The Effectiveness of Using Foot Orthotics as the Sole Intervention for the Treatment of Patellofemoral Pain Syndrome

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THE EFFECTIVENESS OF USING FOOT ORTHOTICS AS THE SOLE INTERVENTION FOR THE TREATMENT OF PATELLOFEMORAL PAIN SYNDROME

By

Byron Horner

MASTERS' THESIS

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THE EFFECTIVENESS OF USING FOOT ORTHOTICS AS THE SOLE INTERVENTION FOR THE TREATMENT OF PATELLOFEMORAL PAIN SYNDROME

ABSTRACT

Patellofemoral pain syndrome (PFPS) is a common diagnosis treated by health care personnel. This study investigates the effectiveness of foot orthotics in the treatment of PFPS. Fourteen subjects experiencing PFPS participated. Each completed a Functional Pain Assessment (FPA) consisting of walking, stairs, biking, squatting and resting (sitting). Function was assessed using the Activities of Daily Living Scale (ADLS). After the initial FPA and ADLS, foot orthotics were placed in the shoes of participants and worn for the duration of the study. No other intervention was given. Follow-up testing was performed immediately after insertion of orthotics, after two weeks and again at four weeks in which subjects completed the FPA and ADLS. Results indicate that orthotics do not immediately decrease pain (p=.29). However, after two and four weeks, significant improvement was found (p=.004, p=.002) respectively. Functional improvements were found at both two and four weeks (p=.042, p=.014) respectively. This study does support the use of orthotics in the treatment of PFPS.
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DEFINITION OF TERMS

Arthrokinematics: The movement of joint surfaces.

Casting: A method of capturing the contours of the foot; typically done with the foot in subtalar neutral position.

Closed chain: When the distal end of the chain is fixed on the ground.

Crepitus: Disruption of the normally smooth joint surfaces. Is often associated with cartilage damage and joint degeneration.

Dorsiflexion: Movement around a horizontal axis between the talus and the medial and lateral malleolus resulting in a decrease in joint angle.

Eversion: An increase in the medial angulation of the calcaneus with the tibia.

External tibial torsion: Lateral twisting within the shaft of the tibia.

Femoral anteversion: Forward or anterior torsion of the femoral neck.

Genu varum: The medial angle of the tibiofemoral joint (knee) less than 180 degrees (bow legs).

Genu valgum: The medial angle of the tibiofemoral joint (knee) greater than 195 degrees (knock knees).

Inversion: An increase in the lateral angulation of the calcaneus with the tibia.

Kinematic chain: A series of joints in which movement of one joint produces movement in another.

Kinematics: The study of movement.

Open chain: When the distal end of the kinematics chain is free to move in space.

Orthotic: An orthopedic device used to support, align, or correct deformities to improve the function of movable segments of the foot.

Plantarflexion: Movement around a horizontal axis between the talus and medial and lateral malleolus, resulting in an increased joint angle.
**Post:** The portion of an orthotic used to control abnormal movement.

**Pronation:** Movement of the subtalar joint composed of abduction, eversion, and dorsiflexion of the calcaneus.

**Subtalar Neutral:** The position of the subtalar joint in which it is neither pronated or supinated, and the head of the talus can be palpated equally on the medial and lateral side.

**Supination:** Movement of the subtalar joint composed of adduction, inversion, and plantarflexion of the calcaneus.

**Tibial vara:** Bowing of the tibia with a medial concavity.

**Valgus force:** The force applied to the lateral surface of the joint.

**Varus force:** The force applied to the medial surface of the joint.
# TABLE OF CONTENTS

1. **ABSTRACT** .......................................................................................................................... i

2. **ACKNOWLEDGEMENTS** ..................................................................................................... ii

3. **DEFINITION OF TERMS** ................................................................................................. iii

4. **TABLE OF CONTENTS** ...................................................................................................... v

5. **LIST OF TABLES** ............................................................................................................... x

6. **LIST OF FIGURES** ............................................................................................................ xi

7. **CHAPTER 1** ....................................................................................................................... 1

   Introduction ................................................................................................................................. 1

   - Background to Problem ........................................................................................................ 1
   - Problem Statement ................................................................................................................ 2
   - Purpose .................................................................................................................................. 2
   - Significance of the Problem .................................................................................................. 2
   - Hypotheses ............................................................................................................................ 3

8. **CHAPTER 2** ....................................................................................................................... 4

   review of the literature and conceptual framework ................................................................. 4

   Anatomic and Biomechanical Considerations ......................................................................... 4

   - Subtalar Joint ....................................................................................................................... 4
   - Talocrural Joint (Ankle) ....................................................................................................... 7
   - Tibiofemoral Joint (Knee) .................................................................................................... 8
   - Patellofemoral Joint ............................................................................................................. 10
   - Classification of Disorders at the Patellofemoral Joint ...................................................... 13
   - Excessive Lateral Pressure Syndrome .................................................................................. 13
   - Global Patellar Pressure Syndromes ................................................................................... 14
   - Patellar Instability ................................................................................................................. 14
   - Lower Extremity Biomechanical Dysfunction ..................................................................... 16
   - Malalignment of the Patella .................................................................................................. 17
   - Muscle Weakness ............................................................................................................... 18
   - Leg Length Discrepancy ....................................................................................................... 20
   - Excessive Pronation ............................................................................................................. 20
   - Direct Patellar Trauma ......................................................................................................... 21
Soft Tissue Lesions and Abnormalities ................................................................. 22
Overuse Syndromes ............................................................................................ 23
Apophysitis ............................................................................................................. 25
Osteochondritis Dissecans of the Patella ........................................................... 26
Common Treatment Strategies ............................................................................ 27
Stretching ............................................................................................................... 27
Open and Closed Chain Exercise ........................................................................ 27
Functional Exercise .............................................................................................. 30
Exercise Prescription ............................................................................................. 31
Patellar Taping ....................................................................................................... 33
Foot Orthotics ....................................................................................................... 36
Types of Foot Orthotics ....................................................................................... 37
Rigid Orthotics ...................................................................................................... 38
Semirigid Orthotics ............................................................................................... 38
Semi-elastic Orthotics ........................................................................................... 39
Flexible Orthotics ................................................................................................. 39
Orthotic Fabrication ............................................................................................. 40
Molding/Casting .................................................................................................. 41
Posting .................................................................................................................... 43
Biomechanical Changes with Foot Orthotics ..................................................... 44
Effectiveness of Orthotics in Treating PFPS ...................................................... 45
Measuring Subtalar Motion and Position ............................................................. 49
Determining Subtalar Neutral ............................................................................. 51
Functional Rating Scales ....................................................................................... 53
Pain Rating Scales ................................................................................................. 55
The Stabilizer® .................................................................................................... 56
Summary ............................................................................................................... 57

9. CHAPTER 3 .................................................................................................. 59

Methodology ....................................................................................................... 59
Study Design ......................................................................................................... 59
Research Design ................................................................................................. 59
Study Sequence .................................................................................................... 59
Study Related Problems ....................................................................................... 61
Methodological Advantages ................................................................................ 62
Study Site and Subjects ....................................................................................... 63
Study Site ............................................................................................................. 63
Subjects and Inclusion Criteria ......................................................................... 64
Equipment and Instruments ................................................................................... 64
Reliability and Validity ........................................................................................ 65
Universal Goniometer ........................................................................................... 65
Polar Heart Rate Monitor ..................................................................................... 65
14. APPENDIX B ............................................................................................... 96
   Informed Consent .................................................................................... 96

15. APPENDIX C ............................................................................................... 99
   Data Collection Form ............................................................................ 99
   Section 1 (completed by participants) ................................................... 99
   Data Collection Form ........................................................................... 100
   Section 2 (researcher data collection form) .......................................... 100
   Knee Special Tests .............................................................................. 100
   Postural Screen of Knee and Ankle ................................................... 100

16. APPENDIX D ............................................................................................... 101
   Instructions for special tests ............................................................... 101

17. APPENDIX E ............................................................................................... 105
   Activities of Daily Living Scale ......................................................... 105

18. APPENDIX F ............................................................................................... 109
   Functional Pain Assessment .............................................................. 109

19. APPENDIX G ............................................................................................... 111
   Subject’s Wearing Schedule ............................................................. 111

20. APPENDIX H ............................................................................................... 112
   Study Sequence .................................................................................. 112

21. APPENDIX I ............................................................................................... 113
   Recruitment Posting ........................................................................... 113

22. APPENDIX J ............................................................................................... 114
   Pilot Study Sequence .......................................................................... 114

viii
23. APPENDIX K ......................................................................................... 115
   Example of random order of FPA categories ...................................... 115
24. APPENDIX L ......................................................................................... 116
   Instructions for each activity ............................................................. 116
25. APPENDIX M ......................................................................................... 118
   Data Entry form ................................................................................ 118
26. Subject .................................................................................................. 118
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Subject demographics</td>
<td>73</td>
</tr>
<tr>
<td>2. P-value for each comparison of FPA criteria over a 4-week period</td>
<td>76</td>
</tr>
<tr>
<td>3. ADLS mean scores and standard error over 4-week period</td>
<td>77</td>
</tr>
<tr>
<td>4. Pearson Correlation Coefficients for all measurements</td>
<td>79</td>
</tr>
<tr>
<td>5. Significance of evaluation tools</td>
<td>80</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Palpation of STJN</td>
<td>42</td>
</tr>
<tr>
<td>2.</td>
<td>Prone STJ measurement</td>
<td>49</td>
</tr>
<tr>
<td>3.</td>
<td>Mean scores for all FPA categories over a 4-week period</td>
<td>75</td>
</tr>
<tr>
<td>4.</td>
<td>Change in function over the 4-week period</td>
<td>78</td>
</tr>
<tr>
<td>5.</td>
<td>Lines bisecting lower leg and ankle</td>
<td>95</td>
</tr>
<tr>
<td>6.</td>
<td>Alignment of goniometer</td>
<td>95</td>
</tr>
<tr>
<td>7.</td>
<td>Anterior Drawer</td>
<td>102</td>
</tr>
<tr>
<td>8.</td>
<td>Varus/Valgus Stress Test</td>
<td>103</td>
</tr>
<tr>
<td>9.</td>
<td>Apprehension Test</td>
<td>103</td>
</tr>
<tr>
<td>10.</td>
<td>Clarke’s Sign</td>
<td>104</td>
</tr>
<tr>
<td>11.</td>
<td>Passive Patellar Tilt</td>
<td>104</td>
</tr>
<tr>
<td>12.</td>
<td>Appley’s Test</td>
<td>105</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

Background to Problem

Patellofemoral pain syndrome (PFPS) is probably the most prevalent disorder involving the knee.\textsuperscript{1,2,3,4,5,6} The effects of PFPS can range from slight discomfort during activity to the inability to perform activities of daily living. This condition is often aggravated by very common activities such as walking up and down stairs and ramps, squatting, or sitting for an extended period of time. It has been estimated by several clinicians in orthopedic and sports medicine clinics that 25\% of all knees evaluated were diagnosed with PFPS.\textsuperscript{1} Even though PFPS is common, there is little consensus as to its cause or management.

An individual diagnosed with PFPS may complain of a variety of symptoms, such as point tenderness or diffuse pain around the patella, and the sensation of the knee giving way. The presence and/or intensity of these symptoms are also varied among individuals.\textsuperscript{3} As a result, precise diagnosis, classification, and treatment is difficult.\textsuperscript{3} Therefore, significant discrepancies exist in reported outcomes for various treatment options.

Treatment of PFPS has traditionally consisted of exercises to improve the dynamic stability of the knee structures. Specific exercises are suggested which strengthen the vastus medialis oblique to improve patella tracking.\textsuperscript{7,8,9} In addition,
flexibility training, proprioceptive training, endurance training, external supports such as taping and bracing of the patella, foot orthotics, medications, and surgery in severe cases have also been reported. There is no consensus as to the best treatment for PFPS.

Problem Statement

Several studies have shown foot orthotics in conjunction with other treatments to be effective in treating PFPS. However, the effects of foot orthotics as the sole intervention are still unclear.

Purpose

The purpose of this study was to determine the effectiveness of corrective foot orthotics as the sole intervention for treatment of PFPS. This was measured by change in pain level, and by improvement on the ADLS.

Significance of the Problem

It has been estimated that 25% of all knees evaluated in orthopedic and sports medicine clinics are diagnosed with PFPS. No studies were found that isolated the effects of orthotics without also implementing an exercise program or other treatment modalities. Should this study show orthotics to be effective in alleviating the symptoms of PFPS, the time and cost of treating PFPS could be greatly reduced. Because of the lack of evidence in support of orthotics as a sole treatment, insurance does not typically cover the cost of orthotic fabrication. Should this study, as well as future studies, show orthotics to be an efficient and effective treatment option for PFPS, insurance coverage could become more readily available to cover the cost of orthotics for the PFPS population.
Hypotheses

Due to the biomechanical relationship of the subtalar joint and knee, it is thought that correcting malalignment of the subtalar joint may help resolve patellofemoral pain. To study this theory, the following null-hypotheses have been addressed. The use of foot orthotics as the sole treatment for PFPS will not:

1) Significantly reduce perceived pain, as measured by the Functional Pain Assessment, immediately after orthotic application.

2) Significantly reduce perceived pain, as measured by the Functional Pain Assessment, following two and four weeks of orthotic wear.

3) Show significant improvement in knee function, as measured by the Activities of Daily Living Scale, following two and four weeks of orthotic wear.

4) Reveal correlation between changes in the Functional Pain Assessment scores and changes in the Activities of Daily Living Scale scores within the four week trial.
CHAPTER 2
REVIEW OF THE LITERATURE AND CONCEPTUAL FRAMEWORK

Anatomic and Biomechanical Considerations

The stance phase of gait is a closed chain activity requiring cooperation of the foot, ankle, knee, and hip. Each joint must be able to adapt to changes that can be imposed by forces anywhere within this kinematic chain. Should one of these components fail to function properly, injury to any of the joints within the chain may result. Clinical observation indicates that PFPS is the most common lower extremity complaint. Abnormal patellofemoral mechanics are suspected as one of the primary causes of PFPS.

Subtalar Joint

The subtalar joint is composed of three articulations between the talus and the calcaneus. The largest articulation is the posterior articulation. The concave inferior surface of the talus, and the convex superior surface of the calcaneus form this articulation. Two convex facets on the neck of the talus and two concave facets on the calcaneus form the other two articulations, the anterior and middle. The posterior articulation is separated from the anterior and middle articulations by the tarsal canal which runs obliquely across the foot. The subtalar joint has very strong ligaments and as a result, it is a very stable joint. It has a total range of motion of 30°, 10° of inversion, and 20° of eversion. The interosseous talocalcaneal ligament runs through the tarsal canal and holds the subtalar joint closed. The posterior and lateral talocalcaneal ligaments and the medial colateral and lateral colateral ligaments of the ankle also
contribute support to the subtalar joint. Several muscles act on the subtalar joint in conjunction with other joints. The triceps surae (gastrocnemius and soleus) cross the subtalar joint and attach to the posterior calcaneus as the achilles tendon. The primary function of the triceps surae is plantarflexion. The achilles tendon continues and attaches at the talocalcaneonavicular (TCN) joint. This combined attachment produces hind foot supination on a weight-bearing foot, providing a rigid base for support. Other plantarflexor muscles crossing the subtalar joint are the plantaris, the tibialis posterior, the flexor hallucis longus, the flexor digitorum longus, and the peroneus longus and brevis. The most significant of these muscles is the tibialis posterior. Its primary action is supination of the foot, but it also acts to control pronation of the foot during gait. This will be discussed in more detail in following sections.

The muscles of dorsiflexion are the tibialis anterior, the extensor hallucis longus, the extensor digitorum longus, and the peroneus tertius muscles. According to the Rancho Los Amigos Medical Center's Handbook, Observational Gait Analysis, the tibialis anterior and the extensor muscles are significant because they control the pronation force produced during heel contact of gait by resisting plantar flexion and eversion through the weight acceptance phases of gait.

The arthrokinematics of the subtalar joint are dependent on whether it is weight bearing or not. For example, pronation of the non-weight-bearing subtalar joint is made up of abduction, eversion, and dorsiflexion of the calcaneus. The opposite is true for supination. When the calcaneus is weight-bearing, it is unable to dorsiflex/plantarflex or
abduct/adduct. Therefore, pronation of the weighted subtalar joints consists of eversion of the calcaneus, and plantarflexion and adduction of the talus.\textsuperscript{11}

This change of component movement makes sense when the rules of convex and concave movement are considered. When a convex joint surface is moved on a stable concave surface, the convex surface will glide in the opposite direction as the moving segment. When the concave segment is moved, the gliding will occur in the same direction as the moving segment. When the joint is non-weight-bearing, the calcaneus is free to move and the convex posterior articular surface of the calcaneus will glide in the opposite direction of the calcaneus and the concave articulations on the middle and anterior articular surfaces will glide in the same direction as the calcaneal movement. However, when the talar surfaces are moving the associated gliding will be opposite.\textsuperscript{11}

During the gait cycle, the subtalar joint and foot must fulfill two important roles. First, they must act as a shock absorber and adapt to the contour of the ground. At the beginning of the stance phase of gait (heel contact), the subtalar joint moves from supination into pronation because of the ground forces generated at contact. Pronation is the loose packed position of the subtalar joint and foot that frees the joints of the foot to absorb the ground reaction forces and to mold to the contour of the ground, thus providing a stable foundation for the remainder of the stance phase.\textsuperscript{13} Second, they must convert into a rigid lever in preparation for push-off. This is accomplished from approximately mid-stance through the remainder of stance phase as the subtalar joint supinates, which places the foot and subtalar joint in the closed pack position.\textsuperscript{10} This changes the foot from a moldable shock absorber to a rigid lever prepared for push-off.
Talocrural Joint (Ankle)

The talocrural joint is composed of the superior portion of the talus that fits into a mortise type joint formed by the lateral malleolus of the tibia and the medial malleolus of the fibula. The lateral malleolus extends further distally and is situated more posteriorly than the medial malleolus. This mortis provides primarily a concave surface that will articulate with the body of the talus. The tibia and fibula are held close together by the crural interosseous ligament. Other ligaments contributing strength to the distal tibiofibular joint are the anterior and posterior tibiofibular ligaments and the interosseous membrane. "The function of the talocrural joint is dependent upon the integrity of the tibiofibular mortise." 11(p 383) Normal range of motion for the ankle is considered to be 20° of dorsiflexion and between 30° and 50° of plantarflexion.11

The shape of the talus corresponds to the shape of the distal end of the tibia and plays a major role in the mechanics of not only the ankle, but also of the entire lower extremity.14 The tibia widens at its distal end and contains a small projection medially. This projection will correspond to the groove on the superior surface of the talar body. The superior surface of the body of the talus is wider anteriorly than posteriorly. The body of the talus is convex when viewed from the anterior or posterior side, and concave from the side view.14

Several ligaments contribute to the stability of the ankle. Medially, the deltoid ligament has fibers originating from the medial malleolus, attaching to the navicular, the talus, and the calcaneus helping to control medial distraction. It also checks motion in
extreme eversion. Laterally, the ankle is supported by a series of three ligaments; the anterior and posterior talofibular ligaments and the calcaneofibular ligament.\textsuperscript{11,14}

As stated above, the congruency of the mortis joint plays a major role in the mechanics of the lower extremity. Tiberio, described the connection between the subtalar joint and the lower leg as follows:

"When the subtalar joint pronates during ground contact, the calcaneus everts and the head of the talus slides medially and plantarflexes. The medial movement of the head of the talus results in a medial rotation of the body of the talus. Because of the tight fit of the talus into the ankle joint mortis, the lower extremity must internally rotate. With supination this process is reversed."\textsuperscript{10}

This has been accepted as an accurate model by many authors.\textsuperscript{3,13,15,16} Subtalar joint pronation, tibial internal rotation and knee flexion are interdependent and necessary for normal kinematics of the lower extremity during gait.\textsuperscript{11}

Tibiofemoral Joint (Knee)

The knee is formed by the articulation of the tibia with the femur. It is considered to have two degrees of freedom of motion.\textsuperscript{11} Normal range of motion is considered to be between 130° and 140° of flexion, and 5° to 10° of extension. Flexion and extension occur around a coronal axis. Medial and lateral rotation occur around a vertical axis.\textsuperscript{11} The articular surfaces of the knee are the medial and lateral condyles of the femur and the medial and lateral tibial plateaus. Between the two femoral condyles anteriorly is the patellar groove in which the patella glides during knee movement. It must be noted that the lateral femoral condyle is not as long as the medial femoral condyle. This actually improves the joint congruency, and compensates for medial angulation of the femur. As a result of this angulation, the tibia and femur form a medial angle of 185° to 190°.\textsuperscript{11} As
described by Norkin and Levangie, "if this medial angle is less than 180° an abnormal condition known as genu varum exists. If this angle is greater than 195° the condition is called genu valgum." The congruence of the knee is further increased by cartilaginous menisci that are attached to the surface of the tibial plateau. Along with increasing joint congruency, they also help to distribute force, reduce friction, and assist in maintaining normal knee arthrokinematics.

Because of the incongruence found at the knee joint, several intra-articular motions occur. As the knee flexes, the femoral condyles glide anteriorly on the tibial plateaus. If this did not occur, the condyles would roll off the posterior aspect of the tibia. During extension the opposite is true. Rotation of the femur also occurs during the last 30° of extension. Because the lateral condyle is shorter, its movement is limited when compared to that of the medial condyle. As motion stops at the lateral condyle, the medial condyle continues to move creating a medial rotation of the femur on the tibia. This rotation is commonly referred to as the screw home mechanism. According to Norkin & Levangie this is most evident during the final five degrees of extension.

The knee is stabilized by several structures. As mentioned above, the menisci help reduce joint incongruency. Ligaments and muscles must work together to insure the stability of this joint. Medially, the knee is supported primarily by the medial collateral ligament. It originates from the medial femoral condyle and inserts into the proximal tibia. Its main role is to resist valgus forces applied at the knee. Laterally, the knee is supported by the lateral collateral ligament and the iliotibial band (ITB). The lateral collateral ligament originates from the lateral femoral condyle and inserts into the lateral
proximal portion of the tibia. Its main functions are to resist varus forces at the knee and to contribute to controlling lateral rotation of the tibia. The ITB is formed from the fascia of the tensor fascia lata, the gluteus maximus, and the gluteus medius muscles. Along the shaft of the femur it attaches to the linea aspra and inserts into the lateral tubercle of the tibia distally.$^{11}$

Located in the center of the knee joint are the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL). The ACL originates from the anterior tibia and extends posteriorly and superiorly to attach to the posteromedial aspect of the lateral femoral condyle. Its main function is to resist anterior sheer forces of the tibia. It also plays a role in restricting medial rotation. The PCL originates from the posterior tibia and extends posteriorly and superiorly to attach to the medial aspect of the medial condyle. Its main role is to prevent excessive posterior displacement of the tibia on the femur. It also helps to restrict medial rotation.$^{11,14}$

Muscles also play an active role in stabilizing the knee. Medially, the sartorius, gracillis, and the semistendinosus aid in resisting valgus forces. Anteriorly, the quadriceps muscles help prevent posterior displacement of the tibia. Posteriorly, the hamstrings help to prevent anterior tibial translation. The iliotibial tract, popliteus tendon, and the biceps femoris add support laterally.$^{11}$

**Patellofemoral Joint**

The patella is a triangular shaped sesamoid bone with three main articular facets on its posterior surface, the medial, odd, and lateral facets. There is wide variability in the contour of the articular surfaces between individuals. The consistent landmarks are
the lateral facet, medial facet, and the odd facet. Also, on the posterior surface and at the approximate center is a vertical ridge that corresponds to the patellar groove between the femoral condyles.\(^{17}\)

Stabilization of the patella is a very complex system comprised of both passive and active elements, tendons, and ligaments.\(^{18}\) The patellar tendon passively controls the upward glide of the patella from the tibia. Its insertion points are the apex of the patella and the anterior tibial tubercle.\(^{18}\) Portions of the medial and lateral patellar retinaculum also merge with the patellar tendon to help support it from excessive medial and lateral gliding. Passive stabilization is primarily offered by the medial and lateral retinacula. Active stabilizers affect both retinacula because they originate from active structures.\(^{18}\) Superior active stabilizers are the quadriceps muscles that insert into the patella via the quadriceps tendon. The vastus medialis and the vastus lateralis contribute stabilization to the patella medially and laterally respectively. The ITB adds both active and passive support to the knee laterally with its attachment to the lateral retinaculum.\(^{18}\) The hip adductors may also contribute some active stabilization medially to the patella because of their attachment to the FPAtus medialis. The consistency of this contribution is questioned in the literature.\(^{7,8}\)

The primary purpose of the patella is to act as a pulley for the extensor mechanism giving it a greater mechanical advantage. The ability of the patella to perform this function adequately depends on its ability to properly glide within the femoral condyles.\(^{17}\)

Norkin and Levangie describe the mechanics of the patella as follows:
"In full knee extension, the patella sits on the anterior surface of the distal femur. With knee flexion, the patella slides distally on the femoral condyles, seating itself between the femoral condyles. In full flexion it sinks into the intercondylar notch. As the patella travels distally during flexion, it undergoes some rotation around the vertical axis as well as medial tilting. This is to accommodate asymmetry of the femoral condyles. The patella also rotates around an anterior-posterior axis to remain in the intercondylar notch as the femur undergoes rotation in relation to the tibia. When the femur medially rotates on the tibia, the upper portion of the patella will follow while the inferior portion will remain medially with the tibia."

Fu et al\(^\text{19}\) describe the total contact surface of the patella as the knee progresses through its range of motion. At extension, the majority of contact is at the inferior portion of the patella. As the knee continues to flex, this contact area shifts superiorly to ninety degrees of flexion at which point the upper portion of the patella is reached. During this first ninety degrees, the femur is in contact with a majority of both the medial and lateral facets of the patella. Beyond ninety degrees, the amount of contact area decreases with more contact being focused on the outer edges of the respective facets.\(^{19}\) This change in contact surface on the patella has implications for the design of a treatment program for PFPS.

In order to effectively treat PFPS, an understanding of the kinematics of the lower extremity is essential. Because of the many points of attachment, the mechanics of the patella are continually changing in relation to the surrounding structures. For example, because of its connection to the tibia via the patellar tendon, the direction of patellar glide may be altered by excessive internal rotation of the tibia. This rotation may be the result of excessive pronation at the subtalar joint as previously mentioned, causing the patella to track more laterally, possibly leading to PFPS. When investigating the source of pain in the patella or in any segment of the lower extremity, it is necessary to evaluate the mechanics of each segment throughout the entire chain.
Classification of Disorders at the Patellofemoral Joint

Classification of patellofemoral disorders are diverse and inconsistent. Several authors have developed a classification system that attempts to incorporate the wide range of symptoms, the physiologic deterioration, and the mechanical anomalies commonly seen in the PFPS population. A brief introduction to several of the more common diagnoses follows.

Excessive Lateral Pressure Syndrome

Tightness of the soft tissues on the lateral side of the patella, primarily the retinaculum, results in excessive lateral pressure syndrome. With the tightness of the lateral tissues, the lateral border of the patella is tilted laterally and the compressive force on the lateral facet is increased. The patella, however, maintains its position within the trochlea of the femur. Because the patella is laterally tilted, the medial tissues may become symptomatic because of an increased strain on them. During examination, a practitioner will find a decrease in the amount of medial play in the patella because of the tightness of the lateral retinaculum. Tightness and tenderness upon palpation over the lateral retinaculum and tilting of the patella are also significant clinical signs. In addition, a patient may report tenderness around the medial border of the patella secondary to the strain on the medial soft tissues. This condition may be caused by congenital tilting of the patella and over time adaptive shortening of the lateral soft tissues result.
Global Patellar Pressure Syndromes

The concepts presented for lateral patellar pressure syndrome apply to global patellar pressure syndrome in that tightness of the bordering soft tissues are altering patellar mobility and increasing the compression on the patellofemoral joint. Tightness of both the medial and lateral retinacula and other related soft tissue create an increase in pressure across all articular surfaces. Trauma and/or immobilization of the knee may also cause this condition. Clinical findings may include a decrease in both medial and lateral patellar mobility. Pain may not be localized to either the medial or lateral borders of the patella or retinacula.

Conservative treatment has been effective in treating patellar compression syndromes. Initial treatment should focus on restoring normal mobility to the patella in all deficient planes of movement by stretching the tight retinacula. Subsequent focus is on stretching surrounding muscles and exercising to help restore normal balance between quadriceps muscles. Anti-inflammatory medications, knee braces, patellar taping, and orthotics to control pronation have also been used as complimentary treatments. Wilk et al strongly suggest exercises that increase compressive forces at the patellofemoral joint, such as biking, resisted knee extensions, and deep knee bends be withheld until patellar mobility has been regained.

Patellar Instability

Patellar instability refers to excessive medial and/or lateral movement of the patella. Patellar subluxation and dislocation are examples of diagnoses given for patients with patellar instability. Explanations of the characteristics of both diagnoses follow.
Subluxation

Frequently patellar subluxation is associated with patellar tilt.\textsuperscript{21} It is defined in several sources,\textsuperscript{17,18,21} as the abnormal positioning of the patella within the trochlea, either medial or lateral. Lateral subluxation is the most common and usually occurs within the first few degrees of flexion.\textsuperscript{17} Subluxation may or may not be symptomatic. A person with instability may feel the knee is giving way particularly when the foot is stationary and the leg rotates. Individuals may also report feeling like the patella is catching with pain generally around the medial and inferior aspect of the patella. Clinicians should suspect instability in a patient when the knee is flexed 20° -30° and the patella can be laterally displaced 50% of the total patella width over the edge of the lateral condyle.\textsuperscript{3}

Traditional interventions for instability focus on strengthening the quadriceps, and improving the balance between the medial and lateral muscles. A myriad of braces have been developed to help control excessive patellar movement.\textsuperscript{3} Surgery to tighten lax tissues, as well as to release tight tissues, have also been a common treatment option.\textsuperscript{3}

Dislocation

Grelsamer and McConnell define three types of patellar dislocations. First, fixed dislocation is a congenital problem in which the trochlea is not developed and the patella has never been aligned properly. Second, habitual dislocation is characterized by an extremely tight extensor mechanism with lateral patellar dislocation when the knee flexes. Tightness of the quadriceps can be secondary to scarring from trauma to the
extensor mechanism, or from a neuromuscular disease. In these two instances, surgery to correct the deformity is generally necessary.  

Third, episodic or recurrent dislocation is an occasional dislocation of the patella. This may be from traumatic or atraumatic sources in which the patella is pulled completely out of the trochlea. Most often the patella is pulled off the lateral edge of the lateral condyle of the femur, although dislocation in any direction is possible. The patella is particularly vulnerable when the leg is externally rotated and a valgus force is applied. Once a person has had a dislocation, recurrent dislocation is quite common. 

In addition, injury to articular surfaces and the surrounding soft tissues is very common.

Nonsurgical treatment for dislocations is basically the same as that prescribed for subluxation. However, outcomes of the treatment are not as good. Stabilization of the patella is the goal of treatment. This is accomplished through the use of strengthening exercises for the quadriceps muscles, braces and/or patellar taping to give support to the patella during activity. Orthotics and a stretching program may be implemented to correct any malalignment of the lower extremity. In cases in which dislocation persists, surgery may be indicated. The goal of the several types of surgery is to correct the patellar alignment. This is accomplished by making alterations in the dysfunctional soft tissues, correcting bony malalignments, or a combination of the two.

**Lower Extremity Biomechanical Dysfunction**

In many patients, patellofemoral pain may be the result of a biomechanical dysfunction within a segment of the lower extremity. Research concerning the anatomical joint angles and function of the joints in the lower extremity and the
relationship to the incidence of PFPS is a popular topic.\textsuperscript{3,5,8,10,13,23,24} Although the results of these studies are very difficult to compare because of differences in purpose and methodology, there is a consensus that alteration of one or more joints within the kinematic chain of the lower extremity may predispose a patient to symptoms of patellofemoral pain. An alteration of normal joint mechanics changes the relationship of the articular surfaces and may increase the joint reaction force applied to a specific articulation. This increases the likelihood of developing pain particularly in an individual who does a lot of running or walking. The following section will discuss several possibilities contributing to biomechanical dysfunction of the lower extremity and how it can lead to PFPS.

\textbf{Malalignment of the Patella}

Malalignment of the patellofemoral joint is considered a major cause of anterior knee pain and may be the result of anatomical abnormalities of any segment throughout the lower extremity.\textsuperscript{25} Previous sections have discussed different problems that may be the result of improper patellar alignment. Hertling and Kessler implicate femoral anteversion, external tibial torsion, tibia vara, and congenital recurvatum as potential factors contributing to malalignment of the patella.\textsuperscript{14} In addition, the length of the patellar tendon plays a major role in aligning the patella. Patella alta is defined as an abnormally long patellar tendon which allows the patella to sit superiorly on the femoral condyles.\textsuperscript{14} The opposite condition is known as patella baja which is a shortening of the patellar tendon forcing the patella to glide inferiorly on the femoral condyles.\textsuperscript{14} Several treatment options will be discussed in future sections to correct patellar malalignment.
Muscle Weakness

The strength of the quadriceps muscles has received a lot of attention from practitioners and researchers alike as a potential cause of PFPS. A lack of equilibrium between the vastus medialis oblique (VMO) and the vastus lateralis (VL) is suspected as a reason for lateral tracking of the patella. It is believed that if the VMO weakens, greater lateral patellar tracking will occur and possibly lead to PFPS. As a result, many clinicians have attempted to utilize exercise in an effort to strengthen the VMO to restore proper muscle balance and normal patellar tracking. However, studies dealing with the ability to strengthen the VMO relative to the VL have been disputed in the literature.

In order to change the resultant pull of the quadriceps, one must be able to isolate medial or lateral muscles from the rest of the muscles in that group. For example, in order to increase the medial pull of the VMO, a person must be able to work the VMO with more intensity when compared to the VL. Laprade et al. used surface electromyographic (EMG) activity to compare the activity of the VMO relative to the vastus lateralis during five isometric exercises. This study consisted of twenty female control subjects and nine female subjects with PFPS. The five exercises examined were knee extension, hip adduction, medial tibial rotation, and the combinations of hip adduction with knee extension, and medial tibial rotation with knee extension. The authors found no significant difference between the experimental and control group with respect to VMO:VL proportions. This finding may indicate that VMO weakness may not be the sole culprit in developing PFPS. The authors did find that medial tibial rotation coupled with extension elicited the greatest VMO activity relative to the VL. However,
the difference was not statistically significant when compared to extension alone. Maximal hip adduction with simultaneous maximal knee extension did not result in increased recruitment of the VMO. These results concur with similar studies.

Hanten et al. studied the effects of exercises in isolating the VMO from the other quadriceps muscles. They suspected there would not be significant differences in the EMG activity of the VMO and VL during maximal isometric contractions of hip adduction and medial tibial rotation. The authors utilized indwelling fine-wire electrode EMG. Twenty-five healthy volunteers participated in this study. Their results differ from those by Laprade et al. in that there was a significant difference in VMO activity during hip adduction. They did agree that medial tibial rotation made no significant difference.

Several studies have looked at quadriceps strength in general to determine if there is a correlation between weakness and developing PFPS. Vaatainen et al. found a 21% decrease in peak torque and a 25% decrease in force output for the quadriceps muscle when patients with chondromalacia patellae were compared to healthy subjects. There is consensus in the literature supporting the presence of quadriceps weakness among patients with patella femoral pain. However, there is not consensus on whether this weakness is a primary cause of PFPS or if the weakness is secondary to the pain. Clinicians continue to report positive outcomes for patients with PFPS using strengthening programs, whether or not quadriceps weakness is the cause of patellar pain. It is not known how strengthening decreases PFPS, but Powers suggests that quadriceps
strengthening may shift the area of contact thus altering the pressure over a particular articulation, possibly relieving a symptomatic area.¹

Leg Length Discrepancy

It should be intuitive after discussing the principals of biomechanics within the lower extremity and their potential effects on patellar mechanics that leg length differences will change the mechanics of both lower extremities. Compensations made to accommodate a leg length discrepancy may include excessive foot pronation, forefoot abduction, flexed knee gait, and flexed knee stance on the longer leg.³ No literature was found focusing on the prevalence of leg length difference in a population with PFPS. In addition, leg length difference was not mentioned by any authors as criteria for inclusion or exclusion for their study. The author of the current study agrees with Wilk et al³, that leg length may play a role in causing PFPS either directly or indirectly by the associated compensations in the mechanics of the kinematic chain. Leg length discrepancies can usually be corrected simply with the use of a heal lift inserted into the shoe. In more severe cases, the soles of the shoe can be modified to compensate the shorter leg.

Excessive Pronation

Excessive pronation is often the cause of patellofemoral malalignment.⁵,²³ Because of the tight ankle mortice joint connecting the foot to the lower leg, excessive subtalar pronation during stance phase of gait will alter the rotational mechanics of the tibia and, thus, alter the congruency of the tibiofemoral joint, as well as the patellofemoral joint.¹³ The timing of abnormal pronation may be a major factor in determining if excessive pronation will lead to injury.¹⁰ For example, excessive
pronation during midstance may have more potential for producing pain than if it occurs
during contact phase. Excessive pronation will delay the external rotation of the lower
leg and will force compensations to be made throughout the leg. This changes the
alignment of the patella in relation to the tibial tuberosity and the trochlea. For example,
excessive subtalar pronation also results in increased medial tibial rotation which forces
the patella to track more laterally. As mentioned before, these changes in alignment
shift the areas of contact between the patella and the trochlea and femoral condyles and,
as a result, may increase compressive forces and friction to the articular cartilage. To
treat excessive pronation, orthotics and other arch supports are often prescribed. The
purpose of the orthotic is to help control the motion of the subtalar joint (STJ) during
closed chain activities. How this is accomplished will be discussed in greater detail in
future sections.

Direct Patellar Trauma

Direct patellar trauma is a common occurrence. Most can remember hitting their
knee on the bedpost or falling and hitting their knee on the ground. Collisions in contact
sports are also very common causes of patellar trauma. Direct blows to the patella may
lead to breakdown of the articular cartilage, particularly if dislocation or fracture
occurs. Articular damage can be suspected if the patient continues to complain of
diffuse pain around the anterior portion of the knee after the initial incident has had time
to heal. Crepitus during range of motion is also a common clinical symptom, if the
cartilage has been damaged.
Typically, treatment for this type of injury is conservative with surgery being performed only if small fragments of frayed tissues can be removed to decrease friction and pain. Treatment should initially focus on restoring normal range of motion. This has been shown to facilitate articular cartilage healing. Following the restoration of normal range of motion, selective exercises that do not significantly increase compressive forces of the patellofemoral joint should be performed. It is important that the exercises not be painful. A stretching program for the entire lower extremity should also be instigated. It is common for symptoms resulting from patellar trauma to persist for several months.

Soft Tissue Lesions and Abnormalities

Any soft tissue surrounding the patellofemoral joint can become irritated and become a source of pain around the patella. The most problematic structures according to Wilk et al. are the patellar plica, the infrapatellar fat pad, the medial patellofemoral ligament, the bursa, and the distal iliotibial band. Obviously, structures mentioned earlier such as the medial and lateral retinacula may be sources of patellar pain.

Common symptoms of patellar plica syndrome include aching in the knee when in a seated position and catching with associated popping or snapping during knee movement. Crepitation and swelling are also common. Atrophy of the quadriceps and tightness of the hamstrings are also frequently associated with plica injury. Patients with this problem should be instructed on a well-balanced stretching program to decrease anterior compression over the patella. A strengthening program to strengthen the atrophied quadriceps must be carefully monitored. Many commonly used exercises such
as resisted knee extensions and squats should be avoided because of the increased anterior pressure over the patella produced during these activities. 

Fat pad syndrome usually is a result of direct patellar trauma. Surgery may also create scaring and inflammation in the fat pad. Symptoms include tightness and pain when palpating over the patellar tendon. Severe swelling may also be present. Treatment typically focuses on stopping the inflammatory process and preventing atrophy of the quadriceps and loss of motion of the knee.

Bursitis may also occur from trauma to the patella. The symptoms may be very similar to those of fat pad syndrome. Initially the bursa may be swollen and very sensitive to palpation. Treatment is also similar with efforts directed toward controlling inflammation. The same precautions should be used when implementing a strengthening and stretching program.

The iliotibial band (ITB) is a very common source of anterior knee pain because of its attachments to the patella and the lateral retinaculum, particularly in the athletic population. Irritation of the ITB is usually the result of excessive friction, as a tight ITB repeatedly glides over the lateral condyle of the femur. Again, treatment is geared toward inflammation control and stretching of the tight tissues. Aggravating activities should be restricted until symptoms have subsided.

Overuse Syndromes

Grelsamer and McConnell define overuse syndrome as "strictly the result of excessive or inappropriate activity without the slightest hint of malalignment."
They also postulate that this is why one person develops pain while another does not even though they are performing the same activities. However, Hertling and Kessler claim that "patellar tendinitis rarely, if ever, occurs in knees without predisposing physical findings found in tracking problems."[14(p362)]

Tendinitis is an inflammatory reaction involving the tendon, the tendon sheath, or both. It is possible that only a specific section of the tendon is affected. The most common tendinitis in the knee is patellar tendinitis. Symptoms include pain located near the inferior border of the patella. The symptoms are usually first noticed following activities requiring explosive use of the quadriceps such as jumping, running, and walking up and down stairs. Symptoms usually subside initially with rest, but with continued activity, the pain may become more severe and persistent, limiting participation in certain activities. Another type of tendinitis is quadriceps tendinitis. According to Puddu et al., this condition occurs more often in patients over 40 years old. Onset and progression of symptoms is similar to that mentioned with patellar tendinitis except that pain is felt near the superior border of the patella.

Treatment of tendinitis is dependent on what stage the patient is in. Blazina’s Classification of stages from Fox and Pizzo are as follows:

Stage 1: Pain after sports activity.
Stage 2: Pain at the beginning of sports activity, disappearing with warm-up and sometimes reappearing with fatigue.
Stage 3: Pain at rest and during activity; inability to participate in sports.
Stage 4: Rupture of the patellar tendon.

Treatment for the first two stages typically consists of an adequate warm-up with stretching and eccentric exercises for all muscles of the lower extremity. Hertling and
Kessler also emphasize the use of eccentric exercise in the treatment of this condition. Following activity, ice is applied to the knee to help curb the inflammatory process. In addition, anti-inflammatory medications and other modalities to control inflammation may be helpful. Modification of activities may also be necessary. For stage 3 a similar approach may be used except on a less intense progression. Stage 4 will require surgery to repair the ruptured tendon. Following surgery, the treatment is similar to stage 3 activities.

Apophysitis

Some authors refer to these conditions as a form of tendinitis located at the junction of the tendon and bone. Others consider both to be an actual traction applied to the apophysis. There are two types of apophysitis common at the knee. Osgood-Schlatter's disease and Sinding-Larsen-Johansson syndrome. Osgood-Schlatter's disease is considered to be a partial avulsion of the patellar tendon from the tibial tubercle. It has traditionally affected adolescent boys more often than girls, but this gap may be narrowing as young girls become more involved in athletics. Most patients with this condition present with some form of extensor mechanism inefficiency. Usual symptoms include pain around the tibial tuberosity with use of the knee and with palpation. Swelling around the tibial tuberosity is also very common and an enlarged tibial tuberosity may persist into adulthood. According to Wilk et al and Grelsamer and McConnell, patella alta and tight hamstrings are also prevalent in this population.

The presentation of Sinding-Larsen-Johansson disease is very similar to that of Osgood-Schlatter's disease and patellar tendonitis except the symptoms originate from
the avulsion of the patellar tendon from the inferior aspect of the patella.\(^{3,17,18,32}\)

Treatment for both conditions must start with a good explanation of etiology to the patient, parents, and coaches. Current treatment trends are different than traditional approaches. Originally, a person was not allowed to continue participation in activities such as running, biking, and jumping. Cylinder casts were also used to immobilize the knee.\(^{32}\) Currently, treatment focuses on stretching hamstrings, quadriceps strengthening, and modalities for pain relief. Individuals are generally allowed to continue their activities as tolerated. Ice is typically used afterwards to help control pain and inflammation.\(^{3,17,32}\) Both conditions are typically self-limiting conditions with little to no carryover of symptoms into adulthood.\(^{3}\)

**Osteochondritis Dissecans of the Patella**

Grelsamer and McConnell define osteochondritis dissecans as “partial or total separation of an intra-articular bone fragment with overlying articular cartilage in the absence of acute trauma.”\(^{17(p97)}\) Bone necrosis is also commonly associated with this disorder. This is a rare condition which can occur in any joint but the knee is the most common.\(^{32}\) The femoral condyles and the facets of the patella are common sites for bone degeneration.\(^{32}\) Symptoms include pain behind the patella that worsens during squatting, walking, and going up and down stairs. Joint swelling and crepitus with movement are common. Some patients report giving way of the knee. Others report locking or catching of the knee.\(^{3}\) Radiographs are important for the diagnosis of this condition.

Treatment of osteochondritis dissecans is still controversial. However, conservative, non-surgical treatment similar to that described for other conditions of the
patellofemoral joint, has shown positive results.\textsuperscript{17} Surgery to remove free particles or to reattach them can be performed should the conservative approach fail.

**Common Treatment Strategies**

Several treatment strategies have been discussed in conjunction with specific disorders. This section will discuss specific principles relating to the different treatment activities. The treatments to be discussed are stretching, open and closed chain exercise, taping techniques, and orthotics.

**Stretching**

During the section on classification of disorders, tightness of tissues was often mentioned as a contributing factor to the condition. Although important to any treatment plan for PFPS, it is beyond the scope of this paper to discuss the different methods of stretching and mobilizing soft tissues. A well-balanced stretching program should focus on the muscles of the quadriceps, hamstrings, gastrocnemius, and the soleus. The passive structures surrounding the knee such as the medial and lateral retinacula, must also be stretched to help properly position the patella. Because of the effects of the kinetic chain, proper tissue length is essential throughout the chain in order to obtain optimal function.

**Open and Closed Chain Exercise**

It is evident from the literature that the most often applied treatment for patellofemoral pain is exercise.\textsuperscript{1,2,3} Strengthening the quadriceps muscles particularly the VMO is the front line of treatment. There is a myriad of different exercises that a person can perform to accomplish the goal of strengthening the quadriceps. These exercises can
be categorized as either open or closed chain. An exercise is said to be an open chain exercise if the distal segment of the limb doing the work is free to move in space. A closed chain exercise is one in which the working extremity is in contact with the supporting surface and is not free to move in space. Traditional exercises used for the treatment of patellofemoral pain have been primarily open chain. This makes good sense because PFPS is typically worsened by closed chain activities such as climbing stairs, or running.

Open chain exercise may be the only option if the patient is unable to bear weight on an injured extremity. However, as suggested by Kisner and Colby, "open chain exercise alone will not adequately prepare a patient for functional weight bearing activities." Understanding the biomechanics of the patellofemoral joint is essential when determining what types of exercise would be best for the patient. Powers suggests two important factors to be considered when making this decision. First, a person should consider the joint reaction forces generated at the patellofemoral joint. Reaction force is dependent on the angle of the joint and the tension of the muscles. During open chain exercise, the amount of force required to extend the knee increases as the knee extends from 90° to 0°. Second, the contact area between the patella and the femur decreases as the knee extends. Therefore, during the final few degrees of open chain knee extension, the maximum force is required from the quadriceps and the contact area is at its least.

If one considers the mechanics of the patellofemoral joint during closed chain exercises, they would find that the amount of quadriceps force is quite minimal when the
leg is in extension. The muscle activity increases as the knee flexes. The contact area continues to increase during flexion. Therefore, in a closed chain exercise such as squatting, the contact area of the patella on the femur increases as the quadriceps forces increase. This is an important factor to consider when formulating an exercise program for a patient with patellofemoral pain. Escamilla et al. and Fulkerson & Hungerford agree with the principles of Powers. Escamilla et al. compared knee forces and muscle activity during open chain and closed chain exercises. They found that quadriceps activity was greater in open chain exercises between $15^\circ - 65^\circ$ of knee angle, while activity was greater in closed chain activities when angles were greater than $83^\circ$. They also reported that the activity of the vasti muscles was significantly higher during closed chain exercise, and rectus femoris activity was higher during open chain exercise. This is an important finding if improving the strength and balance of the VMO and VL is the goal of the exercise. Patellofemoral compressive forces generally increased with knee flexion and decreased with extension. However, they reported that the compressive forces decreased near full flexion in open chain exercises. Open chain exercises produced greater forces at angles less than $57^\circ$ and closed chain exercises generated more force at angles greater than $85^\circ$. They also found that between $15^\circ - 29^\circ$ of knee flexion, tibiofemoral compressive forces were the greatest in open chain flexion and extension. Between $71^\circ - 95^\circ$ of flexion, these forces were greatest in closed chain. The results of this study suggest that if individuals with PFPS are given closed chain exercises, the knee motion should be kept in the low to mid-ranges of motion as this is the range of least patellofemoral compressive force in closed chain. This range of motion is also the most
functional range used by the knee and, therefore, the exercises may be more beneficial in restoring normal function.

Several studies have shown that with exercise alone, patellofemoral pain can often be decreased. The goal of the exercise should be considered before the patient is instructed to perform it. In order for an exercise to be most effective, the principals of joint reaction forces at various joint angles must be considered. The reaction forces of open and closed chain activities must also be considered. A combination of open and closed chain exercises used through the range of least compression should yield the best results, particularly during the acute phase. However, as Escamilla et al. suggest, if increasing VMO and VL balance is the goal, closed chain exercises that avoid flexion beyond 45° may be the best option.

Functional Exercise

The goal of any therapy program should be to assist the patient in returning to their normal activities as soon as possible without symptoms. As mentioned, open chain exercises as well as static closed chain exercises have limited carryover to functional activity. These exercises play an important role in the initial phases of treatment to prevent additional atrophy and to begin to build a stronger foundation on which functional activities may be added. Functional exercises can begin to restore strength, power, and endurance. Caution must be taken when this phase of treatment begins. In many situations this type of activity is what initiated the pain in the first place.

Molnar counseled that functional activity begin with exercises that are low impact. Care should be taken to consider the principles of biomechanics during each
exercise. For example, biking with the seat at a height that does not force extreme knee flexion or swimming using strokes that do not require a whip kick can be productive activities. Any exercises should be done in moderation with gradual progression as tolerated. If pain or crepitus begin to return, the patient should back off to avoid exacerbation of the condition. Slowly, the patient’s daily activities should be added to the treatment program until they can resume these activities without pain.

**Exercise Prescription**

Determining the proper intensity and duration for an exercise program is very important. An optimal training program must be established only after an individual has undergone testing to determine their current health status and response to exercise. Several tests have been developed to aid in making the above determinations. Both maximal and submaximal exercise testing are commonly employed. Maximal exercise tests are the most accurate, but are very strenuous for the subjects, and often require special equipment to gather data. As a result, maximal exercise tests are used only when necessary. Exercise capacity can be estimated using submaximal tests. The object of submaximal exercise testing is to determine an individual's heart rate (HR) response in relation to the amount of oxygen they consume. Data is collected for submaximal testing by monitoring the HR for at least two points during the test. Each test defines the times at which the HR is to be measured. For example, the YMCA Cycle Ergometry Protocol uses two to four stages of exercise, each stage comprising 3-minutes of continuous exercise. The heart rate is recorded during the last 15-30 seconds of the third minute of each stage. Once the HR has plateaued, the subject progresses to the next 3 minute stage.
Again, the HR is taken during the last 15-30 seconds of this stage. When two heart rates of 110 beats per minute or higher, have been obtained, the test can be stopped. The HR and work rate performed is plotted on a graph and the resulting line is extrapolated on to a nomogram to estimate the maximal oxygen consumption. The American College of Sports Medicine (ACSM) recommends that submaximal cycle tests be performed in 3 minute stages. The first stage is considered a warm up stage, in which the steady state heart rate will be raised. Steady state is the point in which the body is receiving enough oxygen to support the needed ATP (energy) for that level of exercise and the heart rate levels off. For the majority of individuals, the steady state is reached around 3 minutes of constant submaximal exercise.

The Astrand-Ryhming test is another example of a submaximal cycling test. The duration for this test is set at six minutes, which is within the ACSM guidelines for submaximal testing. The work load is determined for each subject based on their gender and activity level. The speed is also predetermined at 50 rpm. Heart rates are obtained during minutes 5 and 6 and the average of these two rates are plotted on a nomogram to estimate cardiovascular fitness. Other commonly used tests are the 12 minute run, and the 6 minute walk test.

Submaximal exercise is intended to be performed for extended periods of time, 10 minutes or longer. The ACSM recommends individuals exercise for 20-60 minutes at an intensity of between 50 and 85% of their heart rate reserve. For individuals with a lower fitness level, the ACSM recommends an intensity of 40-50% of their heart rate reserve. In many cases, interval training is used in which a person will work at a more intense
work load for a shorter period of time, rest, then perform the exercise again. During interval training, adequate rest is essential to successfully complete the exercise program. Rest is necessary to allow the energy to be replenished, and is usually completed within 5 minutes.\textsuperscript{37} It is not the intent of this study to test the cardiovascular system. However, it is the intent of this study to stress the musculoskeletal system without causing cardiovascular fatigue. Therefore, the current study is based on the protocols of submaximal exercise testing and prescription described above.

**Patellar Taping**

Patellar taping is used in conjunction with other treatments in the treatment of PFPS. The most popular taping technique is that of McConnell.\textsuperscript{1} The McConnell program incorporates specific taping techniques dependent on the position of the patella. Specific exercise and stretching activities are done to restore balance to the patellofemoral complex. The main purpose of taping is to correct lateral tracking of the patella and, as a result, decrease associated pain. The goal of taping, according to Greslamer and McConnell,\textsuperscript{17} is to immediately decrease pain by 50%. If this does not happen, the tape is to be reapplied. Should taping continue to fail to reduce pain, the patient may have a condition other than malalignment for which taping is not appropriate.\textsuperscript{17}

The effectiveness of taping the patella has been studied by several authors in a variety of conditions.\textsuperscript{6,33,39,40} It is difficult to make comparisons between the studies because of differences in methodology. Initial studies reported extremely good results. McConnell reported that 92% of patients were pain free following eight treatment
sessions. 

Gerrard, in Clinical Orthopedics, 1989, reported a 96% success rate after just five treatments of taping. A weakness to these studies is that neither had a control group.

More recent controlled studies have not been as favorable. Larsen et al. studied the effectiveness of patellar taping in controlling lateral tracking of the patella. Twenty healthy men underwent a series of three radiographs to determine the position of the patella. One side was used as a control in which no tape was applied, the other knee was the experimental side in which tape was applied to draw the patella medially. The two sides were compared and the results showed that the tape was effective in medially gliding the patella. The subjects then performed an exercise regimen to see if the tape would be effective in maintaining the medial glide during exercise. Their results show the tape to be unsuccessful at controlling the patella during exercise. The authors of this study did find that exercise alone caused the patella to rest in a more lateral position when compared to the initial radiograph.

Kowall et al. also studied the efficacy of patellar taping in the treatment of patients with patellofemoral pain. Twenty-five patients with patellofemoral pain were placed in one of two groups. One group underwent a standard physical therapy program and the other group underwent the same program with the addition of patellar taping. A visual analog scale was used to monitor any change in pain. Strength and electromyographic activity were also measured. Results indicated that both groups reported a decrease in pain with no significant difference for those who were in the taped
group. The groups were then compared for strength and muscle activity, and again no significant difference was found.39

Gillear et al52 studied the effect of patellar taping on the onset of the VMO and VL in patients with patellofemoral pain. Fourteen male subjects with PFPS performed step-up and step-down activities once with their knees taped and once without tape. When muscle activity between VMO and VL was compared without tape, no difference in onset time was found. However, with taping, onset of the VMO occurred earlier in the activity while there was no change in the onset of the VL. They postulated that earlier onset time of VMO would prevent abnormal lateral tracking of the patella and thus reduce the symptoms of PFPS. To the knowledge of the author of this study, no follow-up studies have been performed to validate this idea.

McConnell originally developed this taping technique as both an immediate and a long-term solution to the problem of patellofemoral pain.1 Recent research does not support these claims. If the tape is not effective in an exercise program, its effectiveness in activities of daily living must also be questioned.

Further, taping has some undesirable effects. Friction rub on the skin from the patella pulling laterally and the tape pulling medially and allergic reaction to the adhesive material on the tape.17 To the knowledge of the author of the current study, the question of increased compressive forces placed on the patellofemoral joint with this technique has not been addressed.
Foot Orthotics

Grelsamer and McConnell in their text “The Patella A Team Approach,” use a definition by Bordelon to define an orthotic: “An orthotic device is an orthopedic appliance or apparatus used to support, align, prevent or correct deformities, or to improve the function of the movable parts of the foot.” As mentioned in earlier sections, malalignment of the patellofemoral joint can result from abnormal function in the foot and/or subtalar joint. The purpose of foot orthotics, when used by patients with PFPS, is to correct malalignment of the patellofemoral joint by correcting dysfunctions in the foot and subtalar joint, and as a result, decrease associated knee pain.

Orthotics are most commonly used in an effort to control excessive subtalar pronation. Mechanically, when the subtalar joint over pronates, the tibia must internally rotate to compensate. Internal rotation of the tibia increases the obliquity in the pull of the patella (increased Q-angle) causing it to track more laterally. Larson states “correcting overpronation with orthotics and providing an athlete with a stretching and strengthening program will relieve symptoms in most cases.” His conclusion is supported by Eng and Pierrynowski, who studied 20 adolescent female patients with PFPS. The subjects were placed in two groups, a control group who were treated only with an exercise program and the experimental group who were treated with the same exercise program with the addition of soft foot orthotics. A visual analog scale was used to measure the level of pain. They found that both groups reported a decrease in pain but decrease was significantly greater in the group treated with orthotics in combination with an exercise program.
Saxena and Haddad\textsuperscript{16} performed a retrospective review of 102 patients treated for PFPS. Several treatment modalities were used in the treatment of these patients including semiflexible orthoses. Results of this review indicate that by four weeks, 2\% of the patients reported being free of PFPS. 76.5\% reported less pain, 16.7\% said their symptoms had not changed, and only one patient reported having worse symptoms.\textsuperscript{16}

It is evident from the research that orthotics can play an important role in the treatment of many different types of knee pain, particularly PFPS. Several authors have postulated that the benefit seen with the use of orthotics comes from changing the mechanical alignment of the lower extremity, thereby altering where the compressive forces are applied to the patellofemoral joint.\textsuperscript{5,13,17} The author of this study is unaware of any study that used orthotics as the only treatment for PFPS.

Types of Foot Orthotics

Foot orthotics are categorized by their material or purpose. The most commonly used categorization is by material. Materials can be categorized as flexible, semiflexible, semirigid, and rigid. The type of material used to build the orthotic will depend on its purpose. Johanson et al\textsuperscript{43} suggests the selection of the type of orthotic be based on: "1) the ability of the orthotic components to control pronation and 2) the type and severity of the patient's symptoms."\textsuperscript{43(p159)} In general, the more flexible the orthotic is, the more shock absorption it will provide. The more rigid orthotic will provide more mechanical control and support to the foot and lower extremity. However, experts differ as to the materials they use. A study by Nigg et al\textsuperscript{23} studied 12 subjects to determine the amount of mechanical change that could be accomplished using a variety of material
combinations in orthotics. Their results showed the softer orthotics to be the most effective at controlling the amount of total foot eversion. The harder materials allowed nearly twice as much movement to occur. They also concluded that the rigidity of the foot was the biggest factor influencing the amount of movement. A brief discussion of each type of orthotic and the indications for each type follow. The primary source of this overview is based on the descriptions presented by Greisamer and McConnell.  

Rigid Orthotics  

Rigid orthotics are made from hard materials such as stainless steel, hard plastics, and fiberglass/graphite composites. These materials are used when the primary purpose of the orthotic is optimal control of foot and subtalar mechanics. This type of orthotic may also be necessary for heavier patients when soft orthotics would be compressed and ineffective. Good strength, durability, ability to control motion, lightweight, and are not bulky are benefits of rigid orthotics. Drawbacks include difficulty in working with the rigid materials. Rigid orthotics are not easily adaptable. Most clinics do not have the necessary equipment to produce or adjust these orthotics on site so time is lost by sending them to a lab for fabrication and alterations. They often are more costly than other types of orthotics. In addition, they do not absorb shock and are the least comfortable to wear compared to orthotics made from softer materials. Compliance may be a concern with rigid orthotics.  

Semirigid Orthotics  

Semirigid orthotics are created with thermoplastics, fiberglass and graphite composites. They are slightly more flexible than the rigid orthotic. Like the rigid
orthotic, they are quite durable and provide good motion control to the foot and subtalar joint. Minor adjustments to a semirigid orthotic may be made by a clinician. Because of only slight flexibility in the materials, semirigid orthotics are not good shock absorbers. Grelsamer and McConnell suggest this type of orthotic be used by the athlete who requires significant motion control but only minimal shock absorption. 17

Semiflexible Orthotics

Materials used to make semiflexible orthotics can be a combination of flexible materials and thin material from the rigid group. Other materials used can include leather-covered cork or rubber and acrylics. This type of orthotic can be purchased over-the-counter and easily custom fit by a trained clinician without the use of sophisticated and expensive equipment. Benefits of these orthotics are their ability to control joint motion, though not as well as more rigid types, and their ability to absorb shock. This type of orthotic is less expensive than the rigid orthotic and much more comfortable to wear. However, they are thicker than more rigid materials and therefore require more room in the shoe. They are not as durable and as mentioned, they do not provide as much motion control. 17

Flexible Orthotics

Flexible orthotics are generally made from various forms of foam rubber and foam polymers. 17 Examples of these materials are plastazote, rubber, polyurethane foam, and styrene butadiene rubber (SRB). 17 Each type of material has its benefits. For example, SRB is easily moldable to the foot, whereas, polyurethane foam is not easily molded but does allow the foot to breathe. This type of orthotic is typically the type that
can be purchased over-the-counter. They are less expensive than other custom built orthotics. They are lightweight, comfortable, and are the best source of shock absorption. However, their durability and their ability to control motion are limited. Heavier patients or patients placing high loads on this orthotic during athletic activities will completely compress the orthotic minimizing its effectiveness. Grelsamer and McConnell suggest this type of orthotic be used primarily as a temporary device to determine if an orthotic will help the patient. They may also be used while the patient is waiting for the custom orthotics to be made. Flexible orthotics can also be used in cases where shock absorption is the primary goal.

Orthotic Fabrication

The materials to be used in the production of an orthotic are a very important factor in determining how successful the orthotic will be in controlling movement. The shape, location of support, and length of the orthotic are also important. As reported by Nigg et al, the amount of foot laxity will play a major factor in determining what type of materials should be used and the length, shape, amount, and location of posting to be used. There are three basic lengths used in orthotics: Metatarsal length, sulcus-length, and full-length.

Metatarsal-length orthotics run from the posterior rim of the calcaneus to the heads of the metatarsals. This type of device is used primarily to control motion of the rear foot and provide support to the arch. Metatarsal length orthotics do not add support to the forefoot and do not add significant support to the foot beyond the mid-stance phase of gait. This type of orthotic is less cumbersome to wear and can be worn in a wide
variety of shoes because it does not extend into the toe box of the shoe. Control of the rear foot is the main objective for this length of orthotic.

Sulcus-length orthotics also begin at the posterior rim of the calcaneus but extend forward to the web space of the toes. Orthotics of this length can be built with all types of materials. However, flexible and semiflexible are the most common. Sulcus-length orthotics provide the best control for patients with PFPS and athletes. With this length of orthotic, control can be given to both the rearfoot and the forefoot. This type of orthotic can be bulky and as a result, the shoes they can be worn in may be limited.

Full-length orthotics extend from the posterior border of the heel forward beyond the ends of the toes. A variety of materials can be used in each orthotic of this length. For example, rigid or semirigid material may be used up to the metatarsal heads or web spaces of the toes and a softer material may be used to extend beyond the toes. This type of orthotic can give support to the foot during the entire weight-bearing phase of gait. They can also be used to correct foot and toe deformities such as bunions or hammer toes. The ability to wear this length of orthotic may require some patients to be more selective with shoes they wear to allow enough room for the orthotic particularly in the toe box.

**Molding/Casting**

There are several methods used to mold a custom orthotic. Most casting methods are done with the subtalar joint in its neutral position. Neutral position of the STJ (STJN) has been defined in several different ways. Norkin and Levangie define the neutral position as follows: "The point from which the calcaneus will invert twice as many
degrees as it will evert. It is encountered when the subtalar joint is fully supinated and then carried two-thirds of the way through to maximum pronation. Hertling and Kessler and Grelsamer and McConnell describe a method of determining subtalar neutral which can be used for both open and closed chain positions. This method is done by palpating the medial and lateral edges of the talar head with the thumb and forefinger. The STJ is then slowly inverted and everted until the talar head can be palpated equally on both sides at which point the neutral position has been found. Because of the simplicity of this method, it is commonly used clinically.

The mold of the foot is most often taken with the foot in neutral position with the patient in a non-weight-bearing position. Plaster of paris strips are applied to the foot as it is held in its neutral position. When the plaster has dried it is removed, leaving a negative mold of the neutral foot. A positive mold is then made by pouring liquid plaster into the negative cast. Once the plaster is dry, the cast is removed and the positive impression is used to form the orthotic.

The use of soft moldable foam to make a negative impression of the foot is also used clinically. When using this method, the patient is seated in a chair with the knees bent to approximately 90°. The subtalar joint is held in the neutral position and the foot is pressed into the foam, leaving the impression of the foot in the foam. Plaster is then poured into the impression and allowed to dry, forming a positive impression of the foot. The impression is then used to mold the material to be used in the orthotic.
Finally, Grelsamer and McConnell describe an up-and-coming method of casting and producing orthotics. They discuss a computer-generated model of orthotic. The clinician uses a scanner to produce an image of the foot. This image is then transmitted to a computer which analyzes the image. Semirigid and rigid materials are then formed by a computerized mill that forms the orthotics. This method eliminates the need to produce impression molds in the clinic. It also cuts down on the time necessary to fabricate an orthotic because there is no drying time. A drawback to this method is the cost of the equipment needed for each phase of the process.

**Posting**

The location and severity of dysfunction determine the amount and location of posting to be used in the orthotic. The goal of treatment is a key factor in making these determinations. Control of subtalar pronation is one of the most common dysfunctions for which orthotics are prescribed. There is disagreement as to the most effective location for posting. More controlled studies are needed to determine the adequacy of each method in controlling different dysfunctions. Johanson et al studied the effects of different types of posting on controlling excessive pronation. They used orthotic shells with no posting, orthotics posted in the forefoot, the rearfoot, and combined forefoot and rearfoot posting. Their results indicate that each type did help decrease the amount of pronation regardless of the deformity. An interesting finding in this study was that there was no significant difference in the amount of control provided by the orthotics posted in both the forefoot and rearfoot when compared to the rearfoot posting alone.
As a general rule, forefoot posting is used to correct the alignment of the forefoot by bringing the ground closer to the medial border of the foot, thus not allowing the forefoot to over pronate.\textsuperscript{46} Rearfoot posting is primarily used to help hold the STJ near the neutral position during the contact phase of gait.\textsuperscript{43,46} Because the purpose of an orthotic in most cases is to help the foot and STJ maintain positions close to neutral, the amount of posting is determined by severity of dysfunction.

**Biomechanical Changes with Foot Orthotics**

This section will review the effects of orthotics on subtalar pronation, tibial rotation, tibial femoral alignment, and patellofemoral alignment (Q-Angle). Several studies have tried to determine the effects of orthotics on subtalar joint pronation.\textsuperscript{5,13,16,23,43-46} Nawoczenski et al credit orthotics in the reduction of maximum pronation, maximum pronation velocity, time to maximal pronation, and total rearfoot motion.\textsuperscript{44} Other studies support the reduction in total pronation.\textsuperscript{13,43} It makes sense from a biomechanical standpoint that orthotics can be an effective treatment for PFPS especially if PFPS is caused by malalignments of the lower extremity.

David Tiberio presented a biomechanical model that linked movement of the STJ to rotation of the tibia, as well as rotation on up the chain.\textsuperscript{10} As the subtalar joint pronates, the tibia is forced to internally rotate. Cornwall and McPoil\textsuperscript{15} propose that, because the relationship between rearfoot motion and tibial rotation are interconnected, measuring the amount of tibial rotation is an accurate measurement of rearfoot motion. In theory, a foot orthotic that alters the position of the STJ can control abnormal tibial
rotation. Nigg et al suggest that orthotics do decrease the amount of internal tibial rotation.\textsuperscript{23}

When the leg is in a closed chain and the tibia internally rotates, the femur will also rotate.\textsuperscript{10,11} The internal rotation of the tibia and femur force the patella to track more laterally in relation to the trochlea (increased Q-angle). If orthotics can alter the rotation of the tibia and femur by preventing internal rotation, they will help to maintain a more desirable Q-angle. This concept was studied by Klingman et al. who used radiographs to measure the change in patellar position with the use of a semirigid orthotic in subjects with at least 6° of pronation.\textsuperscript{50} Radiographs were taken of the patellofemoral joint before and after the placement of the orthotic. They concluded that all subjects had significant change in lateral patellar displacement with a mean change of 1.08 mm. Paired $t$ tests revealed the difference between pre- and post-orthotic measurement was significant $p<.05$, with $t = 8.28$. In order for the change to be significant, the critical value for $t$ was 1.75. It can be concluded from this study that semirigid orthotics can affect the patellofemoral alignment in patients with excessive subtalar pronation. Because 1.08 mm of patellar shift was documented in this study, it is still not clear as to how much change is necessary to illicit a clinically significant change in patellofemoral pain.

Effectiveness of Orthotics in Treating PFPS

The literature supports the use of orthotics in treating PFPS. Gross et al. studied the effectiveness of orthotic shoe inserts in the long-distance runner.\textsuperscript{51} They received 357 responses to a questionnaire that was given to 500 distance runners. All runners were presently using, or had previously used shoe inserts. They were asked to specify the
type of orthotic device worn (rigid, semirigid, or flexible), the diagnosis for which the orthotics were indicated, the duration of use, and were they still wearing the orthotic.

The runners were also asked to subjectively rate their response to the orthotics. Flexible orthotics were worn by 63% of participants, 23% wore semirigid, and 14% wore rigid orthotics. The diagnoses among the group were excessive pronation (31.1%), plantar fasciitis (20.7%), Achilles tendinitis (18.5%), leg length discrepancy (13.5%), patellofemoral disorders (12.6%), shin splints (7.2%), and miscellaneous diagnosis (4.9%). Results of this study indicated that 30.8% of the subjects had complete relief, 44.7% reported great improvement, 15.8% had slight improvement, 7.5% experienced no change, and 1.2% reported their symptoms worsened or they developed a new diagnosis.

The orthotics were most effective in treating those runners with excessive pronation and leg length discrepancies, and was least effective at treating shin splints. However, all diagnostic groups experienced significant improvement. The level of participation in running activities did not have a significant impact on the orthotic effectiveness. This study also reported a strong correlation between good outcome and continued use of the orthotic.

The results of this study by Gross et al do not indicate which type of orthotic provided the best results. Determining which orthotic type was most beneficial for the different diagnosis would also be valuable clinical information. Because it is not known if other treatments were received along with the orthotics, it can not be assumed that the orthotics were the only variable producing the change.

Way conducted a single-subject study in which thermoplastic foot orthotics were
used in conjunction with other modalities to treat a female college athlete for acute PFPS. This subject presented with a mild bilateral forefoot varus and increased forefoot pronation from mid to terminal stance phases of gait. This study contained four phases: 1) initial baseline, 2) intervention phase, 3) withdrawal phase, 4) a second intervention phase. The withdrawal phase was implemented to determine whether the changes observed during the initial intervention phase were due to the intervention or to maturation. During the two intervention phases a thermoplastic foot orthotic was inserted into the subject's shoes. The tools used to collect data were a visual analog scale and part of a functional index questionnaire. The subject was treated every 2 to 3 days for a total of 10 weeks. Way reported that this subject reported that significant improvement was noticed during both intervention phases. During the baseline and withdrawal phases the subject either remained the same or their symptoms worsened, suggesting that the improvements observed were related to the orthotic intervention. For this subject, maximum improvement was observed in less than 2 weeks following orthotic wear.

The results of the Way study are consistent with those found by Eng and Pierrynowski who studied the effects of soft orthotics in the treatment of PFPS. They studied 20 adolescent female subjects ages 13 to 17. These subjects presented with either excessive forefoot varus or calcaneal valgus. Subjects were assigned to a control group in which only an exercise program was prescribed or to the experimental group in which subjects were given the same exercise program with the addition of soft orthotics. Subjects were asked to complete a Visual Analog Scale for the following activities: walking, running, sitting for 1 hour, ascending stairs, descending stairs, and squatting.
Subjects were re-tested at 2, 4, 6, and 8 weeks. They concluded that both groups showed a decrease in pain but the experimental group showed the greatest improvement. They also found that significant improvement was made in the experimental group by the fourth week. The authors recommend future studies be done in which orthotics are the only intervention.\(^5\)

It is evident in the literature that orthotics do play a significant role in treating individuals with PFPS.\(^5,13,15,16,51,52\) It appears that orthotics are most beneficial for individuals who have malalignments of the foot or subtalar joint. These malalignments can generate excessive joint forces with the patellofemoral joint and over time may lead to PFPS. It has been found that increased rearfoot varus may be a contributing factor in PFPS and should be addressed during the assessment of an individual with PFPS.\(^53\)

Other studies have attempted to identify other factors predisposing individuals to PFPS and those factors which may influence treatment outcome. Factors such as age, gender, height weight, activity level, muscle flexibility, joint laxity, patellar positioning, ankle joint mechanics, and quadriceps strength have all been investigated.\(^53,54\) The authors conclude that no single variable can be a reliable predictor for the onset of PFPS. However, it was determined that younger subjects with lower body weight, and those who demonstrated significant strength gains of the quadriceps had a better long term prognosis.\(^54,55\) When orthotics have been implemented in the studies reviewed, significant improvement was found in each case. The literature also suggests that a trial period using a temporary orthotic for at least four weeks should be tried to determine if the orthotic will be an effective solution.\(^5,51,52\)
Measuring Subtalar Motion and Position

To determine the total range of motion available within a joint, there must be a defined starting point or (point zero) from which the measurements are made. For the subtalar joint, point zero remains a point of controversy in the literature. Clinically, the most often used method is described by Elveru et al.\textsuperscript{56} This method is done with the patient lying prone with the side to be measured extended off the plinth approximately six inches. The opposite leg is positioned with the knee bent and the leg is abducted and allowed to externally rotate until it rests on the plinth. A line is drawn on the lower portion of the leg that represents a medial and lateral bisection. Another line is drawn at the midpoint of the heel. Total range of motion is then measured using a goniometer. The arms of the goniometer are aligned with the lines drawn on the leg and the heel. The range is then quantified by measuring the degrees of movement as the calcaneus is moved through maximal inversion and eversion.\textsuperscript{56} A weakness of this method is the assumption that the zero point is where the two lines are parallel. This may not be true for every individual. This method of measurement has not been found to be reliable, especially for intertester reliability.\textsuperscript{57,58}

Other authors suggest STJ range of motion be measured using the subtalar neutral position as the zero point.\textsuperscript{56,58,59} Determining this position is also a source of controversy.
in the literature and will be discussed later. Once the STJ is placed in neutral, measurements are made with a goniometer with the arms aligned as suggested by Elveru et al. The heel is then maximally inverted and everted to determine the available range of motion. The major problem with this approach is the inability to precisely position the STJ in neutral. Errors in positioning the STJ in neutral will decrease the accuracy of the joint measures, thereby significantly reducing reliability.

Elveru et al. reported intratester reliability for measuring the subtalar joint neutral (STJN) position. Subjects were measured in the prone position. They drew lines, centered vertically, on the posterior surface of the leg and ankle. The STJN position was located by palpating the talar head and inverting and everting the foot until the talar head could be felt evenly on both the medial and lateral side. The intraclass correlation coefficient (ICC) was .77; the intertester reliability ICC was .25. They also reported higher intratester reliability, when using this method, for total range of motion and poor reliability for intertester reliability. These results are similar to those found in a study by Picciano et al. The intratester reliability may be high enough to be clinically acceptable but intertester reliability is not. The authors suggest that in order for repeated measurements to be reliable, the same person should perform them.

Radiographs, while less common clinically, are a more reliable method for measuring joint angles. Once the radiograph is developed, a goniometer can be aligned with the tibia and calcaneus that will measure the tibial-calcaneal angle. Radiographs are taken with the joint in full inversion and eversion. Total range can be calculated as the sum of the two angles. Benefits of this method include the elimination of estimating
landmark positions and the ability to see the joint being measured. Drawbacks include the cost of equipment and the time it takes to have radiographs taken. This is not a practical method to use within most clinical settings.

Finally, motion analysis equipment such as The Motion Analysis Expert Vision® system and high shutter speed cameras combined with computer software such as The Peak Performance Motion Analysis System® and The Metrecom Skeletal Analysis System® can be used to record joint motion. The cameras used in these systems track the movement of reflective markers that have been placed on specific landmarks. The computer software then analyzes and quantifies the motion. Again, this method of analysis is more reliable than manual techniques. However, the equipment is very expensive and analysis requires significant set up time that is often not available in a clinical setting.

Determining Subtalar Neutral

Subtalar joint neutral (STJN) position has many uses, including range of motion measurements, determining the degree of postural anomalies, and is the standard position of the foot when casting for orthotics. As mentioned previously, STJN can be defined as the point at which the joint is neither pronated nor supinated. According to Elveru et al, the first method for determining STJN position was developed by Root et al, 1971. This method was based on the theory that there is a 2:1
ratio of inversion to eversion. To determine the neutral position, the total range of
motion was measured with a protractor. This method is not as clinically friendly as other
methods because of the time required to measure and calculate the angle.

A more convenient method to determine the STJN position has been developed. The patient lies on a plinth with the leg to be measured hanging off the end of the table. The posterior edge of the heel is positioned parallel to the ground. The therapist then draws a line with a marker bisecting the lower portion of the leg. The therapist determines the medial lateral midpoint of the heel; no line is drawn. The medial and lateral borders of the talar head are palpated using the thumb and first finger of the medial hand. To help in locating these landmarks the foot can be maximally pronated to make the medial head more prominent, and maximally supinated to more easily palpate the lateral head. To place the foot in STJN, the therapist grasps the heads of the fourth and fifth metatarsals with the thumb and forefinger of the lateral hand and slowly inverts and everts the foot until the medial and lateral talar heads can be felt equally on both sides. This position is maintained while a goniometer is used to measure the joint angle with reference to the line drawn down the midline of the lower leg. Because this technique is quick and requires only a universal goniometer, it is commonly used clinically. It has been determined that this method is fairly reliable when performed by the same therapist over a short period of time with reliability of .77 (ICC). Reliability decreases significantly when intertester reliability was considered .25 (ICC).

Another advantage to this method is that it can be modified to be used while the foot is on the ground, a closed chain (CC) position. Evaluation of the STJ in a CC
position is essential because this is the position it functions in. Lattanza et al.\textsuperscript{59} studied the difference between eversion of the STJ in open chain (OC) and CC. The measurements were referenced from the STJN position as described by Elveru et al.\textsuperscript{56} Neutral position, in CC, was determined by palpation of equal protrusion of the talar head medially and laterally as the subject inverted and everted the STJ while on a BAPS\textsuperscript{®} board. They reported 37\% more eversion of the subtalar joint in CC in comparison to OC. This significant clinical finding suggests that in order to have a true picture of the joint function, we must measure it in both open and closed chain positions.

It is thought that STJN measurements may be more reliable when made in a weight-bearing position, because errors made in passively moving the joint are eliminated.\textsuperscript{60} Smith-Oricchio and Harris\textsuperscript{60} studied the intertester reliability of three experienced testers measuring subjects in prone OC position and in standing CC. They determined that the reliability was significantly higher during CC measurements. They determined the ICC to range from 0.25 to 0.60 for prone measurements. The ICC for bilateral stance was 0.91 and 0.75 for unilateral stance.

**Functional Rating Scales**

Several instruments have been developed to test the function of the knee. Some of the more common include the Lysholm Knee Scale, the Cincinnati Knee Scale, and the Western Ontario and McMaster Universities’ Osteoarthritis Index (WOMAC).\textsuperscript{61} Other guidelines have been set to measure knee function such as those of the International Knee Documentation Committee (IKDC), which focuses on ligamentous injuries, and those of the Knee Society, which assesses outcomes of knee arthroplasty.\textsuperscript{61} One of the limitations
to these tools is that they were developed to test the function of a patient with a specific diagnosis or procedure. Another limitation to these and other tools is the scaling system used to quantify the level of impairment. The author of the current study has been unable to find reasoning as to why the specific scales were used for any measuring instrument.

The Knee Outcome Survey was developed at the University of Pittsburgh to address the limitations inherent in the existing functional knee rating scales. This survey is not specific to any particular knee diagnosis and is intended to be used as a general measure of knee function. The Activities of Daily Living Scale portion of this survey was developed to assess both symptoms and functions that are apparent in a variety of conditions of the knee. The content for this scale was based on the review of the existing instruments such as the Cincinnati and the WOMAC. The symptoms included were pain, stiffness, swelling, instability, and weakness. Functional limitations included were difficulty with regard to walking on level surfaces and stairs, standing, kneeling, squatting, sitting, and rising from a sitting position.

Irrgang et al tested the reliability, internal consistency, concurrent and construct validity, and responsiveness of the Activities of Daily Living Scale portion of the Knee Outcome Survey. They studied 397 subjects who were referred to physical therapy for a variety of knee problems. The Activities of Daily Living Scale was administered at the initial visit, again at one, four, and eight weeks of therapy. Other measurement scales were administered to each patient as well, such as the Lysholm Knee Scale, to compare the reliability and validity of this new scale to the already established scales. They concluded that the Activities of Daily Living Scale is an effective and accurate scale to
rate functional impairments from a variety of knee pathologies. They determined that this scale is reliable, valid, and responsive to measuring the function of the knee at any given time as well as to measure any changes over time. To further establish credibility to this survey, research is needed by a source independent of the University of Pittsburgh.

The Patellofemoral Health Status Survey was developed by Worell et al\textsuperscript{62} from the Knee Outcome Survey developed by Irrgang et al.\textsuperscript{61} Although the Knee Outcome Survey has been found to be reliable, valid, and responsive, no studies have been done to test the Patellofemoral Health Status Survey for these criteria.

**Pain Rating Scales**

Numerous scales have been developed in an effort to quantify pain. A study by Piotrowski\textsuperscript{63} reported the frequency of various pain assessments used in a variety of settings. Piotrowski found the Minnesota Multiphasic Personality Inventory (MMPI/MMPI-2) was the most commonly used measure, followed by the Beck Depression Inventory and the McGill Pain Questionnaire. These instruments are designed to measure the health status and associated dysfunction of chronic pain patients. These tests are commonly administered in a psychological testing environment but are also done by a variety of healthcare professionals.

Numerical and visual analog scales are commonly used in physical therapy settings to measure a patient's level of pain. Visual analog scales of several varieties such as a 10 cm line or a thermometer in which the patient makes a mark symbolizing where his/her pain level is on the continuum are common clinical measures.\textsuperscript{64} Ease of administering the test and the ability to do repeated tests are some of the clinical benefits
to this type of measure. The lack of objectivity defining each level of pain makes comparison between patients very difficult. Clinically, the scores are typically interpreted simply as a general change in symptoms for the individual patient. ^63

Visual analog scales are not only used clinically, they are also used in studies as a means to measure change over time. Several studies have used a visual analog scale as at least part of their measuring system. ^5,11,13,39,60 Each of these articles have all indicated that visual analog scales are a valid and reliable measure of pain level over time. The Functional Pain Assessment used in the current study is a compilation of several visual analog scales. No studies have been conducted to determine if the summation of the included visual analog scales is a valid or reliable measure of change in overall pain.

**The Stabilizer®**

The shoe insert chosen for this study was the Stabilizer®. It is made from a combination of rigid and flexible polyurethane. This semirigid insole is structured to provide cushioning, arch support, and stability to the foot. The Stabilizer® was initially produced as the insole to the Asics X-Caliber® running shoe. When the shoe was no longer produced, the insole began to be marketed by ©Spectrum Sports, Twinsburg, Ohio, as a separate insole. There is no published literature regarding the amount or location of posting built into the Stabilizer®. Published literature is also nonexistent regarding any clinical trials utilizing the Stabilizer®. The lack of published literature was confirmed in conversation with Kenneth Leighton, President, Spectrum Sports (May 2000). The stabilizer was selected based on the clinical opinion of Barb Hoogenboom, MHS, PT, SCS, ATC, and after trial and comparison of a variety of inserts by the author
Summary

It is evident from the literature that physical therapy plays a major role in the treatment of PFPS. The general treatment program consists of a quadriceps strengthening program as well as a stretching program to restore normal joint alignment and function. Other treatments utilize braces, taping, and less frequently foot orthotics to further improve biomechanical alignment. Studies have reported impressive statistics representing a positive outcome for most of these treatments. McConnell\textsuperscript{6} reported a success rate of 92\% in her initial study and later reported 96\% in an athletic population and 75\% success in workers compensation patients when patellar taping was used in conjunction with strengthening and stretching. Kowall et al\textsuperscript{39} refuted the tape as being a significant factor in outcome success as they compared subjects receiving only physical therapy to those receiving the same treatment with the addition of patellar taping as described by McConnell. Saxena et al\textsuperscript{16} reported a 78.5\% reduction in pain with the utilization of foot orthotics combined with a physical therapy program. A retrospective study by Donatelli et al\textsuperscript{46} supported the trend found by Saxena. They stated that 96\% of the patients treated with a prescribed orthotic reported a reduction in pain. The author of the current study was unable to find any studies reporting negative results for the use of orthotics in the treatment of PFPS.

Worrell et al\textsuperscript{62} investigated the health status of patients with PFPS who were treated in physical therapy and by surgery. They compared patients treated in successive years from 1993-1996. They reported lower satisfaction rates for patients treated in 1996.
in comparison to the other years. They speculate this decline in satisfactory outcomes may be due to an increased number of patients enrolled in managed care organizations, a selection bias, or a maturation effect. The findings of Worrell et al \(^{62}\) are consistent with those found by Vaatainen et al \(^{65}\) and Milgrom et al \(^{66}\), who reported between 33 and 47 percent of patients treated conservatively with physical therapy or with surgery still had knee symptoms at a four to six year follow up. Worrell did not address the exact treatment used in these studies, but these findings do not reflect the excellent outcomes reported by the authors above.

In order to determine the long-term effectiveness of orthotics in reducing PFPS, carefully controlled studies are needed. Several studies have been discussed that have incorporated orthotics into the treatment program. However, no studies were found that used orthotics as the only intervention. Using orthotics as the only intervention removes the complicating variables such as stretching and strengthening. By eliminating the need to continue a strict strengthening and stretching program over an extended period of time, patient compliance to the study should also increase, allowing more accurate conclusions to be made concerning the long-term benefits of orthotics in the treatment of PFPS.
CHAPTER 3
METHODOLOGY

Study Design

Research Design

This quantitative quasi-experimental study was constructed as a modified time series design \((O_1 X_1 O_2 X_2 O_3 X_3 O_4)\) utilizing a sample of convenience of individuals with patellofemoral pain. The difference in treatment times "X" is that \(X_1\) represents an acute intervention with orthotics during the initial visit, \(X_2\) represents the intervention over a two week period of time and \(X_3\) represents the intervention four weeks from the initial testing session. The difference in the data collection points "O" is that \(O_1\) represents pretest data collected before orthotics were issued, \(O_2\) represents the immediate response to the orthotics, and \(O_3\) and \(O_4\) represent the post-test data at two and four weeks respectively. Subjects who met the inclusion criteria underwent the experimental procedure. Subjects acted as their own control.

Study Sequence

The tester became familiar with the screening procedures. A pilot study was conducted on five asymptomatic volunteers to determine the tester’s reliability in measuring the position of the subjects’ STJ. Measurements of the STJ were taken with the volunteers in a bilateral stance position, using the method described in (Appendix A).

Once the pilot study was completed, 14 subjects were recruited for the study. The study subjects read and sign the informed consent form. (See Appendix B). They
then filled out the appropriate portion of the data collection form. (See Appendix C).

Subjects were screened for the inclusion/exclusion criteria using the special tests found in the Data Collection Form. (See section 2 of Appendix C). These tests include anterior and posterior drawer tests, varus and valgus stress tests, apprehension test, Clarke’s Sign, passive patellar tilt, and Apley’s test. For specific instructions for administering these tests see Appendix D. If the tester found evidence of possible ligament or soft tissue damage the subject was referred to their physician for further investigation. Participants were then measured to determine the position of the STJ see Appendix A. A universal goniometer was used to make the measurement with the patient standing on both feet on a raised platform, as this has been shown to be a reliable method of measurement.

Each subject completed the Activities of Daily Living Scale (ADLS) (Appendix E). Subjects also completed a Functional Pain Assessment (FPA), consisting of a series of five activities. These activities included sitting (at rest), a 6-minute walk, walk up and down a flight of 14 stairs four times, 10 knee bends to 90°, and a stationary bike for 6 minutes. A separate visual analog scale to rate the subject’s pain was filled out immediately following each activity within the FPA (Appendix F).

Each subject was given “The Stabilizer®” to insert into his/her shoes. The inserts were to be worn throughout the day. Complete instructions for wear time was given verbally to each subject as well as in writing and taken home as a reminder (Appendix G). The position of the subjects STJ was measured again with the subjects standing on the inserts. After the orthotics had been inserted into the subjects’ shoes, the subjects again performed the testing protocol mentioned above and filled out a blank FPA.
following each activity. Follow-up appointments were scheduled at two and four weeks. Subjects were contacted by telephone each week to verify wear time and to have a chance to ask any questions. During each follow-up appointment, the subjects were asked to fill out a blank ADLS, and to perform the FPA as performed on the first visit. Again, each portion of the FPA was completed after the corresponding activity. At the end of the fourth week, all data was analyzed to determine if any significant changes had taken place in the function level and symptom level of the knee. See Appendix H for an outline of the study sequence.

Study Related Problems

Several problems were anticipated during this experiment, including the subjects' failure to wear the orthotics, inability to complete the activities on the first visit due to fatigue or pain, and unwillingness to return for the follow-up sessions. Subject non-compliance was addressed by providing the subjects with a copy of Appendix G, informing them of the wear schedule and to act as a reminder to be placed in a prominent place in their home, such as on the refrigerator door or on the bathroom mirror. In addition, subjects received a weekly phone call to ask about wearing time and to determine if any adjustments were needed. Discomfort due to the orthotics could have prompted the subject to stop wearing the orthotic. This was addressed by instructing the subjects to gradually increase wearing time over the space of several days. Every effort was made to insure a proper fit of the orthotic.

If a subject could not complete the FPA due to fatigue, he/she was allowed to perform the activities at a lower intensity level. This was not a problem as the prescribed
intensity level was below that recommended by the ACSM for submaximal exercise. Rest periods of five minutes were given between each phase of the protocol. Five-minute rest periods have been reported as adequate to restore energy stores during submaximal workloads. If a subject could not complete the activities because of pain, it was noted on the FPA and the time or repetitions completed was recorded for future comparisons.

Unwillingness to attend future testing sessions was the privilege of the subject. However, this concern was addressed by educating subjects about the potential discomforts they may experience because of the stresses of the FPA. Also, allowing the subject to dictate the intensity at which they performed if they could not maintain the prescribed intensity removed concerns about fatigue. Informing the subjects that the FPA was to be completed only once during follow-up visits decreased the anxieties concerning future testing sessions. Each subject was given the phone number and e-mail address of the tester and were instructed to call or write if any concerns arose.

Methodological Advantages

The advantages of using this methodology are:

(1) All tests are based on the subject's functional ability.

(2) The Stabilizer® is easily accessible, relatively inexpensive, and easily adjusted to fit into a shoe.

(3) All measures are commonly used in a clinical setting by physical therapists.

(4) The results are outcome-based. As mentioned above, the FPA is functionally based.
The activities within the FPA are activities that typically cause patients with PFPS the most discomfort. Using the FPA allowed the tester and the subjects to monitor progress during activities commonly performed by the subject. The shoe inserts (The Stabilizer®) used in this study were relatively inexpensive when compared to a custom-fit orthotic. These inserts were purchased from a local sporting goods store. The inserts were trimmed, if necessary, to fit comfortably into the shoes of each subject. The measurements used in this study are commonly used in a clinical setting. Visual Analog Scales are frequently used to monitor the pain level of patients and several types of functional scales are used to determine the level of function for each patient. The ADLS does not require special training to administer. The method used to measure the STJ is also commonly used in clinical settings. In this study, the measurements of the STJ were made with the subjects in a standing position, the functional position of the lower extremities. It has been shown that reliability is higher when measurements are made in a closed chain position. The outcome of this study was not only based on reduction of pain associated with PFPS but also on whether the subjects were better able to perform their activities of daily living.

**Study Site and Subjects**

**Study Site**

Testing for this study was conducted in the Recreation Center and the Field House on the Allendale campus of Grand Valley State University. Several flights of stairs, several stationary bikes, and an indoor track were available and used for testing.
Subjects and Inclusion Criteria

Fifteen subjects meeting the inclusion criteria set forth were selected from a sample of convenience. The men and women selected for this study participated on a voluntary basis. They ranged from 19-32 years of age. They must have had symptoms of PFPS for at least two months. Symptoms may have included crepitus, pain under and or around the patella not associated with inflammation of surrounding soft tissues. These symptoms may have been exacerbated by activity or may have been present at rest. Subjects were excluded from this study if they were currently wearing an orthotic, or currently being treated by a physical therapist for PFPS. Subjects who had surgery to either lower extremity were not permitted to participate in this study. Subjects were also excluded from this study if they had a history of neuromuscular disease, hypertension, cardiovascular disease, taking any prescribed pain or anti-inflammatory medication, had a fracture or other traumatic injury of any part of either lower extremity within the past two years, or had any signs of ligament injury during a lower extremity scan.

Equipment and Instruments

Equipment used in this study included a goniometer, shoe inserts (The Stabilizer®), heart rate monitor, FPA, and the ADLS. A hand held 360° goniometer with one-degree increments was used to measure the angle of the STJ to establish baseline positioning of the STJ for each subject. It was also used to measure the change in STJ position while the subject was standing on the inserts. A Polar® heart rate monitor was used to maintain a work intensity of 50-60% of maximal heart rate to standardize workload. An over-the-counter semirigid orthotic, The Stabilizer®, specific
for shoe size was used in both shoes to help control the movement of the subtalar joint during the described activities as well as throughout the subjects’ activities of daily living. The FPA was utilized to allow subjects to rate their pain before and after orthotic intervention. These scales were compared using analysis of variance for a single-factor repeated measures design. Finally, the ADLS, described by Irrgang et al, was used to measure change in function over time for each subject.

**Reliability and Validity**

**Universal Goniometer**

The literature reviewed did not address the validity of the goniometer in measuring the actual angle of a joint. It is assumed that aligning the arms of the goniometer with bony landmarks on each end of the joint will be representative of the joint angle. Reliability of the goniometer is high when used to measure joint angles of the extremities especially when specific testing positions are used. The size of the goniometer should be representative of the joint size. Intra-tester reliability is better than the inter-tester reliability for measurements using a goniometer.

**Polar Heart Rate Monitor**

Heart rate monitors are used in many settings including physical therapy clinics to maintain a specific work intensity. These monitors are considered to be accurate and reliable tools to track heart rate.
Activities of Daily Living Scale

The Activities of Daily Living Scale was developed as a self reporting survey. It has been found to be reliable, valid, and responsive for measuring functional limitations as a result of a variety of knee disorders.  

Procedure

Subject Recruitment

Subjects were recruited on a volunteer basis. Introduction to the study was by word of mouth, flyers posted in key areas on the GVSU campus, sporting equipment stores in the Grand Rapids area, and advertisements in the GVSU paper, the Lanthorn. A sample of the flyer is found in Appendix I.

Pilot Study

A pilot study was conducted on five healthy individuals. This allowed the tester to become familiar with measuring procedures and to determine the tester’s reliability in measuring the angle of the STJ. This study was done in conjunction with a movement sciences course lab and was supervised by Jim Scott of the movement science department. Subtalar joint position of five voluntary subjects was measured using a universal goniometer with the subject standing in bare feet on a raised level surface. Appendix A outlines the protocol used for this measurement. Each subject was measured three separate times on this occasion by the same tester. To prevent the tester from remembering the previous measurements, the measurements were not made on the same subject consecutively. The measurements were recorded by a third person and were not seen by the tester until all measurements had been made. The data was analyzed using an
intraclass correlation coefficient to determine the intra-rater reliability of the tester.
Appendix J contains an outline of instructions used for this pilot study.

Collecting Baseline Data

The subjects filled out section 1 of the subject data form containing generic information about the subject (Appendix C). Before subjects were accepted for this study, they were given a lower extremity scan, consisting of the special tests outlined in section 2 of Appendix C, to screen for any signs of ligament damage. The tests were scored as positive (+) if there were signs of damage and negative (-) if the results were normal. Instructions for administering each special test along with the criteria for determining (+) or (-) are in Appendix D. The subjects then stood in bare feet on a raised platform to measure the angle of the STJ (Appendix A).

Testing Protocol

All subjects performed the FPA with the activities in random order. The order for the activities was randomly prearranged, comprising 24 possible combinations of the four testing activities (walk, bike, squat, stairs). All combinations were entered into a computer twice and then assigned a random number. The list of combinations was then sorted in ascending order. From this list, the FPA was assigned to the subjects in sequential order. For example, the first subject was assigned combination order #1. The second subject received combination order #2. This continued until all combinations had been used at which time they were recycled starting at #1 again. A summary of the randomizing process as well as an example of all combinations used is found in
Appendix K. The instructions for each activity of the functional pain assessment are located in Appendix L.

Based on the literature presented under exercise prescription, the duration of the testing activities was six minutes to allow subjects to reach the steady state and to continue for another three minutes at the same intensity level. To prevent subjects from becoming fatigued during testing, testing was done at a low intensity, 50-60% of predicted maximum heart rate. Five minutes of rest was given between each functional activity to allow adequate recovery from the previous test.

A subject began with a six minute walk on the indoor track in the recreation center. They walked at a pace that maintained 50-60% of their predicted maximal heart rate. Predicted maximal heart rate was calculated by using the formula 220 - age. The subject was then instructed to mark the walking portion of the Visual Analog Scale. The subject rested for five minutes. The subject then walked up and down a flight of 14 stairs four times. Again the pace was determined by the percent of predicted maximal heart rate described above. The subject was instructed to mark the stairs portion of the Visual Analog Scale. A five minute rest period was given. Next, the subject performed a series of 10 deep squats. The squats were performed beside a wall so a subject could use the wall to regain his/her balance if necessary, but were not be allowed to assist the squat with his or her arms. A platform was placed behind the subject at a height that stopped the subject when the knees reached 90°. The tester demonstrated the squats and gave verbal cueing as needed. When the squats were completed, the corresponding Visual Analog Scale was marked. The final activity was a six-minute bike ride on a stationary
bike. The seat was positioned at a height in which the knee maintained 5° -10° of flexion at the bottom of the down stroke. The pace of the ride was again adjusted so the subject stayed within a 50-60% of predicted maximum heart throughout the ride. Upon completion, the corresponding FPA section was marked.

After the pre-testing, the subjects were given a pair of The Stabilizer® shoe inserts. The size of the insert was based on the subjects’ shoe size. At this time they were instructed on the wearing schedule for the inserts. Subjects were expected to wear shoes that would accommodate the insert throughout the day. The inserts were trimmed to insure a comfortable fit in the shoes. The subjects then repeated the FPA, filling out a blank visual analog scale for each activity. Subjects were then dismissed. Follow-up tests were scheduled at two and four weeks. During each follow-up testing session, subjects filled out a separate ADLS and repeated the FPA only once, filling out the appropriate Visual Analog Scale for each component.

Wearing Schedule

It was expected that subjects wear shoes that would accommodate the inserts. They were also expected to wear the inserts in both shoes as much as possible. Should they become uncomfortable, inserts were to be removed for one hour, or until the pain subsided, at which time the inserts were to be placed back in the shoes. This process of wear and rest continued until the inserts could be worn continuously throughout the day. If a different pair of shoes was worn, the inserts were to be placed in those shoes. In the event the inserts would not fit into a pair of shoes, and an alternative pair was not
available, the subject was asked to change the shoes again as soon as possible to a pair that would accommodate the inserts.

Testing Consistency

The consistency of these procedures was expected to be high but was assessed. The same tester gave instructions and performed each phase of the testing procedure for every subject.

Potential Hazards

There were several potential hazards that the subjects may have been exposed to during the course of this study. By the nature of the FPA, the subjects' symptoms may have been exacerbated. If the symptoms became a problem, the subjects were able to discontinue that activity at any time and record the pain level on their FPA for the given activity. The time or the number of repetitions completed at the time of stop was also recorded. If a subject's symptoms persisted beyond 48 hours, that subject was referred to an appropriate health care provider. The subjects were also at risk for falling, ankle sprains, and knee sprains, while walking up and down the stairs, particularly when walking with the inserts for the first time. The tester provided close guarding, and the subjects were able to grab the handrail as necessary. Finally, it was possible that subjects may have experienced discomfort in their feet or legs during the first few days of wearing the inserts. As noted, subjects could have removed the inserts until such symptoms subside.
Data Analysis

Pre and post-test data for the ADLS and the FPA were compared and analyzed for statistical differences. Comparisons were made between all observation periods of the FPA using ANOVA tests for repeated measures to determine if and/or where significant changes occurred. See Appendix M for a sample of the data analysis form. Pre and post-tests of the ADLS were compared using ANOVA tests to determine if functional changes have occurred. This analysis was followed up with a t-test to determine if the change was statistically significant. Comparisons were also made between the degree of pronation or supination measured during baseline data collection and the amount of change in symptom level and function. Finally, comparison was also made between the FPA and the ADLS using the Pearson’s Product Moment correlation to determine correlation between function and pain level.

Study Limitations

Several limitations existed within this study. First, the reliability of measuring subtalar joint position is poor. Although measurements taken while the subject is in a closed chain position have been shown to be more reliable than when done in open chain, the fact that a relatively inexperienced tester performed the measurements may have jeopardized the reliability of the STJ measures. Second, the sample size may not be large enough to produce statistically significant results that can be generalized to the general population. Third, subjects presented with a varying amount of subtalar dysfunction; however, all subjects received the same amount of correction with the shoe insert. Because the amount of correction was the same for each subject, the percentage of
overall change was different for each subject. For example, an orthotic with 2° of medial
posting brought a person with only 4° of pronation closer to STJN position than it did in
the patient with 8° of pronation. This may have altered the amount of relief each subject
received. The conclusions drawn from this study must be limited to the Stabilizer®
insert. Finally, the four-week duration of this study did not allow the long-term effects of
the orthotics to be addressed. Finally, the fact that there was not a control group that did
not receive the orthotics, prevents the author from concluding that the observed changes
were due to the orthotics and not time.
CHAPTER 4

RESULTS AND DATA ANALYSIS

Characteristics of Subjects

A total of 15 subjects began participating in this study. Of the 15, 9 were female and 6 were male. One female subject withdrew from the study because large blisters formed on both feet after wearing the orthotics for one week. Table 1 is a summary of the subject demographics with mean and standard deviation (STDEV) for each category.

Table 1. Subject demographics

<table>
<thead>
<tr>
<th>SUBJECT PROFILE</th>
<th>MEAN ± STDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>24 ± 3.7</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>165.6 ± 41.9</td>
</tr>
<tr>
<td>STJ Angle before orthotics(degrees)</td>
<td>6.5° ± 3.86° pronation</td>
</tr>
<tr>
<td>Change in STJ after orthotics (degrees)</td>
<td>3.1° ± 1.5° toward supination</td>
</tr>
</tbody>
</table>

STJ: Subtalar Joint

Techniques of Data Analysis

The data received from this sample were analyzed using multivariate statistics for repeated measures data. Wilks' lambda was used to test for significant change in overall scores for the ADLS and the FPA. Pearson Correlation Coefficient was used to determine the correlation between the change in the ADLS and change in the FPA. Pearson Correlation Coefficient was also employed to determine whether there was a correlation between the change in STJ angle and changes in the ADLS and/or the FPA. All tests were run using n=14 as this was the number of subjects who participated for all
four weeks of the trial period. Significance was determined by comparing the probability (p-value) to the significance level (alpha), which was set at $\alpha = 0.05$.

**Pilot Study**

The pilot study was conducted on five subjects to determine tester reliability for measuring STJ position. Results of a one way ANOVA resulted in Intrarater Correlation Coefficient (ICC) = .986. This suggests the tester in this study is able to reliably measure the angle of the STJ.

**Results**

The FPA was scored by measuring the placement of the mark to the nearest millimeter. A lower FPA score is associated with less pain. The ADLS was scored by summing the responses. A higher ADLS score is associated with better function. There was no significant change in perceived pain as measured by the FPA immediately following the insertion of the foot orthotic for any of the FPA categories. All categories had a p-value greater than .05. However, changes were significant between post-orthotic scores on the initial testing session and week two for all FPA criteria. At week four, the changes were significant in all FPA categories when compared to week two except for at rest and walking which had p-values of .290 and .064 respectively. A summary of the mean scores for each FPA category and the mean total (sum of all FPA categories) over the four week period is represented in Figure 3. Table 2 represents the difference in mean scores for each category of the FPA. For example, Rest 2-Rest 1 represents the change that occurred between pre and post-orthotic measurements taken on day one. Rest 3-Rest 2 represents the difference between measurements taken at week two from
the post-orthotic measurements on day one. Rest 4 – Rest 3 represents the change between week four and week two. A summary of p-values for each comparison of each portion of the FPA is listed in Table 2.

Figure 3. Mean scores for all categories of the Functional Pain Assessment over a four-week period.
(mm): millimeters
Table 2. p-values for each comparison of Functional Pain Assessment criteria over a four-week period.

<table>
<thead>
<tr>
<th>TEST</th>
<th>p-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest 2 – Rest 1 (Day 1)</td>
<td>.190</td>
</tr>
<tr>
<td>Rest 3 – Rest 2</td>
<td>.021*</td>
</tr>
<tr>
<td>Rest 4 – Rest 3</td>
<td>.290</td>
</tr>
<tr>
<td>Walk 2 – Walk 1 (Day 1)</td>
<td>.140</td>
</tr>
<tr>
<td>Walk 3 – Walk 2</td>
<td>.015*</td>
</tr>
<tr>
<td>Walk 4 – Walk 3</td>
<td>.064</td>
</tr>
<tr>
<td>Bike 2 – Bike 1 (Day 1)</td>
<td>.931</td>
</tr>
<tr>
<td>Bike 3 – Bike 2</td>
<td>.030*</td>
</tr>
<tr>
<td>Bike 4 – Bike 3</td>
<td>.009*</td>
</tr>
<tr>
<td>Squat 2 – Squat 1 (Day 1)</td>
<td>.166</td>
</tr>
<tr>
<td>Squat 3 – Squat 2</td>
<td>.007*</td>
</tr>
<tr>
<td>Squat 4 – Squat 3</td>
<td>.002*</td>
</tr>
<tr>
<td>Stairs 2 – Stairs 1 (Day 1)</td>
<td>.474</td>
</tr>
<tr>
<td>Stairs 3 – Stairs 2</td>
<td>.029*</td>
</tr>
<tr>
<td>Stairs 4 – Stairs 3</td>
<td>.001*</td>
</tr>
<tr>
<td>Total 2 – Total 1 (Day 1)</td>
<td>.292</td>
</tr>
<tr>
<td>Total 3 – Total 2</td>
<td>.004*</td>
</tr>
<tr>
<td>Total 4 – Total 3</td>
<td>.002*</td>
</tr>
</tbody>
</table>

When comparing the ADLS over the four-week period, significant changes were observed between each test period. No immediate change was measured for the ADLS. The scale required the subjects to consider function over the past one to two days when completing the scale, making observation of immediate change in function inappropriate using the ADLS. Change between the initial testing session and week two was significant (p=.042), indicating an overall improvement in function. Change between week two and week four was significant (p=.014), also indicating improved function. (Table 3 summarizes the ADLS means and standard error for each week). Figure 4
shows the trend for functional improvement over the four-week period. The slope of the line between the initial test and week two and the slope of the line between week two and week four may be misleading if one considers significant difference. This is because analysis of variance (ANOVA) proceeds sequentially explaining the total variation in the ADLS first by comparing week two to day one. With this portion of the total variation accounted for, the ANOVA then proceeds to a comparison of week four to week two using the remaining unexplained variation in the ADLS. Thus, a smaller mean difference between week two and week four could have a smaller p-value than a larger mean difference between day one and week two.

Table 3. Activities of Daily Living Scale mean scores and standard error over a four-week period.

<table>
<thead>
<tr>
<th></th>
<th>AVERAGE ± STANDARD ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAY 1</td>
<td>66.0 ± 1.90</td>
</tr>
<tr>
<td>WEEK 2</td>
<td>71.6 ± 1.77</td>
</tr>
<tr>
<td>WEEK 4</td>
<td>72.6 ± 1.58</td>
</tr>
</tbody>
</table>
Pearson Correlation Coefficient revealed a correlation between changes in FPA at week two and ADLS at week four (r = -.682 & p = .007) indicating a negative correlation. This suggests that as the FPA score decreased, the ADLS score increased. The change in angle (pre-orthotic – post-orthotic) of the left STJ had no significant correlation to changes in either the FPA or the ADLS. However, Pearson Correlation did reveal a moderate correlation between change in the right STJ angle and the total score of the FPA at week four (r = .658 & p = .010). Table 4 summarizes the correlation coefficients for comparisons between all measurement instruments.
Table 4. Pearson Correlation Coefficients for all measurements (r-value)

<table>
<thead>
<tr>
<th></th>
<th>ADLS WK 1 – WK 2</th>
<th>ADLS WK 2 – WK 4</th>
<th>FPA WK 1 – WK 2</th>
<th>FPA WK 2 – WK4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADLS WK 1 – WK 2</td>
<td>1.00</td>
<td>-0.299</td>
<td>-0.007</td>
<td>0.259</td>
</tr>
<tr>
<td>ADLS WK 2 – WK 4</td>
<td>-0.299</td>
<td>1.00</td>
<td>-0.682</td>
<td>-0.211</td>
</tr>
<tr>
<td>FPA WK 1 – WK 2</td>
<td>-0.007</td>
<td>-0.682**</td>
<td>1.00</td>
<td>0.041</td>
</tr>
<tr>
<td>FPA WK 2 – WK 4</td>
<td>0.259</td>
<td>-0.211</td>
<td>0.041</td>
<td>1.00</td>
</tr>
<tr>
<td>Right STJ CHANGE</td>
<td>0.063</td>
<td>0.057</td>
<td>-0.223</td>
<td>0.658*</td>
</tr>
<tr>
<td>Left STJ CHANGE</td>
<td>-0.252</td>
<td>-0.365</td>
<td>0.236</td>
<td>-0.178</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.05 level.
* Correlation is significant at the 0.01 level.
ADLS: Activities of Daily Living Scale
FPA: Functional Pain Assessment
STJ: Subtalar Joint

There was no correlation to changes in FPA or the ADLS and gender over the four week period.

Significance of Evaluation Tools

A Wilks’ lambda test revealed that each category measured by the FPA was a significant indicator of change in pain over time except walk and bike for this subject population. Also, the ADLS was not a statistically significant measure of change in function over time for this population although it was very close (p= .054). Table 5 shows the resultant p-value for each category of the FPA and the ADLS.
Table 5. Significance of Evaluation Tools over four weeks (p-value)

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>p-VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGNIFICANCE OF α=.05*</td>
<td></td>
</tr>
<tr>
<td>REST</td>
<td>.044*</td>
</tr>
<tr>
<td>WALK</td>
<td>.106</td>
</tr>
<tr>
<td>BIKE</td>
<td>.056</td>
</tr>
<tr>
<td>SQUAT</td>
<td>.026*</td>
</tr>
<tr>
<td>STAIR</td>
<td>.009*</td>
</tr>
<tr>
<td>TOTAL</td>
<td>.017*</td>
</tr>
<tr>
<td>ADLS</td>
<td>.054</td>
</tr>
</tbody>
</table>

The null-hypotheses evaluated in this study follow with the results given for each:

1) The use of foot orthotics as the sole treatment for PFPS will not significantly reduce perceived pain, as measured by the Functional Pain Assessment, immediately after orthotic application. This null-hypothesis could not be rejected.

2) The use of foot orthotics as the sole treatment for PFPS will not significantly reduce perceived pain, as measured by the Functional Pain Assessment, following two and four weeks of orthotic wear. This null-hypothesis was rejected.

3) The use of foot orthotics as the sole treatment for PFPS will not show significant improvement in knee function, as measured by the Activities of Daily Living Scale, following two and four weeks of orthotic wear. This null-hypothesis was rejected.

4) There will be no correlation between changes in the Functional Pain Assessment scores and changes in the Activities of Daily Living Scale scores. This null-hypothesis was rejected.
CHAPTER 5
DISCUSSION AND IMPLICATIONS

Discussion of Findings

The purpose of this study was to determine the effectiveness of corrective foot orthotics as the sole intervention for treatment of PFPS. To accomplish this, the following null-hypotheses were evaluated:

Immediate Change in Pain

To determine overall changes within the FPA the total (sum of all categories) was used. Visual analog scales have been proven to be valid and reliable instruments in determining changes in pain. However, it has not been determined whether the summation or (total) of several visual analog scales within an instrument such as the FPA is a reliable or valid measure of overall change. It was assumed for the current study that the total of the FPA was indicative of overall change. The following results are based on the total FPA score. There was no significant change between pre and post orthotic FPA score (p=.474). However, the trend was for subjects to have a decrease in total FPA score. Lack of significance may have attributed to the fact that the subjects completed two consecutive FPA’s not allowing subjects to return to their initial pain level. The mean at rest score for trial one was 1.9mm and the at rest score for trial two was 3.6mm with p=.19. This increase in resting pain may account for the lack of significant change between trial one and trial two on day one. As a result, the author failed to accept the hypothesis that the use of foot orthotics as the sole treatment for PFPS will significantly
reduce perceived pain, as measured by the FPA, immediately after orthotic application.

Change in Pain at Two and Four Weeks

Week two showed significant decrease in total pain perception as measured by the FPA (p=.004). All categories within the FPA showed significant decrease in pain. Refer to Table 2 for p-values of each activity. This trend in decreased pain continued through week four (p=.002) for total change. Again, all categories within the FPA showed significant improvement except resting and walking which had p-values of .290 and .064 respectively. The mean resting score actually increased between week two and week four (.357mm, 1.14mm). This may have been the result of the subjects increasing their activity level during this period of time. Also, these two activities require the knee to use less motion resulting in less compressive forces at the patellofemoral joint which may account for the lack of significant change in perceived pain. Many subjects subjectively reported participating in activities that they had not previously been able to perform. However, at week four the mean at-rest score was still less than scores reported on day one (1.14mm, 1.92mm). These results agree with past studies of Way and Eng & Pierrynowski who reported that by two weeks significant improvement was noted in pain. Eng & Pierrynowski reported that improvement continued over a four-week period. Based on the results of this study the author rejects the null-hypothesis that the use of foot orthotics as the sole treatment for PFPS will not significantly reduce perceived pain, as measured by the FPA, following two and four weeks of orthotic wear.
Change in Function at Two and Four Weeks

The trend over the four-week period was for scores on the ADLS to improve. Change in ADLS between day one and week two was significant with \( p = .042 \). Change between week two and week four was also significant with \( p = .014 \). These results indicate an overall improvement in function as measured by the ADLS. Over the four-week period 12 of the 14 subjects reported that their knees had improved in both pain and function. Two of these subjects reported complete pain relief and no functional limitations. Of the remaining two subjects, one reported no change in symptoms and the other reported symptoms being slightly worse. This distribution of relief is similar to that found by Saxena et al.\(^1\) and Gross et al.\(^5\), in which a few subjects reported complete relief, the majority reported significant improvement, a few reported no change, and approximately 1% reported their symptoms were worse.

Correlation of Instrumentation

There was no direct correlation between FPA changes and ADLS changes for consecutive testing periods. However, significant improvements were found at week two and week four for both FPA and ADLS. There was no direct correlation between changes in FPA scores and ADLS scores during a given time. It appears that there was a delay from the time pain subsided and function improved. The results of this study showed a correlation between the change in FPA scores of the initial testing session and week two
and the change of ADLS between weeks two and four. This may have been the result of several factors. Subjects have dealt with PFPS for an extended period of time; it may have taken time before the subjects were confident enough to challenge their current functional abilities. Another factor may have been habits of compensation. For example, if an individual was unable to kneel without pain, he/she would develop habits to compensate. Once the pain has been eliminated, the subject may still avoid kneeling and maintain the compensatory habit. Another factor altering the correlation of the ADLS with the FPA was the interpretation of the questions on the ADLS by each subject. By observation, it was evident that the questions were not interpreted consistently as a group or by the subjects individually from week to week. While completing the ADLS on week two, several subjects commented that they had not attempted to challenge the criteria within the ADLS. Therefore, the ADLS may not have accurately measured current function. This author rejects the null-hypothesis that there will be no correlation between changes in the FPA scores and changes in the ADLS scores based on the correlation between changes in FPA scores at week two and changes in ADLS at week four.

Other Findings of Interest

It was determined through analysis of the data of this study that the bike (p=.056) and walk (p=.106) portions of the FPA were not significant variables in measuring pain for this subject population. The other factors such as squats and stairs account for the majority of the change in total FPA scores with p=.044 for change at rest, p=.026 for squat, and p=.009 for the stairs. Bike and walk may not have been significant variables
secondary to the fact that these activities do not produce as much joint reaction force as
do squatting and walking up and down stairs.

**Application to Practice**

The results of this study relate to the clinical practice of physical therapy in several ways. First, it is evident that foot orthotics are an effective treatment for PFPS and therefore should be considered a valuable component of an initial treatment plan. Second, *The Stabilizer*® shoe insert used in this study was a generic, over-the-counter orthotic that can be purchased at just a fraction of the cost of a custom fit orthotic. Because the majority of subjects in this study demonstrated overall improvement, it may be unnecessary to customize orthotics for all individuals. The results of this sample indicate that a two-week trial may be sufficient to determine if an individual will benefit from the use of orthotics in treating PFPS. It cannot be determined from this study how long a trial period should continue before the decision is made whether or not a custom orthotic is necessary. Again, a custom orthotic may be unnecessary and a poor use of resources if a generic, over-the-counter orthotic will resolve the symptoms.

The theory behind this study was that if the biomechanical alignment of the patellofemoral joint improved by correcting the STJ alignment, the symptoms of PFPS would decrease. However, the amount of correction within the STJ did not correlate to changes in either the ADLS or the FPA. This suggests that patients with PFPS may benefit from shoe inserts whether or not there is poor mechanical alignment.

**Limitations**

The results of this study apply only to the use of *The Stabilizer*® as the orthotic.
Other orthotic devices may produce different results. The long-term benefits of the orthotics cannot be determined as a four-week trial is not sufficient time to observe whether a plateauing effect will occur or if so, when.

Sample

The sample size of 14 subjects between the ages of 19 and 32 is not representative of the general population. Therefore, in order for these results to be representative of the general population, the sample size must be considerably larger and include a broader range of age groups.

Study Design

A major limitation to this study was the lack of consistency of when subjects attended the testing session. For example, several subjects arrived at the testing site complaining that they had been standing all day at work while others arrived prior to beginning daily activities. This lack of consistency may have decreased the validity of both the FPA scores and the ADLS scores. Results based on the ADLS may have been skewed by inconsistent interpretation of the questions within the scale.

Another limitation to this study was the lack of a control. Subjects were compared against themselves over the four-week period. With the lack of control, it could not be concluded that the orthotic was the only variable contributing to change.

Modifications to Current Study

After reviewing the results of this study, the following modifications would be recommended: First, control the time at which subjects are tested. This would tend to reduce the variation in level of fatigue and pain prior to beginning a testing session.
Within the study design the subjects should wear the orthotic for four weeks and then withdraw the orthotic for four weeks to determine if their symptoms return. If improvement is evident during the first four weeks followed by an exacerbation of symptoms during the four weeks of withdraw, the case is stronger in support of orthotics.

The time to complete each testing session could be reduced by eliminating the bike and walk segments of the FPA since they were not significant variables. By eliminating these activities, testing time would be cut to less than half. Because the time of each testing session would be reduced, it may be possible to increase the frequency of testing which would allow for more accurate conclusions to be drawn as to when significant changes occurred.

Suggestions for Future Research

The author suggests several possibilities for future research relating to foot orthotics and PFPS. One idea stated previously would be to design a study with a period of orthotic withdrawal following the wearing of orthotics to determine if symptoms return. This period of withdrawal would be followed by another period of wear equal to the time of withdrawal to determine if symptoms decline. A second suggestion would be to use a similar design utilizing two groups; one using a generic orthotic and the other using a customized orthotic to determine whether there is a significant difference in the effects of the type of orthotic used. Results of this type of study may be used to increase the efficacy of a customized orthotic. A third study would be to conduct a follow-up study of more than two years to determine long-term results as well as subject compliance in relation to wearing of orthotics. Finally, studies need to be conducted that
investigate the recovery time needed to return to normal activities when orthotics are used as part of the treatment plan versus a plan in which orthotics are not prescribed. These subjects could be followed over an extended period of time to determine the long-term benefits, and whether there is a difference in the recurrence of the symptoms requiring follow-up medical attention.

**Conclusion**

Patellofemoral pain is a very common complaint of patients within a physical therapy practice. Although the results of this study did not identify the means by which orthotics relate to decreasing symptoms, it is evident that they can be an effective option for treatment of PFPS.

Current research is not conclusive as to the best treatment for PFPS. However, based on this study, as well as other similar studies, orthotics should be considered as a viable option in conjunction with other treatments that have been found to be beneficial in the treatment of PFPS. By implementing a comprehensive treatment plan that includes the use of foot orthotics, the resurgence of PFPS and the need for recurrent therapy may be minimized, thus reducing the overall cost for treatment.

Implementation of the modifications and further research as mentioned above would increase the efficacy for the use of orthotics in the treatment of PFPS. These studies may also identify the population for which orthotics are best suited.
REFERENCES


89
12. The Pathokinesiology Service and the Physical Therapy Department Rancho Los Amigos Medical Center. *Observational Gait Analysis*. Downey, CA; Los Amigos Research and Education Institute, Inc. 1996: 8-10.


APPENDIX A

MEASURING SUBTALAR JOINT ANGLE

I. Position
   a. Subject stands on a raised platform with weight evenly distributed
   b. Subject faces away from tester

II. Preparation
   a. Draw a line centered down the distal 1/3 of the lower leg.
   b. Place a mark centered on the calcaneous.

III. Measure
   a. Align goniometer with the line on the leg and the mark on the calcaneous.
   b. Read goniometer and record measure.
APPENDIX B

INFORMED CONSENT

I understand that this study is designed to study the effectiveness of foot orthotics in the treatment of pain, that is located around the kneecap. Knowledge gained from this study may impact the procedures used by physical therapists in the treatment of patients with knee pain. It is anticipated that 10 volunteers will participate in this study.

I also understand that:

1. Participation in this study will require one initial testing session that is expected to last for approximately 1.5 hours. I will also be expected to attend two follow-up testing sessions at two and four weeks from my initial session that will take approximately 1 hour each. Initial testing procedures will require me to walk on an indoor track for 6 minutes, walk up and down one flight of 14 stairs four times, ride a stationary bike for 6 minutes, and perform 10 deep knee bends. I will be able to perform these activities at a pace that is comfortable to me, and will be given a rest period of 5 minutes between these activities. I may also stop at any point during any activity for any reason without penalty. Each of the above activities will be done 2 times on my first day but will only be done 1 time on the two follow-up sessions.

2. I will be expected to wear shoes that will allow me to wear the shoe insert provided to me by the researcher on a daily basis. The researcher will provide verbal and written instructions to me concerning wearing time. I will also receive two phone calls by the researcher to insure wearing time is going as expected. I may call the researcher with any questions as they arise.

3. I will be required to go to the Allendale campus of Grand Valley State University for pre-and post-testing, a total of 3 visits. I will not be compensated for driving expenses.

4. I have been selected for this study because I am between the age of 18 and 35 and I have been experiencing pain in my knee/knees for at least 2 months, but am not currently being treated by a physical therapist for this condition.

5. It is not anticipated that this study will lead to physical or emotional trauma. Possible physical risks include; muscle soreness either immediate or delayed, an increase in knee pain that may or may not be resolved with the use of the foot orthotic, injury resulting from falling while walking up or down the stairs, or a mishap during any of the activities. Benefits include a free screening of my knee. I will be issued a foot orthotic free of charge. My knee pain may be resolved through my participation in this study.
6. I will not be asked to provide any information that may be incriminating to me in any way and any information I provide will be kept confidential.

7. I will be provided with a summary of the results of this study upon my request.

I acknowledge that:

1. I have been given the opportunity to ask questions regarding this study and that these questions have been answered to my satisfaction.

2. In giving my consent, my participation in this study is strictly voluntary. I will not be reimbursed for any costs associated with participation in this study.

3. Should I be injured or require further medical treatment for any condition that may or may not be related to this study, I will not receive financial compensation or coverage from the researcher or from Grand Valley State University. If I am injured during the course of the testing process, appropriate medical personnel will be contacted.

4. In providing my consent, I understand that I may withdraw myself from this study at any time without penalty by contacting the individuals listed below:

   Byron Horner  
   Study Author  
   (616) 895-7294

   Jolene Bennett  
   Thesis Chairperson  
   Physical Therapy Department  
   (616) 364-0496

   Jolene Bennett  
   Thesis Chairperson  
   Physical Therapy Department  
   (616) 364-0496

   Professor P. Huizenga  
   Human Subjects Review Board  
   GVSU  
   (616) 895-2472

5. I give my permission to the researcher to use the information collected in this study for the purpose of publication in the scientific literature. I understand that I will not be identified by name in any publication.
6. I acknowledge that I have read and understand the above information and that I agree to participate in this study.

______________________________  ______________________
Participant Signature            Date

______________________________  ______________________
Witness                          Date

___ I am interested in receiving a summary of the results.

Address: ________________________ City: ______ State: ___ Zip: ______
APPENDIX C

DATA COLLECTION FORM

Section 1 (completed by participants)

Subject ID number

Age: _______ Weight: _______ Shoe Size: _______

1. Do you have a history of neurological injury (i.e. stroke, traumatic brain injury, cerebral palsy etc.)? If so, please specify and explain.

2. Approximately when did you begin experiencing knee pain? (Date) _______

3. What activities make your knee pain worse? (Circle all that apply)
   - Walking
   - Running
   - Standing (how long? _______)
   - Kneeling
   - Kneeling
   - Squatting
   - Stairs
   - Biking
   - Sitting (how long? _______)
   - Sports (specify _______)
   - Other: _____________________

4. Have you ever had surgery on either leg or foot? If so, please describe type and date.

5. Have you ever been diagnosed with a cardioFPAcular disease or any other heart condition (i.e., heart attack, bypass surgery, angioplasty, uncontrolled hypertension/blood pressure, etc)? If yes, please describe.

6. Select the amount of physical activity below that best describes you. Each session must consist of at least twenty minutes of continuous activity. Activities may include but are not limited to walking, jogging, swimming, tennis, basketball, etc.
   a. less than 1 time per week
   b. 1-2 times per week
   c. 3-4 times per week
   d. 5 or more times per week
DATA COLLECTION FORM

Section 2 (researcher data collection form)

Subject ID number

KNEE SPECIAL TESTS

<table>
<thead>
<tr>
<th>Special Tests</th>
<th>Result</th>
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<tbody>
<tr>
<td>Anterior Drawer</td>
<td></td>
</tr>
<tr>
<td>Posterior Drawer</td>
<td></td>
</tr>
<tr>
<td>Varus Stress</td>
<td></td>
</tr>
<tr>
<td>Valgus Stress</td>
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</tr>
<tr>
<td>Apprehension Test</td>
<td></td>
</tr>
<tr>
<td>Clarke’s Sign</td>
<td></td>
</tr>
<tr>
<td>Passive Patellar Tilt</td>
<td></td>
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<tr>
<td>Apley’s</td>
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POSTURAL SCREEN OF KNEE AND ANKLE

<table>
<thead>
<tr>
<th>Dysfunction</th>
<th>Degree/Classification</th>
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<tr>
<td>Genu Valgum</td>
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<tr>
<td>Lateral Tibial Torsion</td>
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<tr>
<td>Genu Varum</td>
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<tr>
<td>Medial Tibial Torsion</td>
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<tr>
<td>Subtalar Joint Angle (initial)</td>
<td></td>
</tr>
<tr>
<td>Subtalar Joint Angle (standing on inserts)</td>
<td></td>
</tr>
<tr>
<td>Shoe Wear Pattern (heel)</td>
<td>Medial / Lateral / Center</td>
</tr>
</tbody>
</table>
APPENDIX D

INSTRUCTIONS FOR SPECIAL TESTS

Anterior Drawer:

I. Position
   a. Subject lying supine on table
   b. Position leg with hip flexed to 45° and knee flexed to 90°
   c. Stabilize foot on table by sitting on the subject's foot

II. Action
   a. Place hands around the proximal end of the tibia
      * Insure that hamstrings are relaxed
   b. Place thumbs at tibial plateaus
   c. Pull the tibia forward on the femur
   d. Repeat process on other knee

III. Results
   a. Score test (-) if movement is less than or equal to 6 mm
   b. Score test (+) if movement is more than 6 mm
      * Movement should be compared to the opposite leg before an accurate score can be given.

Posterior Drawer:

I. Position
   a. Same as for Anterior Drawer

II. Action
   a. Push tibia posteriorly with the heels of the hands.

III. Results
   a. Score the test (+) if the tibia moves excessively on the femur when compared to the opposite knee.
   b. Score the test (-) if the tibia does not move excessively on the femur when compared to the opposite knee.
Varus/Valgus Stress Test:

I. Position
a. Subject lying supine on table with knee fully extended.
b. Place subject's ankle between your waist and forearm.
c. Palpate medial and lateral joint line with fingers.

II. Action
a. Apply varus and valgus force alternately with the heals of the hands to the medial and lateral side of the tibia.

III. Result
a. Score the test (+) if a gap of 5 mm or more is felt at the joint line.
b. Score the test (-) if a gap of less than 5 mm is felt.
* Repeat this process with the knee flexed to 20° and 30°

Apprehension Test:

I. Position
a. Subject lies supine
b. Flex knee to 30°
c. Have quadriceps relaxed

II. Action
a. Slowly push the patella laterally

III. Result
a. Score the test (+) if the subject contracts the quadriceps muscles to realign the patella.
* The subject's facial expressions may also indicate apprehension and should be addressed further with the subject.
b. Score the test (-) if the subject remains relaxed throughout the process.
**Clarke's Sign:**

I. Position
   a. Subject lies relaxed in supine
   b. The knee is to be tested in full extension, 30°, 60°, and 90° of flexion.

II. Action
   a. Press down lightly on the subject's patellar tendon above the upper pole of the patella with the web space of the hand.
   b. The subject then contracts the quadriceps while the tester is applying pressure.
      * Repeat this several times, gradually increasing pressure.
   c. Repeat the above process with the knee positioned in all designated angles.

III. Results
   a. Score the test (+) if the subject has increased pain or they are unable to hold the contraction.
   b. Score the test (-) if the subject is able to sustain the contraction without pain.

---

**Passive Patellar Tilt:**

I. Position
   a. Subject lies supine
   b. Knee is extended
   c. Quadriceps are relaxed

II. Action
   a. Grasp the patella with thumb and 1st and 2nd fingers.
   b. Lift the lateral edge of the patella from the lateral condyle
      * Be careful to lift the patella straight up.

III. Results
   a. Score the test (+) if the resultant angle of the patella is less than 10°.
**Appley's:**

I. Position
   a. Subject lies prone
   b. Flex knee to 90°
   c. Subject's thigh is held to the table by tester's knee
   d. Hold subject's ankle with both hands.

II. Action
   a. The tester medially and laterally rotates the tibia with distraction at the ankle
   b. Note any restrictions, excessive movements, or discomfort.
   c. Repeat medial and lateral rotations with compression at the ankle.
   d. Note any discomfort or restrictions.

III. Results
   a. Score the test (+) if discomfort, restriction, or excessive motion is experienced in the knee.
   b. Score the test (-) if range of motion is normal and there is no discomfort.
      * (+) test with distraction is likely ligamentous.
      * (+) test with compression is likely meniscus.
APPENDIX E

ACTIVITIES OF DAILY LIVING SCALE

Subject ID number: ______

Instructions: The following questionnaire is designed to determine the symptoms and limitations that you experience because of your knee while you perform your usual daily activities. Please answer each question by circling the statement that best describes you over the last 1 to 2 days. For a given question, more than one of the statements may describe you, but please circle ONLY the one statement that best describes you during your usual daily activities.

Symptoms
1. To what degree does pain in your knee affect your daily activity level?
   -5- I never have pain in my knee.
   -4- I have pain in my knee, but it does not affect my daily activity.
   -3- Pain affects my activity slightly.
   -2- Pain affects my activity moderately.
   -1- Pain affects my activity severely.
   -0- Pain in my knee prevents me from performing all daily activities.

2. To what degree does grinding or grating of your knee affect your daily activity level?
   -5- I never have grinding or grating in my knee.
   -4- I have grinding or grating in my knee, but it does not affect my daily activity.
   -3- Grinding or grating affects my activity slightly.
   -2- Grinding or grating affects my activity moderately.
   -1- Grinding or grating affects my activity severely.
   -0- Grinding or grating in my knee prevents me from performing all daily activities.

3. To what degree does stiffness in your knee affect your daily activity level?
   -5- I never have stiffness in my knee.
   -4- I have stiffness in my knee, but it does not affect my daily activity.
   -3- Stiffness affects my activity slightly.
   -2- Stiffness affects my activity moderately.
   -1- Stiffness affects my activity severely.
   -0- Stiffness in my knee prevents me from performing all daily activities.
4. To what degree does swelling in your knee affect your daily activity level?
-5- I never have swelling in my knee.
-4- I have swelling in my knee, but it does not affect my daily activities.
-3- Swelling affects my activity slightly.
-2- Swelling affects my activity moderately.
-1- Swelling affects my activity severely.
-0- Swelling in my knee prevents me from performing all daily activities.

5. To what degree does slipping of your knee affect your daily activity level?
-5- I never have slipping of my knee.
-4- I have slipping of my knee, but it does not affect my daily activity.
-3- Slipping affects my activity slightly.
-2- Slipping affects my activity moderately.
-1- Slipping affects my activity severely.
-0- Slipping of my knee prevents me from performing all daily activities.

6. To what degree does buckling of your knee affect your daily activity level?
-5- I never have buckling of my knee.
-4- I have buckling of my knee, but it does not affect my daily activity level.
-3- Buckling affects my activity slightly.
-2- Buckling affects my activity moderately.
-1- Buckling affects my activity severely.
-0- Buckling of my knee prevents me from performing all daily activities.

7. To what degree does weakness or lack of strength of your leg affect your daily activity level?
-5- My leg never feels weak.
-4- My leg feels weak, but it does not affect my daily activity.
-3- Weakness affects my activity slightly.
-2- Weakness affects my activity moderately.
-1- Weakness affects my activity severely.
-0- Weakness of my leg prevents me from performing all daily activities.

Functional Disability with Activities of Daily Living

8. How does your knee affect your ability to walk?
-5- My knee does not affect my ability to walk.
-4- I have pain in my knee when walking, but it does not affect my ability to walk.
-3- My knee prevents me from walking more than 1 mile.
-2- My knee prevents me from walking more than ½ mile.
-1- My knee prevents me from walking more than 1 block.
-0- My knee prevents me from walking.
9. Because of your knee, do you walk with crutches or a cane?
   -3- I can walk without crutches or a cane.
   -2- My knee causes me to walk with 1 crutch or a cane.
   -1- My knee causes me to walk with 2 crutches.
   -0- Because of my knee, I cannot walk even with crutches.

10. Does your knee cause you to limp when you walk?
    -2- I can walk without a limp.
    -1- Sometimes my knee causes me to walk with a limp.
    -0- Because of my knee, I cannot walk without a limp.

11. How does your knee affect your ability to go up stairs?
    -5- My knee does not affect my ability to go up stairs.
    -4- I have pain in my knee when going up stairs, but it does not limit my ability to go up stairs.
    -3- I am able to go up stairs normally, but I need to rely on the use of a railing.
    -2- I am able to go up stairs one step at a time with use of a railing.
    -1- I have to use crutches or a cane to go up stairs.
    -0- I cannot go up stairs.

12. How does your knee affect your ability to go down stairs?
    -5- My knee does not affect your ability to go down stairs.
    -4- I have pain in my knee when going down stairs, but it does not limit my ability to go down stairs.
    -3- I am able to go down stairs normally, but I need to rely on the use of a railing.
    -2- I am able to go down stairs one step at a time with use of a railing.
    -1- I have to use crutches or a cane to go down stairs.
    -0- I cannot go down stairs.

13. How does your knee affect your ability to stand?
    -5- My knee does not affect my ability to stand. I can stand for unlimited amounts of time.
    -4- I have pain in my knee when standing, but it does not limit my ability to stand.
    -3- Because of my knee I cannot stand for more than 1 hour.
    -2- Because of my knee I cannot stand for more than ½ hour.
    -1- Because of my knee I cannot stand for more than 10 minutes.
    -0- I cannot stand because of my knee.
14. How does your knee affect your ability to kneel on the front of your knee?
   -5- My knee does not affect my ability to kneel on the front of my knee. I can kneel for unlimited amounts of time.
   -4- I have pain when kneeling on the front of my knee, but it does not limit my ability to kneel.
   -3- I cannot kneel on the front of my knee for more than 1 hour.
   -2- I cannot kneel on the front of my knee for more than 1/2 hour.
   -1- I cannot kneel on the front of my knee for more than 10 minutes.
   -0- I cannot kneel on the front of my knee.

15. How does your knee affect your ability to squat?
   -5- My knee does not affect my ability to squat.
   -4- I have pain when squatting, but I can still squat all the way down.
   -3- I cannot squat more than 3/4 of the way down.
   -2- I cannot squat more than 1/2 of the way down.
   -1- I cannot squat more than 1/4 of the way down.
   -0- I cannot squat at all.

16. How does your knee affect your ability to sit with your knee bent?
   -5- My knee does not affect my ability to sit with my knee bent. I can sit for unlimited amounts of time.
   -4- I have pain when sitting with my knee bent, but it does not limit my ability to sit.
   -3- I cannot sit with my knee bent for more than 1 hour.
   -2- I cannot sit with my knee bent for more than 1/2 hour.
   -1- I cannot sit with my knee bent for more than 10 minutes.
   -0- I cannot sit with my knee bent.

17. How does your knee affect your ability to rise from a chair?
   -5- My knee does not affect my ability to rise from a chair.
   -4- I have pain when rising from the seated position, but it does not affect my ability to rise from the seated position.
   -3- Because of my knee I can only rise from a chair if I use my hands and arms to assist.
   -0- Because of my knee I cannot rise from a chair.
APPENDIX F

FUNCTIONAL PAIN ASSESSMENT

Subject ID number: _______

Mark the line at a point that represents the severity of your pain.

At rest: No / ________________________________ /worst pain possible
Pain

Subject ID number: _______

Mark the line at a point that represents the severity of your pain.

During walk: No / ________________________________ /worst pain possible
Pain

Subject ID number: _______

Mark the line at a point that represents the severity of your pain.

During stairs: No / ________________________________ /worst pain possible
Pain
Subject ID number: _______

Mark the line at a point that represents the severity of your pain.

During bike: No / ________________________________/worst pain possible
   Pain

Subject ID number: _______

Mark the line at a point that represents the severity of your pain.

During squat: No / ________________________________/worst pain possible
   Pain
APPENDIX G

SUBJECT'S WEARING SCHEDULE

It is expected that subjects will wear the inserts in both shoes as much as possible. Should they become uncomfortable, inserts should be removed for one hour, or until the pain subsides, at which time the inserts should be placed back in the shoes. This process of wear and rest is to continue until the inserts can be worn continuously throughout the day. If a different pair of shoes is to be worn, the inserts should be placed in those shoes. In the event they will not fit into a pair of shoes, and an alternative pair is not available, the subject should change the shoes again as soon as possible to a pair that will accommodate the insert.
APPENDIX H

STUDY SEQUENCE

I. Recruit Subjects
   a. Obtain subjects shoe size when scheduling appointment to purchase orthotics.

II. Subject to read and sign consent form

III. Subject fills out section 1 of data collection form (Appendix C)

IV. Perform lower extremity screen as outlined in section 2 of data collection form
    (Appendix A)
   a. Follow instructions for special tests as outlined in (Appendix D)

V. Subject completes the Activities of Daily Living Scale (Appendix F)

VI. Begin Activities
   a. Assign the subject the protocol they will perform. See appendix K for instructions for each activity.
   b. Following each activity the subject completes the visual analog scale.
   c. Subjects may have a five minute rest before doing the next selected activity.
   d. Follow this sequence until all activities have been completed.

VII. Remeasure the position of the STJ with the subject standing on the inserts.

VIII. Insert the orthotic into subject's shoes.

IX. Subject will then repeat the activities as described in VI.

X. Answer any questions and schedule return visits for each subject at 2 and 4 weeks.

XI. Return visits
   a. Subjects complete a blank Activities of Daily Living Scale.
   b. Subjects draw the order for which they will do the activities.
   c. Activities are performed only once during return visits.
      1. Follow activity protocol in VI.

XII. Input and Analyze Data
APPENDIX I

RECRUITMENT POSTING

MY KNEE HURTS!

A great opportunity to have your knee pain checked free of charge. A study is being conducted to determine if shoe inserts are beneficial in decreasing knee pain. Volunteers between the ages of 18 - 38 are needed. If you have been experiencing pain around your knee cap for at least 2 months you may qualify. All subjects will receive a screening exam of their legs, and a pair of shoe inserts free of charge. To inquire further please contact:

Byron Horner

Phone: (616) 895-7294

E-mail: hornerb@river.it.gvsu.edu
APPENDIX J

PILOT STUDY SEQUENCE

I. Location
   1. Pilot study will be part of a lab in conjunction with an exercise physiology course.
   2. Pilot study will be completed during one class lab session.

II. Subjects
   1. Subjects may participate on a voluntary basis.
   2. At least five subjects will be studied.
   3. Assign each subject an identification number.

III. Procedure
   1. Measure subtalar joint angle following procedure in Appendix A for each subject.
      a. Report measurement to individual doing recording.
      b. Once each subject has been measured, the recorder will randomly call the subjects back, by number, to be measured a second time.
      c. Once all subjects have been measured for the second time, the recorder will then randomly recall the subjects back for a third measurement.

IV. Analyze Data
   1. Data will be analyzed to determine the tester’s reliability for measuring the subtalar joint angle with the subjects in standing position.
APPENDIX K

EXAMPLE OF RANDOM ORDER OF FPA CATEGORIES

Instructions:

- List all possible combinations of FPA categories twice.
- Assign each combination a random number.
- Sort list in ascending order.
- Assign subjects the FPA in sequential order.

Key:

1 = Walk
2 = Bike
3 = Stairs
4 = Squat

Random order of all FPA categories: (48 combinations)

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APPENDIX L

INSTRUCTIONS FOR EACH ACTIVITY

6 Minute Walk:

I. Location
   1. Indoor track at GVSU

II. Pace
   1. Subject should walk at a pace to maintain an intensity of 50-60% of their predicted maximum heart rate (MHR) as measured by a Polar Heart Rate monitor.
      a. Calculate MHR by 220 - Age
      b. Heart rate window is calculated by MHR X .50 and MHR X .60

Stairs

I. Location
   1. Flight of stairs going to the basement of the Field House, GVSU campus.

II. Pace
   1. Subjects will walk to maintain the 50-60% MHR.

III. Subjects should not be allowed to use the hand rail unless it is to regain balance.

IV. Repetitions
   1. Complete 4 passes up and down 14 steps.

Deep Squats:

I. Location
   1. Perform the squats standing next to a wall.
   2. Subject should not touch the wall unless it is necessary to regain balance.
   3. Place an adjustable stool behind the subject at a height that will stop the squat at 90° of knee flexion.

II. Pace
   1. Perform the squats in a rhythmic manner.
      * Set a metronome at 40 beats per minute.
   2. Give verbal cueing as necessary
6 Minute Stationery Bike Ride:

Location:
   1. Movement science laboratory. Field House. GVSU campus.

Pace:
   1. Ride at a pace to maintain 50-60% of predicted MHR.

Seat Height:
   1. Seat should be adjusted so there is 5°-10° of knee flexion at the bottom of the down stroke.
# APPENDIX M
## DATA ENTRY FORM

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