Mirror Gait Retraining on Kinematics in a Healthy Female Runner: A Case Study

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This thesis titled

Mirror Gait Retraining on Kinematics in a Healthy Female Runner: A Case Study

by

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Abstract

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Mirror Gait Retraining on Kinematics in a Healthy Female Runner: A Case Study

Director of Thesis: Dustin R. Grooms

Background: Previous studies have investigated the effects of a gait retraining program on subjects with patellofemoral syndrome (PFPS). These studies have all found that participants were able to improve lower extremity mechanics, function, and decrease pain. However, it is unknown if mechanics can change in a healthy individual with potential PFPS risk gait. **Purpose:** The purpose of this study was to examine the effects a mirror gait retraining program on frontal plane mechanics in a healthy female runner with excessive hip adduction. **Methods:** A healthy female runner was asked to run on a treadmill while receiving visual (mirror) and verbal feedback during a 2-week, 8-session gait retraining protocol. Kinematic data was collected at screening/baseline and after the protocol was completed. **Main outcome measures:** Peak position during stance phase and excursion from foot strike to peak for the following variables: contralateral pelvic drop, hip internal rotation, and hip adduction. **Results:** Participant reduced peaks and total excursion of hip adduction, hip internal rotation, and contralateral pelvic drop. Peak hip adduction reductions were greater than any other variable in the frontal plane (Percentage change; right: 30.90%, left: 27.35%). **Conclusion:** After a mirror gait retraining protocol, a healthy individual was able to improve gait kinematics that are prospectively linked to the development of PFPS. Further research is warranted to investigate the effects of mirror gait retraining on a larger healthy population.

Preface

Chapter 3 contained within the thesis document serves as a prepublication manuscript. This manuscript has been formatted to meet the guidelines set forth by the *Journal of Athletic Training* and Thesis and Dissertation Services at Ohio University. The reference citation style follows the guidelines of the AMA Manual of Style (10th ed., 2007).

Acknowledgments

I would like to thank the Ohio University Gait Lab and Rachel Robinson for allowing the use of their facility for this study as well as their assistance with subject testing. I would also like to thank Dr. Robert Wayner, Dr. Janet Simon, and Dr. Dustin Grooms for their expertise and guidance throughout the research process.

Table of Contents

Page

List of Tables

List of Figures

Chapter 1: Introduction

Not only do proper running mechanics play a role in an athlete's performance, but they also contribute to injury risk. Many abnormal kinematic gait characteristics have been hypothesized to contribute to pain development.[1] Patellofemoral pain syndrome (PFPS) is one of the most common running related injuries.[2,3] Patellofemoral pain syndrome is defined as having pain along the retro- or peripatellar region that is insidious in nature and that is exacerbated by weight bearing activities.[3] Evidence from a growing number of cross-sectional studies suggests that females with PFPS run with greater hip internal rotation and hip adduction.[3–6] Both motions have been shown to increase the amount of stress on the lateral aspect of the patella and, with repetitive exposure, may result in pain.[3] Because of this, strengthening of the hip abductors is often promoted to improve mechanics and decrease pain associated with PFPS. However, recent studies have suggested that strengthening of the hip muscles does not lead to improvements in hip mechanics during running.[3,7,8] Neuromuscular reeducation through gait retraining has been successful in altering faulty hip mechanics during running.[2,3] Hip adduction, contralateral pelvic drop, and hip internal rotation are common targets in gait retraining programs.[9] Gait retraining programs have been shown to improve biomechanics and decrease patellofemoral pain for up to 3 months post intervention using the same basic methods to reproduce positive outcomes in patient's gait and perceived pain.[9,10] The same study has also found that improved gait mechanics transfer to an untrained task such as a single leg squat.[9] This transferability of gait retraining indicates a possibility neuroplastic change has occurred in the consolidation of the newly learned motor pattern. Clinically, gait retraining programs may be implemented more frequently if they can successfully change the way a patient runs to improve gait kinematics. Results from previous studies show promising improvements in runners' biomechanics, however these results need to be replicated in athletic and non-athletic populations as well as painful and healthy populations to improve gait retraining's clinical relevance for the treatment and possible risk prevention of patellofemoral pain syndrome.

RESEARCH QUESTIONS AND HYPOTHESIS

1. Will a mirror gait retraining program decrease pain and improve running mechanics in female runners?
    a. Completing a 2-week gait retraining program will improve running mechanics in female runners such as contralateral pelvic drop, hip adduction, and hip internal rotation and subsequently decrease their pain.

INDEPENDENT VARIABLES

1. Time
    a. Baseline
    b. Postintervention, 2 weeks

DEPENDENT VARIABLES

1. Perceived pain
2. Contralateral pelvic drop, degrees
    a. Peak and total excursion range of motion from foot strike (initial contact) to peak range of motion
3. Hip internal rotation, degrees

   a. Peak and total excursion range of motion from foot strike (initial contact) to peak range of motion

4. Hip adduction, degrees
   a. Peak and total excursion range of motion from foot strike (initial contact) to peak range of motion

ASSUMPTIONS

1. Calibration of the treadmill and cameras was consistent for each participant.
2. Markers were placed in the same positions for the participant during follow up.
3. All participants will give full effort.
4. Participants will not add activity outside of training plan.
5. Gravity will remain constant.

LIMITATIONS

1. Measurements were obtained at baseline and after two-week protocol was completed; long term effects were not observed.
2. Running mechanics/stride may vary from treadmill running to running outdoors.
3. Small sample size

DELIMITATIONS

1. Participants in the study were already runners and active, otherwise healthy individuals.

2. Participants were able to wear their own running shoes and clothes to eliminate data caused by the use of unfamiliar equipment.

Chapter 2: Review of Literature

Introduction

Running is one of the most popular forms of exercise with upwards of 16-17 million Americans participating in the sport today.[9,11] Patellofemoral pain syndrome (PFPS) is the most prevalent type of knee pain among runners.[2,10] There is a sex bias[3] associated with PFPS with 68% of sufferers of PFPS being female.[2] The gluteus medius and maximus are the primary stabilizers of the hip. Because weakness of this musculature has been identified in individuals with patellofemoral pain, hip strengthening is often advocated for the treatment of patellofemoral pain. Hip strengthening has been shown to result in short term pain reduction.[9,12] Other studies have shown that hip strengthening alone has in some cases increased hip adduction[7], which is the opposite result, and in other cases had no effects on hip mechanics during running.[8] This review will discuss the etiology and epidemiology of patellofemoral pain in addition to the prior findings of mirror gait retraining programs and its proposed neurological effects.

Etiology of Patellofemoral Pain

The etiology of elevated lateral patellofemoral joint stress and subsequent patellofemoral pain syndrome (PFPS) development is considered to be multifactorial. Many abnormal kinematic gait characteristics have been hypothesized to contribute to pain development.[1] At the knee joint, altered tibiofemoral rotation and an increase in femoral adduction during the stance phase of gait have been proposed to result in lateral patellar tracking and increase lateral patellofemoral joint compression.[13–15] These kinematic differences could result from structural abnormalities[16] or altered kinematics at the hip or foot and ankle.[13,14]

It has also been hypothesized that PFPS among runners is typically associated with elevated patellofemoral joint kinetics.[17] Depending on factors such as running speed, foot strike pattern and step length, the patellofemoral joint experiences peak contact forces between 4-10 times a person's body weight.[17–19]

Recent research has indicated the presence of decreased hip muscle strength (abductors and external rotators) in individuals with PFPS.[20–22] Evidence from a growing number of cross-sectional studies suggests that females with PFPS run with greater hip internal rotation and hip adduction.[3–6] Both motions have been shown to increase the amount of stress on the lateral aspect of the patella and, with repetitive exposure, may result in pain.[3] These findings support the theory that increased hip internal rotation and adduction during gait may be a risk factor for PFPS development.[13,14,23] These mechanics have not been reported as consistently in men, therefore rehabilitation goals may need to be sex-specific.[24] Weakness of gluteal muscles have been extensively reported in young individuals with "nonarthritic" patellofemoral pain, which has been suggested to be a precursor of patellofemoral osteoarthritis (PF OA).[25] Altered joint mechanics may be important in disease onset, disease progression, and symptom severity.[25]

Due to these weaknesses, strengthening programs typically aim to increase strength of hip musculature in order to improve hip mechanics with the intent of reducing the incidence of, or symptoms related to, PFPS.[8,26,27] The goal of these programs is to increase hip abductors and external rotators, to decrease the amount of hip adduction and internal rotation exhibited during running. Although it has been shown that these programs improve strength[28] and reduce or might prevent symptoms[27,28], it is not clear whether strengthening the hip actually results in improvement of abnormal hip and knee mechanics during running.[8]

Emerging evidence suggests that trunk mechanics differ between individuals with PFPS and those without it.[24] Snyder et al[7] has published the only study to examine the effects of strengthening the hip abductors and external rotators on normal hip and knee mechanics during running in healthy, active females.[8] With the exception of a small increase in hip adduction excursion, the authors noted no changes in hip and knee kinematics.[8] However, their study did not focus on individuals with abnormal mechanics, which limited its ability to examine potential changes in mechanics.[8] There are conflicting results on whether contralateral pelvic drop is also greater in patients with PFPS compared to pain-free individuals.[24] The effects of different kinematic strategies employed by participants and the effects of fatigue or exertion on kinematics remains unclear at this time.[24]

Epidemiology of Patellofemoral Pain Syndrome

Patellofemoral pain syndrome is defined as having chronic pain along the retro- or peripatellar region that is exacerbated by weight bearing activities.[3]

Patellofemoral pain syndrome is one of the most common musculoskeletal presentations to orthopaedic,[16,20] general practice,[29] and sports medicine clinics.[1,24] The condition is highly prevalent in adolescents and young adults,[1,13] and has been reported to be more common in females than males.[2,30–32]

A high number of individuals with PFPS have recurrent or chronic pain.[24] While physiotherapy interventions for PFP have proven effective compared with sham treatments, results can be disappointing in a proportion of patients.[24] This variability in treatment results may be due to the fact that the underlying factors that contribute to the development of PFPS are not being addressed, or are not the same for all patients with PFP.[24]

Gait Retraining

In a study conducted by Noehren et al,[10] gait retraining to reduce patellofemoral pain occurred with real-time kinematic motion monitor feedback. To determine eligibility for this study, first, individuals completed a video screening where hip adduction was examined; if they visually appeared to exhibit excessive hip adduction indicated by an observable pelvic drop and knees that were nearly touching each other, they were invited back for a full instrumented gait analysis. Potential participants underwent instrumented gait analysis for the entirety of a 30-minute run where they reported their pain levels on a 1-10 scale every 5 minutes. For feedback during retraining, participants were shown their hip adduction angle on a monitor and they were instructed accordingly on how to alter their hip alignment and keep their hip angle within the shaded regions representing 1 standard deviation of normal hip adduction.[10] During the gait retraining protocol used in this study, run time was increased from 15 to 30 minutes over the 8 training sessions.[10] Visual feedback was provided continuously for the first four sessions and gradually removed during the last four sessions.[10] Participants were then tested again following the 8 training sessions during a 30-minute run and pain was recorded. This study found reductions in contralateral pelvic drop, hip adduction, and hip internal rotation following the completion of the training sessions. Limitations noted in this study were lack of a control (healthy) group, poor generalizability of retraining protocol due to technology used, small sample size, and lack of a long term follow up.

Willy et al[9] recognized limitations in the Noehren et al[10] study and utilized those limitations in their 2012 study. In this study, a similar model to the Noehren et al[10] study was used, however, a full-length mirror was added to provide immediate feedback to participants rather than a motion capture system. The Noehren et al[10] study also recognized that patellofemoral pain was a long-term ailment to many participants but the treatment programs were only examined in short term follow up appointments one month after the program was completed. His study changed this to add a 3-month follow-up period to examine the long-term effects of the gait retraining program. At the end of their 8 session, 2-week program, participants demonstrated a notable reduction in their peak hip adduction and contralateral pelvic drop during running at their post treatment measurement.[9] The study also stated that the participants were able to maintain these changes through their 1 and 3-month follow-ups.[9] Limitations noted in this study were that there was no control group, long term effects past 3 months were not noted, and it is unknown if the new running pattern noted post-gait retraining increases the risk of sustaining other injuries.[9]

Chapter 3: Mirror Gait Retraining for Risk Reduction of Patellofemoral Pain in Female Runners[1]

Context: Previous studies have investigated the effects of a gait retraining program on subjects with patellofemoral syndrome (PFPS). These studies have all found that participants were able to improve lower extremity mechanics, function, and decrease pain. There is no current evidence on a healthy individual. Improving abnormal gait mechanics while running may decrease the likelihood of asymptomatic runners with similar gait patterns developing PFPS. **Objective:** To examine abnormal gait biomechanics of female runners without PFPS before and after implementing a mirror gait retraining protocol. **Design:** Case study. **Setting:** University gait lab. **Participants:** One healthy female runner (age = 30 years., height = 67 in, weight = 66.36 kg). **Data Collection and Analysis:** The participant was asked to run on a treadmill at a self-selected pace while instrumented 3D kinematic data was obtained as baseline data. During the 2-week, 8-session gait retraining protocol she was asked to run at a self-selected pace in front of a mirror receiving both visual and verbal feedback to correct improper gait mechanics. Feedback was removed during the last 4 sessions. Once the protocol was complete, she was asked to return for postintervention kinematic data collection for comparison to baseline data. Raw values are presented for pre- and

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[1] This chapter represents a prepublication manuscript to be submitted to the *Journal of Athletic Training* (May 2018). Authors are: Victoria R. Trzyna, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens); Dustin Grooms, PhD, AT, CSCS (School of Applied Health Sciences and Wellness, Ohio University, Athens); Robert Wayner, PT, DPT (School of Applied Health Sciences and Wellness, Ohio University, Athens); Janet Simon, PhD, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens).

postmeasurements of outcome measures. **Results:** Participant reduced peaks and total excursion of hip adduction, hip internal rotation, and contralateral pelvic drop. Peak hip adduction reductions were greater than any other variable in the frontal plane (Percentage reduction; right: 30.90%, left: 27.35%). ***Conclusions:*** After a mirror gait retraining protocol, a healthy individual was able to improve gait kinematics that are prospectively linked to the development of patellofemoral pain syndrome. Further research is warranted to investigate the effects of mirror gait retraining on a larger healthy population. ***Key Words:*** running, biomechanics, mirror re-training, motion capture, patellofemoral pain syndrome.

Key Points

- A healthy female runner who exhibited gait mechanics associated patellofemoral pain syndrome was able to improve gait mechanics to within laboratory means.
- Only one other study examines the effectiveness of mirror gait retraining; this is the only study that examines mirror gait retraining on a healthy runner.

Running is one of the most popular forms of exercise[9] with upwards of 17 million Americans participating in the activity.[11] Not only do proper running mechanics play a role in an athlete's performance, but they also contribute to injury risk. Patellofemoral pain syndrome is one of the most common running related injuries.[2,3] Of the individuals who suffer from symptoms of patellofemoral pain, 68% are female[2]. Therefore, females were the targeted population for this study.

The development of patellofemoral pain syndrome (PFPS) is considered to be multifactorial. Many abnormal kinematic gait characteristics have been hypothesized to contribute to pain development.[1] It has been hypothesized that PFPS among runners is typically associated with elevated patellofemoral joint kinetics.[17] Depending on factors such as running speed, foot strike pattern and step length, the patellofemoral joint experiences peak contact forces between 4-10 times a person's body weight.[17–19] For this reason, running speed will be consistent throughout the study.

Recent research has indicated the presence of decreased hip muscle strength (abductors and external rotators) in individuals with PFPS.[20–22] Evidence from a growing number of cross-sectional studies suggests that females with PFPS run with greater hip internal rotation and hip adduction.[3–6] Both motions have been shown to increase the amount of stress on the lateral aspect of the patella and, with repetitive exposure, may result in pain.[3] These findings support the theory that increased hip internal rotation and adduction during gait may be a risk factor for PFPS development.[13,14,23] These mechanics have not been reported as consistently in men, therefore rehabilitation goals may need to be sex-specific.[24]

Due to these weaknesses, strengthening programs typically aim to increase strength of hip musculature in order to improve hip mechanics with the intent of reducing the incidence of, or symptoms related to, PFPS.[8,26,27] The goal of these programs is to increase hip abductors and external rotators, to decrease the amount of hip adduction and internal rotation exhibited during running. Although it has been shown that these programs improve strength[28] and reduce or might prevent symptoms,[27,28] it is not clear whether strengthening the hip actually results in improvement of abnormal hip and knee mechanics during running.[8]

Emerging evidence suggests that trunk mechanics differ between individuals with PFPS and those without it.[24] Snyder et al[7] have published the only study to examine the effects of strengthening the hip abductors and external rotators on normal hip and knee mechanics during running in healthy, active females.[8] With the exception of a small increase in hip adduction excursion, the authors noted no changes in hip and knee kinematics.[8] However, their study did not focus on individuals with abnormal mechanics, which limited its ability to examine potential changes in mechanics.[8] There are conflicting results on whether contralateral pelvic drop is also greater in patients with PFPS compared to pain-free individuals.[24] The effects of different kinematic strategies employed by participants and the effects of fatigue or exertion on kinematics remains unclear at this time.[24]

Neuromuscular reeducation through gait retraining has been successful in altering faulty hip mechanics during running.[2,3] Gait retraining programs have been shown to improve biomechanics and decrease patellofemoral pain for up to 3 months postintervention.[9]

A previous study on the effects of gait retraining to decrease patellofemoral pain in runners was able to replicate positive results of other gait retraining studies, but noted a limitation in past studies and added a mirror as visual feedback rather than the use of a motion capture system alone.[9] This study conducted by Willy et al,[9] however, did not utilize a group consisting of healthy individuals. In this study, a healthy group was added to investigate if an asymptomatic population with excessive frontal plane hip mechanics had the same response as individuals with PFPS.

METHODS

Participants

Flyers were posted on a University's campus and in the community, emails were sent to University students and athletes, social media posts were made on local running pages, and graphics were posted on digital media boards throughout a University. Informed consent was obtained from all interested participants. This study was approved by the Institutional Review Board.

To be considered for the study, participants had to be currently running at least 10 km (6.2 mi) over the span of at least 3 days per week. The study screened runners without patellofemoral pain, but required they meet biomechanical criteria consisting of having peak hip adduction greater than 1 standard deviation from laboratory means (1 SD = 15°). A single female runner (age = 30 years., height = 1.7 m, weight = 66.36 kg), running 6-10 mi/wk over the span of at least 3 days, met the study's inclusion and exclusion criteria and volunteered to participate in the study.

Inclusion and Exclusion Criteria

To be eligible for this study, participants were required to meet the following criteria: (1) females between the ages of 18 and 40, (2) no cardiac risk factors, (3) running at least 10 km per week over a span of at least 3 days, (4) participants must not have retropatellar or peripatellar pain, (5) peak hip adduction greater than 1 standard deviation from laboratory means; 1 SD from laboratory mean is 15°, normative data was created using 50 healthy female limbs, (6) have read and signed an informed consent form. Participants were excluded from the study if they: (1) had patellofemoral instability or history of patellar dislocation, (2) history of any lower extremity surgery, (3) had patellofemoral pain, (4) were otherwise unhealthy and unable to run on a treadmill.

Three female runners were screened; 1 was excluded due to exhibiting patellofemoral pain, 1 was excluded for not meeting kinematic inclusion criteria, and 1 runner met all the inclusion criteria. This participant agreed to enroll in the study.

Procedures/Data Collection

All interested participants were screened to determine if they met inclusion/exclusion criteria.

Participants visited the Ohio University (OHIO) Gait Laboratory for initial screening and were brought back in for retraining if they met inclusion criteria. All data collection took place in the OHIO Gait Laboratory, housed in the Division of Physical therapy, Grover Center W265, under the direction of the primary investigator, Victoria Trzyna, AT. In addition to the primary investigator, graduate assistants conducted data collection and data processing.

Procedural Timeline

Screening / Baseline

The screening and baseline data served as the same time point. Testing and data collection that occurred at this stage included: completion of the Lower Extremity Functional Scale (LEFS), height and weight measurements for treadmill gait analysis, and biomechanical gait analysis.

After baseline data collection occurred, the participant completed 8 gait retraining sessions over the span of two weeks. During these 2 weeks, the participant was not allowed to run outside of the laboratory. The only running she was allowed to perform was during her 8 sessions of the gait retraining program. During the gait retraining program, the participant ran without collection of three-dimensional kinematic data; the participant focused on feedback only.

After the 2-week protocol, follow up testing and data collection occurred at a separate follow up visit that was not the eighth gait retraining session. The follow-up visit consisted of administering a follow up LEFS and collecting kinematic gait data. After the completion of this follow-up session, the participant was allowed to return to her normal running schedule outside of the laboratory as data collection was completed.

Gait Analysis Procedure

The participant's height and weight were measured to be used in data analysis of their gait. The participant was allowed to wear the running shoes she regularly trains in for the study and running clothing of her choosing that did not include reflective material. 30 retro-reflective markers arranged in clusters were affixed to the subject's trunk and lower extremities using a nonreflective fabric wrap to be recorded using a Vicon 10 camera motion capture system (Vicon, Oxford, UK) (recorded at a rate of 240 Hz). These markers were placed on the trunk, pelvis, femur, shank, and foot.[9] Anatomic landmarks consisting of the right and left ASIS, C7-T1 vertebrae, T12-L1 vertebrae, the medial and lateral femoral condyles, medial and lateral malleolus, and the tip of the second toe were identified for subject digitization in the motion monitor using a digitized stylus.[9] These landmarks were used to identify segment endpoints and to identify joint centers for the analysis of joint motion.

Prior to data collection, motion capture system, recording field of the camera system, and force plate instrumented treadmill (Bertec, Worthington, OH) were calibrated per lab protocol. After camera calibration, participants were asked to stand on the treadmill in a neutral stance for 3D model digitization to identify the body segments previously mentioned for data collection in data analysis software (Motion Monitor, Chicago IL). This calibration process allows the motion capture software to identify anatomical landmarks on the subject to create segments in the data analysis software of the trunk, pelvis, lower leg, and foot. After calibration of the camera and reflective markers occurred, a running trial was completed. All data analysis occurred on a force plate instrumented treadmill (Bertec, Worthington, OH). Force data was collected to determine stance phase of the analyzed limb during running gait. Foot strike and toe off were identified using a 20N threshold on the force instrumented treadmill.

The participant walked for 3-5 minutes as a warm-up at a self-selected pace. After this period, the speed was increased to a comfortable, self-selected running pace that was used for all later training sessions. The subject then ran at that pace for 6 minutes before recording began. Five running strides were collected and used for data analysis. The participant then walked for 2 minutes to allow for a cool-down period.[9] The participant was able to volitionally end their run at any time. If the participant opted to do this, she would not be included in the data analysis or reporting.

Gait Retraining Protocol

On the participant's initial training visit, she was shown her baseline video so that she was able to visualize the abnormal hip and knee alignment she exhibited during running.[9] Three-dimensional motion capture and collection did not occur during the retraining period. During the 2-week, 8-session program (see Figure 1), the participant received immediate mirror feedback of herself running in addition to scripted verbal feedback from the investigator during the allotted feedback time of each session as it was needed.[9] This feedback consisted of the following cues: “run with your knees apart with your kneecaps pointing straight ahead” and “squeeze your buttocks.”[9] Feedback exposure and treadmill runtime were closely monitored. Over the course of the 8 sessions, treadmill runtime was gradually increased from 15 to 30 minutes.[9] During the second half of the protocol, feedback was gradually removed during the final 4 training sessions to shift dependence from external to internal cues and reinforce learning (see Figure 1).[9,33] This was done by a decremental decrease in verbal cueing in addition to reductions in visual feedback by removing the mirror from in front of the subject.[9] It has been shown that during the practice phase of learning a new motor task, an increase in the amount, precision, or frequency if information feedback will benefit performance.[33] Conversely, there are possible detrimental effects to feedback in motor learning which propose that the learner becomes dependent on feedback information which prevents the processing of other sources of information intrinsic to the task. Therefore, to prevent dependence on external cueing to reinforce learning of the desired gait mechanics, external cues were incrementally removed so that the participant had to rely on intrinsic cues as well to maintain the desired gait mechanics.

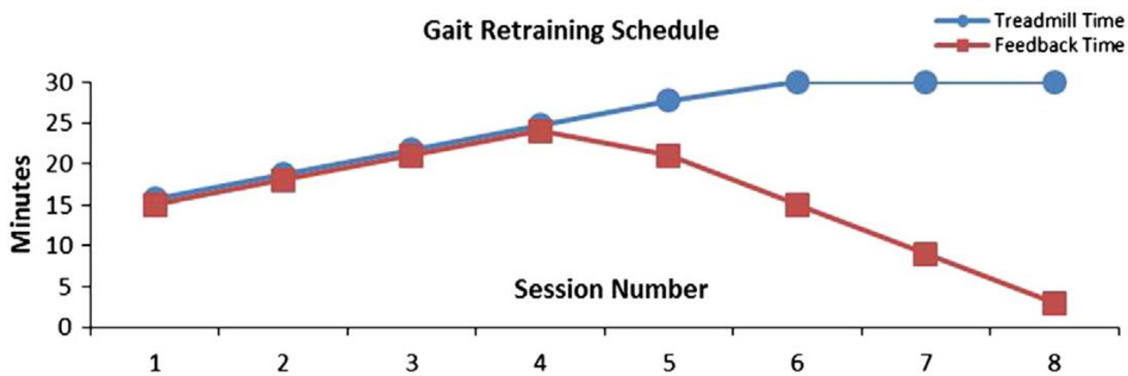


Figure 1. Gait retraining protocol

To ensure that feedback was consistent, the participant was not permitted to run outside of the lab while participating in the gait retraining phase and was asked to verbally attest to her compliance.[9]

Data Reduction

Kinematic data from 5 trials (strides) were filtered with an 8-Hz, low pass, fourth order, zero-lag Butterworth filter. Once this data was filtered it was then normalized for stance phase for comparison of trials in Motion Monitor (Chicago IL) data analysis software.

Statistical Analysis

As this study was a case study, raw values are presented for 1 female subject pre- and post-mirror gait training for the following variables: right and left peak contralateral pelvic drop, contralateral pelvic drop excursion, peak hip adduction, hip adduction excursion, peak hip internal rotation, and hip internal rotation excursion.

RESULTS

All three of the dependent variables showed a decrease from baseline to postintervention measurements. On the right and left limb, peak hip adduction showed the greatest improvement (47.21% and 42.95% reduction in peak motion, respectively) (see Tables 1 and 2). Contralateral pelvic drop showed an improvement of 42.52% reduction in peak motion on the right limb and 26.59% reduction on the left limb (see Tables 1 and 2). Peak hip internal rotation decreased by 73.79% on the right limb and 73.17% on the left limb (Tables 1 and 2). Hip internal rotation total excursion showed an increase in both limbs from baseline (Tables 1 and 2).

Table 1 shows raw values for gait kinematics for variables measured on the right limb; Table 2 shows raw values for gait kinematics for variables measured on the left limb. Figures 2-4 represent pre- and postgait kinematics while running; circle dotted lines represent pre- values, large square dashed lines represent post values, solid black lines represent laboratory means, and small dashed black lines represent 1 standard deviation from the laboratory means.

Table 1. Raw Values, Right Leg

	Baseline	**Postintervention**	**% Change**
CPD Peak (degrees)	12.37	7.11	42.52
CPD Excursion (degrees)	12.16	9.10	25.16
Hip ADD Peak (degrees)	18.30	9.66	47.21
Hip ADD Excursion (degrees)	10.03	7.55	24.73
Hip IR Peak (degrees)	13.05	3.42	73.79
Hip IR Excursion (degrees)	0.10	4.47	-4,370

Table 2. Raw Values, Left Leg

	Baseline	Postintervention	% Change
CPD Peak (degrees)	11.96	8.78	26.59
CPD Excursion (degrees)	12.81	10.02	21.78
Hip ADD Peak (degrees)	15.53	8.86	42.95
Hip ADD Excursion (degrees)	9.24	6.33	31.49
Hip IR Peak (degrees)	9.43	2.53	73.17
Hip IR Excursion (degrees)	0.01	0.82	-8,100

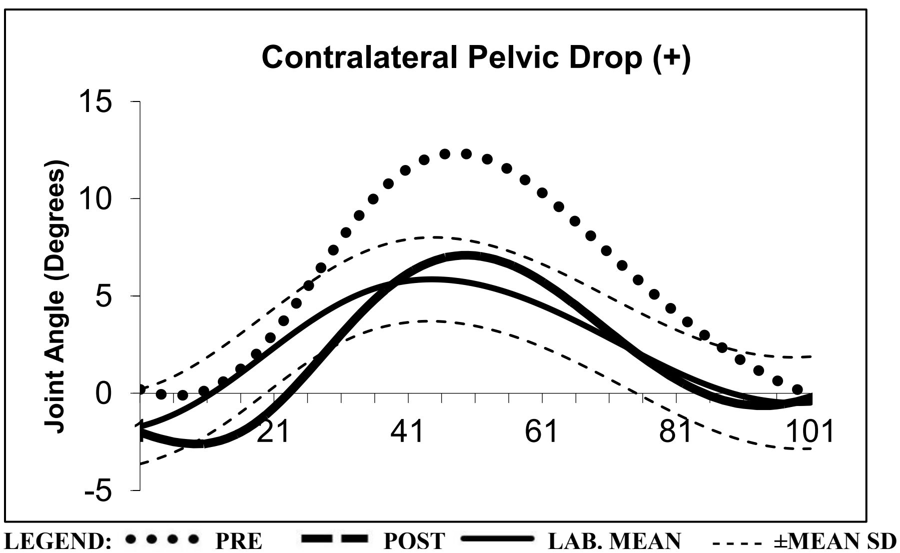
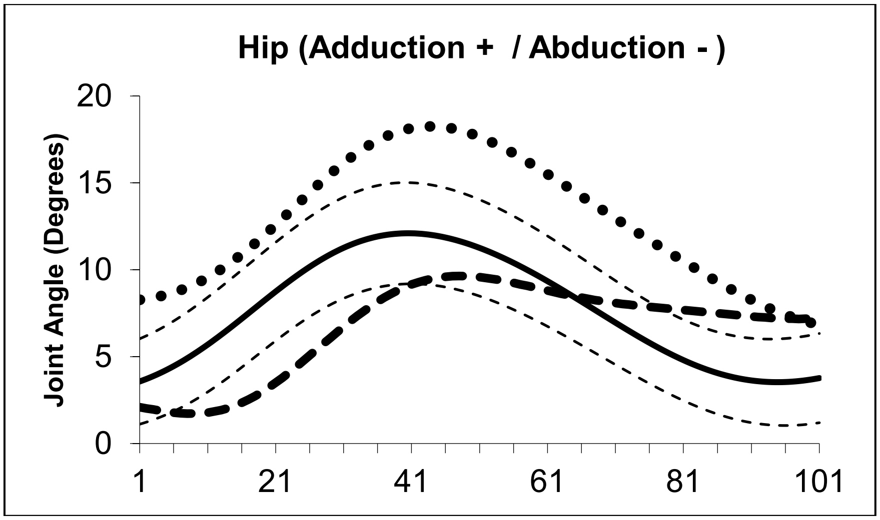


Figure 2. Contralateral pelvic drop.



LEGEND: • • • • PRE ▬ ▬ POST ▬▬▬ LAB. MEAN ---- ±MEAN SD

Figure 3. Hip adduction.

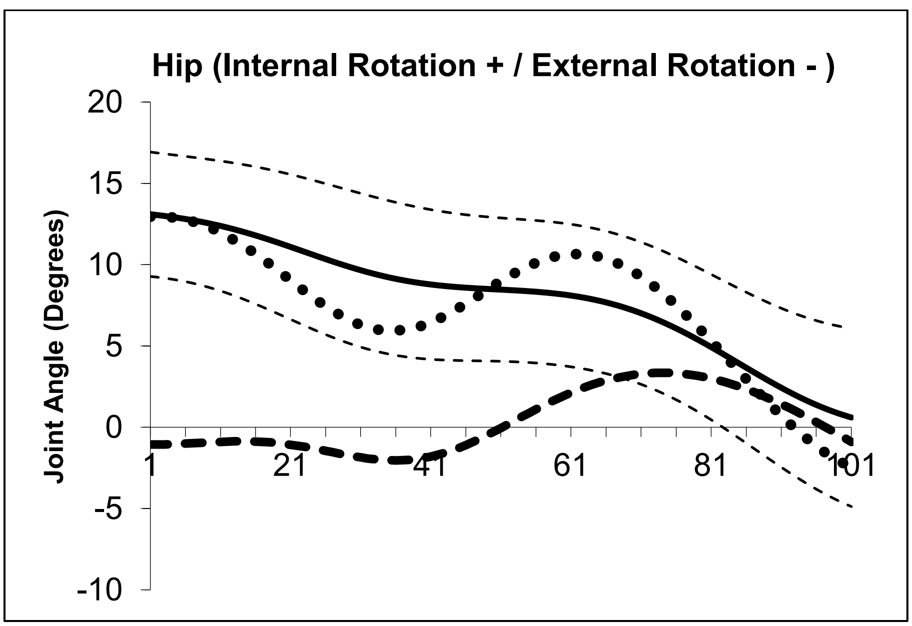


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Figure 4. Hip internal rotation.

The participant was asked to complete a LEFS prior to baseline screening and after post-intervention data collection. Preintervention and postintervention LEFS scores were 80/80 at both testing points.

DISCUSSION

Our primary goal was to determine if a mirror gait retraining protocol would reduce running kinematics previously associated with the development of patellofemoral pain syndrome in a healthy runner. Based on the results from a healthy female runner, mirror gait retraining is an effective way to reduce abnormal gait mechanics in an individual not showing symptoms of patellofemoral pain syndrome. This is the first case study to examine the immediate effects of a mirror gait retraining protocol on a healthy female; no other study has examined the effects of a mirror gait retraining protocol on a healthy population. This intervention showed to be safe on a healthy female runner. She exhibited no adverse reactions due to the training and LEFS scores remained the same from pre- to postintervention.

During running, peak hip adduction showed the greatest improvement of the frontal plane variables, and transverse plane measures of peak hip internal rotation showed the greatest improvement out of all three variables. It was not surprising that the participant improved in all measured variables as she received specific cueing to reduce hip internal rotation, hip adduction, and contralateral pelvic drop by keeping her toes and kneecaps facing straight ahead, keeping a space in between her knees, and to squeeze her buttocks.

Values for hip internal rotation excursion are skewed due to participant's foot position upon foot strike. During baseline measurements she ran with her feet, and subsequently, hip consistently internally rotated, therefore her change in range of motion was not dramatic. However, at postintervention measurements, due to changes in her running mechanics, the participant hit foot strike in a more neutral position and internally rotated as she went through stance phase. This neutral to internally rotated gait versus completely internally rotated gait caused the changes noted.

As a part of data collection, the participant was asked to complete a LEFS at baseline and again post-intervention. Her completions confirmed that at baseline she was a pain free individual with no functional limitations and maintained that through post-intervention measures. Gait retraining had no negative impact on symptoms. However, long term follow ups should be conducted to ensure that her physical state remained the same and she did not begin to develop symptoms speculated to be caused as a result of gait retraining. The LEFS has a minimally clinically important difference of 9,[34] meaning that if the patient had reported a score which decreased at least 9 points she would have begun to experience pain or difficulty with a previously not painful or difficult activity and would no longer be considered a healthy individual if she developed knee pain. In another study examining gait retraining on a population with PFPS, their participants showed an average improvement on the LEFS of 12.1 (SD 2.7) point increase of scores at post intervention testing which exceed the 9 point minimal detectable change[9].

Overall, the changes in kinematics compare favorably compared to previous gait retraining studies. Previously, studies have examined the effects of mirror feedback and augmented feedback on kinematic gait changes. Noehren et al (2011) utilized real-time augmented feedback in their gait retraining protocol.[10] During gait retraining sessions in this protocol, participants ran while 3D kinematic data were collected. The participants were able to see in real time their hip adduction angle depicted on a graph and were instructed to keep their angle within a shaded region representing 1 standard deviation from normal HADD. Similar to this study, the participant was instructed to contract their gluteal muscles, run with their knees pointing straight ahead, and maintain a level pelvis. A study by Willy et al[9] (2012) utilized mirror feedback, as this study did. In the Willy et al[9] gait retraining protocol, participants received the same feedback that was given in this study; they had real time mirror feedback of themselves running versus augmented feedback. In the Willy et al[9] protocol and this study's protocol, participants had a full-length mirror placed in front of them and were given verbal cues to run while squeezing their buttocks, run with their knees and toes facing straight ahead, and to run with a space between their knees. The running and feedback schedules were consistent among all studies; run time was increased from 15 to 30 minutes across the 8 training sessions, feedback was constant during the first 4 sessions and then gradually decreased through the final 4 sessions.

The reductions seen in hip adduction, hip internal rotation, and contralateral pelvic drop are greater than average percent changes in both the Noehren et al[10] and Willy et al[9] studies. This study's participant showed a 47.21% reduction in hip adduction which is greater than the 23% and 16.6% decrease seen in Noehren et al[10] and Willy et al[9] studies respectively. This study is more comparable to the Noehren et al[10] study regarding hip internal rotation than the Willy et al[9] study in that subjects in the Noehren et al[10] study had a greater hip internal rotation measurement at baseline (Noehren: mean 11°; Willy: mean 8.6°) therefore a greater potential for reduction of hip internal rotation, as did the female participant in this study (baseline: 13°). Reductions in contralateral pelvic drop were also greater than the Noehren at al[10] study with this study showing a 42.52% decrease and the Willy et al[9] study showing a 24% decrease.

It is important to note that the amount of change exhibited in this study is outside the standard error of measure for motion capture marker placement according to gait lab averages and previous studies assessing within- and between-day reliability of marker placement for motion capture systems (see Table 3).[35] The variability of marker placement is important when the same subject is being tested on more than one occasion and comparisons are made between the sessions to determine a clinical outcome on a pre/post treatment basis.[35] Because the pre/post differences are greater than the standard error of measure, it can be assumed that improvements in participant's kinematic data did not occur due to changes in examiner's marker placement during gait analysis.

Table 3. Mean Differences Pre- and Postintervention (Degrees)

	SEM*	**Case Study**	**Noehren et al., 2011**	**Willy et al., 2012**
HADD	2.70	8.64	5.5	5.9
CPD	-	5.26	2.3	1.9
HIR	3.20	9.63	2.7	1.5

*Represents standard error of measure of between day mean measurements.[35]
HADD: Hip adduction, CPD: Contralateral pelvic drop, HIR: Hip internal rotation.

Several limitations should be noted in this study. First, as this was a case study, further research needs to be conducted on a larger population and should include both healthy and injured participants. Future research could also continue to focus on only healthy individuals and whether or not they respond the same way as unhealthy individuals. However, it is unlikely that improvements made to this participant's gait mechanics would have occurred in the absence the intervention. A larger sample size of healthy individuals who exhibit abnormal gait mechanics while running should be investigated to determine if they are able to reproduce results similar to those individuals of an unhealthy population. Measurements were obtained at baseline and following the 2-week protocol; long term effects are unknown. Future studies should investigate the retention of trained mechanics at long term follow up dates such as a 1- and 3-month follow up-date, possibly even a year following the implementation of the retraining protocol. It is also important to monitor the participants' health throughout these follow up dates to determine if any newly developed pain or injury was a result of the intervention and altering of mechanics or coincidence. To identify injury risk, future studies should follow two groups of healthy individuals: one that receives gait retraining and one that does not in order to determine risk of injury development. Lastly, due to possible differences of running on a treadmill versus outside, it is unknown whether these mechanics will be maintained outside of the lab.

CONCLUSION

Gait retraining in a female runner with abnormal gait kinematics, who was not exhibiting symptoms of patellofemoral pain, resulted in improvements of abnormal gait mechanics from baseline measures. This study shows promising results in investigating effects of gait retraining on a healthy population. Further research is necessary in examining a healthy population and determining the long-term efficacy of this treatment technique to potentially prevent PFPS development. Future research may also include investigating retention of the learned gait mechanics via neurological imaging.

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Chapter 4: Conclusions

Gait retraining in a female runner with abnormal gait kinematics, who was not exhibiting symptoms of patellofemoral pain, resulted in improvements of abnormal gait mechanics from baseline measures. Improvements exhibited by the participant were a larger percent change than studies conducted previously. These results show promising results in investigating effects of gait retraining on a healthy population. It is interesting that a healthy population could exhibit abnormal gait mechanics similar to a population experiencing patellofemoral pain syndrome, yet present asymptomatically. This raises the question, could mirror gait retraining be used in the future as a preventative measure? If this is a possibility, coaches, especially track and cross-country coaches, and other healthcare providers may want to be educated in gait retraining and consider implementing these corrected gait mechanics at a younger age to prevent patellofemoral related knee pain later in life.

Further research is necessary in examining both healthy and unhealthy populations and determining the long-term efficacy of this treatment technique. Previous studies have only retested subjects up to a 3-month follow-up date; could participants maintain these mechanics longer? Future research may also include investigating retention of the learned gait mechanics via neurological imaging. fMRI imaging may be able to show the examiner changes in brain activity to determine if the implemented gait pattern exists due to motor performance or motor learning.

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Appendix A: Specific Aims

Patellofemoral pain is one of the most prevalent knee conditions in the active population.[9,10] Gait retraining programs have been shown to improve biomechanics and decrease patellofemoral pain for up to 3 months post intervention.[1] Pelvic drop, hip adduction, and hip internal rotation are common variables examined in gait retraining programs.[1] The purpose of this study is to determine the effects of mirror gait retraining on gait kinematics of a healthy female runner.

Gait retraining is able to improve gait mechanics and reduce patellofemoral related pain[2] for up to three months.[2] Past research studies have replicated the same basic methods to reproduce these results and compare the transferability to an untrained task such as a single leg squat.[9,10] However, the effects of mirror gait retraining on a healthy population is unknown. This study's **main objective** is to not only replicate the improved gait mechanics that were found in previous studies, but to determine the efficacy of gait retraining on a healthy population.

This study's **central hypothesis** is that after a 2-week, 8 session gait retraining program, a healthy female runner who exhibits abnormal gait kinematics will show improvements in maladaptive mechanics.

My **long-term goal** is to implement gait retraining programs clinically for patients exhibiting abnormal gait mechanics as a part of their treatment plan to improve the abnormal mechanics creating the problem and to potentially reduce their risk of lower extremity injury. If there is a way to incorporate this protocol into a rehabilitation plan without the use of advanced three-dimensional equipment, clinicians may be able to implement it easier in the clinic and be able to work with a greater number of patients due to lower costs. The **rationale** for this proposed research is that there is a large population of not only runners with patellofemoral pain, but athletes and people in the general population that suffer from this condition as well and this program may be able to benefit all of them, not just trained runners.

Aim 1: To determine if mirror-based gait retraining can improve running mechanics in female runners. We will conduct a pre/post study measuring improvements in contralateral pelvic drop, hip adduction, and hip internal rotation from baseline to post intervention.

Aim 2: To determine the effect of mirror gait retraining on a healthy population. Healthy participants who exhibit similar gait patterns to individuals who have patellofemoral pain will be compared to changes in gait mechanics of an unhealthy population.

Appendix B: Data Procedures Checklist

GAIT LAB SESSION		Time
	Consent Form	2 min
	LEFS Survey	2 min.
	Movement Imagery Questionnaire 3 (Screening process only)	10 min.
	Height and Weight	2 min.
	Treadmill Calibration	10 min.
	Marker Placement • 1 cluster on trunk • 1 cluster on each ASIS • Femur, bilaterally • Shank, bilaterally • Foot – 1 cluster on second toe of each foot	10 min.
	Running Data Collection • Warm Up, walking 3-5 min • Running 6 min • Cool Down 2 min	11-13 min.

Total time: ~ 40-50 min

Appendix C: Data Collection and Surveys

Recruitment Flyer

Attention Runners!

The Ohio University Gait Lab Presents a Study on the Treatment and Prevention of Knee Pain by Improving Running Form

Participants will be required to run on a treadmill and have their form analyzed. Results of the analysis will determine eligibility for treatment. Time commitment is 1 hour!

Female runners aged 18-40 years who run a minimum of 6 miles a week over at least 3 days are eligible to participate!

If interested, contact the OHIO Gait Lab: gaitlab@ohio.edu or (740) 593-4298

If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298	If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298	If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298	If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298	If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298	If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298	If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298	If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298	If Interested Contact OUTA Gait Lab gaitlab@ohio.edu or (740) 593-4298

Lower Extremity Functional Scale

THE LOWER EXTREMITY FUNCTIONAL SCALE

We are interested in knowing whether you are having any difficulty at all with the activities listed below <u>because of your lower limb</u> Problem for which you are currently seeking attention. Please provide an answer for **each** activity.

Today, <u>do you</u> or <u>would you</u> have any difficulty at all with:

	Activities	Extreme Difficulty or Unable to Perform Activity	Quite a Bit of Difficulty	Moderate Difficulty	A Little Bit of Difficulty	No Difficulty
1	Any of your usual work, housework, or school activities.	0	1	2	3	4
2	Your usual hobbies, re creational or sporting activities.	0	1	2	3	4
3	Getting into or out of the bath.	0	1	2	3	4
4	Walking between rooms.	0	1	2	3	4
5	Putting on your shoes or socks.	0	1	2	3	4
6	Squatting.	0	1	2	3	4
7	Lifting an object, like a bag of groceries from the floor.	0	1	2	3	4
8	Performing light activities around your home.	0	1	2	3	4
9	Performing heavy activities around your home.	0	1	2	3	4
10	Getting into or out of a car.	0	1	2	3	4
11	Walking 2 blocks.	0	1	2	3	4
12	Walking a mile.	0	1	2	3	4
13	Going up or down 10 stairs (about 1 flight of stairs).	0	1	2	3	4
14	Standing for 1 hour.	0	1	2	3	4
15	Sitting for 1 hour.	0	1	2	3	4
16	Running on even ground.	0	1	2	3	4
17	Running on uneven ground.	0	1	2	3	4
18	Making sharp turns while running fast.	0	1	2	3	4
19	Hopping.	0	1	2	3	4
20	Rolling over in bed.	0	1	2	3	4
	Column Totals:					

Minimum Level of Detectable Change (90% Confidence): 9 points **SCORE: ____/ 80**

Reprinted from Binkley, J., Stratford, P., Lott, S., Riddle, D., & The North American Orthopaedic Rehabilitation Research Network, The Lower Extremity Functional Scale: Scale development, measurement properties, and clinical application, Physical Therapy, 1999, 79, 4371-383, with permission of the American Physical Therapy Association.

Figure-1: Lower extremity functional scale (LEFS).

Gait Lab Data Collection Form

Walking & Running Clinic

Gait Data Collection Form

Subject Number:	date:			Weight (kg) :		
	LEFT			RIGHT		
	Goniometric	MM neutral	Adjustment	Goniometric	MM neutral	Adjustment
Hip sagittal angle						
Knee sagittal angle						
Ankle sagittal angle						
Gait Speed m/s						
Cadence step/m						

Anatomical Landmark Position		LEFT		RIGHT	
	ASIS	H:	W:	H:	W:
	Lateral Epicondyle	H:	D:	H:	D:
	Lateral Malleolus	H:	D:	H:	D:
	Medial Epicondyle	H:	D:	H:	D:
	Medial Malleolus	H:	D:	H:	D:
	Foot	H:	FF:	H:	FF:
Notes During Data Collection:					
Adverse Events, if any					

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Appendix D: Instrument Reliability

The LEFS is a 20-question clinical measure. Participants ranked the amount a lower extremity injury affects various tasks and activities on a scale of 0-4 with a “0” signifying “extreme difficulty” and a “4” signifying “no difficulty” with a score of 80/80 corresponding to no limitations. The LEFS has previously been validated in PFP populations and a minimal clinically important difference of 9 points has been established.[9,2]

Appendix E: Power Analysis

A power analysis was conducted to determine sample size. Based on an effect size of 0.4, alpha level 0.05, power 0.8, four time points, and a correlation among time points of 0.6 a sample size of 10-15 is needed.