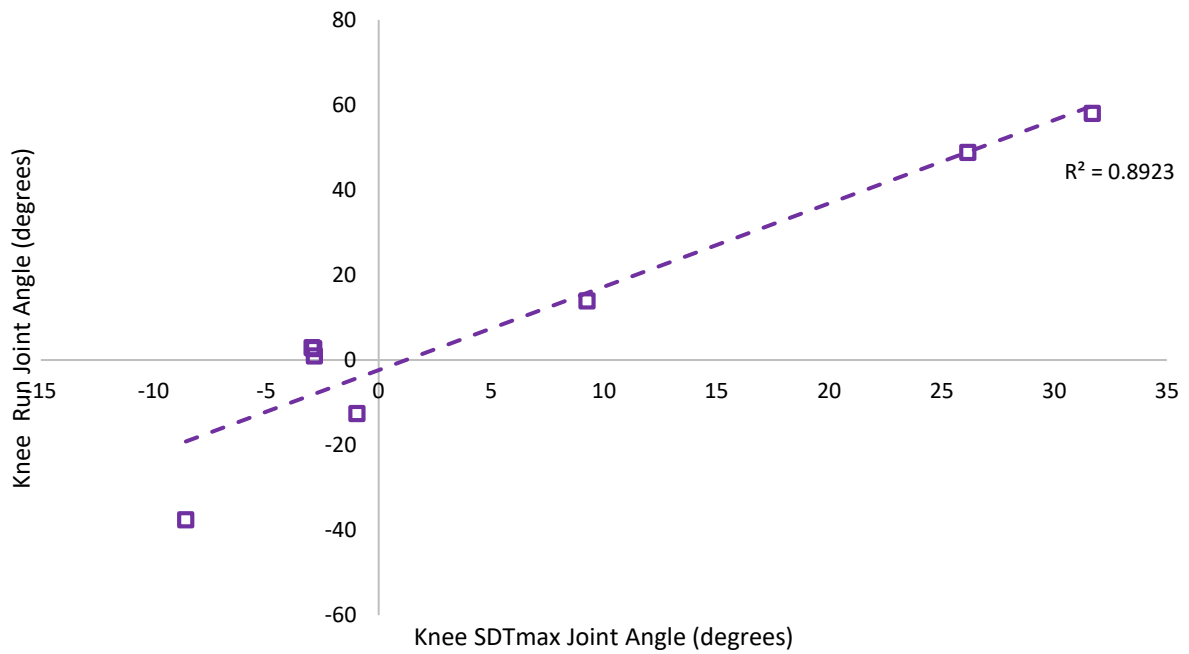


Figure 6. Relationship between the frontal plane knee angle for the run and the SDTmax.



Chapter IV

Discussion

The purpose of this study was to examine the relationship of the kinematics of the knee, hip and trunk in long distance runners with PFPS and healthy controls, during the midstance phase of running and the step-down test. It was hypothesized that there would be no significant interaction between group and condition. We also hypothesized that there would be a strong relationship between conditions within the PFPS individuals. Lastly, it was hypothesized that individuals with PFPS will exhibit increased LPT, LTL, and KVALGUS. The results of the current study suggest that the first hypothesis was supported. The kinematics of the knee, hip, and trunk have no significant differences during the midstance phase of running and the SDT in both the control and PFPS subjects. There was also a strong positive correlation between frontal plane motions of the trunk, hip and knee during the midstance phase of running and the SDT. However, the second hypothesis that individuals with PFPS have an altered joint kinematics compared to healthy subjects was not supported by the data.

The current study showed that there are no significant differences in frontal and sagittal plane kinematics during running and the step-down test. These results are in accordance with Souza et al and Powers et al. Each author reported that they found no significant kinematic differences for the hip during the SDT and midstance of running between those with PFPS and healthy controls^{10,15}. Souza et al used similar methods to the current study; the step height for each individual was normalized to 10% of the subject's height. The authors also analyzed the heel-tap portion of the step-down test and reported no significant kinematic differences between the two tests¹⁵. Powers and colleagues discussed the biomechanical alterations seen between the step-down test and midstance of running. This article looked at the heel-tap kinematics seen

during the step-down test. The authors reported no significant differences between the step-down test and midstance phase of running. They suggested that these results could be due to compensatory mechanisms through muscle recruitment and strength differences¹⁰.

Bazett-Jones et al, showed that when runners are asked to perform a long distance run to exhaustion, frontal plane hip kinematics did not differ between individuals with and without PFPS. These outcomes are similar to the results of the current study that displayed no difference in frontal plane kinematics between groups³¹. Additionally, the present study is in accordance with the study by Noehren et al. Their research showed that individuals with PFPS did not have significant differences in lateral trunk lean or pelvic tilt when compared to healthy age-sex matched controls. These outcomes could be related to different compensation mechanisms such as core activation to stabilize the body and decrease the need for excessive trunk motion⁷. Research by Dierks et al showed comparable findings to the current study that after a prolonged run, there was no kinematic differences between PFPS and healthy controls. Dierks et al suggested that these factors could be due to alterations in muscle strength and activation that can differ between healthy and PFPS individuals³². Future research should look to include information regarding muscular activation patterns and strength in order to determine the contributions to kinematics and possibility of the development of PFPS.

Patellofemoral pain patients usually exhibit increased lateral trunk lean, knee valgus, lateral pelvic drop, and forward trunk lean during running. The present study showed that individuals with PFPS had 6° of lateral trunk lean, 6° of knee valgus, 3° of pelvic drop and 2° of trunk extension in the midstance of running. Previous research stated that individuals with PFPS typically have 4° of lateral trunk lean, 3° of knee valgus, 4° of pelvic drop and 13° of trunk extension during the midstance phase of running³¹. The differences observed between our results

and from those in previous research, could be due to the varied running protocols. Bazett-Jones et al used over the ground running at 4.0 m/s, whereas the current study looked at a treadmill run at 3.0 m/s³¹. These differences in methods between over ground and treadmill running and running speed may have altered the joint kinematics in the present study which would explain the differences observed.

Many research studies looked at prolonged runs and those experiencing knee pain at the time of testing^{7,15,32}. During the current research study, individuals ran at a consistent pace and for a total of 10 minutes, which might not be an adequate amount of time to induce kinematic changes^{7,15,32}. Another factor that could have affected the present study is that no individual experienced knee pain during the testing session. This could result in kinematics being consistent between the two groups of healthy and PFPS^{7,32}. When examining the kinematics during the step-down test at heel strike for individuals with PFPS, it typically shows 2° of lateral trunk lean, 13° of knee valgus, 3° of pelvic drop and 4° of trunk extension²³. In the present study, PFPS subjects presented with 7° of lateral trunk lean, 9° of knee valgus, 3° of pelvic drop and 7° of trunk extension during the step-down test at heel strike. Current outcomes are different than values shown in previous research. One possible explanation is that research by Lewis et al did not standardize box height between subjects. Each individual completed the test from a box that was 16 cm tall²³. The current study standardized the box height to 10% of the subject's height to limit compensations and ensure the task was equally challenging for each individual.

Overall, future research should look to include individuals that are experiencing pain during testing to determine if kinematics are altered only during episodes of pain. No kinematic differences seen between PFPS and healthy controls of the current study could be due to muscular compensations with strength differences or imbalances. These compensatory patterns

would allow for functional movement to remain the same, but strength and activation differences to control the movements.

Limitations. The current study is not without limitations. First, the possibility of error in consistency of motion capture marker placement. To reduce the chance the error, the same researcher placed all makers on each subject within the study. Second, is the age of the subjects used in the study. There was a large range of ages, between 19 and 43 years of age. Several previous studies excluded individuals over 40 to limit possible contributions of age-related joint changes such as osteoarthritis that would alter joint kinematics. Another possible limitation related to age, is the age-sex matches used within the study. Subjects were not matched identically but were matched within 4 years. However, an independent T-test was run to determine any significant differences in age. It was found that there were no statically differences in the ages between the PFPS group and healthy controls ($p < 0.32$). During testing, the treadmill speed was standardized between subjects to decrease the effects of speed on lower extremity kinematics. This could cause a misrepresentation in an individual's pace or general running and subconsciously alter their kinematics.

Conclusion.

The current study provided valuable information regarding the kinematic relationship between the midstance phase of running and the step-down test. Although the two movements are not identical, the current results support that they exhibited similar kinematics. The step-down test can be a useful test to use in a clinical evaluation and rehabilitation setting for runners that are experiencing patellofemoral pain. Clinicians should remember that patellofemoral pain syndrome is a multifaceted injury and should take into account many different aspects that could

be influencing the patient. The step-down test provides a good foundation in predicating joint motions that would occur in functional movements such as running.

Chapter V

Literature Review

Introduction

This review of literature will focus on the anatomy of the lower extremity, including ankle, knee and hip as they interact during running and performing a step-down test. A description of patellofemoral pain syndrome (PFPS), the mechanism of injury and its impacts on everyday life and recreational physical activity. Also, discussed will be how PFPS alters normal biomechanics and kinematics during movement of the lower extremity. Gender differences will also be addressed regarding the prevalence and anatomical biomechanics of the injury. The purpose of this study was to compare the kinematics of the trunk and lower extremity in a population with PFPS during a step-down test compared to the midstance phase of running through a full running gait analysis.

Overall, running has become one of the most common means of exercise, with this the incident of running related injuries has increased specifically within the knee^{2,33-34}. Of knee injuries seen within runners, PFPS is the most prevalent^{2,14-15,18-19,29,31,35-38}. Clinicians commonly use the step-down test in order to evaluate general lower extremity kinematics, this is then correlated to various activities to determine symptom triggers^{2,15}. Despite this, there is little research that looks at the relationship of the step-down test and running, specifically the midstance phase. The following chapter will review pertinent literature and provide evidence to support testing procedures used within the current study.

Running injuries such as PFPS can be caused as a result of factors including both intrinsic: previous injury history, muscle imbalances or weakness, malalignment or anatomical

differences and extrinsic factors: running surface, training schedule or the nature of the sport: a high force, repetitive motion in a single direction^{20-21,39-40}.

Patellofemoral Pain Syndrome

Patellofemoral pain syndrome (PFPS) is one of the most common musculoskeletal injuries in today's society². Nearly 25% of knee injuries that are diagnosed are PFPS³. Benca et al published a meta-analysis looking at running related injuries of no-elite runners. This report reviews 60 peer-reviewed articles regarding musculoskeletal injuries. This analysis found the highest incidence of running related injuries were reported in the knee, with PFPS being among the highest reported injuries³³. Van Gent et al has reported that knee injuries within a running population was between 7.2% and 50% whereas injuries to the leg and foot ranged from 3.4% to 39.3%³⁴. Diagnosis of PFPS is done through a process of exclusion. No structural changes, significant chondral damage or ligament injury are present in diagnosis^{2,12}. Presentation of the injury is chronic or insidious, no known mechanism of injury or blunt trauma³⁻⁴. Many researches have sought out a precise description of symptoms of PFPS. The consensus of data is the patients will present with diffuse anterior or retro-patellar knee pain^{2-3,5-6,41}. There may also be complaints of pain along the medial and lateral patella⁶. Pain is typically described as "achy" but can become sharp with different movements³. PFPS is often seen as a subtle outlet, this means that there is little to no pain during the beginning of activity, but pain often increases as a repetitive activity continues³². People with PFPS exhibit a higher patellofemoral joint stress. This stress is defined as patellofemoral joint reaction force divided by the contact area between the patella and femur. Increased stress to the joint can be a result of increased force, decreased contact area or any combination⁴². Pain in the patellofemoral joint is exacerbated by prolonged sitting, and activities with high quadriceps activity such as, squatting, running, and stair

ambulation^{3,5-6,41}. These activities are associated with increased stress at the patellofemoral joint, which causes excessive compression to the lateral joint facets^{2,4,8,19}. The increased stress and compression is a result of malalignment and/or muscle dysfunction⁸. This condition often becomes chronic and may result in permanent difficulty and pain with activity^{5,7}. If the injury is not properly treated it will lead to osteoarthritis due to a breakdown in structure¹².

Lower Extremity Anatomy

Overview. The relationship between all lower extremity structures play a role in function and kinematics of proper joint and limb movement. If structures begin to affect function, various injuries or pain may occur as a result. There are both anatomical proximal and distal factors that alter patellofemoral movement. Proximal factors include the hip and pelvis, distal factors include the foot and ankle⁷. Three bones play a significant role in PFPS: the patella, femur and tibia. Many soft tissue structures play a role in PFPS. These include major muscle groups, such as, the quadriceps, hamstrings, iliotibial tract, gluteal group, trunk and core stabilizers, gastrocnemius/soleus complex. Smaller muscles such as foot intrinsic muscles which help stabilize the arches of the foot. The patellar tendon also plays a significant role in forces applied to the patella^{3,12}. The patella is the largest sesamoid bone in the body. Its stabilization and alignment are dependent on the quadriceps tendon, fascial retinaculum, and the patellar tendon. Proper stabilization and alignment are needed for proper movement of the patella during knee range of motion⁸.

Bony Anatomy. There are three major bones that constitute the patellofemoral joint. The three bones are the femur, patella, and tibia. The patella is the largest sesamoid bone within the human body. The primary function is to improve the efficiency of knee flexion, by transmitting force generated by the quadriceps muscle⁸. There are other bony structures that

interact with the lower extremity movement such as the pelvis and hip bones and the ankle complex which is the talus and calcaneus.

During movement, each bone is acted upon by muscle, tendon, and ligament forces. These forces cause movement and rotation both normal and abnormal. As one structure is altered, it affects the movement at another structure⁹. Ultimately during flexion and extension of the knee, the patella should glide back and forth in the patellar groove⁸. Muscles attach to bony landmarks putting force through bones as well as force through weight bearing alone. Muscle weakness or tightness will alter movement patterns⁸⁻⁹.

Soft Tissue. Soft tissue of the lower extremity includes tendons, ligaments, and muscles. There are both intrinsic and extrinsic muscles that play a role in strength and movement and stabilization. Within the hip, major muscles studied in PFPS include the gluteus maximus and minimus, and tensor fasciae latae. Major muscles that act on the knee include the hamstring group and the quadriceps group⁸. Two biarticular muscles that influence movement of the lower extremity include the rectus femoris, part of the quadricep muscle group and the gastrocnemius⁴³. The rectus femoris muscle acts on both the hip and knee during movement, whereas the gastrocnemius acts on the knee and ankle⁴³.

The quadriceps muscle group play a significant role in PFPS. The quadriceps are made up of four individual muscles, which form the quadriceps tendon which attaches to the proximal aspect of the patella. Each individual muscle provides a different force vector on the patella. There must be a balance of forces maintained for proper movement. Any excessive muscle tightness, delayed activation or muscle weakness can affect the entire patellofemoral joint motion. This will also put increased strain and demand on the patellar tendon which attaches the distal aspect of the patella to the tibia. The overall force of the quadriceps muscle group is a

posterior pull on the patella⁸. The gastrocnemius and soleus affect not only the knee joint but the ankle and tibia. Tightness will cause the tibia and femur to rotate abnormally, thereby increasing Q-angle and excessive foot pronation^{8,41,44}. This shows how the body works together for optimal movement patterns. If one segment is altered, it will cause changes both up and down the chain from the alteration.

Imbalances and dysfunction of hip muscular can lead to effects of PFPS. Muscles such as the iliopsoas muscle which has a primary function of hip flexion and secondary function of external rotation, tensor fasciae latae which abducts and flexes the hip, the gluteus maximus which causes extension and abduction of the hip, and gluteus minimus which causes flexion and abduction of the hip⁴⁵. Weakness within the iliopsoas can destabilize the pelvis and result in a compensatory anterior pelvic tilt⁸. This increased anterior pelvic tilt can increase the dynamic Q-angle leading to PFPS symptoms⁸. Souza et al studied hip strength in a population with and without PFPS. They recruited 19 subjects with PFPS and 19 controls and looked at kinematics and hip muscle strength. Their results suggested patients with PFPS have significantly reduced strength in the gluteal muscle group and tensor fascia late³⁵. This weakness can lead to compensations during movement, increasing symptoms of PFPS. Weakness within the hip abductors such as the gluteal muscle group can lead to ipsilateral trunk lean and anterior pelvic tilt. Overall, compensatory mechanisms for hip musculature weakness can lead to increased symptoms of PFPS due to lateral trunk lean, anterior pelvic tilt leading to increased knee valgus and increased stress at the patellofemoral joint⁴⁶.

Muscular imbalances and weakness have often been seen within patients with PFPS. These weaknesses can be seen when comparing both healthy and unhealthy populations, but also within individuals between the painful and pain free leg^{8,47}. In a review by Thomee et al they

found most previous research found that individuals with PFPS had lower quadriceps activation than a healthy population⁴⁷.

Quadriceps Angle

Quadriceps angle (Q-angle) measurements are also helpful in evaluating PFPS. Q-angle is a measurement between the patellar tendon and the rectus femoris muscle attachment at the anterior inferior iliac spine^{10,11,29,44}. Static measurements are made using a handheld goniometer with patients laying in a supine position with the knee and hip fully extended and in neutral rotation with no quadricep muscle activation. The angle is calculated from the intersection of two sections crossing the patella. First section is from the anterior superior iliac spine (ASIS) to the midpoint of the patella, the second section is from the anterior tibial tuberosity to the midpoint of the patella^{29,41}. The measurement of the angle that is done while the patient is supine is called the static Q-angle. This angle provides information on the anatomical position before movement occurs^{10,44}. Once the patient is active tracking the movement of the patella by MRI or motion capture can provide information of how the angle changes during movement⁴¹.

This measurement provides information about the knee joint alignment and the pull of the quadriceps muscle group. Normal values for men are 14 degrees and women are 17 degrees due to anatomical differences¹¹. A larger Q-angle would create a large lateral vector, causing the patella to track more laterally during movement and increase lateral facet pressure due to the patella being pulled toward the lateral aspect of the femur^{10,29,41,44}. Previous research by Huberti et al for that increases of the Q-angle by 10% can result in increased patellofemoral joint stress of 45 percent⁴⁸.

There are three major movements of the lower extremity that influence the Q-angle, tibial rotation, femoral rotation, and knee valgus. This is in conjunction with any preexisting structural deformities. External rotation of the tibia will cause an increase in Q-angle due to a lateral movement of the tibia. Whereas, an internal rotation causes a decrease in Q-angle due to a medial movement of the tibia¹⁰. Frontal plane motions of the hip and knee during functional movement will lead to an increase on dynamic Q-angle. This increase is driven by hip adduction and increase lateral joint forces, which increases patellofemoral joint stress¹⁷.

Functional Anatomy

In normal static anatomy, the tibia should be slightly internally rotated. During lower extremity movement, the tibia should be slightly externally rotated relative to the femur so that full extension can occur during gait pattern. This is known as the screw home mechanism of the tibiofemoral joint⁵. The patella is used as a fulcrum to increase the efficiency of the quadriceps muscle group during flexion and extension. Since the patella is known as a gliding joint, it has movement in in multiple planes. The different movement is dependent on different muscle activation during joint range of motion. During open chain movements, the patella follows the path of the tibia. During closed chain movements, since the patella is fixed within the quadriceps tendon, it will glide with the femur as it rotates⁴⁹.

Altered Kinematics

Lower extremity kinematics greatly influence movement quality of the patellofemoral joint during dynamic tasks. Specifically, internal rotation of the femur, adduction of the femur, knee valgus, tibial rotation, and patellofemoral contact pressure¹³. Trunk kinematics have recently been theorized to be affected in patients with patellofemoral pain syndrome. Individuals

with PFPS who display abductor weakness tend to compensate the weakness by leaning toward the stance leg^{7,13}.

Running. During any running activity there will be an increase stress or pressure in the patellofemoral articulation⁶. Factors such as tibial and femoral rotation, muscular weakness, foot postures will affect running and how joint stress is altered. These alterations can increase joint compression and patellar tracking. They may be caused by kinematic or structural abnormalities². Both proximal and distal factors have an effect on the patellofemoral joint. These factors influence each other and will further alter kinematics and cause further alterations both up and down the kinetic chain.

One of the most distal factors include foot posture. Excessive pronation has been shown to increase stress on the patellofemoral joint^{2,5,7,10,12,50}. A pronated foot type causes an increase in fore-foot abduction and rear-foot eversion^{12,50}. The increased foot pronation will increase both tibial and femoral internal rotation which leads to the collapse of the knee, causing a valgus moment^{2,5,10}. During a running assessment, the most evident phase of gait for pronation, resulting in tibial rotation is during midstance¹⁰. In theory, controlling excessive foot pronation would limit tibial and femoral rotation ultimately reducing the stress placed on the patellofemoral joint⁵⁰.

Proximal factors of alterations in kinematics include hip muscular strength, muscle activation, knee flexion and rotation of the femur and Q-angle. Decrease in hip stabilizing musculature has a major effect on altering patellofemoral joint kinematics^{2,6,14,10,15}. Decreased strength of hip abductors allows for excessive femoral adduction. Increased hip adduction leads to a greater dynamic Q-angle^{7,12,32}. This increases the risk of dynamic valgus and patellar maltracking during functional movement^{12,14,32}. The weakness can result in a rolling in of the

femur, increasing the stress at the patellofemoral joint¹⁰. Weakness in hip musculature will create an elevation of the pelvis and a lateral lean to compensate for weakness^{7,14,15}. Ireland et al looked at isometric in a population of female subjects with and without PFPS. The study results found the females with PFPS demonstrated 26% less strength of hip abductors and 36% less strength of hip external rotators when compared to healthy controls. This decrease of strength can result in the increase dynamic valgus previously discussed⁵. Delayed onset muscle activation of hip musculature causes an increase in femoral internal rotation. This relationship is important imbalances between vastus medialis and vastus obliquus and lateralis^{6,12}. These imbalances will increase stress on the patellofemoral joint and alter patellar tracking by placing a more lateral pull on the patella¹². Hip weakness alters the ability to control and stabilize the hip during movement and increase the internal rotation of the femur¹⁴. The increased internal rotation of the femur increases the pressure between the patella and femur^{3,5}. Increases in femoral internal rotation can alter the alignment and ultimately the kinematics of the patellofemoral joint. This rotation can create a dynamic knee valgus during functional activities. The valgus movement will result in an increase of lateral forces acting on the joint. This increased stress will result in an increase of the Q-angle due to unequal pull of the patella^{10,14,15}. Weakness in hip musculature causes a chain reaction in kinematic alterations. Weakness causes increases in tibial and femoral internal rotation, knee valgus, increased joint pressure and even alterations in distal factors such as foot pronation.

PFPS often has decreased performance effects on running and training. Often patients suffering from PFPS alter training to cope with the pain and symptoms of the injury. Dierks et al. found that runners with PFPS often decrease run duration by an average of 10 minutes when compared to a healthy population. Within this study it was also reported that up to 60% of

subjects had to discontinue testing protocol due to discomfort. Strength testing after a prolonged run showed reductions in hip abductors in the PFP group compared to the control¹⁴. On the contrary some authors report no significant differences between healthy and PFPS during prolonged runs³¹. Bazett-Jones reports increased forward trunk lean and hip and knee flexion when compared to a healthy population. Authors report this could be a compensation measure to reduce stress within the patellofemoral articulation in order to reduce knee pain in order to complete the training demand³¹.

Step Down Test. The forward step-down test is commonly used within the health care profession in the diagnosis of PFPS. The test can be used to identify weakness of the lower extremity and core, and dynamic control of the ankle, knee, hip and trunk^{24,49,51}. Loudon et al mentions the benefits of clinically using the step-down test. The research states reasons of efficiency, and little space and equipment required for the test²⁴. Manske et al described the typically seen alterations and overall impression based on anatomical segments that clinicals look for. Most commonly seen compensations include trunk lean, pelvic drop and rotation, hip adduction and rotation and knee valgus. Overall, compensations are seen to maintain balance, perturbations, quality of movement and decrease symptoms²².

The forward step-down test is a functional activity that requires a similar mechanism of stair descent which is a common activity which causes increased pain and dysfunction in people with PFPS^{16,24}. This test requires weight-bearing stress at a variety of knee flexion angles as well as dynamic control and stabilization. Loudon et al described the test as a unilateral functional test performed with the subject standing atop a platform. The subject is instructed to step down toward the floor in a forward motion^{22,24}. The leg stepping toward the floor, touches slightly then the subject returns to the starting position with full extension of the knee. Throughout current

research, the box height used widely varies. Almeida et al and Souza et al used a box height that was in conjunction with the subject's height. The box was set to 10% of the individuals height^{15,29}. This height is used to normalize the height between subjects to ensure a comfortable height and limit compensation due to improper box height^{15,29}. Other research selects a standard box height that ranges from 16 to 24 centimeters^{16,23,24,51}. Earl et al recognized a limitation with the use of a standardized height, knee flexion angles can be affected due to subject's height⁵¹. The lowering-and-rising motion should be controlled through the entire movement. The step leg should not be used to accelerate the subject back to the starting position^{22,24}. For those reason, it makes this test an excellent choice to measure kinematics during a common functional movement for people with PFPS. This test is commonly used to asses knee pain, this is because it mimics functional weight-bearing activities. This test also provides insight to movement of the entire lower kinetic chain²²⁻²⁴.

Poor or abnormal mechanics during the step-down test will place abnormal stress on the knee at both the tibiofemoral and patellofemoral joints¹⁶. The mechanism of a step-down increases lateral patellar tilt and increased lateral contact of the patellofemoral joint⁷. It has been shown that there is a higher patellofemoral joint stress during a forward step-down. Two major factors that contribute to this increased stress are knee flexion angle and quadriceps force⁴². During a step-down test there is an increase in hip adduction, internal rotation and knee abduction which results in an increase in pain and decrease in function¹⁷. The decrease in function can be attributed to faulty tracking of the patella through the full range of motion of the knee. The mistracing of the patella is due to muscular weakness, flexibility and altered muscle activation¹⁹. Stair descent required knee flexion and also eccentric stabilization of the hip and controlled motion of the femur. Weakness of the surrounding musculature can lead to excessive

hip adduction and internal rotation of the femur leading to increased knee valgus¹⁶. There is evidence that muscular weakness will lead to hip drop on the stance leg. It will also lead to a lateral trunk lean over the stance leg in an effort to reduce demand on hip stabilizer muscles^{7,16}. Delayed activation has been seen between vastus medialis and gluteus maximus and vastus medialis obliquus and vastus lateralis which alters stabilization of the hip complex. This also affects optimal patellar tracking by causing a lateral tracking pattern^{4,19}. Knee flexion is associated with increased patellofemoral joint stress as it increases contact area. During stair ambulation knee flexion is often reduced in those with PFPS to attempt to lessen the patellofemoral joint stress⁴.

Overall, populations suffering from PFPS have overall increased range of motion^{15,24,35}. Populations with PFPS often demonstrate many compensations to complete movements and decrease symptoms. These compensations can include increased ipsilateral trunk lean, increased pelvic drop, increased hip adduction and increased knee abduction of valgus^{15,16,23,46}.

Gender Differences

Gender plays an important role in diagnosis of patellofemoral pain, this condition has a higher prevalence in females than males⁵². In fact, females are twice as likely to be affected by this condition as males^{7,12}. There are many biomechanical factors that lead to this increased risk for females. These factors in Q-angle measurements, lower extremity muscle strength, frontal plane measurements including knee valgus, all these factors at both static and dynamic movement⁵². Females have an increased Q-angle, which is first attributed to anatomical gender differences, then muscle strength will factor into the relationship. Structural differences between men and women that attribute to greater Q-angles in females include increased hip adduction and internal rotation²⁸. Ferber et al found that females running at 3.65 m/s exhibited increased hip

adduction and knee abduction or knee valgus than males²⁸. As well, females also have an increase in dynamic knee valgus and decreased strength in the quadriceps and hip stabilizers muscle groups^{12,52}. With an increase in Q-angle, it will lead to an increase in lateral patellar contact for females²⁸. Also reported by Ferber et al was greater energy absorbed in the hip and knee when compared to males²⁸. Females have a larger hip width to femoral length, this will lead to an increase in hip adduction²⁸.

In populations with PFPS, these factors become further aggregated. In PFPS, females have a greater knee flexion, adduction and internal rotation of the hip^{6,117,28}. They also exhibited a reduction in hip abduction and external rotation¹². On average, females have greater peak hip adduction and internal rotation when compared to males. Decreased hip adduction is the best predictor of reduction in function¹⁷. Female runners exhibit an excessive internal rotation of the femur, this leads to malalignment of the patellofemoral joint increasing the prevalence of anterior knee pain²⁸. These factors will contribute to a greater knee valgus and lateral tracking of the patella. This increases the patellofemoral joint stress, leading to an increase in pain⁶. With greater hip adduction and internal rotation of the hip, there is an increase in trunk lean which is a compensatory mechanism for weak hip musculature and a way to try and reduce pain⁷. Females have been shown to have overall weaker muscles of the lower extremity, this leads to poor hip control which leads to increased stress on the patellofemoral joint¹⁷. Due to many different risk factors including anatomical gender differences, decreased muscle strength and control and biomechanical and kinematic differences lead to increased prevalence and incidence of PFPS in the female population.

Summary

Patellofemoral pain syndrome is a very common musculoskeletal injury with no definitive mechanism of injury. Patellofemoral pain syndrome is characterized by pain that increase as activity increases and often affects activities of daily living. Common factors seen during patellofemoral pain syndrome are increased tibial and femoral internal rotation, knee valgus, hip muscle weakness, and a pronated foot type. Each factor can affect structures and functions both up and down the kinetic chain. This injury is unique to an individual as to what causes it so accurate diagnosis of the root problem is critical in targeting treatment. Diagnosis is typically a process of ruling out other traumatic knee joint injuries. With the use of the step-down test kinematics, patellofemoral pain can be assessed, and the root cause of the pain can be addressed individually. The step-down test is a more functionally applicable approach to assess patellofemoral pain syndrome.

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Appendices

Appendix A

(Revised May 2010)

The mission of the Journal of Athletic Training is to advance the science and clinical practice of athletic training.

SUBMISSION POLICIES

1. Submit online at <http://jat.msubmit.net>
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 - b. Authorship form. The Journal of Athletic Training conforms to the International Committee of Medical Journal Editors' Uniform Requirements for Manuscripts Submitted to Biomedical Journals. Each author must be specifically identified in the published manuscript, in accordance with the Uniform Requirements for Manuscripts Submitted to Biomedical Journals: "Authorship credit should be based only on 1) substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; 2) drafting the article or revising it critically for important intellectual content; and 3) final approval of the version to be published. Conditions 1, 2, and 3 must all be met. Acquisition of funding, the collection of data, or general supervision of the research group, by themselves, do not constitute authorship." (Categories borrowed with the permission of the Annals of Internal Medicine.)

Contributors to the manuscript who do not qualify for authorship should be thanked in the Acknowledgments section.

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3. Financial support or provision of supplies used in the study must be acknowledged. Grant or contract numbers should be included whenever possible. The complete name of the funding institution or agency should be given, along with the city and state in which it is located. If individual authors were the recipients of funds, their names should be listed parenthetically.
 4. Authors must specify whether they have any commercial or proprietary interest in any device, equipment, instrument, or drug that is the subject of the article in question. Authors must also reveal if they have any financial interest (as a consultant, reviewer, or evaluator) in a drug or device described in the article.
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 6. The Journal of Athletic Training uses a double-blind review process. Authors and institutions should not be identified in any way except on the title page.
 7. Manuscripts are edited to improve the effectiveness of communication between author and readers and to aid the author in presenting a work that is compatible with the style policies found in the AMA Manual of Style, 10th ed. (Williams & Wilkins), 2007. Page proofs are sent to the author as PDFs for proofreading, and any changes must be returned within 48 hours. Important changes are permitted, but authors will be charged for excessive alterations. Please keep in mind that alterations are costly. Although authors will need to correct any factual or typesetter errors, text changes in

excess of 5 text "blocks" will be billed at \$5 per correction. Figure remakes (replacement figures or minor figure editing) will be billed as follows: black and white figure, \$25; halftone (eg, photograph), \$30; color, \$75.

STYLE POLICIES

8. Each page must be formatted for 8½-by-11-inch paper, double spaced, with 1-inch margins in a font no smaller than 10 points. Include line counts on each page to facilitate the review process. Do not right justify pages.
9. Manuscripts should contain the following, organized in the listed order, with each section beginning on a separate page:
 - a. Abstract and Key Words (first numbered page)
 - b. Text (body of manuscript)
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10. Begin numbering the pages of your manuscript with the abstract page as #1; then, consecutively number all successive pages.
11. Units of measurement shall be recorded as SI units, as specified in the AMA Manual of Style, except for angular displacement, which should be measured in degrees rather than radians. Examples include mass in kilograms (kg), height in centimeters (cm), velocity in meters per second (m N s⁻¹ or m/s), angular velocity in degrees per second (6 N s⁻¹), force in Newtons (N), and complex rates (mL/kg per minute).
12. Titles should be brief within descriptive limits (a 16-word maximum is recommended for all manuscripts except Short Reports and Technical Notes, for which the maximum is 12 words or 85 characters). If a technique is the principal reason for the report, it should be named in the title. If a disability is relevant, it should be named in the title.
13. The title page should also include the name, title, affiliation, and e-mail address of each author, and the name, address, phone number, fax number, and e-mail address of the author to whom correspondence is to be directed. No more than 4 credentials should be listed for each author. The "ATC" credential is under the copyright protection of the Board of Certification. Therefore, the proper listing of an additional state credential is "LAT, ATC" or "ATR, LAT."
14. A structured abstract of no more than 300 words must accompany all manuscripts other than Short Reports and Technical Notes, which require abstracts of no more than 150 words. Type the complete title (but not the authors' names) at the top, skip

2 lines, and begin the abstract. Items that are needed differ by type of article.

Quantitative Original Research articles: Context, Objective, Design, Setting, Patients or Other Participants, Intervention(s), Main Outcome Measure(s), Results, Conclusions, and Key Words.

Qualitative Original Research articles: Context, Objective, Design, Setting, Patients or Other Participants, Data Collection and Analysis, Results, Conclusions, and Key Words.

Meta-Analysis and Systematic Review articles: Objective, Data Sources, Study Selection, Data Extraction, Data Synthesis, Conclusions, and Key Words. **Case Reports:** Objective, Background, Differential Diagnosis, Treatment, Uniqueness, Conclusions, and Key Words.

Clinical Techniques: Objective, Background, Description, Clinical Advantages, and Key Words.

Evidence-Based Practice: Reference/Citation, Clinical Question, Data Sources, Study Selection, Data Extraction, Main Results, Conclusions, Key Words, and Commentary.

Literature Reviews: An author who wishes to submit a literature review is advised to contact the Editorial Office for instructions.

Short Reports and Technical Notes: The JAT will consider manuscripts on topics that are best suited for dissemination in the form of a rapid communication. Short reports should reflect succinct reviews of a specific topic, a historical perspective, or application of a specific statistical procedure. Technical notes should describe results from new or modified experimental methods or advances in instrumentation, data acquisition, or orthopaedic sports medicine-related procedures. Further, they should define, explain, or discuss the technical and scientific aspects of an important and timely topic. Abstracts for these manuscripts should not exceed 150 words, and key words or phrases are limited to 3. Abstract headings should reflect the specific sections salient to the overall theme of the paper. The manuscript should not exceed 2000 words, including the abstract, tables, and figure legends (if applicable). No more than 3 tables or figures should accompany the manuscript. An author who wishes to submit a short report or technical note is advised to contact the Editorial Office in advance regarding the suitability of the topic.

15. Study design should be selected from the choices listed below (courtesy of the Centre for Evidence-Based Medicine [www.cebm.net] and the American Journal of Sports Medicine).

Meta-Analysis: A systematic overview of studies that pools results of 2 or more studies to obtain an overall answer to a question or interest. Summarizes quantitatively the evidence regarding a treatment, procedure, or association. **Systematic Review:** An article that examines published material on a clearly described subject in a systematic way. There must be a description of how the evidence on this topic was tracked down, from what sources, and with what inclusion and exclusion criteria.

Randomized Controlled Clinical Trial: A group of patients is randomized into an experimental group and a control group. These groups are followed up for the variables/outcomes of interest.

Crossover Study Design: The administration of 2 or more experimental therapies, one after the other, in a specified or random order to the same group of patients.

Cohort Study: Involves identification of 2 groups (cohorts) of patients, one which did receive the exposure of interest and one which did not, and following these cohorts forward for the outcome of interest.

Case-Control Study: A study that involves identifying patients who have the outcome of interest (cases) and patients without the same outcome (controls) and looking back to see if they had the exposure of interest.

Cross-Sectional Study: The observation of a defined population at a single point in time or time interval. Exposure and outcome are determined simultaneously. **Case Series:** Describes characteristics of a group of patients with a particular disease or who have undergone a particular procedure. Design may be prospective or retrospective. No control group is used in the study, although the Discussion may compare the results with others published in the literature.

Case Report: Similar to the Case Series, except that only one or a small group of cases is reported.

Descriptive Epidemiology Study: Observational study describing the injuries occurring in a particular sport. **Controlled Laboratory Study:** An in vitro or in vivo investigation in which 1 group receiving an experimental treatment is compared

with 1 or more groups receiving no treatment or an alternate treatment. **Descriptive Laboratory Study:** An in vivo or in vitro study that describes characteristics such as anatomy, physiology, or kinesiology of a broad range of subjects or a specific group of interest. **Qualitative Study:** A study that utilizes qualitative methodology such as grounded theory, phenomenology, ethnography, or case-study approach to understand a phenomenon. Data-collection methods may include participants describing their experiences orally or in writing or research observation of participants' behavior.

16. Begin the text of the manuscript with an introductory paragraph or two in which the purpose or hypothesis of the article is clearly stated and developed. Tell why the study needed to be done or the article written, and end with a statement of the problem (or controversy). Highlights of the most prominent works of others as related to your subject are often appropriate for the introduction, but a detailed review of the literature should be reserved for the Discussion section. In a 1- to 2-paragraph review of the literature, identify and develop the magnitude and significance of the controversy, pointing out differences among others' results, conclusions, and/or opinions. The Introduction is not the place for great detail; state the facts in brief, specific statements and reference them. The detail belongs in the Discussion. Also, an overview of the

manuscript is part of the abstract, not the introduction. Writing should be in the active voice (for example, instead of "Participants were selected," use "We selected participants") and in the first person (for example, instead of "The results of this study showed," use "Our results showed").

17. The body or main part of the manuscript varies according to the type of article (examples follow); however, the body should include a Discussion section in which the importance of the material presented is discussed and related to other pertinent literature. When appropriate, a subheading on the clinical relevance of the findings is recommended. Liberal use of headings and subheadings, charts, graphs, and figures is recommended (see item 14 for exceptions regarding short reports and technical notes).

a. The body of an Original Research or a Meta-Analysis or Systematic Review article consists of a Methods section, a presentation of the Results, and a Discussion of the results. The Methods section should contain sufficient detail concerning the methods, procedures, and apparatus employed so that others can reproduce the results. The Results should be summarized using descriptive and inferential statistics and a few well-planned and carefully constructed illustrations. For more information on preparing research manuscripts, authors are advised to consult the MOOSE and PRISMA statements, which are available through the JAT Web site.

b. The body of a Case Report should include the following components: personal data (age and sex and, when relevant, race, marital status, and occupation but not name or initials), chief complaint, history of present complaint (including symptoms); results of physical examination (example: "Physical findings relevant to the rehabilitation program were ..."); medical history (surgery, laboratory results, examination, etc); diagnosis, treatment and clinical course (rehabilitation until and after return to competition); criteria for return to competition; and deviation from expectations (what makes this case unique).

c. The body of a Clinical Techniques article should include both the how and why of the technique: a step-by-step explanation of how to perform the technique, supplemented by photographs or illustrations, and an explanation of why the technique should be used. The Discussion concerning the why of the technique should review similar techniques, point out how the new technique differs, and explain the advantages and disadvantages of the technique in comparison with other techniques.

d. The body of an Evidence-Based Practice article provides a short review of current scientific literature and applies the findings to clinical athletic training practice. All articles submitted for this section should be concise reviews of published systematic reviews or meta-analyses on topics relevant to the 7 domains of athletic training

- (Prevention, Assessment/Evaluation, First Aid/Treatment, Rehabilitation, Organization/Administration, Counseling, and Education). Reviews of individual, large, controlled clinical trials will also be considered. The review must begin with the complete article title and reference and a statement of the clinical question the review addresses. The rest of the review consists of a summary of the article and must include the following sections: data sources and search terms used; study selection (inclusion and exclusion) criteria; the methods used to extract and review data, including a list of the primary out-come measures; results of the search strategy; and primary outcome measures and conclusions. A separate commentary section should address the application of the information to the clinical athletic training setting. Authors may use supplementary scientific literature (up to a maximum of 5 references) to support the commentary.
- e. The body of a Short Report or Technical Note consists of sections appropriate to the theme of the paper. For a Short Report, these sections will vary with the topic. Section headings should reflect the overall theme of the paper and should organize the material in a logical fashion. Data specific to the relevant findings should be provided if applicable. A summary providing a brief overview of the content should be included. For a Technical Note, the body consists of Introduction, Methods, Results or Key Findings, Commentary, and Conclusions. References should not exceed 10 for either a short report or technical note.
18. Percentages should be accompanied by the numbers used to calculate them. When reporting no difference among groups on a key outcome measure, include a power analysis to demonstrate that the study was adequately powered. The power analysis should quantify the smallest statistically significant difference that would have been detectable with the given sample size. (Additional information on power is available at <http://www.stat.uiowa.edu/~rlenth/Power/> and <http://www.sportsci.org/resource/stats/index.html>.) Never report a single P value as an inequality (eg, $P < .05$) but instead report the exact value (eg, $P = .06$). If, however, the value would be reported as $P = .00$ because of the number of significant digits allowed, then it is acceptable to state $P < .001$. When reporting groups of P values, it is permissible to provide an inequality (eg, "groups were similar on all demographic characteristics [$P < .05$]").
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- Journals:**
1. Boling MC, Padua DA, Creighton RA. Concentric and eccentric torque of the hip musculature in individuals with and without patellofemoral pain. *J Athl Train.* 2009;44(1):7–13.
 2. McDonough EB Jr, Wojtyls EM. Multiligamentous injuries of the knee and associated vascular injuries. *Am J Sports Med.* 2009;37(1):156–159.
- Books:**
1. Ritter MA, Albohm MJ. *Sports Injuries: Your Common Sense Guide.* Traverse City, MI: Cooper Publishing Group; 2008:1–12.
 2. Massey-Stokes M. Body image and eating disturbances in children and adolescents. In: Robert-McComb JR, Norman R, Zumwalt M. *The Active Female: Health Issues Throughout the Lifespan.* Totowa, NJ: Humana Press; 2008: 57–80.
- Presentation:**
- Ross SE, Linens SW, Arnold BL. Balance assessments for discriminating between functional ankle instability and stable ankles. Presented at: 59th Annual Meeting & Clinical Symposia of the National Athletic Trainers' Association; June 20, 2008; St Louis, MO.
- DVD:**
- Athletic Taping and Bracing [DVD]. Champaign, IL: Human Kinetics; 2005.
- Software Manual:**
1. SPSS Base for Windows [computer program]. Version 13.0. Chicago, IL: SPSS Inc; 2005.
- Internet Sources:**
1. Cappaert TA, Stone JA, Castellani JW, Krause BA, Smith D, Stephens BA. National Athletic Trainers' Association position statement: environmental cold injuries. <http://www.nata.org/statements/position/environmentalcoldinjuries.pdf>. *J Athl Train.* 2008;43(6):640–658. Published December 2008. Accessed April 14, 2009.
 2. American College of Sports Medicine. Physical activity & public health guidelines. http://www.acsm.org/AM/Template.cfm?Section=General_Public&TEMPLATE5/CM/HTMLDisplay.cfm&CONTENTID511398. Published 2007. Accessed April 14, 2009.
23. Personal communications are cited in the text as follows: "... (J.A. Smith, written communication, January 2005)." The written or oral nature of the communication is stated, and the communication does not appear in the reference list. Authors must provide written permission from each personal-communication source. A form is available on the JAT Web site and from the Editorial Office.
24. Table Style: 1) Title is bold; body and column headings are roman type; 2) units are set above rules in parentheses; 3) numbers are aligned in columns by decimal; 4) footnotes are indicated by superscript letters; 5) capitalize the first letter of each major word in titles; for each column or row entry, capitalize the first word only. See a current issue of JAT for examples.
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26. Legends to figures are numbered with arabic numerals in order of appearance in the text. Legends should be printed on separate pages at the end of the manuscript.
27. The Journal of Athletic Training follows the redundant publication guidelines of the Council of Science Editors, Inc (CBE Views, 1996; 19:76–77; also available on the JAT Web site). Authors in violation of redundant publication will have sanctions invoked by the Journal Committee of the National Athletic Trainers' Association, Inc.

PUBLICATION POLICIES

28. Original Research manuscripts will be categorized under the following table of contents subheadings: clinical studies, basic science, educational studies, epidemiologic studies, and observational/informational studies.
29. Only Case Reports and Clinical Techniques that define and establish the optimal standard of care or the practice of athletic training will be considered for publication in JAT. Case Reports and Clinical Techniques that do not profoundly affect the standard of care but that contain potentially useful information for athletic trainers will be considered for publication in the NATA News.
30. Media Reviews will appear in the NATA News.

TRUNK, HIP AND KNEE MOTIONS DURING A STEP-DOWN TEST AND RUNNING IN PATELLOFEMORAL PAIN INDIVIDUALS

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There are no conflict of interest or financial disclosure.

Appendix B

Western Washington University Informed Consent

Motions of the Hip and Knee during Single-Leg Step-Down Test and Running

Purpose and Benefit:

This research aims to examine the relationship of leg motion between a single leg step down and running. The connections between the motion of the leg and knee pain are still being investigated world-wide. Due to the influence of hip muscles on knee position, this study will help to better understand the motion of the leg during a functional test and running.

I UNDERSTAND THAT:

1. This research will involve completion of a series of tasks including a 5-minute, low-intensity warm-up on a treadmill, a 10-minute run on a treadmill, five single leg step-downs performed on each leg in front of multiple motion analysis cameras, and a 5-minute, low-intensity cool-down. My participation will require approximately 90 minutes of my time.
2. This research will require the placement of reflective markers on both hips, the outside of both knees, the middle of both thighs, the middle of both calves, the outside of both ankles, and on the top of the foot and heel of both feet for the step-down test and run. I will also have a total of five electrodes on my hips and front and back of my thigh for the leg experiencing knee pain. For marker visibility, I will be asked to wear shorts or tights and a sports bra (women), and to remove my shirt for the running trials and step-down test.
3. There are minimal risks possible for participants. I may experience acute muscle soreness due to the step-down test, a raising and lowering task where I will tap my heel to the ground. I understand that this step-down task may include some additional pain or discomfort if I am currently experiencing pain in the knee. There is also a low falling risk associated with standing on the box for the step-down test and running on the treadmill.
4. Potential benefits of participation will include an increased understanding of my running form. A student participating in this research may benefit from extra credit up to two points in participating classes.
5. My participation is completely voluntary. I am able to withdraw from this research at any time.
6. All information is confidential. This signed consent form will be kept in a locked filing cabinet separate from any other information connecting me to this research. Only the primary investigator and graduate researcher will have access to any data collected in this study. My name will not be associated with any data collected.
7. I must be at least 18 years of age to participate.
8. My signature on this form does not waive my legal rights of protection.
9. This research is conducted by Katie Olinger under the supervision of Dr. Jun San Juan. Any questions that you have regarding the study or your participation may be directed to Dr. Jun San Juan at (360) 650-2336, jun.sanjuan@wwu.edu.

If you have any questions about your participation or your rights as a research participant, you can contact Janai Symons at the WWU Human Protections Administrator (HPA), (360) 650-3220, janai.symons@wwu.edu. If during or after participation in this study you suffer from any adverse effects due to participation, please notify the researcher directing the study or the WWU Human Protections Administrator.

I have read the above description and agree to participation in this study.

Participant's Signature

Date

Participant's PRINTED NAME

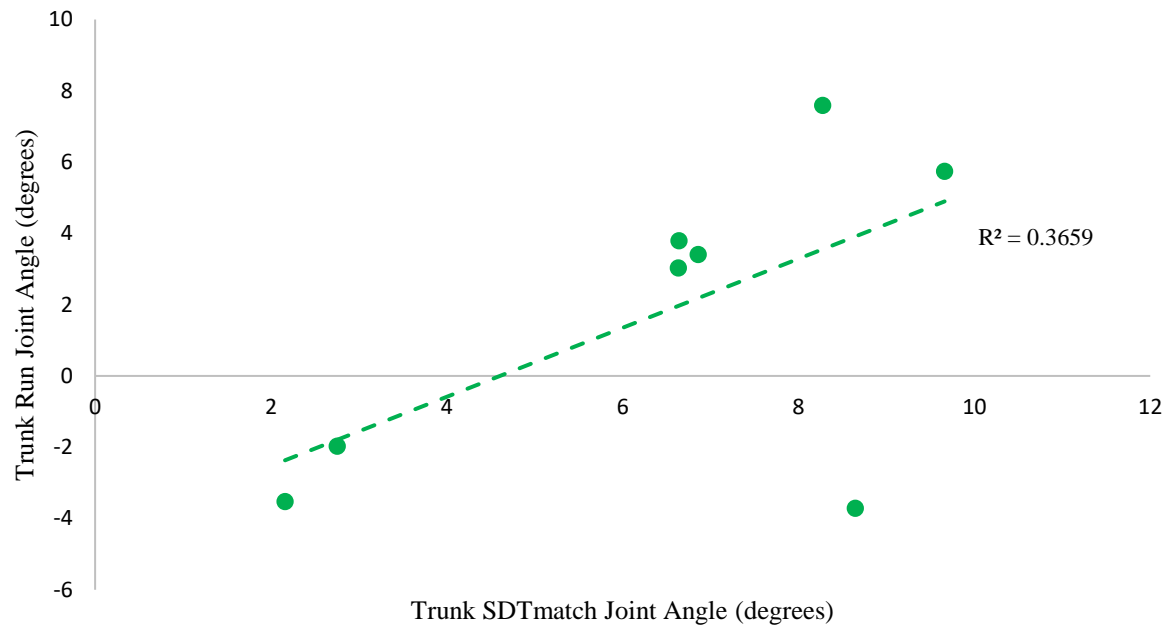
Research Copy

Note: Please sign both copies of the form and retain the copy marked "Participant"

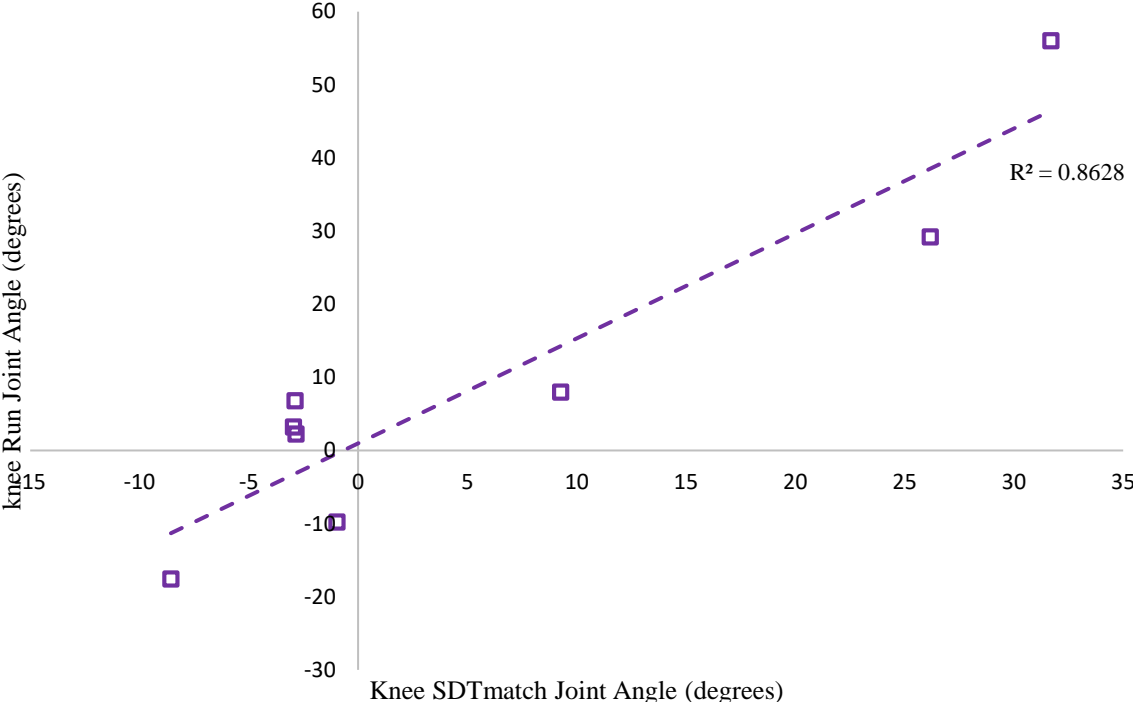
Participant Copy

Appendix C

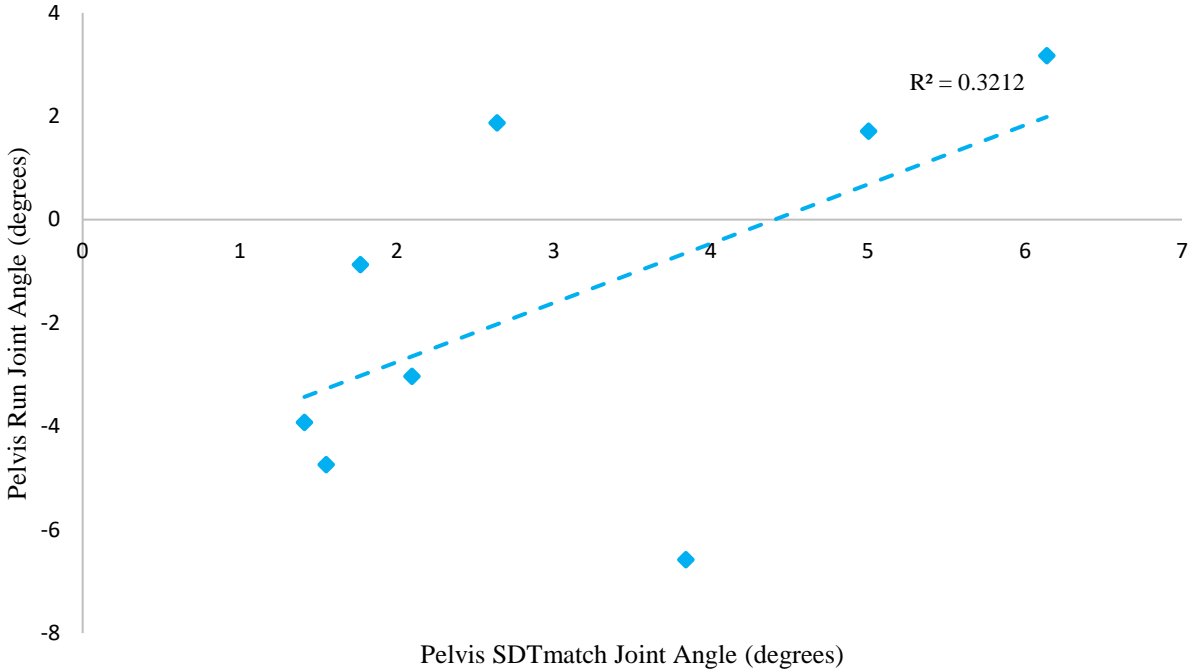
Appendix C1. Relationship between the frontal plane trunk angle for the run and the SDTmatch.



Appendix C2. Relationship between the frontal plane knee angle for the run and the SDTmatch.



Appendix C3. Relationship between the frontal plane pelvis angle for the run and SDTmatch.



Appendix C4. Frontal and sagittal plane average joint ROM in degrees.

Condition	Lateral Trunk Lean	Knee Valgus	Lateral Pelvic Drop	Trunk Flexion
PFPS Run	6.45 ± 2.7	6.11 ± 15.0	3.05 ± 1.8	-2.24 ± 8.4
Control Run	6.30 ± 1.8	4.92 ± 9.2	3.88 ± 1.0	-6.42 ± 6.3
PFPS SDTmatch	1.79 ± 3.8	9.74 ± 23.2	-1.54 ± 3.6	-7.06 ± 3.8
Control SDTmatch	1.64 ± 3.2	7.66 ± 8.9	-1.07 ± 2.6	-6.61 ± 6.2
PFPS SDTmax	7.89 ± 5.0	9.61 ± 29.1	2.78 ± 3.3	-7.01 ± 3.8
Control SDTmax	10.67 ± 4.5	19.96 ± 12.4	4.88 ± 2.6	-5.60 ± 5.4

Appendix C5. Correlation values of frontal and sagittal plane motion.

Motion	Run to SDmatch	p	Run to SDmax	p	SDmatch to SDmax	p
Lateral Trunk Lean	r = 0.605	p < 0.112	r = 0.898	*p < 0.002	r = 0.333	p < 0.421
Knee Valgus	r = 0.929	*p < 0.001	r = 0.945	*p < 0.001	r = 0.960	*p < 0.001
Lateral Pelvic Drop	r = 0.567	p < 0.143	r = 0.685	p < 0.61	r = 0.494	p < 0.214
Trunk Flexion	r = 0.545	p < 0.162	r = 0.444	p < 0.270	r = 0.702	p < 0.052

*indicated significant results p < 0.05