The Immediate Effects of the NuNee Patellar Support on Individuals with Patellofemoral Pain Syndrome

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The Immediate Effects of the NuNee Patellar Support on Individuals with Patellofemoral Pain Syndrome

Nick Linn

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to the School of Medicine
at West Virginia University
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Master of Science in
Exercise Physiology

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Abstract

The Immediate Effects of the NuNee Patellar Support on Individuals with Patellofemoral Pain Syndrome

Nick Linn

Patellofemoral pain syndrome (PFPS) is a common form of anterior knee pain caused by general overuse, muscular weakness or strength imbalances, and poor movement coordination leading to abnormal alignment or mal-tracking of the patella. Recent guidelines do not recommend the use of a knee orthosis due to a lack of evidence supporting their effectiveness. A new patellar support (NuNee, K-Neesio LLC.) which uses distraction force to relieve pressure placed on the patella, has been proposed. The purpose of this study was to examine the immediate effects of the NuNee patellar support on perceived pain, biomechanics, and function in individuals with patellofemoral pain while they perform the modified star excursion balance test. We hypothesized that the use of the NuNee would decrease perceived pain, increase knee flexion angles, decrease knee valgus angles, increase knee extensor moment, and improve knee extensor moment score in the anterior direction of the modified star excursion balance test.

Methods: Thirteen subjects with patellofemoral pain were recruited for this study. Subjects performed three successful trials of the modified star excursion balance test under various conditions (control, sham, and NuNee). Knee joint angles, knee extensor moments, and reach distances were calculated using a 3-D motion capture system and two force plates. Perceived pain was assessed using a visual analog scale following each successful trial. A repeated measures ANOVA was performed to examine differences in biomechanical variables between conditions. A Kruskal-Wallis analysis examined differences in self-reported pain between conditions.

Results: Although a pain level of ≥3 was a criterion for study participation, most subjects reported pain of <3 on a VAS during testing. Perceived pain had minimal decreases between the control and NuNee conditions (1.67 to 1.40). Knee flexion angle increased (-69.44 ±9.675° to -71.62 ±9.731°), and knee valgus angle increased (0.1550 ±6.967° to 1.217 ±6.500°) between the control and NuNee condition. Knee extensor moment increased (1.216 ±0.6074 Nm/kg to 1.683 ±3.887 Nm/kg) between the control and NuNee conditions. Anterior reach distance saw no change (62.06 ±6.054% to 62.83 ±6.025%) between the control and NuNee conditions. No statistical significance was found for any of the tested variables.

Conclusion: No significant differences were found between conditions for any of the tested variables. A larger sample size and increased perceived pain are needed to fully investigate the efficacy of the NuNee patellar support. Although not significant, our findings show enough promise that further research is warranted.
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Chapter 1: Introduction

Patellofemoral pain syndrome (PFPS), also known as runner's knee, is defined by pain located around or behind the patella and provoked by activities such as running, climbing stairs, squatting, and jumping (Crossley, Stefanik, et al., 2016; Gaitonde et al., 2019). This pain is a common form of anterior knee pain with a prevalence of 7% to 35%, with women accounting for roughly 55% of all cases (de Oliveira Silva et al., 2020; Gaitonde et al., 2019). Typical causes include general overuse, muscular weakness or strength imbalances, and poor movement coordination leading to the abnormal alignment or mal-tracking of the patella (Crossley, Stefanik, et al., 2016; Rothermich et al., 2015; Willy et al., 2019). Treatments may include reducing inflammation, orthotics, and physical therapy (Gaitonde et al., 2019). However, recent guidelines do not recommend the use of a knee orthosis due to a lack of evidence supporting their effectiveness (Wallis et al., 2021). A new patellar support (NuNee, K-Neesio LLC.) which uses distraction force to relieve pressure placed on the patella, has been proposed (“Academy of Orthopaedic Physical Therapy Poster Presentation Abstracts (OPO1–OPO223),” 2022). However, the effect of this new support on PFPS remains unknown.

The patellofemoral joint (PFJ) includes the posterior aspect of the patella and trochlea of the femur and is involved in the flexion and extension of the knee (Gaitonde et al., 2019). The patella acts as a lever to increase the effectiveness of the quadriceps in knee extension and decrease the force required by the soft tissues surrounding the joint (Gaitonde et al., 2019). These include the patellar tendon and medial and lateral soft tissues (Anatomy, Bony Pelvis and Lower Limb, Hamstring Muscle - StatPearls - NCBI Bookshelf, n.d.; Sherman et al., 2014). The quadriceps consist of four muscles (rectus femoris, vastus medialis, vastus lateralis, and vastus intermedius) that lie on the thigh's anterior side (Sherman et al., 2014). The four muscle tendons
converge and insert on the patella's proximal aspect, allowing for knee extension (Sherman et al., 2014). Three hamstring muscles (biceps femoris, semitendinosus, and semimembranosus) run posteriorly along the femur, crossing both the hip and knee joints (Anatomy, Bony Pelvis and Lower Limb, Hamstring Muscle - StatPearls - NCBI Bookshelf, n.d.). These muscles play a prominent role in hip extension and knee flexion and are essential in the dynamic stabilization of the knee (Anatomy, Bony Pelvis and Lower Limb, Hamstring Muscle - StatPearls - NCBI Bookshelf, n.d.). The patellar tendon runs distally from the patella to insert into the tibial tubercle (Sherman et al., 2014). The medial and lateral tissues stabilize the patella for proper mechanics (Sherman et al., 2014). Of these tissues, the vastus medialis obliquus is one of the essential muscles in restraining lateral patellar tracking (Sherman et al., 2014).

Several kinetic and kinematic alterations have been observed in individuals with patellofemoral syndrome. Kinetic differences include a reduced knee extension moment and greater hip internal rotation and extensor moments (Baellow et al. 2020; Seeley et al. 2021). The main kinematic differences in individuals with PFPS include decreased knee flexion, increased hip flexion, and increased knee valgus (Baellow et al., 2020; Seeley et al., 2021). However, while running, individuals with PFPS show a decrease in dynamic knee valgus and pelvic frontal plane motion (Yang et al., 2022). An ipsilateral trunk lean has been noted during stepping activities (Nakagawa, Moriya, Maciel, et al., 2012). During functional tests, such as the star excursion balance test, a shorter reach in the anterior direction, indicating decreased dynamic postural stability, is associated with PFPS (Goto et al., 2018). However, the same study reported no kinematic differences between hip and knee joint movements when compared to controls in the posterior direction (Goto et al., 2018). Another study reported a significant difference in
dynamic postural control for individuals with PFPS when compared to controls (Arun et al., 2013).

Treatments for patellofemoral pain include pharmaceuticals, physical therapy, orthosis, and in extreme cases, surgical realignment (Gaitonde et al., 2019; Rothermich et al., 2015). Strengthening the knee and hip through physical therapy is currently considered the most effective treatment for individuals with PFPS (Wallis et al., 2021). Specifically, these exercises should target the quadriceps, hamstrings, hip abductors, and iliotibial band complex (Jones et al., 2015). Recent guidelines advise clinicians against using existing knee orthotics due to their lack of effectiveness (Willy et al., 2019). However, evidence indicates that a combination of patellar orthosis and physical therapy has synergistic effects (Alshaharani et al., 2019; Petersen et al., 2016). At present, there is limited evidence indicating if the NuNee patellar support is an effective treatment for PFPS.

Significance

Tasks like squatting and climbing stairs are daily activities shown to provoke pain in individuals with patellofemoral pain syndrome (PFPS) (Crossley, Stefanik, et al., 2016; Gaitonde et al., 2019). With patellar mal-tracking increasing joint stress and articular cartilage wear, the manufacturer of the NuNee purports that the support works to distract the patella and reduce this stress and wear (Farrokhi et al., 2011). However, there is limited evidence indicating the efficacy of the NuNee as a treatment for PFPS. Examining the immediate effects of this new orthotic may provide more information on how to manage and treat PFPS. This study may also lead to a greater understanding of the mechanism causing the pain and discomfort.
Purpose

The purpose of this study was to examine the immediate effects of the NuNee patellar support on perceived pain, biomechanics, and function in individuals with patellofemoral pain while they perform the modified star excursion balance test.

Overall Design

This study was a repeated-measures, randomized control study design. Subjects with anterior knee pain were recruited to participate in this study. PFPS was confirmed by a licensed clinician. Three conditions were assessed: control, sham, and NuNee. Subjects performed three trials of the modified star excursion balance test in each condition. Pain in each condition was assessed via a standard 10 cm visual analog scale (VAS) (Williamson & Hoggart, 2005). A three-dimensional motion capture system consisting of ten high-speed infrared cameras interfaced with two force plates were used to quantify biomechanical movement parameters. To address Specific Aim 1, we compared perceived pain ratings at the start of data collection and before and after each task. To address Specific Aims 2, 3, and 4, we examined individual biomechanical performance differences with and without the NuNee support. The independent variables of this study are the activity (anterior direction of the modified star excursion balance test) and the NuNee (with NuNee, without NuNee, sham condition). The dependent variables include perceived pain, knee kinematics and kinetics, and task performance. A two-factor repeated-measures ANOVA was used to compare outcome variables between conditions (control, sham, NuNee) and performance during the anterior direction of the modified star excursion balance test (anterior). Post-hoc analyses were performed when appropriate.
Specific Aims

Specific Aim 1, Pain: Examine the effect the NuNee patellar support on pain in individuals with patellofemoral pain during the anterior direction of the modified star excursion balance test.

Hypothesis 1: Use of the NuNee will decrease perceived pain, as assessed on a visual analog scale when compared to the control and sham conditions.

Specific Aim 2, Kinematics: Examine lower-extremity kinematics with and without the NuNee during the anterior direction of the modified star excursion balance test.

Hypothesis 2a: Use of the NuNee will result in increased knee flexion angle during the modified star excursion balance test when compared to control and sham conditions.

Hypothesis 2b: Use of the NuNee will result in decreased knee valgus angle during the modified star excursion balance test when compared to control and sham conditions.

Specific Aim 3, Knee Extensor Moment: Examine lower-extremity knee extensor moment with and without the NuNee during the anterior direction of the modified star excursion balance test.

Hypothesis 3: Use of the NuNee will result in increased knee extensor moment during the modified star excursion balance test when compared to control and sham conditions.

Specific Aim 4, Function: Examine lower-extremity function with and without the NuNee during the anterior direction of the modified star excursion balance test.

Hypothesis 4: Use of the NuNee will result in an improved score in the anterior direction during the modified star excursion balance test when compared to control and sham conditions.
Limitations of the Study

This study is not without limitations, and we acknowledge the following limitations a-priori. One limitation is that with the wide range of causes and generalized pain in the anterior knee area, there is a possibility for diagnostic error. Another limitation is that we are not directly examining the patellofemoral joint, but rather the actions of the tibiofemoral joint and having to make assumptions about the patellofemoral mechanics. We are also only looking at functionality. Without the use of electromyography or strength assessment, we can only speculate what the mechanism for changes in function or pain may be. There is also potential for human error when applying the NuNee support. Application is slightly generalized and may not be applied directly to the center of the patella. Lastly, only symptomatic individuals were tested. With a lack of a control group, normal values will not be established.

Glossary of Terms

**Patellofemoral pain syndrome (PFPS):** pain located around or behind the patella and provoked by activities like running, climbing stairs, squatting, and jumping (Gaitonde et al., 2019).

**Distraction force:** force applied to a body part to separate bony fragments or joint surfaces  
(Definition of Distraction by Medical Dictionary, n.d.).

**Kinetics:** branch of mechanics in which forces produce or change the motion of a segment  
(Kinetics Definition & Meaning - Dictionary.Com, n.d.)

**Kinematics:** branch of dynamics where motion is considered apart from masses and force  
(Kinematics Definition & Meaning - Merriam-Webster, n.d.).

**Valgus:** knee axis passes lateral to joint center (knock-knee) (Sharma et al., 2010).

**Ipsilateral:** situated or appearing on or affecting the same side of the body (Ipsilateral Definition & Meaning - Merriam-Webster, n.d.).
Chapter 2: Review of Literature

Patellofemoral Pain Syndrome: An Overview

Patellofemoral pain syndrome (PFPS) is classified as poorly defined pain occurring around or behind the patella, which is aggravated when the knee is flexed by weight-bearing activities such as squatting, stair ambulation, or running (Crossley, Stefanik, et al., 2016; Gaitonde et al., 2019; Willy et al., 2019). General overuse, muscular imbalances, or movement coordination deficits causing abnormal alignment or mal-tracking of the patella are associated with this pain (Crossley, Stefanik, et al., 2016; Rothermich et al., 2015; Willy et al., 2019). PFPS is often found in adolescents and adults younger than 60, with the highest prevalence in those between 12 and 19 years old (Gaitonde et al., 2019; Willy et al., 2019). Women account for roughly 55% of all cases (Gaitonde et al., 2019). Being one of the most common knee conditions, with a prevalence of 7% to 35%, it accounts for 1.5% to 7.3% of all patients seeking medical care (de Oliveira Silva et al., 2020; Willy et al., 2019). The onset of symptoms can be slow or acutely develop and worsen (Willy et al., 2019). One in three individuals report continued symptoms twelve months following treatment, and one in four experience persistent symptoms twenty years after initial diagnosis (de Oliveira Silva et al., 2020). This persistent pain is associated with a higher body mass index due to pain-related fear limiting physical activity and impaired quality of life (de Oliveira Silva et al., 2020).

Patellofemoral Anatomy

The patellofemoral joint (PFJ) increases the effectiveness of the extensor mechanisms acting on the knee (Gaitonde et al., 2019). The components of these mechanisms include bony and soft tissue structures (Abulhasan & Grey, 2017). The bony structures include the trochlea of the femur and the posterior aspect of the patella (Gaitonde et al., 2019). The trochlea is located
on the anterior aspect of the distal femur and with a centralized trochlear groove (Sherman et al., 2014). This groove continues distally down the femur and transitions into the medial and lateral condyles (Sherman et al., 2014). The patella resides within this trochlear groove and connects these extensor mechanisms to the quadriceps and patellar tendon (Sherman et al., 2014).

The soft tissues include the patellar tendon, the quadriceps mechanism, and other medial and lateral tissues (Gaitonde et al., 2019; Sherman et al., 2014). The patellar tendon extends from the inferior pole of the patella and inserts on the tibial tuberosity (Sherman et al., 2014). The quadriceps mechanism consists of four muscles (rectus femoris, vastus medialis, vastus lateralis, and vastus intermedius) which lie on the anterior aspect of the thigh (Abulhasan & Grey, 2017; Sherman et al., 2014). These muscles converge into the quadriceps tendon, which inserts on the superior aspect of the patella (Cox et al., 2021). Other medial soft tissues include the medial patellofemoral ligament, the medial patellotibial ligament, and the medial retinaculum (Sherman et al., 2014). Lateral tissues include the oblique lateral retinaculum, the patellotibial band, and the epicondylopatellar bands (Sherman et al., 2014). The hamstring muscles (biceps femoris, semitendinosus, and semimembranosus) run posteriorly along the femur and cross both the hip and knee joints (Anatomy, Bony Pelvis and Lower Limb, Hamstring Muscle - StatPearls - NCBI Bookshelf, n.d.). While these muscles do not play a role in knee extension, they are vital in the dynamic stabilization of the knee (Anatomy, Bony Pelvis and Lower Limb, Hamstring Muscle - StatPearls - NCBI Bookshelf, n.d.).

Pathophysiology

Patellofemoral pain syndrome is associated with a wide range of causes, such as general overuse, muscular imbalances, or movement coordination deficits leading to the abnormal alignment or mal-tracking of the patella (Willy et al., 2019). Tracking of the patella refers to the
dynamic motion of the patella within the trochlear groove during knee movements (LLopis & Padrón, 2007). Patellofemoral mal-tracking or malalignment increases the joint's stress and shear forces, resulting in pain (LLopis & Padrón, 2007). PFPS is generally associated with an increased lateral translation or a rotational malalignment of the patella (LLopis & Padrón, 2007).

Overuse occurs by loading the PFJ at high magnitudes, frequencies, or a rapid increase in activity (Rothermich et al., 2015; Willy et al., 2019). These increases in PFJ loading can cause an individual to experience supraphysiologic overload and lead to pain (Willy et al., 2019). Muscular imbalances refer to the loss of muscle size, strength, force, flexibility, or delayed muscle activation (Crossley, Stefanik, et al., 2016; Rothermich et al., 2015; Willy et al., 2019). These imbalances are especially present in the vastus medialis of the quadriceps, which is the primary restraint to lateral patellar tracking (Rothermich et al., 2015; Sherman et al., 2014). Weaknesses in the gluteus medius and maximus can increase ipsilateral lean, resulting in greater external forces in the sagittal and transverse planes (Rothermich et al., 2015). This dynamic imbalance increases the demand for the quadriceps and may result in greater PFJ compression and patellar mal-tracking (Rothermich et al., 2015). Individuals with PFPS also present with hip abductor and hip external rotation weakness (Rothermich et al., 2015). Hip weakness can lead to movement coordination deficits increasing knee valgus and Q-angles during dynamic movements, which increase the lateral stress on the PFJ (Gaitonde et al., 2019; Willy et al., 2019).

**Diagnosis**

The differential diagnosis of patellofemoral pain syndrome (PFPS) can be extensive and should include a medical history and physical examination (Gaitonde et al., 2019). An accurate diagnosis is based on a cluster of signs and symptoms which rule out other pathologies (Willy et
al., 2019). Individuals should be asked about previous knee injuries or surgeries and recent activity levels (Gaitonde et al., 2019). With PFPS being a common form of overuse injury, changes in activity levels should also be noted (Gaitonde et al., 2019). Questionnaires such as the Knee Injury and Osteoarthritis Outcome Score (KOOS) can help guide the history-taking process and aid in diagnosis (Roos & Lohmander, 2003). Physical examinations should be done on individuals presenting with symptoms indicative of PFPS and can be done through active or passive processes (Fredericson & Yoon, 2006; Gaitonde et al., 2019; Nijs et al., 2006). The primary feature of PFPS is poorly defined pain occurring around or behind the patella, which intensifies as the knee flexes during weight-bearing activities (Gaitonde et al., 2019; Willy et al., 2019). However, pain or stiffness may also increase during prolonged sitting with the knee flexed (Gaitonde et al., 2019).

The KOOS is a self-administered questionnaire that evaluates knee injuries' short- and long-term effects (Roos & Lohmander, 2003). It consists of forty-two questions in five separately scored subscales: pain, other symptoms, function in daily living (ADL), function in sport and recreation (Sport/Rec), and knee-related quality of life (QOL) (Roos & Lohmander, 2003). A shortened version of the KOOS has been developed and validated, specifically for patellofemoral pain, and only consists of eleven questions that focus on pain and quality of life (Crossley et al., 2018).

During a physical examination, clinicians should examine the knee and hip through various tests when diagnosing PFPS (Crossley, Callaghan, et al., 2016; Gaitonde et al., 2019). Squatting maneuvers, such as the eccentric step test, are the most effective at diagnosing PFPS, as pain during these activities is a crucial feature of PFPS (Crossley, Callaghan, et al., 2016; Crossley, Stefanik, et al., 2016; Nijs et al., 2006). Pain while palpating the area can suggest PFPS
or be used to diagnose other causes of anterior knee pain (Crossley, Callaghan, et al., 2016). Tenderness along the medial and lateral edges of the patella indicates PFPS, whereas tenderness at either pole indicates tendinopathy (Crossley, Callaghan, et al., 2016; Fredericson & Yoon, 2006). Other tests have low sensitivity and limited diagnostic accuracy (Crossley, Callaghan, et al., 2016).

It has been suggested that PFPS can lead to patellofemoral arthritis or chondromalacia patella; however, there is no conclusive evidence about this relationship (Willy et al., 2019). Similar to PFPS, patellofemoral arthritis and chondromalacia patella also involve a malalignment of the extensor mechanisms of the knee (Habusta et al., 2022; Kim & Joo, 2012). Patellofemoral arthritis results from a loss of articular cartilage between the patella and the trochlear groove (Kim & Joo, 2012). Chondromalacia patella is a disorder in which the hyaline cartilage of the PFJ softens, leading to tearing, fissures, or erosion (Habusta et al., 2022). While these conditions present very similarly to PFPS, PFPS does not involve structural defects (Gaitonde et al., 2019).

**Treatments**

Treatments for patellofemoral pain syndrome (PFPS) include analgesic pharmaceuticals, knee orthosis, physical therapy, and in extreme cases, surgical realignment (Gaitonde et al., 2019; Rothermich et al., 2015). Nonsteroidal anti-inflammatory drugs (NSAIDs), glucocorticoids, and anabolic steroids are pain-reducing treatments for patellofemoral pain syndrome (Gaitonde et al., 2019; Heintjes et al., 2004). However, because these pharmacotherapy methods are limited to any chemical processes which would decrease the pressure on the patellofemoral joint, they are usually an additive to physical therapy (Heintjes et al., 2004). Recent guidelines advise against knee orthoses as a treatment for PFPS due to their lack of effectiveness for long-term treatment (Smith et al., 2015; Willy et al., 2019). However,
evidence indicates that patellar orthosis has synergistic effects when combined with physical therapy (Alshaharani et al., 2019; Petersen et al., 2016; Sisk & Fredericson, 2020). Physical therapy focused on strengthening the knee and hip is the most effective treatment for PFPS (Wallis et al., 2021). Exercises should involve strengthening and stretching the quadriceps, hamstrings, hip abductors, and iliotibial band complex (Jones et al., 2015). With the various contributing factors of PFPS, physical interventions should be individualized to the patient’s needs (Gaitonde et al., 2019). Surgical realignment is another possible treatment; however, these operations should not be considered unless symptoms persist after six to twelve months of nonoperative interventions (Rothermich et al., 2015).

**Biomechanics of Patellofemoral Pain Syndrome**

Patellofemoral pain syndrome (PFPS) is associated with several kinetic and kinematic differences during a variety of tasks when compared to unaffected individuals. The primary kinetic differences include reduced knee extension moment and greater hip internal rotation and extensor moments (Baellow et al., 2020; Seeley et al., 2021; Weiss & Whatman, 2015). Kinematic differences involve decreased knee flexion, increased hip flexion, and increased knee valgus (Baellow et al., 2020; Herrington, 2014; Seeley et al., 2021).

During stepping, stair ambulation, and squatting tasks, lower peak knee extensor moments, reduced knee flexion, an ipsilateral trunk lean, and increased knee abduction have been observed (Crossley et al., 2004; Herrington, 2014; Nakagawa, Moriya, Maciel, et al., 2012; Nakagawa, Moriya, MacIel, et al., 2012; Salsich et al., 2001). Decreased knee extensor moments are considered a quadriceps avoidance strategy to avoid aggravating symptoms (Salsich et al., 2001). Reductions in knee flexion are also considered adaptations adopted due to increased pain (Crossley et al., 2004). An ipsilateral trunk lean and increased knee abduction angle are
associated with weakness within the hip abductors and altered gluteus medius activation (Nakagawa, Moriya, Maciel, et al., 2012; Nakagawa, Moriya, MacIel, et al., 2012). This trunk lean increased knee abduction places increased stresses on the patellofemoral joint (PFJ), leading to worsening symptoms (Nakagawa, Moriya, MacIel, et al., 2012). Increases in hip flexion angle and extensor moments have also been noted in individuals with PFPS (Seeley et al., 2021). These findings may be from individuals compensating to rely more on the hip than the knee (Seeley et al., 2021). During functional tests, like the star excursion balance test (SEBT), individuals with PFPS have a shorter anterior reach distance than those without (Goto et al., 2018; Gribble et al., 2012). However, no kinematic differences in the knee or hip have been observed in the posterior directions (Goto et al., 2018; Gribble et al., 2012). Individuals also report slight increases in pain during the anterior direction, which is believed to be from the high level of quadriceps activation (Goto et al., 2018; Gribble et al., 2012). A similar study reported that individuals with PFPS present significant differences in dynamic stability compared to controls (Arun et al., 2013).

**Bracing and Patellofemoral Pain Syndrome**

Recent guidelines advise clinicians against the use of existing knee orthotics on individuals with patellofemoral pain syndrome (PFPS) due to a lack of evidence supporting their effectiveness (Willy et al., 2019). Studies on the immediate effect of patellar bracing have conflicting results suggesting that brace selection may be key (Sisk & Fredericson, 2020). However, there is evidence indicating that a combination of patellar orthosis and physical therapy has synergistic effects (Alshaharani et al., 2019; Petersen et al., 2016).

During single-leg squats and unilateral step-landings, the Stability Through External Rotation of the Femur (SERF) strap resulted in a significant reduction in pain according to a visual analog scale (VAS) (Herrington, 2013). The same study reported a decrease in dynamic
knee-valgus angles during both tasks (Herrington, 2013). Another study examined the effects of the Powers™ strap while running and during a single-leg squat (Greuel et al., 2019). The Powers™ strap resulted in decreased dynamic knee valgus and a significant drop in pain score on a VAS (Greuel et al., 2019). Both braces work to externally rotate the femur, as increased internal rotation is associated with PFPS (Greuel et al., 2019; Herrington, 2013). A study examining the immediate effects of an elastic brace on quadriceps muscle activation during stair ambulation, hopping, and walking, reported a pain reduction of 33-56% on a visual analog scale (VAS) (Kölle et al., 2020). However, no difference in muscle activation was noted (Kölle et al., 2020). McCrory et al. investigated the effect of the Protonics™ knee brace, which reduces knee extension moment by applying resistance to knee flexion during walking gait and a lateral step up (McCrory et al., 2007). While the pain was reduced, no differences were found in lower extremity alignment associated with PFPS (McCrory et al., 2007). These findings suggest that these braces only reduce symptoms without targeting the potential mechanism of pain (Kölle et al., 2020; McCrory et al., 2007). Further, with the extensive pathophysiological causes of PFPS, these studies show that the choice of brace may impact effectiveness (Sisk & Fredericson, 2020).

The use of the Protonics™ knee braces resistance has also been compared with elastic sport cords for exercise therapy (Alshaharani et al., 2019). In this study, individuals resisting the brace during exercises reported greater GROC scores, which assess the subject's self-perceived progression, than those using the sport cords (Alshaharani et al., 2019). However, while no statistical significance was found in other outcome measures, like hip external rotation or pain, the use of the Protonics™ knee brace did result in improved values suggesting clinical relevance (Alshaharani et al., 2019). A study comparing the effect of a patellar brace with exercise therapy to exercise therapy alone found no significant differences in pain or knee function (Lun et al.,
This study also included a knee sleeve treatment as a pseudo-control group finding no differences between either group (Lun et al., 2005). This is believed to be due to the enhanced sensory feedback a brace or sleeve provides the knee (Lun et al., 2005). Another study found that using a patellar realignment brace during physical therapy resulted in better KOOS scores and less pain at six- and twelve-week follow-ups compared to non-braced patients (Petersen et al., 2016). However, after one year, there was no difference between the groups (Petersen et al., 2016).

The conflicting results of knee bracing for PFPS suggest that brace selection may be key. Braces like the SERF, Powers™ strap, and realignment braces all work to address potential mechanisms of injury, which may be why these have shown to be effective (Sisk & Fredericson, 2020). The NuNee patellar support applies a distractive force to relieve pressure placed on the patella.

**Modified Star Excursion Balance Test**

The star excursion balance test (SEBT) is a functional test based on rehabilitation exercises for the lower extremity (Picot et al., 2021). The test assesses dynamic postural control, examines functional deficits, and identifies risks for future injury (Picot et al., 2021). The SEBT involves an individual standing on one foot in the center of eight lines, with 45° between each, and reaching as far as they can in each direction (Picot et al., 2021). The SEBT has been simplified since its creation to only include three directional lines: anterior (ANT), posteromedial (PM), and posterolateral (PL) (Picot et al., 2021). This modified star excursion balance test (mSEBT) reduces the redundancy of testing directions while maintaining the consistent and reliable data obtained from the SEBT (Picot et al., 2021). Performance on the mSEBT is dependent on the knee and ankle kinematics, strength and coordination of the lower extremity,
and the sensorimotor aspects of postural control (Picot et al., 2021). ANT reach distance is associated with ankle dorsiflexion, while the PM and PM directions are correlated with frontal plane stabilization, mediolateral postural stability, and proximal function (Picot et al., 2021). As patellofemoral pain is aggravated during activities like squatting and climbing stairs, the mSEBT is an effective tool for evaluating the biomechanics of PFPS (Gribble et al., 2012). The ANT reach is associated with a high level of quadriceps activity and replicates movements similar to stair ambulation, commonly observed during PFPS studies (Gribble et al., 2012).
Chapter 3: Methods

Subjects

Recruitment efforts were made around West Virginia University by asking various classes if any student has or knows someone who has patellofemoral pain syndrome (PFPS). Further efforts were made through the WVU physical therapy clinic, contacting various WVU athletic teams and clubs, and posting flyers around the Morgantown area. When diagnosed, the clinician informed the patient of the study and instructed them to contact the researchers to schedule data collection. If a provider did not refer a potential subject, but rather the potential subject learned about the study through advertisements, they were screened by a clinician before data collection. A checklist was made using the study’s eligibility criteria, listed below, to determine if they qualified. This checklist can be found in Appendix B.

Thirteen subjects (3 male, 10 female; age = 23.31 ±7.24 years; mass = 72.60 ±11.07 kg; height = 169.12 ±8.00 cm) were recruited for this study. Seven subjects reported pain only in their left knee, two reported experiencing pain only in their right knee, and four reported pain in both knees. If pain was reported in both knees, the more painful side was assessed. A total of nine subjects tested their left side, and four tested their right. Subjects reported a pain level of ≥3 during activities like squatting, climbing stairs, or running. Pain duration ranged from 5-120 months (mean = 44.08 ±35.80 months).

Study Eligibility:

Inclusion -

- Diagnosed with patellofemoral pain by a clinician
- Reported symptoms for ≥ 3 months
- Pain around the patella during activities like squats, climbing stairs, or running
  - Reported having a pain level of ≥ 3 during functional activities
  - ≤ 45 years old
  - Fluent in English

Exclusion -

- Previous knee surgery on the affected leg (i.e., ACL reconstruction, knee arthroscopy, knee replacement)
- Other spine or lower extremity surgery or injuries ≥ 3 months
- Currently involved in interventions for patellofemoral pain
- Knee pain not diagnosed as PFPS
- Individuals with PFPS from a hypermobile patella

An apriori power analysis was performed based on previous research by Nakagawa et al. (Nakagawa, Moriya, Maciel, et al., 2012). Specifically, they examined knee biomechanics between individuals with and without PFPS. They reported 9.2 ±5.0° of knee valgus during a single-leg squat in those with PFPS and 5.8 ±3.4° in unaffected participants. Using these data, we determined our target sample size to be 16. Our target was approximately 50% males and 50% females. Despite rigorous recruitment efforts, this study did not reach the targeted sample size and should be noted when interpreting our results.

Procedures

Upon confirmation of eligibility, subjects were scheduled to complete informed consent and testing in the Mountaineer Sports Medicine Research Laboratory at WVU. If a subject was not referred and screening was needed, testing was scheduled for another day. After thoroughly
explaining the study, written consent was obtained for this WVU IRB-approved study. During the consenting process, subjects were encouraged to ask questions or voice concerns they may have had. Prior to data collection, subjects were asked to refrain from strenuous activity and pain medications for twenty-four hours. For data collection, subjects wore snug-fitting shorts, t-shirts, and lab-provided shoes (Nike Air Zoom Pegasus 38 TB) and were given time to change if needed. Researchers then collected subject height, weight, and limb length of the affected side. Limb length which was used to normalize the reach distance after data collection (Picot et al., 2021). Measurements were done in the supine position, from the ASIS to the medial malleolus (Picot et al., 2021).

A 3D motion capture system (Vicon, Nexus) used cluster markers to collect data. Per the manufacturers’ specifications, these markers were placed on the left and right feet, shank, and thighs, as well as the sacrum and mid-thoracic spine regions. Due to this study only being interested in the lower extremity, no markers were placed on the subjects’ upper extremity. Calibrations of motion capture cameras and the subject were also done to manufacturer specifications and the standard operating procedure of the lab.

Subject and segment calibration occurred after marker clusters had been placed on the body. Hip joint centers were calculated by the computer using the Bell equation (Bell et al., 1990). This equation estimates the joint center to be 19% of the inter-ASIS distance posterior, 30% distal, and 14% medial to the ASIS (Bell et al., 1990). Knee joint centers were defined by the mid-point of the medial and lateral epicondyles. Similarly, the mid-point of the medial and lateral malleoli defined the ankle joint centers. Foot length was found using the second distal phalanx. All anatomical landmarks were located by palpation and identified for the computer with a cluster wand. After proper calibration, the subject performed the modified star excursion
balance test without the NuNee on their affected side. However, only the data from the anterior direction are included in this thesis.

The NuNee was then applied according to the manufacturer's instructions presented on their website. After cleaning the knee with an alcohol wipe, the adhesive patch was applied directly over the patella while standing with a slightly bent knee (How to Wear NuNee - NuNeeTM, n.d.). The manufacturer also encourages individuals to shave the area to minimize pain upon removal (How to Wear NuNee - NuNeeTM, n.d.). To allow time for proper adhesion, the adhesive patch was applied prior to completing a questionnaire (How to Wear NuNee - NuNeeTM, n.d.). The knee wrap is to fit snugly with the kneecap and patch at its center (How to Wear NuNee - NuNeeTM, n.d.). The distracting mechanism should Velcro to either side of the knee so that one inch of space is left between the center and the patch before attachment (How to Wear NuNee - NuNeeTM, n.d.). The sham condition included the adhesive patch and wrap without the distractive mechanism (Figure 1). The sham and NuNee conditions were randomized using a random number generator.

Using a laboratory iPad, subjects then completed the knee injury and osteoarthritis outcome score questionnaire (KOOS) via the REDCapTM database. The KOOS includes five individually scored subscales: pain, symptoms, function in daily living (ADL), function in sport and recreation (Sport/Rec), and knee-related quality of life (QOL) (Roos & Lohmander, 2003). A Likert scale is used for each question where questions will have five answer choices scored from 0 (no pain or problems) to 4 (extreme pain or problems) (Roos & Lohmander, 2003). The five-subscale scores are calculated by the following equation: \(100 - \frac{\text{mean score} \times 100}{4}\) and presented in percentage form (Roos & Lohmander, 2003). Scores of zero represent extreme pain or problems, while scores of one hundred represent no pain or problems (Roos & Lohmander,
The KOOS viewed by subjects can be found in Appendix C. Additional questions about symptom duration, pre-injury activity levels, current pain level, and pain description were collected.

![NuNee support conditions](image)

*Figure 1– NuNee support conditions. Left - NuNee; Right - sham*

The modified star excursion balance test (mSEBT) consists of three lines running in the anterior, posteromedial, and posterolateral directions (Picot et al., 2021). While this study was only interested in the anterior direction, as shown in Figure 2, subjects completed all three phases of the test (Picot et al., 2021). This line emanated from the center of the force plate of the individual’s affected side. Individuals stood on their effected lower extremity with their hands on their hips with the most distal aspect of the great toe at the origin of the lines (Picot et al., 2021). From this position, they reached with the opposite foot as far as possible while maintaining balance and then returned to their starting position (Picot et al., 2021). The test was repeated
until three successful trials were completed. Trials were repeated if: (1) the subject fell or placed
their non-stance foot on the ground, (2) any part of the stance foot moved or raised, and (3) the
subjects' hands were removed from their hips (Picot et al., 2021). Researchers provided a
demonstration of the test upon explanation. A maximum of three practice trials were performed
to allow the subject to familiarize themselves with the movement while researchers gave any
needed instruction. Subjects were given up to three minutes of rest between trials to minimize
fatigue and pain provoked by the test (de Salles et al., 2009). After each successful trial, subjects
rated the pain experienced during the test using a standard 10-cm visual analog scale (VAS). An
example of the VAS presented can be found in Appendix D. Researchers also recorded the
number, if any, of failed attempts.

In addition, subjects were asked to describe the pain typically experienced during
functional activities and following successful completion of each condition. Researchers
provided a list of sample descriptors pulled from the short-form McGill pain questionnaire
(Melzack, 1987). This list, as shown to subjects, can be found in Appendix D.
**Data Analysis**

Kinematic data were collected at a rate of 200 Hz and filtered using a fourth-order, zero-lag, low-pass Butterworth filter with a cutoff frequency of 8 Hz. Kinetic data were collected at a rate of 1000 Hz and filtered using a fourth-order, zero-lag, low-pass Butterworth filter with a cutoff frequency of 8 Hz. After data collection, the raw data was exported from The MotionMonitor software within the motion capture system and imported into a MATLAB (Version R2022b, The MathWorks Inc., Natick, MA) program and processed. Biomechanical analysis of the experimental data was done separately.

Knee flexion on the X-axis was used to determine the beginning and end of each testing phase. Using the g-input function within Matlab, two points were selected on a graph of knee flexion. Reach direction was normalized using the following equation:

\[
\frac{\text{mean of the three trials (cm)}}{\text{measured limb length (cm)}} \times 100 \text{ (Picot et al., 2021).}
\]

Researchers used these normalized values to calculate each subject's normalized composite score (normCOMP score (%)) with the following equation:

\[
\frac{\text{normANT(%) + normPM(%) + normPL(%)}}{3} \text{ (Picot et al., 2021).}
\]

Maximum knee
flexion, valgus, and extensor moment will be calculated during each phase and averaged between conditions and trials.

**Statistical Analysis**

Statistical analysis was performed in SPSS software (IBM, version 28, Armonk, NY). Descriptive statistics like central tendencies (mean, median, etc.) and dispersions (ranges, standard deviations) were completed for all variables not being measured within the study. These included age, mass, and other demographic information. Tested variables had a similar analysis and were given graphical displays to observe the data distribution.

A repeated-measures ANOVA was done to test the hypotheses presented in our specific aims. Condition (control, sham, NuNee) was the independent variable. The following are our dependent variables: perceived knee pain, knee valgus angle, knee flexion angle, knee extensor moment, and the composite score achieved during the anterior direction of the mSEBT. If the Mauchly’s Test of Sphericity was not significant, the “sphericity-assumed” p-value was used. However, if the Mauchly’s Test of Sphericity was significant (p<0.05), then the Huynh-Feldt p-value in the repeated measures ANOVA was used instead to determine significance between conditions. If significance was found, a Tukey post-hoc test was performed to determine which conditions were statistically different. The alpha value was set to 0.05. Our pain data from the VAS surveys we skewed to the left. Thus, due to a non-normal distribution, a Kruskal-Wallis test was performed to compare between conditions. Additionally, a Chi-Squared analysis was used to compare pain description between conditions and typical pain.
Chapter 4: Results

Pain

Specific Aim 1 was to examine the effect the NuNee had on perceived pain. Pain data were not normally distributed; therefore, a non-parametric statistical analysis was required. A Kruskal-Wallis Test was performed using the average VAS for each condition (control, sham, NuNee) and was not statistically significant between conditions (p = .435). The average value for each condition was <3, which was below our inclusion criterion definition of “clinically significant.” Medians and interquartile ranges of VAS ratings for each condition (control, sham, NuNee) are shown in Table 1. These values are provided in lieu of means and standard deviations because the data are non-normally distributed.

Table 1 - Medians and interquartile ranges of VAS ratings for each condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Median</th>
<th>Interquartile Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.67</td>
<td>1.19-2.55</td>
</tr>
<tr>
<td>Sham</td>
<td>2.13</td>
<td>1.31-2.38</td>
</tr>
<tr>
<td>NuNee</td>
<td>1.40</td>
<td>0.71-1.80</td>
</tr>
</tbody>
</table>

Subjects were asked to describe the pain typically experienced during functional activities as well as the pain experienced during each testing condition. Figure 3 shows the distribution of pain descriptors across each condition. A Chi-Squared test between the conditions revealed that the descriptors of sharp, stabbing, and tender were used significantly less between conditions. Subjects could use more than one descriptor at a time, so we were unable to layer our analysis for further examination, given our small sample size. The Chi-Square values for each
Typical pain refers to the pain subjects typically feel during functional activities, while control, sham, and NuNee pain descriptions reflect the pain felt during those testing conditions. Sharp was the most common descriptor reported for “typical” pain. Four subjects reported it following the control condition, and none reported it after the NuNee condition.

**Figure 3** - Pain descriptions for each condition. Typical pain description refers to how subjects would typically describe their pain. Pain descriptions for control, sham, and NuNee refer to the pain felt during that condition.
Table 2 - Chi-Square test between condition pain description. Condition = typical, control, sham, NuNee. * = p<0.05.

<table>
<thead>
<tr>
<th>Chi-Square p-value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Shooting</td>
<td>.882</td>
</tr>
<tr>
<td>Stabbing</td>
<td>.005*</td>
</tr>
<tr>
<td>Dull</td>
<td>.583</td>
</tr>
<tr>
<td>Sore</td>
<td>.101</td>
</tr>
<tr>
<td>Aching</td>
<td>.541</td>
</tr>
<tr>
<td>Tender</td>
<td>.041*</td>
</tr>
<tr>
<td>Pinching</td>
<td>.228</td>
</tr>
<tr>
<td>General</td>
<td>1.00</td>
</tr>
<tr>
<td>Local</td>
<td>.786</td>
</tr>
<tr>
<td>Other</td>
<td>.687</td>
</tr>
</tbody>
</table>

**Kinematics**

Specific Aim 2 was to examine the lower-extremity kinematics for each condition. Repeated-measures ANOVAs were performed on knee flexion and knee valgus angles between conditions. Knee flexion angle also showed no significance between conditions (p = .104). Knee valgus had no significance between conditions (p = .420). Means and standard deviations of both knee valgus and knee flexion are reported in Table 3.

**Knee Moments**

Specific Aim 3 was to examine the lower-extremity knee extensor moments. Repeated measures ANOVAs were performed on knee extension and frontal plane moments to compare between the conditions. Knee extensor moment did not achieve significance (p = .725). Knee frontal plane moment also showed no significance (p = .106). Means and standard deviations of both knee extensor and knee frontal plane moments are reported in Table 3.
Table 3 - Means, standard deviations, and significance levels for all biomechanical variables.

<table>
<thead>
<tr>
<th></th>
<th>Knee Flexion Angle (deg)</th>
<th>Knee Valgus Angle (deg)</th>
<th>Knee Extension Moment (Nm/kg)</th>
<th>Varus/Valgus Moment (Nm/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-69.44 ±9.68</td>
<td>0.16 ±6.97</td>
<td>1.22 ±0.61</td>
<td>0.37 ±0.88</td>
</tr>
<tr>
<td>Sham</td>
<td>-70.88 ±8.90</td>
<td>0.87 ±6.88</td>
<td>1.41 ±1.06</td>
<td>0.08 ±0.28</td>
</tr>
<tr>
<td>NuNee</td>
<td>-71.62 ±9.73</td>
<td>1.22 ±6.50</td>
<td>1.68 ±3.89</td>
<td>-0.72 ±1.80</td>
</tr>
<tr>
<td>Sig. (p-value)</td>
<td>.104</td>
<td>.420</td>
<td>.760</td>
<td>.104</td>
</tr>
</tbody>
</table>

**Function**

mSEBT

Specific Aim 4 was to examine lower-extremity function in terms of normalized anterior reach distance. A repeated measures ANOVA was performed on normalized anterior reach scores between conditions. No significance was found between the conditions (p = .538). An additional ANOVA was done on the total composite score from the mSEBT, which found significance (p < .001). A pairwise comparison revealed that the control condition differed from the sham and NuNee conditions (p < .001). However, no difference was found between the sham and NuNee conditions (p = .601). Means and standard deviations of both normalized ANT reach distance and total composite score are reported in Table 4.
Table 4 - Means and standard deviations of ANT reach distance and total composite score for each condition. mSEBT score as a percent of knee function, with a higher score representing greater function. ANT Reach Distance = reach distance in the ANT direction normalized to subject limb length; Total Composite Score = total score of mSEBT

<table>
<thead>
<tr>
<th></th>
<th>ANT Reach Distance (%)</th>
<th>Total Composite Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>62.06 ±6.05</td>
<td>76.63 ±5.38</td>
</tr>
<tr>
<td>Sham</td>
<td>62.79 ±5.97</td>
<td>82.18 ±5.22</td>
</tr>
<tr>
<td>NuNee</td>
<td>62.83 ±6.03</td>
<td>82.57 ±4.94</td>
</tr>
<tr>
<td>Sig. (p-value)</td>
<td>.538</td>
<td>&lt;.001*</td>
</tr>
</tbody>
</table>

KOOS

To further examine function, we also surveyed the participants about their knee function using the Knee Injury and Osteoarthritis Outcome Score (KOOS). However, the KOOS does not reveal function between conditions but rather the subject’s perception of their overall function. The pain category of the KOOS does not evaluate an individual’s level of pain, but rather how their pain affects their function. Pain magnitude is reported in the pain section of the results. Scores for each subscale of the KOOS, as well as the average total score, are reported in Table 4. These data provided insight for further interpretation of our results.
Table 5 - Means and standard deviations of each subscale of the KOOS. The total average score represents the combined average of each subscale. KOOS scored from 1-100 with higher scores reflect greater function. ADL = function in daily living; Sport = function in sport and recreation; QOL = knee related quality of life.

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Average</th>
<th>St. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms</td>
<td>64.29</td>
<td>±12.71</td>
</tr>
<tr>
<td>Pain</td>
<td>65.60</td>
<td>±10.91</td>
</tr>
<tr>
<td>ADL</td>
<td>75.57</td>
<td>±12.02</td>
</tr>
<tr>
<td>Sport</td>
<td>46.54</td>
<td>±14.05</td>
</tr>
<tr>
<td>QOL</td>
<td>46.63</td>
<td>±12.13</td>
</tr>
<tr>
<td>Average Score</td>
<td>59.72</td>
<td>±9.42</td>
</tr>
</tbody>
</table>
Chapter 5: Discussion

The purpose of this study was to examine the immediate effects of the NuNee patellar support on perceived pain, biomechanics, and function in individuals with patellofemoral pain while they perform the modified star excursion balance test. While current guidelines for treating patellofemoral pain do not recommend the use of a knee orthosis, conflicting results suggest that brace selection may be key (Wallis et al., 2021). The NuNee patellar support applies a distractive force to relieve pressure placed on the patella (“Academy of Orthopaedic Physical Therapy Poster Presentation Abstracts (OPO1–OPO223),” 2022). However, there is limited evidence indicating the efficacy of the NuNee patellar support.

Pain

Specific Aim 1 was to examine the effect the NuNee had on perceived pain using a 10 cm visual analog scale (VAS). We hypothesized that the use of the NuNee would result in a decrease in perceived pain. Our study revealed no significant differences in pain between conditions. Thus, when interpreting our results, pain severity upon starting data collection may be important as only two subjects could be classified as having moderate (31 mm to 69 mm) or severe (70 mm to 100 mm) pain (Collins et al., 1997; Kelly, 2001). Although a pain level of ≥3 was a criterion for study participation, most subjects reported pain of <3 on a VAS during testing. Subjects were asked to limit pain provoking activity for 24 hours leading to data collection. This may have impacted baseline pain measurements.

Limited research has been done on individuals with PFPS and bracing while performing the ANT direction of the mSEBT. However, many studies examine the effect of bracing on pain in similar unilateral movements. Additionally, studies examine multiple functional tasks, whereas the current only investigated the mSEBT. Increasing the number of practice trials of the
mSEBT prior to testing or having subjects perform other functional activities to provoke pain may have led to greater VAS ratings throughout the study. When proposed at the 2022 combined sections meeting of the American Physical Therapy Association, the NuNee was tested during a single functional test of stair ambulation, squatting, or running, depending on which was most provocative (“Academy of Orthopaedic Physical Therapy Poster Presentation Abstracts (OPO1–OPO223),” 2022). This initial study reported that their subjects experienced an average pain decrease of 52.1% (3.38 to 1.62) on a numerical rating scale (NRS) when the NuNee was applied. The current study only tested individuals on the mSEBT and only reported a 16.2% (1.67 to 1.40) decrease with the NuNee. Thus, pain reduction may be individualized based on the activity performed. Other studies have tested the effect of bracing during multiple activities. Herrington (2013) examined the use of the SERF strap during a single-leg squat and a step-landing. Greuel et al. (2019) investigated the effect of the Powers™ strap on pain during a single-leg squat and running on an indoor track. Kölle et al. (2020) tested six activities: stair ambulation, hopping, sitting and standing from a chair, and treadmill walking. Each study reported a significant reduction in pain when the orthosis was applied (Greuel et al., 2019; Herrington, 2013; Kölle et al., 2020). While the ANT direction of the mSEBT is associated with high quadriceps activation similar to single-leg activities, multiple tasks may be needed to produce a sufficient amount of pain (Goto et al., 2018; Gribble et al., 2012). Aminaka et al. (2008) investigated the effect of patellar taping on individuals with PFPS during the ANT direction of the star excursion balance test (SEBT). Patellar taping works by applying structural support to the patella to correct abnormal tracking and mal-alignment (Sisk & Fredericson, 2020). Aminaka et al. (2008) reported that individuals with PFPS experienced decreased pain between taping and no-taping conditions.
Typical pain descriptions and pain descriptions during conditions were also noted. Subjects were allowed to use one or more descriptors at a time. Use of the descriptors of sharp, tender, and pinching decreased between the three conditions, with sharp decreasing the most from four to zero, while the description of sore increased from two to five. It is also important to note the difference between typical and control pain descriptions. Sharp was only reported by four subjects during the control condition, while eleven reported it being a typical sensation. Additionally, four subjects reported stabbing pain in their typical description, and zero used this description for any of the testing conditions.

**Kinematics**

Specific Aim 2 was to examine the effect the NuNee had on the lower-extremity kinematics for each condition. We hypothesized that the use of the NuNee would result in an increased knee flexion angle and decreased knee valgus angle. No statistical differences were found. Although knee flexion did not result in statistical significance, a pairwise comparison was performed because the p-value was nearing significance. This revealed that knee flexion differed most during the control and NuNee conditions (p = .084).

Limited research has been done on individuals with PFPS and bracing while performing the ANT direction of the mSEBT. However, many studies have examined the effect of bracing on knee kinematics in similar unilateral movements. A study on the SERF strap’s effect on knee valgus angle during a single-leg squat reported a significant decrease (Herrington, 2013). Unlike the NuNee, the SERF strap works to externally rotate the femur, directly addressing a known cause of dynamic knee valgus and PFPS (Herrington, 2013). Another study examined the effects of the Powers™ strap, which also works to externally rotate the femur, and found similar results (Greuel et al., 2019). McCrory et al. (2007) investigated the effect of the Protonics™ knee brace
on lower extremity alignment during walking gait and a lateral step up. The Protonics™ knee brace applies a resistance to knee flexion reducing knee extension moments (McCrorry et al., 2004). However, similarly to the current study, no differences in lower extremity angles were found (McCrorry et al., 2004). All of this suggests that knee orthosis, which does not target the potential cause of dynamic knee valgus, may have no impact. Aminaka et al. (2008) examined the effect of patellar taping on individuals with PFPS during the ANT direction of the SEBT. Similar to the current study, no significant differences in knee flexion were found. While both studies saw slight increases in flexion angle, the use of the NuNee resulted in a greater difference. These slight increases in knee flexion may also explain the changes in dynamic knee valgus. Bazett-Jones et al. (2022) noted that in single-leg loading tasks, as knee flexion angles increase, knee valgus angles also increase. Additionally, due to the nature of the ANT direction of the mSEBT, ankle dorsiflexion may limit peak knee flexion angles. Rabin et al. (2016) noted that low levels of dorsiflexion are associated with decreased peak knee flexion angles. Individuals with PFPS are shown to have decreased dorsiflexion due to insufficient gastrocnemius flexibility (Piva et al., 2005). Thus, while the current study observed slight increases in knee flexion angles between conditions, a lack of dorsiflexion may have limited these results.

**Kinetics**

Specific Aim 3 was to examine the effect the NuNee had on the knee extensor moment for each condition. We hypothesized that the use of the NuNee would result in an increased knee extensor moment. A secondary analysis was done on knee frontal plane moments. Our study revealed no significant differences in knee moments between conditions. While our data may not be significant, knee extension moments increased by 38% between the control and NuNee
conditions. Additionally, our study observed a change in frontal plane moments between the control and NuNee conditions moving from positive varus moments to negative valgus moments. Further, while frontal plane moments did not result in statistical significance, a pairwise comparison was performed because the p-value was nearing significance. This revealed that frontal plane moments differed most during the control and NuNee conditions (p = .092).

Although limited research has been done on individuals with PFPS and bracing while performing the ANT direction of the mSEBT, many studies have examined the effect of bracing on knee moments in similar unilateral movements. Powers et al. (2004) found that the use of the On-Track Patellar Tracking System resulted in a significant increase in the knee extensor moments during stair ambulation. This patellar tracking system works similarly to patellar taping and realignment braces by applying a constant medial pull to the patella (Powers et al., 2004). During a lateral step-up, Ernst et al. (1999) compared knee extensor moments between various patellar taping conditions (tape, placebo, no tape, and uninvolved side). They reported a significant increase in knee extensor moments during the taping condition compared to the placebo and no-tape conditions (Ernst et al., 1999). Additionally, no differences were found between the uninvolved side and the taping conditions (Ernst et al., 1999). Ernst et al. (1999) suggests that increases in knee extension moments may be due to an increase in the length of the quadriceps lever arm as a result of improved patellar alignment and tracking. Additionally, a change in patellar position may increase vastus medialis activity (Ernst et al., 1999). The vastus medialis is one of the essential muscles in restraining lateral patellar tracking (Sherman et al., 2014). Thus, improved patellar alignment through taping or bracing may augment activation of the vastus medialis, allowing for a greater and more efficient contraction. However, the current study did not investigate muscle activation or measure patellar alignment. Decreased knee
extensor moments are considered a quadriceps avoidance strategy to avoid aggravating symptoms in individuals with PFPS (Salsich et al., 2001). Thus, while slight, the decrease in pain observed in the current study may also be related to increased extension moment.

Limited research has been conducted on knee frontal plane moments in individuals with PFPS in various orthosis. Greuel et al. (2019) observed that the use of the Powers™ strap resulted in an increased internal knee adduction moment during single-leg squats. This was credited to the straps mechanism of transversely correcting the hip, decreasing dynamic knee valgus (Greuel et al., 2019). The current study observed the opposite. Upon application of the NuNee, frontal plane moments decreased, moving from positive external varus moments to negative external valgus moments. The NuNee’s mechanism may target activities in the sagittal plane more so than the frontal plane. Thus, while quadriceps activity may have increased, leading to greater knee extensor moments, there may have been no changes in hip abductor activity, allowing for the increased negative valgus moment. However, this is only speculation, as electromyography was not used during this study.

Function

mSEBT

Specific Aim 4 was to examine the effect the NuNee had on lower-extremity function for each condition. We hypothesized that the use of the NuNee would result in an improved score in the ANT direction of the modified star excursion balance test. Our study found no significant changes in ANT reach between conditions. However, the total composite score was found to be significant between conditions. A pairwise comparison revealed that the sham and NuNee conditions differed from the control condition. Further analysis showed that the posterolateral (PL) direction differed the most between sham and NuNee conditions and the control condition
(p < .001). Additionally, the PL direction is the only direction which resulted in a noticeable increase between conditions. This change in total composite score is thought to result from a learning effect as all subjects completed the control condition first while the sham and NuNee conditions were randomized. Subjects may have also experienced increased confidence in either their ability to perform the task or that they would not experience pain during the task following the control condition due to the low levels of pain. Due to the nature of the ANT direction of the mSEBT, ankle dorsiflexion may limit ANT reach distances. Hoch et al. (2011) and Kang et al. (2015) note a significant correlation between dorsiflexion and performance on the ANT direction of the SEBT, whereas Robinson and Gribble (2008) reported that hip flexion accounts for 86% to 95% of the variance in the posterior directions. A study examining the effect of patellar tapping on the ANT direction noted improvements in ANT reach distance (Aminaka & Gribble, 2008). Researchers believed this to be a result of enhanced vastus medialis activation (Aminaka & Gribble, 2008). Increased activation of this muscle is thought to increase stability allowing for greater reach distances (Aminaka & Gribble, 2008). However, compared to healthy controls, individuals with PFPS had significantly lower ANT reach distances regardless of tape (Aminaka & Gribble, 2008).

KOOS

To further assess Specific Aim 4, subjects completed the Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire. KOOS ratings reflect the individual’s perception of knee function based on five subscales: symptoms, pain, activities of daily living (ADL), sport and recreation (Sport), and quality of life (QOL) (Roos & Lohmander, 2003). A score of zero would reflect an individual having no function, or extreme problems, while a score of one hundred indicates total function or no problems (Roos & Lohmander, 2003). In our study, subjects
reported the greatest scores on the ADL subscale (75.57 ±12.02). The lowest reported subscales were Sport (46.54 ±14.05) and QOL (46.63 ±12.13). These values align similarly with Petersen et al. (2016). Healthy adults are reported to score around 90 for all five subscales, with women reporting slightly lower function than men (Baldwin et al., 2017).

Activities of daily living include general walking gait, ambulating stairs, sitting and standing from a chair or toilet, and other non-exercise-related activities. PFPS is typically aggravated during weighted knee flexion. Thus, a higher average score is expected. The Sport subscale refers to activities known to aggravate PFPS, so lower scores are expected. QOL represents the individual’s awareness and confidence toward their knee. Lower QOL scores may explain why more significant results were not found throughout this study. A lack of confidence may have led to hesitation when performing the mSEBT to avoid pain.

**Limitations**

Further limitations of this study were noted upon reflection. First, despite an aggressive recruitment campaign, we did not reach our goal of n = 16. Second, although subjects reported experiencing an average pain of ≥3 during functional activities, they did not experience clinical levels of pain (<3) during testing. Increasing the number of practice trials of the mSEBT prior to testing or having subjects perform other functional activities to provoke pain prior to data collection may have led to greater VAS ratings throughout the study.

**Future Research**

Future research on the efficacy of the NuNee is needed. This study only investigates the biomechanical variables observed in the knee. Examining the kinematic and kinetic actions at the hip and ankle may provide more insight into the NuNee’s effect. Additionally, examining potential changes in muscle activation may provide insight into the NuNee’s mechanism. The
current study found limited differences in pain. In our study, the NuNee was applied immediately before data collection and only worn for approximately ten minutes. Timing of application and length of use on pain reduction should be further studied. Future research should also investigate other functional activities associated with PFPS. Investigating the differences between active and sedentary individuals may better identify the target population of the NuNee, as it was originally designed for active individuals. This study only examined the immediate effects of the NuNee. The long-term influences on pain and function are still unknown.

Conclusions

This study examined the immediate effects of the NuNee patellar support on individuals with patellofemoral pain while performing the modified star excursion balance test. No significant differences were found between conditions for any of the tested variables. A larger sample size and increased perceived pain upon arrival for data collection are needed to fully investigate the efficacy of the NuNee patellar support. Although our results are inconclusive, these preliminary findings reveal that the NuNee patellar support may show promise as a therapeutic intervention for treating patellofemoral pain.
References


Science in Sports and Exercise, 44(9), 1747–1755. https://doi.org/10.1249/MSS.0B013E318256903A


Appendix A - Informed Consent

Non-Medical Informed Consent for Research

<table>
<thead>
<tr>
<th>Principal Investigator (PI)</th>
<th>Jean McCrory, PhD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department</td>
<td>Human Performance</td>
</tr>
<tr>
<td>Co-Investigator(s)</td>
<td>Nick Linn, Corrie Mancinelli, PT, PhD, GCS and Kate Jochimsen, PhD, ATC</td>
</tr>
<tr>
<td>WVU IRB Protocol #</td>
<td>2210657219</td>
</tr>
<tr>
<td>Research Project Title</td>
<td>The Immediate Effects of the NuNee Patellar Support on Individuals with Patellofemoral Pain Syndrome</td>
</tr>
</tbody>
</table>

Introduction

You have been asked to participate in this research study. The research has been explained to you by an authorized member of the research team. This research is being conducted to fulfill the requirements for a masters degree in Exercise Physiology from the Department of Human Performance at West Virginia University. This research is being conducted under the supervision of the Principal Investigator listed above.

What is the purpose of this study?

The purpose of this study is to examine the immediate effects of the NuNee patellar support on perceived pain, biomechanics, and function in individuals with patellofemoral pain while performing the modified star excursion balance test. WVU expects to enroll approximately 30 participants in the research study.

What will you be asked to do?

Following informed consent, we will use 3-dimensional (3D) motion analysis testing with surface-mounted retroreflective markers and a 10-caera motion analysis system (Vicon, Hauppauge, NY) and 2 force platforms (Bertec, Worthington, OH) to collect kinetic and kinematic data during the modified star excursion balance test. Standing calibrations will be used to create participant-specific models to determine segment pose and ankle and knee joint centers. Subjects will then perform the modified star excursion balance test under three different conditions. Study personnel will provide verbal instructions and demonstrations of the tasks. Three trials for each condition will be collected. Participants will also be asked for fill out the Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire as well as other questionnaires regarding basic demographics and symptoms. Study Personnel will also record participants affected limb length which will be used to normalize data. This will be completed in a single testing session and should last approximately one to two hours.
What are the possible risks and discomforts?

The tasks associated with this study, performance of exercises, have typical risks associated with any physical exertion, including post-activity soreness or in rare cases, muscle strains. All activities in this study are considered standard of care and have no greater risks associated with them than typical exercise or physical therapy evaluation and treatment. We will apply stickers to your skin during the 3-dimensional functional assessment and surface electrodes during hip strength testing and 3-dimensional functional assessment. There is a small risk of skin irritation from these markers and electrodes.

In addition, there is always the risk of uncommon or previously unknown side effect(s) or event.

If you don’t want to take part in this study, are there other choices?

The alternative is not to participate in the study. You do not have to participate in this study.

Will you benefit from taking part in this study?

You may or may not directly benefit from participating in this research. The knowledge gained from this research may eventually benefit others.

Will you receive any payment for taking part in this study?

You will not be paid for participating in this study. Your data, research results, or any other information related to this research or used in this research study may contribute to a discovery. In some instances, your data, your research results, the discoveries, or any other information related to this research study (even if identifiers are removed) may be of commercial value. The information may be sold, patented, or licensed by the Principal Investigator and West Virginia University for use in other research or the development of new products. You will not retain any property rights, and you will not be eligible to share in any monetary or commercial profit that the Principal Investigators, West Virginia University, or their agents may realize.

Who will see the information that you give?

We will keep your information as confidential as possible. However, if the law requires that we disclose your confidential information, every effort will be made to limit the use and disclosure of the information. Your name will not be used in the publication of information about the research.

Your research records could be subpoenaed by court order or may be inspected by federal regulatory authorities without your additional consent.

There are instances where the researcher is legally required to provide information to the appropriate authorities. This could include the mandatory reporting of information about behavior that is imminently dangerous to you or others, such as suicide, child abuse, etc.

We will make every effort to safeguard your data, but as with anything online, we cannot guarantee the security of data transmitted via the Internet. Third-party applications used in this study may have Terms of Service and Privacy policies outside of the control of West Virginia University. To reduce this risk, all the data will be protected with a password. Additionally, all paper consent forms will be kept in a locked file cabinet in a faculty office (HSC South 8501A.
which requires key entry) located inside the research laboratory (HSC South 8501 which requires keycard entry). The only identifiable information will be the signed consent form. All other data collected will be deidentified.

**Will your information be used for future research?**

Identifying information might be removed from your private information collected as part of this research. The information could be used for future research or distributed to another Principal Investigator for future research without obtaining additional informed consent.

**HIPAA Authorization**

Federal and state privacy laws, including the Health Insurance Portability and Accountability Act (HIPAA), require West Virginia University to obtain your permission before using or disclosing your protected health information for purposes of this research project.

You do not have to sign this authorization. However, if you choose not to sign the authorization, you will not be able to participate. The decision you make regarding this HIPAA Authorization will not affect your health care, enrollment in health plans, or eligibility for benefits.

**Persons/Organizations Providing the Information**

Patient / WVUHS

**Persons/Organizations Receiving the Information**

- The research site(s), including West Virginia University Health System (WVUHS), WVU Medicine, University Health Associates, and the research and medical staff.
- Health care providers who provide services to you as part of this research.
- Laboratories and other people and groups that review your health information as part of this research in compliance with the research protocol.
- The members and staff of the institutional review board assigned to oversee the research.
- The West Virginia University Office of Human Research Protections and the West Virginia University Office of Sponsored Programs.
- WVU Department of Human Performance research staff.

**The Following Information Will Be Used**

Information from your existing medical records and new information about you that is created or collected during this research, such as history, clinic visit notes, nursing and staff notes, laboratory results, x-rays, demographic data, imaging scans, and study forms.

**The Information is Being Disclosed for the Following Reasons**

- Review of your data for quality assurance purposes
- Publication of research results (without identifying you)
• Other research purposes such as: 1) developing better understanding of how we can improve the treatment of patellofemoral pain syndrome 2) improving the design of future related studies.

You may Cancel this Authorization at Any Time by Writing to the Principal Investigator

Jean McCrory, PhD
Department of Human Performance
1 Medical Center Drive
8604B Health Sciences Center South
Morgantown, WV 26506

If you cancel this authorization, any information that was collected cannot be withdrawn. Once information is disclosed, according to this authorization, the recipient may re-disclose it, and then the information may no longer be protected by federal regulations.

This authorization will expire at the end of the research unless you cancel it before that time.

Signatures

Participant/Legally Authorized Representative (LAR) Signature
I have read this HIPAA Authorization form describing how my protected health information will be used. I have had a chance to ask questions about the use of my protected health information and I have received answers to my questions. I agree to the use of my protected health information for this research.

Participant/LAR Signature

Printed Name

Date
Who should you contact if you have questions or concerns?

If you have any questions, concerns, or complaints about this research, contact

Principal Investigator Name: Jean McCrory, PhD
Telephone Number: (304)293-0442
Email: jlmccrory@hsc.wvu.edu

Co-Investigator: Nick Linn
Telephone Number: (918)269-0785
Email: nl00015@mix.wvu.edu
Laboratory Contact: sportsmedresearch@hsc.wvu.edu

If you are hurt or injured from being in this research, you should contact either the principal investigator or co-investigator listed above.

For information regarding your rights as a participant in research or to talk about the research, contact the WVU Office of Human Research Protections (OHRP) at (304) 293-7073 or by email at IRB@mail.wvu.edu.

Do you have to participate in this study?

Participation in this research study is voluntary. You are free to withdraw your consent to participate at any time. If you withdraw or do not wish to participate, your future care or status at West Virginia University will not be affected.

In the event new information becomes available that may affect your willingness to participate in this research, the information will be given to you so that you can make an informed decision about whether or not to continue your participation.

WVU Student participants:
If you do not wish to participate or if you choose to withdraw, your class standing, and grades will not be affected and will involve no penalty to you.

WVU Employee participants:
If you do not wish to participate or choose to withdraw, your employment status at West Virginia University will not be affected.

Do you want to be contacted with information about future studies?

Future research may be conducted for which you may be eligible. If you are interested in being contacted for future research, please indicate so by completing this section. Leaving the box blank is seen as NOT giving consent.

☐ Yes, I want to be contacted.
☐ No, I do not want to be contacted.

Signatures

Participant Signature Section

You have been given the opportunity to ask questions about the research and you have received answers concerning areas you did not understand. Upon signing this form, you will receive a copy.

I willingly consent to participate in this research.

Printed Name:

________________________________________

Signature:

________________________________________

Date:

Consenting Individual Signature Section (Authorized Staff)

The participant has had the opportunity to have questions addressed. The participant willingly agrees to be in the study.

Printed Name:

________________________________________

Signature:

________________________________________

Date:
# Appendix B – Eligibility Checklist

<table>
<thead>
<tr>
<th>Eligibility Criteria</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 18 to 45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patellofemoral pain</td>
<td></td>
<td></td>
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<tr>
<td>Knee pain ≥ 3 months</td>
<td></td>
<td></td>
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<tr>
<td>Pain level ≥3 during functional activities</td>
<td></td>
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<tr>
<td>Hypermobile patella/patellar instability</td>
<td></td>
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<tr>
<td>Previous surgery to affected knee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current spine or lower extremity injuries (other than knee pain)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currently involved in interventions for patellofemoral pain</td>
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</tbody>
</table>

## Clinical Screening

<table>
<thead>
<tr>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td>Eccentric Step Test</td>
</tr>
<tr>
<td>Palpation</td>
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</tbody>
</table>
Appendix C - KOOS

KOOS

Please complete the survey below.
Thank you!

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities.

Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms
These questions should be answered thinking of your knee symptoms during the last week.

1) S1. Do you have swelling in your knee?

- Never
- Rarely
- Sometimes
- Often
- Always

2) S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?

- Never
- Rarely
- Sometimes
- Often
- Always

3) S3. Does your knee catch or hang up when moving?

- Never
- Rarely
- Sometimes
- Often
- Always

4) S4. Can you straighten your knee fully?

- Always
- Often
- Sometimes
- Rarely
- Never

5) S5. Can you bend your knee fully?

- Always
- Often
- Sometimes
- Rarely
- Never

Stiffness
The following questions concern the amount of joint stiffness you have experienced during the last week in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

6) S6. How severe is your knee joint stiffness after first wakening in the morning?

- None
- Mild
- Moderate
- Severe
- Extreme
### 7. How severe is your knee stiffness after sitting, lying or resting later in the day?

- None
- Mild
- Moderate
- Severe
- Extreme

### Pain

8. How often do you experience knee pain?

- Never
- Monthly
- Weekly
- Daily
- Always

### What amount of knee pain have you experienced the last week during the following activities?

9. Twisting/pivoting on your knee

- None
- Mild
- Moderate
- Severe
- Extreme

10. Straightening knee fully

- None
- Mild
- Moderate
- Severe
- Extreme

11. Bending knee fully

- None
- Mild
- Moderate
- Severe
- Extreme

12. Walking on flat surface

- None
- Mild
- Moderate
- Severe
- Extreme

13. Going up or down stairs

- None
- Mild
- Moderate
- Severe
- Extreme

14. At night while in bed

- None
- Mild
- Moderate
- Severe
- Extreme

15. Sitting or lying

- None
- Mild
- Moderate
- Severe
- Extreme
16) P9. Standing upright
- None
- Mild
- Moderate
- Severe
- Extreme

Function, daily living
The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

17) A1. Descending stairs
- None
- Mild
- Moderate
- Severe
- Extreme

18) A2. Ascending stairs
- None
- Mild
- Moderate
- Severe
- Extreme

For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

19) A3. Rising from sitting
- None
- Mild
- Moderate
- Severe
- Extreme

20) A4. Standing
- None
- Mild
- Moderate
- Severe
- Extreme

21) A5. Bending to floor/pick up an object
- None
- Mild
- Moderate
- Severe
- Extreme

22) A6. Walking on flat surface
- None
- Mild
- Moderate
- Severe
- Extreme

23) A7. Getting in/out of car
- None
- Mild
- Moderate
- Severe
- Extreme
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>24)</td>
<td>A8. Going shopping</td>
</tr>
<tr>
<td>26)</td>
<td>A10. Rising from bed</td>
</tr>
<tr>
<td>27)</td>
<td>A11. Taking off socks/stockings</td>
</tr>
<tr>
<td>28)</td>
<td>A12. Lying in bed (turning over, maintaining knee position)</td>
</tr>
<tr>
<td>29)</td>
<td>A13. Getting in/out of bath</td>
</tr>
<tr>
<td>30)</td>
<td>A14. Sitting</td>
</tr>
<tr>
<td>31)</td>
<td>A15. Getting on/off toilet</td>
</tr>
<tr>
<td>32)</td>
<td>A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc.)</td>
</tr>
</tbody>
</table>

For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.
33) A17. Light domestic duties (cooking, dusting, etc.)

- None
- Mild
- Moderate
- Severe
- Extreme

Function, sports and recreational activities
The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the last week due to your knee.

34) SP1. Squatting

- None
- Mild
- Moderate
- Severe
- Extreme

35) SP2. Running

- None
- Mild
- Moderate
- Severe
- Extreme

36) SP3. Jumping

- None
- Mild
- Moderate
- Severe
- Extreme

37) SP4. Twisting/pivoting on your injured knee

- None
- Mild
- Moderate
- Severe
- Extreme

38) SP5. Kneeling

- None
- Mild
- Moderate
- Severe
- Extreme

Quality of Life

39) Q1. How often are you aware of your knee problem?

- Never
- Monthly
- Weekly
- Daily
- Constantly

40) Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

- Not at all
- Mildly
- Moderately
- Severely
- Totally
### Q3. How much are you troubled with lack of confidence in your knee?
- Not at all
- Mildly
- Moderately
- Severely
- Totally

### Q4. In general, how much difficulty do you have with your knee?
- None
- Mild
- Moderate
- Severe
- Extreme
Appendix C - Pain

Pain descriptions:

Description of Pain:

- Sharp
- Shooting
- Dull
- Sore
- Aching
- Tender
- Pinching
- General
- Local
- Other

Visual Analog Scale:

<table>
<thead>
<tr>
<th>Subject #: __________</th>
<th>Condition: __________</th>
<th>Trial: __________</th>
</tr>
</thead>
</table>

No Pain

Worst Pain Imaginable