THE EFFECT OF A PATELLOFEMORAL KNEE BRACE ON QUADRICEPS MUSCLE ACTIVITY

By

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THE EFFECTS OF A PATELLOFEMORAL KNEE BRACE ON QUADRICEPS MUSCLE ACTIVITY

By

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Patellofemoral pain syndrome (PFPS) is one of the most common musculoskeletal disorders seen in sports medicine clinics today. The basic etiology of this syndrome remains unknown. The exact cause of PFPS has been thought to vary from patient to patient; therefore, a thorough investigation of history for each patient is necessary. The methods to treat PFPS vary greatly ranging from quadricep strengthening to patellofemoral bracing. Research has been conducted on the effects of the patellofemoral brace on patellar alignment, but little is known on the effect of the patellofemoral brace on quadriceps muscle activity. Therefore, the purpose of the present study was to assess the effect of a patellofemoral knee brace on quadriceps muscle activity.

Twenty-three health subjects who had no history of previous knee injury participated in this study. Prior to testing, each subject’s 1-maximum repetition (1-RM) for CKC (leg press), and OKC exercises (knee extension), were recorded. At least 48 hours later the subjects returned for testing. Electromyographic (EMG) electrodes were
placed over the non-dominant leg’s vastus medialis (VM) and vastus lateralis (VL) muscles, as well as the patella. A three-minute warm-up on a stationary bike was followed by 5 repetitions of both the knee extension and leg press exercises performed at 75% of the subject’s 1-RM. The order of conditions was randomized prior to testing. Muscle activity was recorded using surface EMG during the concentric and eccentric phases of each exercise. The data were analyzed to identify interactions.

The analyses demonstrated no significant interactions between knee extension and leg press exercises during the braced and unbraced conditions. However, there was a significant main effect between the braced and unbraced conditions regardless of exercise type and phase of exercise. The results revealed greater muscle activation during the braced condition versus the unbraced condition suggesting that a patellofemoral brace positively effects muscle activity. Further research is needed to assess the effects a patellofemoral knee brace on quadricep muscle activity during OKC and CKC exercises with patellofemoral pain subjects.
CHAPTER 1
INTRODUCTION

The knee is a very important joint in the body, being involved in locomotion and stability of the lower extremity. The knee’s involvement in locomotion causes it to be a common site for injury. These injuries can be painful and often debilitating taking an athlete out of competition. Patellofemoral pain syndrome (PFPS) is one of the most common musculoskeletal disorders affecting young adults. PFPS is often misdiagnosed as anterior knee pain, chondromalacia patella, patellar pain syndrome, patellofemoral arthralgia, patellar pain, and patellar femoral pain. The basic etiology of this syndrome is still unknown, but numerous predisposing factors have been mentioned in the literature.

Many muscles work together to enable the knee joint to be functional. The main muscle groups are the pes anserinus, hamstrings, and the quadriceps. The pes anserinus muscle group consists of the gracillis, sartorius, and the semitendinosus (a hamstring muscle). The hamstrings are composed of the semitendinosus, semimembranosus, and biceps femoris. The quadriceps include the vastus medialis, vastus lateralis, vastus intermedius, and rectus femoris.

The vastus medialis obliquus muscle (VMO) of the quadriceps muscle group has been thought to be a major contributor to patellofemoral joint pain. The VMO pulls the patella medially during knee extension and has been reported to fire later than the vastus lateralis (VL) in people with patellofemoral joint pain. This firing pattern may effect patellar tracking, causing the patella to track laterally because the VMO is not firing on
time. Exercises that focus on VMO activity are emphasized to normalize the VMO:VL firing ratio to correct the patellar tracking pattern. Reducing the abnormality of this ratio has been thought to decrease patellofemoral joint pain. Knee braces, specifically patellar braces, have been thought to help with this process. The patellofemoral knee brace places pressure on the lateral side of the patella to deter lateral movement.

There has been much debate on what type of rehabilitation program should be implemented for athletes with patellofemoral pain. Treatment techniques frequently used include quadriceps exercises focusing on the VMO, patellar taping, electrical stimulation to guide quadriceps exercises, nonsteroidal anti-inflammatory agents, and patellofemoral knee braces. A consensus on which rehabilitation program works best has not been reached.

Knee pain is a common complaint in sports medicine clinics, accounting for 23 to 31% of the injuries. Of that percentage patellofemoral joint pain is the most common. The high volume of patellofemoral injuries makes it important to understand the many different ways to treat them. Previous studies have addressed the efficacy of patellofemoral knee braces for the prevention or treatment of anterior knee pain. Only one study had been found that investigated muscle activity, and muscle activity changes, while wearing a knee brace. Therefore, it becomes important to expand upon previous research to understand what is happening muscuarly while wearing a knee brace.

Statement of the Problem

The VMO is a major focus in the rehabilitation of patellofemoral pain; strengthening the VMO and improving the firing sequence with the VL are primary concerns. While an athlete is progressing through rehabilitation, it is common practice
to have them wear a knee brace to facilitate greater medial tracking. The knee brace has been shown to improve medial tracking, but the ramifications of potential changes in VMO activity while wearing the brace have not been thoroughly studied. It has been theorized that the VMO may not be as active while wearing the knee brace. Since the brace is pushing the patella medially during knee extension, the VMO does not have to work to pull the patella medially. If this is true, the knee brace may interfere with VMO training during functional rehabilitation. Therefore, the purpose of this study was to collect data on VMO and VL activity using surface electromyography (EMG) during exercises, with and without a patellofemoral knee brace.

**Hypotheses**

Five hypotheses were identified for this investigation.

- Vastus medialis (VM) and Vastus lateralis (VL) muscle activity will be reduced while wearing a knee brace as compared to not wearing a knee brace.

- Open kinetic chain (OKC) exercises will have greater VM and VL muscle activity as compared to closed kinetic chain (CKC) exercises when performed without a knee brace.

- OKC exercises will have greater VM and VL muscle activity as compared to CKC exercises when performed with a knee brace.

- OKC exercises will have greater VM and VL muscle activity as compared to CKC exercises during the first 45° of motion when performed without a knee brace.

- OKC exercises will have greater VM and VL muscle activity as compared to CKC exercises during the first 45° of motion done with a knee brace.

**Definition of Terms**

Four definitions were identified for this investigation.

- Closed kinetic chain (CKC) - a movement whereby the foot or hand is on the ground or some other surface. For the purpose of this study, the CKC exercise involves the use of the leg press machine.
Malalignment - lower extremity alignment factors associated with PFPS include femoral neck anteversion, genu valgum, knee hyperextension, Q angle, tibia varum, and excessive rearfoot pronation.\textsuperscript{55}

Open kinetic chain (OKC) - a movement whereby the foot or hand is off the ground.\textsuperscript{2} For the purpose of this study, OKC involves the use of the lower extremity performing concentric and eccentric knee extensions on the knee extension machine.

Patellofemoral Pain Syndrome (PFPS) - anterior knee pain that is often diffuse and along the medial aspect of the patella. Later, patellar pain and retropatellar pain are also seen.\textsuperscript{44}

**Assumptions**

Five assumptions were identified for this investigation.

- It was assumed that the subjects accurately performed all testing procedures as instructed by the tester.
- It was assumed that the subjects performed all the testing procedures/exercises to the best of their ability.
- It was assumed that all subjects gave accurate and honest answers to the medical history questionnaire.
- It was assumed that the surface EMG detected and displayed accurate quadriceps activity during the exercises.
- It was assumed that the brace remained in the proper location on the subject throughout testing.

**Limitations**

Three limitations were identified for this investigation.

- All of the subjects tested had healthy knees with no previous history of patellofemoral pain. Therefore, the subjects did not normally wear a patellofemoral knee brace.
- Subjects may not have performed to their best ability during testing procedures.
- The subjects being tested did not have prior experience with a knee brace; therefore, they were not acclimatized to the feel of exercise while wearing a knee brace. Accommodation of the knee brace was not possible due to the limitation of available knee braces.
Significance of Study

All rehabilitation programs should incorporate a functional aspect where the rehabilitation exercises specifically mimic their sport. It is important to ensure that the necessary muscles are being targeted during these functional exercises thereby enhancing the rehabilitation process. Athletes with patellofemoral pain often continue to participate in their chosen sport while going through a rehabilitation program. In order for continued participation, the athletes may wear a knee brace to help decrease the pain during the activity. Only one study had been found that determined the changes of muscular activity while wearing a knee brace during open chain activities, while no known studies we found that investigated CKC exercises. Does the knee brace prolong the rehabilitation process by not allowing the VMO to be functionally rehabilitated? It is important for athletic trainers to know if the application of a knee brace decreases the firing of the VMO. The results of this study may give athletic trainers and rehabilitation specialist the answer they need to adjust patellofemoral rehabilitation programs accordingly. Therefore, once adjusted, VMO exercises done without the knee brace will not be in contradiction with functional exercises done with the knee brace.
CHAPTER 2
REVIEW OF LITERATURE

In the literature, there have been numerous studies conducted on the issue of Patellofemoral pain syndrome (PFPS). This topic is widely debated and there are many different views on the causative factors of PFPS. No consensus exists on a generic PFPS rehabilitation program. An overview of PFPS as well as a brief review of anatomy is needed for the purposes of this study. A review of the current literature concerning PFPS will reveal a need for more research in the area of rehabilitation.

Patellofemoral Pain Syndrome

Patellofemoral pain is the most frequent musculoskeletal disorder involving the knee seen in sports medicine clinics. Many studies have verified the prevalence of patellofemoral pain as the most common clinical condition presented to clinicians who treat musculoskeletal conditions. Patellofemoral pain was demonstrated by Deveraux and Lachmann to be the diagnoses of 25% of all knees evaluated in a sports injury clinic over a five year period. According to McConnell, patellofemoral pain affects one in four of the general population. In addition, the incidence of this disorder can also be seen in a study conducted by Finestone et al. in a military setting. Throughout 14 weeks of basic training 84 out of 395 knees were diagnosed as having overuse patellofemoral pain. This high incidence of patellofemoral pain seen in these studies encourages more extensive research on the topic so that a better understanding and consensus of treatment may be reached.
The symptoms of PFPS are many and often vary from person to person in severity. The most common symptom in patients with PFPS is anterior knee pain. Pain is generally diffuse and arising from the anterior aspect of the knee along the medial aspect of the patella; however, lateral patella pain and retropatellar pain are also seen. This anterior knee pain often arises during and after physical activity that increases patellofemoral compressive forces. These activities include loading of the lower extremity in walking up and down stairs, squatting, and prolonged sitting with knees flexed. During an assessment of an athlete with patellofemoral pain the Patellar Grind Test is often positive and palpation of the medial and lateral borders of the patella cause pain. Some other symptoms that may be present include swelling, loss of motion, and a sensation of giving way or instability of the knee joint.

Anatomy

The knee joint is surrounded by many muscle complexes that work together providing lower extremity stability and locomotion. The muscle complexes involved in knee motion are the quadriceps, hamstrings, pes anserine, and gastrocnemius/popliteus/plantaris. All of these muscles are involved in knee function and most have some role on patellar tracking. Many bones are also involved in this joint and they include the femur, patella, tibia and fibula.

The patella is classified as a sesamoid bone and it is the largest in the human body. This sesamoid bone is located in the tendon of the quadriceps femoris muscle and is triangular in shape. The patella articulates between the two femoral condyles in the groove provided. The patella acts to increase the leverage of the tendon of the quadriceps femoris muscle, maintaining the position of the tendon when the knee is flexed, and protecting the knee joint. Patellar tracking within the groove is dependent upon the pull
of the quadriceps muscles and patellar tendon, the shape of the patella, and the depth of the femoral condyles.\textsuperscript{2,57}

The quadriceps muscles include vastus medialis (VM), vastus lateralis (VL), vastus intermedius (VI), and rectus femoris (RF). The VM originates on the medial linea aspera of the femur. The VM inserts into the tibial tuberosity via the quadriceps tendon, patella, and patellar tendon. This muscle serves to extend the knee as well as function as a major medial stabilizer for the patella.\textsuperscript{2} During knee extension the VM pulls the patella medially due to its orientation relative to the patella.\textsuperscript{44} The VM is angled at approximately 55° from the longitudinal axis of the femur aiding in medial patellar pull.

The VL originates on the lateral linea aspera of the femur. It inserts into the tibial tuberosity via the patella and patellar tendon. The VL also functions to extend the knee. During knee movement and patellar tracking, the VL pulls laterally on the patella. The VI originates on the anterior and lateral surfaces of the body of the femur. This muscle also inserts on the tibial tuberosity via the patella and patellar tendon. The main function of this muscle is knee extension pulling the patella proximally and laterally.\textsuperscript{2,57}

The RF muscle is the only two-jointed quadriceps muscle. It originates on the anterior inferior iliac spine, and attaches on the tibial tuberosity via the patella tendon. This muscle functions as a hip flexor as well as a knee extensor. During patellar tracking the RF muscle pulls the patella proximally and laterally.\textsuperscript{2,57}

**Contributing Factors of PFPS**

The source of patellofemoral pain has been in debate and cannot be sufficiently pinpointed. Authors suggest several possibilities as to the origin of PFPS described in detail in the following paragraphs.
Several etiologies are mentioned by Brody and Thein\textsuperscript{7} in their review of nonoperative treatments for patellofemoral pain. Intrinsic and extrinsic factors include quadriceps insufficiency, hamstrings and iliotibial band inflexibility, lateral retinacular tightness, femoral anteversion, a wide pelvis, excessive pronation, knee ligament injury, acute trauma, instability, immobilization, and overuse.\textsuperscript{7,14,39} In a review of current PFPS issues Thomee et al.\textsuperscript{55} discusses three major contributing factors of PFPS. These factors include lower extremity and/or patellar malalignment, muscular imbalance, and overactivity. Another factor contributing to PFPS involves abnormal patellar tracking which may be caused by decreased VMO strength compared to the VL, or the firing rate of the VL before the VMO.

**Malalignment**

Lower extremity malalignment factors include femoral neck anteversion, genu valgum, knee hyperextension, quadriceps angle (Q-angle), tibia varum, and excessive rearfoot pronation.\textsuperscript{55} These malalignment factors are seen in people with patellofemoral pain, however these factors may also be seen in 60 to 80\% of the normal population. This questions the use of the term malalignment.\textsuperscript{47} Patellar malalignment refers to the configuration of the trochlea and the inter-relationship between the patella and femoral surfaces.\textsuperscript{55}

**Muscular Imbalance**

Muscular imbalances associated with flexibility have been discussed as important factors contributing to knee pain. This is usually referred to as quadriceps or hamstring muscle tightness.\textsuperscript{55} This has also been demonstrated in decreased knee extensor strength in people with PFPS, but it is undetermined whether this decreased strength causes or is a result of PFPS.\textsuperscript{55} The muscular imbalance associated with firing sequence between the
VMO and the VL has also been discussed. The VMO has been shown to have a slower reflex response time than the VL as measured by EMG. This type of imbalance may lead to patellar tracking problems.

**Patellar Tracking**

A commonly accepted cause of patellofemoral pain is related to abnormal patellar tracking within the trochlear groove which increases patellofemoral joint stress. Insall et al., using radiographic examination, stated that patellar tracking abnormalities were the major cause of patellar pain. This abnormal patellar tracking and increased joint stress is believed to increase shearing and compression associated with articular cartilage wear and subsequent degeneration. The articular cartilage itself has been dismissed as a source of symptoms. It has been proposed that the subadjacent endplate is exposed to pressure variations that would normally be absorbed by healthy cartilage, and this pressure then stimulates pain receptors in the subchondral bone. This tracking problem is believed to be caused by a muscular imbalance of the dynamic stabilizers of the patella. This imbalance leads to excessive lateral forces in relation to the medially directed forces acting on the patella. This patellar tracking problem has often been conservatively treated by strengthening the dynamic stabilizers of the patella. These dynamic stabilizers include pes anserinus and semimembranosus muscles, biceps femoris, VM, VL, VI, and RF. The VMO has been implicated as being the primary medial stabilizer of the patella.

**Vastus Medialis Oblique**

The VMO has been identified as the distal fibers of the VM. Lieb and Perry stated that these distal fibers are angled approximately 55° from the longitudinal axis of the femur. This increased angle gives the VMO a mechanical advantage allowing the
muscle to be proficient in preventing lateral patellar subluxation. Consequently, the VMO has been thought to counterbalance the lateral pull of the larger VL to ensure patellar stability within the trochlear groove. The VMO is very important in this role, and according to some studies investigators have found differences in VMO and VL activity. These differences suggest that the lateral pull of the VL is not adequately counteracted by the medial pull of the VMO. This greater lateral pull results in lateral tracking and malalignment of the patella causing patellofemoral pain.

VMO-VL firing rate differences have been thought to be another contributing factor to PFPS. In studies where the VMO had been thought to be weaker than the VL, authors suggest that the timing of the muscle contractions may also differ. The VL has been believed to contract before the VMO in concentric and eccentric quadriceps activity instead of simultaneously. This hypothesis has been supported by Voight and Wieder, who found that activation of the VMO in subjects with patellofemoral pain was delayed as compared to the VL during a patellar tendon tap. Morrish and Woledge also reported a shorter reflex response time of the VL compared to the VMO in patients with patellofemoral pain. In contrast, normal individuals had significantly earlier VMO firing versus the VL in the same study. In contrast, a study conducted by Powers et al. found no timing or intensity differences between the VM and VL in patients with patellofemoral pain.

**Treatment for Patellofemoral Pain**

**Operative**

Operative treatment for patellofemoral pain should always be a last resort, and only if nonoperative conservative treatments have been unsuccessful. These treatment methods are often directed at treating malalignment, extensor mechanism abnormalities,
or injured cartilage. Some of these operative treatments include lateral retinacular release, proximal realignment procedures, elevation of the tibial tubercle, anteromedial tibial tubercle transfer and elevation, articular cartilage procedures, and patellectomy.\textsuperscript{55}

**Non-operative**

Non-operative treatment of patellofemoral pain is always preferable to operative treatment. Every non-operative protocol should be exhausted before surgery is considered. A successful non-operative or conservative treatment first requires a thorough analysis of predisposing anatomical, physiological and lifestyle factors.\textsuperscript{7} Once these have been established the causative factor of the pain may be identified and corrected through a rehabilitation program. Conservative interventions include patient education, mobilization techniques, modalities, medications, acupuncture, quadriceps strengthening, taping, and bracing.\textsuperscript{5,7} These have also been used in combination to create a well rounded rehabilitation program.\textsuperscript{3,5,7}

Patient education is very important with any injury and especially with patellofemoral pain. The patient must be informed on the contributing factors and the treatments available, therefore enabling them to modify and minimize possible causes of their pain. Patient education is also important for recurrent patellofemoral pain, so the patient may avoid exacerbating symptoms.\textsuperscript{7} Self-management becomes an important role in the long-term care of knee injuries. Patient education should come first in the management of patellofemoral pain followed by the chosen rehabilitation protocol.

Mobilization techniques such as patellar manipulation and muscle stretching have been investigated as non-operative treatments of patellofemoral pain. Patellar mobilizations can be applied when soft tissue shortening produces an imbalance such as a lateral glide, tilt, or rotation of the patella.\textsuperscript{7} Rowlands et al.\textsuperscript{48} compared a group of
patients who received a patellar mobilization procedure with a group that received detuned ultrasound. The patellar mobilization involved a manual sustained glide followed by high-velocity low-amplitude manipulation. The patellar mobilization group demonstrated significantly lower levels of pain than the control group at a 1-month follow-up, but no difference was found in functional outcome between groups.48

Muscle stretching techniques involve the lateral structures of the knee such as the iliotibial band, lateral retinacular tissues, and other surrounding muscular complexes such as the quadriceps, hamstrings, and gastrocnemius. Doucette and Goble13 studied patients with lateral patellar compression, and found that after an 8-week rehabilitation program the patients that were pain free had an improved Ober’s test and an improved congruence angle averaging 6.6°. A study conducted by Smith et al.51 found a correlation between patellofemoral pain and poor hamstring and quadriceps flexibility. Tightness in the gastrocnemius muscle can contribute to patellofemoral pain by increasing dynamic pronation, which in turn increases patellofemoral joint reaction forces.7,15,27,50

The goal of modalities in the treatment of patellofemoral pain is to decrease pain. This is primarily achieved through the use of ice, however ultrasound, phonophoresis, and iontophoresis have also been used.1,7 Modalities such as electrical stimulation have been used to facilitate quadriceps muscle activity. Bohannon6 used VMO electrical stimulation to prevent patellar subluxation during a rehabilitation protocol. Electrical stimulation is helpful in muscle reeducation for individuals with acute pain, edema, or significant weakness who are unable to activate their quadriceps.7

**Quadriceps strengthening**

Quadriceps strengthening is an important part of patellofemoral pain rehabilitation. A rehabilitation program often consists of a combination of quadriceps strengthening and
another chosen non-operative treatment.\textsuperscript{7} The mechanism by which strengthening decreases patellofemoral pain symptoms and functional ability has not been established. The wide spread use of this method indicates its importance in the over all PFPS rehabilitation process.

Natri et al.\textsuperscript{39} investigated factors that may predict long-term outcome in chronic PFPS. Forty-nine subjects with unilateral PFPS were enrolled in the study and underwent a 6-week conservative treatment protocol. The protocol consisted of rest, nonsteroidal anti-inflammatory medication, and intensive quadriceps strengthening exercises. A follow-up evaluation was performed at 6 months and 7 years post the 6-week protocol. The results of the study indicated that restoration of quadriceps strength and function to the affected extremity was important for long-term patient recovery.

Witvrouw et al.\textsuperscript{61} investigated open kinetic chain (OKC) versus closed kinetic chain (CKC) exercises for patellofemoral pain. The subjects were divided into two groups and they either performed OKC or CKC exercise protocols. Each subject was evaluated with a subjective outcome assessment, functional outcome assessment, muscle-strength measurement, and muscle length measurement prior to 5 weeks into training, and 3 months after training. The CKC group had a few significantly better functional results for some of the tested parameters compared to the OKC group. However, after the protocols were completed both groups demonstrated a significant increase in overall functionality, as measured by the Kujala scale, and a decrease in pain. Therefore, the authors concluded that both OKC and CKC exercises lead to improved subjective and clinical outcome scores in patients with anterior knee pain.\textsuperscript{61}
Another study was conducted by Doucette and Goble\textsuperscript{13} to assess exercise on patellar tracking. Twenty-eight subjects and 56 knees diagnosed with lateral patellar compression syndrome were studied. The subjects participated in a five-stage rehabilitation program designed to meet each subject’s specific needs using VMO exercises. These exercises included straight leg raises (SLR) with external rotation, squats, seated leg press, single knee dips, and others. Doucette and Goble\textsuperscript{13} found that patellar tracking was improved with VMO strengthening in lateral patellar compression syndrome.

All of the above studies focused on quadriceps strengthening exercises to decrease PFPS symptoms. Strengthening with a patellofemoral brace was not studied in any of these studies. The exercises used to strengthen the quadriceps in a PFPS rehabilitation protocol need to be investigated while wearing a patellofemoral knee brace.

**Patellofemoral taping**

Patellofemoral taping is another method employed by rehabilitation specialists to treat PFPS. This technique was devised by McConnell and has been utilized to create a passive correction of lateral patellar tracking, tilt, and rotation.\textsuperscript{28} Studies investigating its ability to correct patellar alignment during quadriceps rehabilitation thereby decreasing pain associated with PFPS have been conducted.\textsuperscript{34,16} Other investigations include EMG activity of the quadriceps with and without patellar taping\textsuperscript{19,40} and patellofemoral taping used in combination with other treatments such as exercise and modalities mentioned above.

Worrell et al.\textsuperscript{62} investigated the effect of patellar taping on patellar position as determined by magnetic resonance imaging (MRI) in patients with patellofemoral pain. Static MRI was used with the knee at eight different angles of knee flexion to determine
the placement of the patella in the trochlear groove. Patellar placement was determined by digitization of patellofemoral congruence angle, lateral patellar displacement, and lateral patellar angle. The authors concluded that patellar taping influenced patellar position, produced less lateral patellofemoral congruence angle, and a more medial lateral patellar displacement, at 10° of knee flexion during the static MRI.

Another study conducted by Kowall et al.28 also studied patellar taping in the treatment of patellofemoral pain. This study incorporated a control group utilizing a physical therapy program and a second group that underwent a physical therapy program combined with patellar taping. The activity of the VM and VL muscles were assessed during a CKC step-up and step-down exercise using surface electromyography (EMG) electrodes. Both groups experienced a statistically significant decrease in the frequency of pain, but no significant difference between the groups in their improvement as measured by a visual analog pain scale. The EMG activity of the symptomatic knees increased significantly from the beginning to the end of therapy for both groups, which was not seen in the asymptomatic knees. The increase in EMG activity was not significantly different between the two testing groups.28

Ernst et al.16 investigated knee kinetics with and without patellar tape in patients with PFPS. This study examined the effect of McConnell patellar taping on a single-leg vertical jump and lateral step-up. Maximal knee extensor moment, knee power, and vertical jump height were measured using a force platform and motion analysis system. The results indicated greater knee extensor moment and power with patellar taping than without.16
The effect of patellar taping on pain and neuromuscular performance was studied in subjects with patellofemoral pain by Ng and Cheng\textsuperscript{40}. The study was a pre-test post-test treatment design with the order of treatment randomized. Fifteen subjects performed a single leg stance with the stance leg in $30^\circ$ of knee flexion and wearing a weight belt equivalent to 20\% of their body weight, with and without the patellar tape. The results of the study indicated that patellar taping significantly decreased patellofemoral pain and VMO to VL EMG ratio. The VMO was found to be less active with the patellar tape and the researchers advised caution when taping and rehabilitation for PFPS are used together\textsuperscript{40}. This study indicated that further research is needed on this topic, possibly including patellofemoral bracing and EMG activity. These same results may occur with application of a patellofemoral brace which may undermine rehabilitation protocols, therefore further research is warranted.

A similar study was conducted by GilIeard et al.\textsuperscript{19} on the effect of patellar taping on the onset of VMO and VL muscle activity in persons with patellofemoral pain. Fourteen female subjects with patellofemoral pain walked up and down stairs with and without patellar taping. The results indicated that taping of the patellofemoral joint changed the timing of the VMO and VL activity during step-up and step-downs in patients with patellofemoral pain. The onset of VMO activity in particular occurred earlier with patellar taping during both tasks\textsuperscript{19}. These conclusions are in contrast to the above study indicating that further research in the area of EMG activity and patellar realignment devices are needed.

\textbf{Patellofemoral bracing}

Patellar braces are designed to assist in correct tracking of the patella in the trochlear groove, to decrease pain, and prevent patellar subluxation or dislocation.\textsuperscript{42}
These patellar braces are normally constructed of neoprene material with or without a patellar relief hole in the sleeve over the patella. Felt, rubber, or gel inserts may be placed in positions above, below, medial, or lateral to the patella to limit and control patellar tracking as the knee extends. These braces may also include medial and lateral stays to provide stability to the brace and to prevent wrinkling of the elastic material.

The use of patellofemoral bracing as a treatment technique and its effect on quadriceps muscle activity is what this study is focusing on. Many studies have been conducted advocating the use of a patellofemoral brace in either prevention or treatment of patellofemoral pain. A few studies indicated no significant relationship between bracing and patellar kinematics. Only one study had been found that investigated EMG activity of the VMO and VL with and without the use of a patellofemoral knee brace. These studies will be discussed to indicate the further need for more research.

A study conducted by Worrell et al. investigated the effect of patellar taping and bracing (Palumbo Brace, DynOrthotics LP, Vienna, VA) on patellar position as determined by MRI in patients with patellofemoral pain. During the study, static MRI images were taken at 8 different angles of knee flexion. It was concluded that patellar bracing and taping influenced patellar position at 10° of knee flexion during a static MRI condition. The researchers also agree that more investigation is needed to determine etiological factors and long-term outcomes of conservative and surgical treatment.

Shellock et al. were involved with a case study to determine the effect of applying a newly developed patellar realignment brace to a patient with lateral subluxation of the patella. The brace had a viscoelastic silicone insert with a guide designed to counteract patellar subluxation. MRI information taken during active movement indicated that the
brace corrected the lateral displacement of the patella. The patient involved in the study also underwent physical rehabilitation and had no painful symptoms 4 months later.49 This was a case study involving only one subject; therefore, more research is needed with additional subject participation to determine the effect of the patellar realignment brace.

Another research team, BenGal et al.4 investigated the role of the knee brace in prevention of anterior knee pain. The knee brace incorporated a silicon patellar support ring and was worn by 27 subjects (21 men, 6 women), who had no previous history of anterior knee pain, while performing increasingly intensive exertion exercises. As the exercise intensity increased, anterior knee pain syndrome appeared more frequently. Male athletes wearing the braces before the exercise sessions had significantly less incidence of PFPS than those that did not wear the brace. The researchers concluded use of the knee brace may be an effective way to prevent anterior knee pain in people performing intensive physical activity.4 More intensive investigation needs to be completed regarding this subject, feasibility prevents everyone participating in intensive physical exercise from wearing a knee brace. A look at what the knee brace is accomplishing while being worn needs to be investigated.

Another investigation was done on the patellar brace to assess its effect on performance in a knee extension strength test in patients with patellar pain.31 Lyshom et al.31 used a Cybex-II to test strength performance with and without the brace in 24 patients with patellofemoral arthralgia. Twenty-one patients improved their performance in the strength test with the brace than without the brace. Fourteen patients performed at least 95% of their control leg strength while wearing the brace. The researchers concluded that the results support the use of this brace in conservative management of
patients with patellofemoral arthralgias. The researchers in this study also advocate the use of a brace as a supplement in a quadriceps rehabilitation program to improve the effect of the training. The activity of the quadriceps needs to be examined while wearing the patellar brace to determine if this supplementation during quadriceps rehabilitation is appropriate.

Contrary to the above studies, Muhle et al. found no stabilizing effect of the tested brace in patients with patellar subluxation or dislocation during active joint motion. Muhle et al. examined 21 patients with clinical evidence of patellar subluxation or dislocation with kinematic MRI with and without a patellar realignment brace. The researchers found no statistically significant differences in the patellofemoral relationships before or after wearing the patellar brace.

The study conducted by Powers et al. indicated similar results concerning the effect of bracing on patellar kinematics in patients with patellofemoral joint pain. Kinematic MRI of the patellofemoral joint was taken through the ranges of 45 to 0° of knee flexion with and without a patellofemoral joint brace. The results indicated no statistically significant difference between the braced and unbraced trials.

One study was done concerning patellar bracing and its effect on quadriceps EMG activity. This study was conducted by Gulling et al. on 16 athletically active individuals who were all concurrently participating in physical therapy. All subjects demonstrated symptoms indicative of PFPS but had no history of knee surgery or traumatic knee ligamentous injury. Each subject was then tested on an isokinetic dynamometer (Kin-Com) with and without the patellofemoral brace (U1004-patellar stabilizer). Surface EMG activity was recorded from the VMO and VL during three
maximal concentric/eccentric quadriceps contractions at an angular velocity of 180°/second. The EMG data indicated that the application of the patellar brace produced significantly smaller IEMG (integrated EMG) signals than the non-braced condition in both muscles and both contractions. The IEMG data were also significantly greater for the VMO than the VL in both conditions, and during the concentric muscle contraction compared to the eccentric muscle contraction.

The results demonstrate that patellar bracing may lower neuromuscular activation of the quadriceps muscles during isokinetic knee extension. The researchers suggested this decrease of IEMG activity was a contribution in the reduction of symptoms of PFPS. By reducing stronger muscle contractions lateral patellar tracking may incidentally be reduced also. This study was conducted with only an OKC exercise. Similar investigations conducted with CKC are needed. Additionally, a study on a non-injured population would give researchers a better idea of the patellar brace’s effect on quadriceps activity. Further investigation is warranted to support or refute the findings of this study.

**Electromyography**

Surface EMG has been used in research to detect muscle activation. More specifically surface EMG has been used in studies when the activity of the quadriceps muscles was collected. There are many considerations that must be addressed when surface EMG is utilized.

A differential electrode configuration should be used with surface EMG. This configuration relates to the detection surface of the EMG electrode. This detection surface should consist of two parallel bars, both 1.0 cm long, 1-2mm wide, and 1.0 cm apart. A bandwidth of 20-500 Hz should be used with a roll-off of at least 12dB/octave,
and a common mode rejection ratio of >80dB. The noise should be <2uV rms (20-400 Hz) and an input impedance > 100 meg ohms.\textsuperscript{11}

The two electrodes should be placed on the midline of the muscle belly to receive the best signal. The electrodes on the midline of the muscle belly need to be between the myotendinous junction and the nearest innervation zone. The detection surfaces should be oriented perpendicular to the length of the muscle fibers.\textsuperscript{11}

Gulling et al.\textsuperscript{21} conducted a study on the effects of patellar bracing on quadriceps EMG activity during isokinetic exercise. The EMG electrodes were placed in the centers of the VMO and VL muscle bellies along the longitudinal axis of the muscle fibers and the centers of the electrodes were placed 3.0 cm apart. The two ground electrodes were placed over the medial and lateral malleoli. Raw EMG signals were collected at a sampling frequency of 1000 Hz, pre-amplified at a 1,000,000:1 gain, and processed through an analog to digital (AD) conversion. This rectified EMG activity was then integrated and stored on an IBM microprocessor and analyzed over the 10-35 degree arc of motion.\textsuperscript{21} This type of EMG set-up is similar to the process that will be utilized in the current study.

Ng and Cheng\textsuperscript{40} used a similar set up in a study investigating the effects of patellar taping on pain and neuromuscular performance in subjects with PFPS. Two pairs of Ag/Ag Cl surface electrodes with a diameter of 1 cm were used to record the EMG muscle activity of the VMO and VL. These electrodes were placed over the mid-point of both muscles along the muscle fiber directions. Each electrode on the same muscle was separated by 2.5 cm. The electrodes were attached to an input box and an amplifier that performed linear enveloping between 15-1000 Hz and a differential amplification of
1000x. The common mode rejection ratio (CMRR) of the amplifier was 80dB. The rectified full wave signal was input into an AD converter, which sampled at 2500 Hz and the digitized signals were sent to a personal computer with Global Lab software for analysis.40

Lam and Ng29 investigated the activation of the quadriceps muscle during semisquatting with different hip and knee positions in patients with anterior knee pain. This study did not apply patellofemoral tape or a brace during the exercises. Active surface electrodes with a built-in gain of 1000x and a band pass filter of 20-450 Hz were applied along the fiber direction of the muscles to detect muscle signals. Raw EMG signals were input into a data acquisition unit that performed AD conversions at a sampling frequency of 500 Hz. This digitized EMG data were then integrated over time and output to a personal computer for display and storage.29

The above studies used similar EMG parameters to determine muscle activation. These parameters varied depending on the type of software that was utilized for each individual study. Many of these parameters seen in the above studies will be utilized in the current study and will vary according to the software utilized.
CHAPTER 3
METHODS

The goal of this study was to gain information that would help in the development of rehabilitation protocols for patellofemoral pain. These protocols may change to benefit the athlete with a greater understanding of muscle function when performing these exercises with and without the patellar stabilizing brace. To accomplish this we utilized a within subject repeated measures design.

Subjects

Twenty-three healthy subjects from the University of Florida’s student body were recruited for this investigation. The subjects were between the ages of 18 and 30 years and did not have a history of any lower extremity injury. The subjects were also resistance trained and familiar with the knee extension and leg press exercise. Prior to participating, each subject read and signed an informed consent agreement approved by the university’s Institutional Review Board.

Instrumentation

Electromyography (EMG)

A Myopac EMG system (Run Technologies, Laguna Hills, CA) was used to collect the raw EMG signal. The unit specifications for the EMG included a frequency bandwidth of 10-1000 Hz, CMRR of 110 dB, input resistance of 1 MΩ, and a sampling rate of 2000 Hz. Following sampling, EMG data underwent an AD conversion and was stored on a PC-type computer using the DATAPAC 2000 (Run Technologies, Laguna Hills, CA) analogue data acquisition, processing, and analysis system.
Patellofemoral Knee Brace

The Patella Stabilizer with Universal Buttress by Müeller® was utilized for this study. This knee brace is secured to the leg by two Velcro straps, one below and one above the patella. Four different sizes (S, M, L, XL) were available for use by the subjects depending on the manufactures specifications of each subject’s knee and calf girth.

Measurements

One Repetition Maximum (1-RM)

The 1-RM test followed light cycling on a stationary cycle for 3 minutes and a warm-up set of 10 repetitions using low resistance (approximately 10% of body weight for the knee extension and 50% of body weight for the leg press). The 1-RM test for the knee extension exercise was assessed first, followed by the leg press. A five-minute recovery period was taken between exercises. For both exercises the weight was progressively increased (2.2kg for the knee extension and 4.4kg for the leg press) until the subject could no longer complete the concentric phase of the lift unassisted. The maximal weight the subject was able to lift concentrically unassisted was used as the 1-RM.

Muscle Activity

 Quadriceps muscle activity of the dominant leg during open kinetic chain (OKC) and closed kinetic chain (CKC) knee extension was determined from the amplitude of the EMG signal. To begin this procedure, each subject’s skin was shaved and cleaned with isopropyl alcohol to reduce skin impedance. Immediately following, bipolar 1-cm Ag/AgCl surface electrodes were placed parallel with the muscle fibers at a point midway between the motor point and the musculotendinous junction of the vastus medialis (VM).
and vastus lateralis (VL) using an inter-electrode distance of 1.5-cm. The electrode placements were confirmed with manual muscle testing and checked for cross-talk with real time oscilloscope displays.

After placement was confirmed, the maximal EMG activity of both muscles were measured and recorded during a 1-RM lift on the leg press and the leg extension machine. After a brief rest period, muscle activity was recorded during the concentric and eccentric phases of each exercise, which was done at 75% of the subject’s 1-RM. The first 45° and the second 45° of both the concentric and eccentric phases of each exercise were marked on the EMG with a manual switch controlled by the researcher. This manual switch was activated at the start of the concentric phase and released on the eccentric phase to distinguish the different contractions from each other on the EMG signal. The acquired raw signals were digitally processed using a symmetric root mean square (RMS) algorithm, with a 10-msec time constant. All muscle activity recorded during testing was expressed as a percentage of the normalization base (% 1-RM).

**Procedures**

Each subject reported to the Athletic Training/Sports Medicine Research Laboratory on two separate occasions. During the first session, each subject was assessed for his or her 1-RM on the leg extension and leg press exercises. When the 1-RM testing was completed the session was over and the subject was free to leave.

The subjects returned for the second session after a period of at least 48-hrs following the first session. During this session, each subject was assessed for quadriceps activity while performing both the knee extension and leg press exercises. For each exercise the resistance used was equivalent to 75% of the previously determined 1-RM. The subjects were also assessed under two conditions during these exercises; braced and
unbraced. During the braced condition, each subject wore a patellar stabilizing brace on the dominant leg. The brace was fitted according to the manufacturers specifications and based on the circumference of the knee and calf. The order of the four conditions; OKC braced, OKC unbraced, CKC braced, and CKC unbraced were randomly assigned and counterbalanced. A five-minute recovery period separated each condition.

After the 1-RM was done on the second day for normalization of the EMG, the knee extension and leg press exercises were performed. Five repetitions of each exercise were performed and the measurement took place during both the concentric and eccentric phases. A switch controlled by the researcher distinguished the concentric phase from the eccentric phase. A metronome was used to control for the rate of movement, which consisted of a three-second concentric and a three-second eccentric phase. When all four conditions were completed the session was over and the subject was free to leave.

**Data Analysis**

SPSS 11.0 for Windows (SPSS, Inc., Chicago, IL) was used for statistical analysis. Two repeated-measures ANOVAs with three within-subject factors were used to analyze the data. The three factors were exercise (OKC, CKC), treatment(braced, unbraced), phase of exercise (first and final 45° concentrically, first and final 45° eccentrically). An ANOVA was completed for each muscle (VM, VL). Tukey’s HSD Post hoc analyses were used to locate the differences of interest if significant interactions resulted from the ANOVAs. An alpha level of p < .05 was set *a priori* for all statistical analyses.
CHAPTER 4  
RESULTS  

The purpose of this study was to examine the effects of a patellofemoral knee brace on quadriceps muscle activity during open kinetic chain (OKC) and closed kinetic chain (CKC) knee extension exercises. Male and female college-age subjects were recruited for this study. Each subject performed OKC and CKC chain exercises with and without a brace in a randomly assigned order. Quadriceps electromyographic (EMG) activity was recorded for each condition.  

Subject Demographics  

Twelve male and 11 female students from the University of Florida participated in this study. All of the subjects were healthy and had no history of previous knee injury. Subject demographic data are presented in Table 4.1.  

Table 4.1 Subject demographics (means ±SD).  

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 23</td>
<td>23±2.71</td>
<td>171.06±6.96</td>
<td>68.91±12.17</td>
</tr>
</tbody>
</table>

Vastus Medialis  

The ANOVA for vastus medialis (VM) EMG activity did not reveal a significant interaction between the type of exercise, the braced condition, and the phase of exercise \(F_{(3,92)}=0.772, p=0.514\). It also failed to reveal a significant interaction between the type of exercise and the braced condition \(F_{(1,92)}=3.417, p=0.078\). However, a significant interaction between the type of exercise and the phase of exercise \(F_{(3,46)}=59.67, p=0.000\)
was revealed. The Tukey HSD post hoc analysis determined that differences of 4.44% or greater were considered significant (Table 4.2).

Table 4.2. Normalized VM activity during OKC and CKC knee extension (Mean ±SD)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Concentric</th>
<th>Eccentric</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90° to 45°</td>
<td>45° to 0°</td>
</tr>
<tr>
<td>OKC</td>
<td>90.0±4.4%</td>
<td>78.8±4.4%</td>
</tr>
<tr>
<td>CKC</td>
<td>84.0±4.8%</td>
<td>44.4±3.8%</td>
</tr>
</tbody>
</table>

* Significantly greater than CKC during same phase of exercise (p<.05).
† Significantly greater than OKC during same phase of exercise (p<.05).

A statistically significant interaction was also observed between the braced condition and the phase of exercise \([F(3,46)=4.917, p=0.004]\). The Tukey HSD post hoc analysis determined that differences of 4.44% or greater were considered significant (Table 4.3).

Table 4.3. Normalized VM activity during braced and unbraced conditions (Mean ±SD)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Concentric</th>
<th>Eccentric</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90° to 45°</td>
<td>45° to 0°</td>
</tr>
<tr>
<td>Braced</td>
<td>91.4±5.0%</td>
<td>62.0±4.1%</td>
</tr>
<tr>
<td>Unbraced</td>
<td>82.6±3.2%</td>
<td>61.2±2.7%</td>
</tr>
</tbody>
</table>

* Significantly greater than unbraced during same phase of exercise (p<.05).

The ANOVA for the VM revealed no significant main effect for exercise type \([F(1,23)=.836, p=0.371]\), suggesting no difference in EMG activity between OKC and CKC knee extension. However, significant main effects for braced condition \([F(1,23)=5.082, p=0.034]\) and phase of exercise \([F(3,92)=67.075, p=0.000]\) were observed. The normalized EMG activity when the knee brace was used (75.5 ±3.9%) was significantly higher than when it was not used (69.4 ±2.3%). The Tukey HSD post hoc analysis for the phase of exercise determined that differences of 3.4% or greater were considered significant. Therefore, the normalized EMG activity when the VM was contracting eccentrically from 45° to 90° of flexion (81.2 ±3.0%) was significantly
greater than when it was contracting eccentrically from full extension to 45° of flexion (60.1 ±3.0%), and when it was contracting concentrically from 45° of flexion to full extension (61.6 ±3.1%). However, the normalized EMG activity during the same phase of exercise was significantly lower than when the VM was contracting concentrically from 90° to 45° of flexion (87.0 ±3.8%).

**Vastus Lateralis**

The ANOVA for vastus lateralis (VL) EMG activity did not reveal a significant interaction between the type of exercise, the braced condition, and the phase of exercise [F(3,46)=0.750, p=0.526]. It also failed to reveal significant interactions between the type of exercise and the braced condition [F(1,92)=.024, P=.879] and between the braced condition and the phase of exercise [F(3,46)=0.750, p=0.526]. However, a significant interaction between the type of exercise and the phase of exercise [F(3,46)=75.20, p=0.000] was revealed. The Tukey HSD post hoc analysis determined that differences of 4.44% or greater were considered significant (Table 4.4).

| Table 4.4. Normalized VL activity during OKC and CKC knee extension (Mean ±SD) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Concentric      | Eccentric       |                 |                 |
| Exercise        | 90° to 45°      | 45° to 0°       | 0° to 45°       | 45° to 90°      |
| OKC             | 86.9±4.3% *     | 86.7±4.2% *     | 66.0±4.2% *     | 66.3±4.2%       |
| CKC             | 74.5±2.9%       | 40.7±2.9%       | 54.6±2.6%       | 82.8±3.3% †     |

* Significantly greater than CKC during same phase of exercise (p<.05).
† Significantly greater than OKC during same phase of exercise (p<.05).

The ANOVA for the VL revealed no significant main effect for the braced condition [F(1,23)=1.128, P=0.300]. However, significant main effects for the type of exercise [F(1,23)=9.756, P=0.005] and the phase of exercise [F(3,92)=43.778, p=0.000] were revealed. The normalized EMG activity of the VL was greater during OKC exercise
(76.5 ±3.7%) as compared to CKC exercise (63.2 ±2.5%). The Tukey HSD post hoc analysis determined that differences of 3.40% or greater were considered significant. The normalized EMG activity when the VL was contracting eccentrically from 45° to 90° of flexion (74.6 ±2.8%) was significantly greater than when it was contracting eccentrically from full extension to 45° of flexion (60.3 ±2.9%), and when it was contracting concentrically from 45° of flexion to full extension (63.7 ±2.6%). Also, the normalized EMG activity was significantly greater when the VL was contracting concentrically from 90° to 45° of flexion (80.7 ±2.3%) as compared to all other phases of the knee extension exercises.
CHAPTER 5
DISCUSSION

The primary goal of this investigation was to determine if a patellofemoral knee brace would alter quadriceps activity during open kinetic chain (OKC) and closed kinetic chain (CKC) knee extension exercises. To accomplish this we examined 23 subjects without a history of knee pain. Quadriceps electromyographic (EMG) activity of the vastus medialis (VM) and vastus lateralis (VL) were obtained from each subject while they performed OKC and CKC exercises with and without a knee brace. Two ANOVAs were utilized to analyze the data collected.

Vastus Medialis

We initially hypothesized that VM activity would be reduced when the subjects wore the knee brace compared to when they did not. We further hypothesized that this would occur regardless of the type of exercise (OKC versus CKC). However, this did not occur, as VM activity during both the OKC and CKC exercises increased when the knee brace was worn. Specifically, when the data from both exercises and each phase of exercise were pooled together, the VM activity was actually greater during the braced condition. When separated by phase of exercise, the braced conditions resulted in greater activity both concentrically and eccentrically when the knee was in the more flexed phase. Bracing had no effect on VM activity during the final 45° of knee extension.

VM activity was greatest when the muscle was contracting concentrically from 45° of flexion to full extension. This was not affected by the knee brace. When the type of exercise was compared, VM activity during this phase was significantly greater in the
OKC compared to the CKC. However, when the VM was contracting eccentrically from 45° to 90° of flexion, the activity was greater in the CKC.

**Vastus Lateralis**

Like the VM, we initially hypothesized that VL activity would be reduced when the subjects wore the knee brace compared to when they did not. We further hypothesized that this would occur regardless of the type of exercise (OKC versus CKC). However, this did not occur, as no differences were observed between the braced and unbraced conditions when comparing the VL activity during both the OKC and CKC exercises.

Unlike the VM, the greatest VL activity occurred when the knee was extending from 90° to 45° of flexion. When the type of exercise was compared, VL activity was greatest during the OKC exercise. This was observed during the final 45° of extension concentrically and eccentrically. However, when the knee was in a more flexed position the eccentric activity was greater during the CKC exercise.

**Patellofemoral Bracing**

The concept behind the present study was similar to a study conducted by Gulling et al.\textsuperscript{21} that investigated the effect of patellar bracing on quadriceps EMG activity during isokinetic exercise. However, the results of the present study are in contrast to their results. Gulling et al.\textsuperscript{21} reported significantly greater EMG readings in subjects performing isokinetic exercises during a non-braced condition versus a braced condition. In the present study, we observed significantly greater quadriceps EMG activity when the patellar brace was worn (Figure 5-1).
Figure 5-1. VM EMG activity during braced conditions significantly greater than the Unbraced Condition (P ≤ 0.05)

The significant decrease in quadriceps EMG activity after the application of the brace was thought by Gulling et al\textsuperscript{21} to induce a weaker muscle contraction reducing abnormal patellar tracking and decreasing symptoms of patellofemoral pain syndrome (PFPS). The conflicting results may be attributed to the type of subjects and the exercise protocol utilized in each study. Gulling et al.\textsuperscript{21} used subjects who were suffering from patellofemoral pain at the time of the study and they performed only an isokinetic OKC exercise protocol. In the present study, only healthy subjects were used and they completed both an OKC exercise (knee extension) and a CKC exercise (leg press) protocol. Healthy subjects were chosen to examine if the application of the brace would have a similar effect on the quadriceps muscle activity of individuals without patellofemoral pain. The results may suggest that healthy subjects respond differently to the patellofemoral brace application compared to subjects with patellofemoral pain. The CKC exercise (leg press) was used to incorporate a functional aspect, and a CKC exercise (knee extension) was used to assess the efficacy of a frequently used rehabilitation tool.
These exercises are very different from an isokinetic exercise. It is possible that the fixed speed with the isokinetic exercise may have produced different EMG readings seen in the Gulling et al.\textsuperscript{21} study. A metronome was utilized in the current study in an attempt to control for speed alterations during the exercise. The subjects in the existing study may have deviated slightly from the constant speed that was set by the metronome, therefore producing different results. In addition, the brace applied pressure on the EMG surface electrodes, which may have caused higher EMG activity readings during the braced condition compared to the non-braced condition. Gel from the surface electrodes was observed around the area after brace application, which may suggest more topical pressure on the electrodes compared to the non-braced condition. This possible limitation was not noted in the study conducted by Gulling et al.\textsuperscript{21} The inability to allocate an accommodation period to the patellofemoral knee brace has been mentioned as a limitation in the present study. The previous studies that examined the effects of knee bracing on muscle activation also failed to examine the idea of an accommodation period.\textsuperscript{21,41} It is possible that muscle activation was affected by the application of the knee brace, which was not controlled for through an accommodation period.

A previous study by Osternig and Robertson\textsuperscript{41} examined the effects of prophylactic knee bracing on lower extremity joint position and muscle activation during running. The results of this study revealed a significant reduction of EMG activity in 73% of the subjects with the braced condition compared to the non-braced condition. The results of this study were also in contrast with the present study. Unlike the present study, Osternig and Robertson\textsuperscript{41} used a knee brace with a polyaxial hinge instead of a patella stabilizing brace. They also utilized a running protocol instead of a CKC and OKC exercise
protocol. In both studies EMG activity was assessed. The running protocol was completed on a treadmill, possibly producing different EMG activity patterns compared to the leg press and knee extension exercise done in the present study. The leg press and the knee extension exercises were done at 75% of the subject’s 1-RM. It is likely that this would produce an overall higher EMG readings, resulting in the differences found between the studies. In addition to the differences stated, Osternig and Robertson\textsuperscript{41} incorporated only 6 subjects in their study. This limited number may have affected the statistical significance that was seen during the braced condition. The present study included 23 subjects who all performed both exercises with and without the patellofemoral brace. The adequate number of subjects increases the statistical power of the present study reinforcing the significant differences found.

**Patellofemoral Taping**

Another treatment often incorporated in a rehabilitation protocol for patellofemoral pain is patellofemoral taping. The studies conducted on this treatment can be compared to the investigations mentioned above as well as the present study, because of the mechanisms that influence patellar tracking. Both the patellar brace and patellar taping attempt to aid the patella in proper tracking through the trochlear groove.

Kowall et al.\textsuperscript{28} studied patellar taping in the treatment of patellofemoral pain. VM and VL activity was assessed during a CKC step-up and step-down exercise using surface EMG electrodes. This study revealed an increase in EMG activity over time during a rehabilitation program that utilized patellar taping.\textsuperscript{28} The results of this study would be similar to the present study if the increase in EMG activity was seen immediately after the patellar tape was applied. The change in the EMG activity seen by Kowall et al.\textsuperscript{28} was not noted until later in the rehabilitation protocol, which limits the comparison that
can be made to the present study. The effect of patellar taping on pain and neuromuscular performance was studied in subjects with patellofemoral pain by Ng and Cheng.\textsuperscript{40} Their results indicated that patellar taping significantly decreased patellofemoral pain and VMO to VL EMG ratio. The VMO was found to be less active with the patellar tape, which is in contrast to the results of the current study.\textsuperscript{40} Unlike the present study, Ng and Cheng\textsuperscript{40} used subjects that presented with patellofemoral pain. The subjects used in the current study had no history of previous knee pain.

The major difference between patellofemoral taping and patellofemoral bracing that needs to be considered is the placement of the device on the skin. The patellofemoral tape is normally based on the McConnell\textsuperscript{34} taping technique. This technique involves the application of tape only over the patella to aid in patellar tracking through the trochlear groove. Patellofemoral bracing encompasses the entire knee area, leaving the patella free, with a buttress surrounding the patella to aid in patellar tracking. The pressure of the brace on the quadricep muscle group may explain the increased EMG activity found with brace application in the present study. This increase in pressure caused by the patellofemoral brace is not seen with the use of patellofemoral taping.

**Exercise Comparison**

The results observed regarding the phase of exercise and exercise type are important to note although these results did not directly relate to the hypotheses of the present study. Unlike the previous studies mentioned, the results of the present study were very similar to results found in studies that investigated OKC and CKC exercises with EMG. A recent study done by Clements et al\textsuperscript{9} compared quadriceps EMG activity during OKC and CKC exercises. The EMG activity was collected during an isometric contraction using the leg press and the knee extension machine at 30°, 60°, and 90° of
flexion. The results revealed that the OKC exercise had significantly higher EMG activity at 30° of knee flexion when compared to the CKC exercise at 30°. The current study revealed similar results as the second phase of the concentric contraction (45° to 0° of knee flexion) was significantly greater in the OKC compared to the CKC (Figure 5-2). However, the second phase of the eccentric contraction (45° to 90° of knee flexion) was significantly greater in the CKC as compared to the OKC in the present study (Figure 5-3). Similar to these findings, Clements et al.9 reported significantly higher EMG activity in the CKC exercises at 60° and 90° of knee flexion compared to the OKC exercises in the same ranges. The results for the present study were reported regardless of the braced condition. A knee brace was not used in the Clements et al.9 investigation.

![Con 45 to 0 degrees of knee flexion](image.png)

Figure 5-2. Concentric 45° to 0° of knee flexion during CKC and OKC exercises significant interaction (P ≤ 0.05)
Escamilla et al.\textsuperscript{17} also conducted a study that revealed comparable results to the present study. The OKC exercises produced significantly greater quadriceps EMG activity between 15-65\textdegree{} of knee flexion and the CKC exercises produced significantly greater quadriceps EMG activity at knee angles greater than 83\textdegree{}. These results are similar to the current study as well as the study conducted by Clements et al.\textsuperscript{9}. The similarities among the studies are important to mention. Although the present study produced different EMG activity than previous studies that investigated patellofemoral bracing, the basic muscle activity of the quadriceps has been seen in multiple earlier studies.

The results regarding the phase of exercise are also important to notice. The ANOVAs for both the VM and VL revealed significant interactions between phase of exercise. The EMG activity for the VM was greater during the concentric phase of motion, compared to the eccentric phase. However, the difference was not statistically
significant. The EMG activity during the VL’s concentric phase of motion was significantly greater than the eccentric phase. These results can be compared to a study conducted by Kellis and Baltzopoulos on muscle activation differences between eccentric and concentric isokinetic exercise. The results of this study revealed greater EMG activity during the concentric motion compared to the eccentric motion.

Kellis and Baltzopoulos used an isokinetic dynamometer without a knee brace, whereas the present study utilized the knee extension and leg press machines with and without a patellofemoral knee brace. In the present study, the results for the phase of motion were reported in combination of both the braced and non-braced conditions. Although the study protocols were different they produced similar EMG activity readings for the VM and VL.

**Clinical Implications**

Many studies have verified the prevalence of patellofemoral pain as the most common clinical condition presented to clinicians who treat musculoskeletal conditions. The exact cause of this syndrome is not clear, and varies from patient to patient. The present study was an investigation into one of the many methods used to treat patellofemoral pain.

The results of this study suggest that quadriceps muscle activation increases with the application of a patellofemoral knee brace. These results would support the use of a patellofemoral brace during a rehabilitation protocol for patellofemoral pain. However, it is important to be aware of the circumstances of the study protocol. Only healthy subjects who had no previous history of knee pain participated in the study, therefore subjects who have patellofemoral pain may respond differently to the knee brace as suggested by Gulling et al. The conflicting results between the current study and the
study conducted by Gulling et al.\textsuperscript{21} suggests that rehabilitation specialists treat with caution when utilizing a knee brace as part of a rehabilitation protocol.

Although a significant interaction was not revealed between the type of exercise, the braced condition, and the phase of exercise, it is important to note that the results did follow the trend observed in previous studies.

**Summary**

Patellofemoral pain is the most frequent musculoskeletal disorder involving the knee seen in sports medicine clinics.\textsuperscript{3,44} The prevalence of this syndrome has lead to extensive research in the area of rehabilitation. Many studies have been conducted advocating the use of a patellofemoral brace in either prevention or treatment of patellofemoral pain.\textsuperscript{4,31,49} Of the studies conducted on patellofemoral bracing, only one investigated the effect of the brace on quadriceps muscle activation.\textsuperscript{21} The purpose of the present study was to assess the effect of a patellofemoral knee brace on quadriceps muscle action.

Twenty-three subjects with no previous history of knee pain were utilized in the current study to evaluate a healthy subject’s response to a patellofemoral brace. Each subject performed OKC and CKC exercises with and without a patellofemoral knee brace. Surface EMG was utilized to assess quadriceps muscle activity during each exercise and braced condition. The data were analyzed to identify interactions.

The data analysis demonstrated a significant increase in EMG activity of the quadriceps when the patellofemoral brace was applied, regardless of the exercise type. The results did not indicate a significant interaction between the type of exercise, the braced condition, and the phase of exercise. These results indicated that when the type of exercise is considered, OKC and CKC, there is no significant difference in the braced and
unbraced conditions. The results of this study and the conflicting conclusions to the Gulling et al.\textsuperscript{21} investigation call for more extensive research on patellofemoral bracing and the effect of the brace on quadriceps muscle activity.

**Implications for Future Research**

The results of this study suggest a need for future research in the area of patellofemoral bracing. This study is the first known study to investigate patellofemoral bracing on quadriceps activity during OKC and CKC exercises. Previous investigations studied subjects with patellofemoral pain using an isokinetic dynamometer.\textsuperscript{21}

It is evident that a more extensive investigation is needed into the effects of a patellofemoral knee brace on quadriceps muscle activity. Future research should consider subjects with and without patellofemoral pain as well as OKC and CKC exercise protocols. This would allow a comparison to be made between the patellofemoral pain group and the non-injured group.

Future studies examining the effect of patellofemoral bracing on quadriceps activity should consider an accommodation period for the patellofemoral brace. This accommodation period would control for any immediate muscle activation differences that may be present with brace application. This added control may allow for more reliable results.

Another aspect that may be considered during future investigations is the use of fine wire EMG. Fine wire EMG would decrease the effect that the surface EMG may have had on the results of the present study. The pressure applied to the surface EMG electrodes with the brace application may be eliminated with the use of fine wire EMG, therefore adding to the validity of the results.
1. TITLE OF PROTOCOL:

The effect of a patellofemoral knee brace on quadriceps activity.

2. PRINCIPAL INVESTIGATOR:

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2502 NW 16th Avenue
Gainesville, FL 32605
Home: (352) 378-1337
Cell: (352) 235-0101
haskin02@hotmail.com

3. SUPERVISORS

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P.O. Box 118205
(352) 392-0580 ext. 1332
mpowers@hhp.ufl.edu

4. DATES OF PROPOSED PROTOCOL:

From February 15, 2003 to February 15, 2004

5. SOURCE OF FUNDING FOR THE PROTOCOL:

Unfunded
6. SCIENTIFIC PURPOSE OF THE INVESTIGATION:

Patellofemoral pain is a common phenomenon in the physically active, and the patellofemoral knee brace is frequently advocated in rehabilitation protocols. The effect of the knee brace on the activation of the quadriceps muscles has not been thoroughly researched. This study may give professionals in the field of rehabilitation a better understanding of what is happening when their athlete applies a patellofemoral knee brace. This study will attempt to add to this knowledge base, thereby assisting rehabilitation specialists in precise programs to allow athletes to return to activity faster and with better long-term results.

7. DESCRIBE THE RESEARCH METHODOLOGY IN NON-TECHNICAL LANGUAGE:

The purpose and procedures of the study will be explained to each subject and they will be asked to read and sign an Informed Consent. Once the forms have been completed and consent is given, the subjects will have their one repetition maximum assessed for the leg extension and leg press exercises. This involves beginning with a very lightweight for each exercise and progressing until a weight is reached that cannot be lifted one time. We will be using the protocol recommended by the National Strength and Conditioning Association. The subjects will then be asked to return at least 48 hours after their first day and will have one spot on their medial quadriceps (VMO) and one spot on their lateral quadriceps (VL) cleaned with isopropyl rubbing alcohol and any hair in those two places shaved off. Surface electromyography electrodes will be placed on these two areas to record muscle activity of the quadriceps muscles. Prior to performing the next tasks, the subject will warm up for 3 minutes on an exercise bike. The subjects will then perform one maximal effort for each exercise using the maximum weight obtained from the first session. The EMG measurements collected by this contraction will be used to normalize the data of the other exercises. Once this is complete the subject will then perform five repetitions of each exercise using 85% of the maximum weight obtained from session one. Each exercise will be performed twice, once while wearing a patellofemoral knee brace and again without the patellofemoral knee brace. The order of the exercises and the order of bracing (or not) will be randomly assigned. Quadriceps muscle activity will be recorded during the 5 repetitions of each exercise performed by the subject. There will be 5 minutes of rest between each testing condition. Measurements of subjects’ performances on all the tasks will be coded and analyzed in an anonymous fashion to maintain subject confidentiality.

8. POTENTIAL BENEFITS AND ANTICIPATED RISK

The data collected may not directly benefit the subjects involved in the study. The study may ultimately benefit people with patellofemoral pain by facilitating a faster return to activity. Subjects performing some of the tasks for the first time may be at risk of injury due to unfamiliarity of the tasks or equipment. Consistently following proper set-up procedures and performing several practice trials for each task should minimize this risk.
A National Athletic Trainers Association licensed athletic trainer (ATC/L) who will assess and treat any injuries that may occur will be present for all exercise and testing sessions.

9. DESCRIBE HOW PARTICIPANTS WILL BE RECRUITED, THE NUMBER AND AGE OF THE PARTICIPANTS, AND PROPOSED COMPENSATION:

Participants will be recruited from courses taught within the College of Health and Human Performance. The principle investigator will asked the instructors permission before recruiting subjects. No student will be recruited from any class taught by the principal investigator. All subjects will be informed by the principal investigator as to what the study is investigating. A total of 24 voluntary subjects will be recruited. Subjects will range in age from 18-30 years. Subjects who have had knee surgery of any type, and subjects who have a history of knee pain other than anterior knee pain will be excluded from the study. There will be no direct compensation for any subject.

10. DESCRIBE THE INFORMED CONSENT PROCESS:

To ensure the subject’s voluntary, affirmative agreement to participate in the study informed consent will be obtained prior to any testing. A subject coding system will be used to protect each subject’s confidentiality. Subjects will be assured that they may withdraw from the study at any time with no consequence.

Principal Investigator

_________________________________________  ________________________  
Principal Investigators’ Signature                     Date

Supervisor

_________________________________________  ________________________  
Supervisors’ Signature                     Date

I approve this protocol for submission to the UFIRB:

_________________________________________  ________________________  
Department Chairs’ Signature                     Date
Protocol Title: The effects of a patellofemoral knee brace on quadriceps muscle activation.

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study: The purpose of this research study is to determine the effects of a knee brace on thigh (quadriceps) muscle contraction using surface electromyography (a device that measures muscle activity).

What you will be asked to do in the study: You will be asked to report for two testing times. The first testing time will be to determine how much weight you can lift one time on a leg press and a leg extension exercise machine. Before doing this, you will first warm up by riding a stationary bicycle for three minutes. You will then perform five repetitions on the leg press machine with a very lightweight. The weight will continuously be increased and you will be asked to lift it one time. This will continue until we reach a weight you are unable to lift. After a five-minute rest you will be asked to repeat the same procedure on the leg extension machine. For the leg extension, you will only use the non-dominant leg (the one you normally kick a ball with). You will be asked to return for the second session at least 48 hours later. At that time, your non-dominant leg will be prepped and five adhesive electrodes will be placed on the skin of your thigh muscles. If necessary a small area of skin will be shaved to allow for electrode placement and the skin will be cleaned with alcohol. These electrodes allow us to measure the muscle activity (how much it contracts) when you exercise. They only collect or read the electrical activity of the muscle, thus they do not transmit an electrical current into your body. You will be asked to lift the maximum weight obtained from the first session one time for each exercise. After that, you will be asked to lift a portion (85%) of the weight from the first day three times each, doing each exercise two times. One of the times you do the exercises you will be asked to wear the knee brace, the order is determined by chance. Your quadriceps muscle function will be recorded during each of the exercises. Once you are done with the second day of testing you have completed the study. If you have had knee surgery of any type or if you have a history of knee pain other than anterior knee pain you will not be included in the study.

Time required:
First testing session: 20 minutes
Second testing session: 1 hour and 30 minutes
**Risks and Benefits:**
There are no direct benefits from your participation in this study. You may have some mild leg muscle soreness 24-48 hours following the study. As with any type of exercise, there is a slight risk of musculoskeletal injury such as a sprain or a muscle pull. A certified athletic trainer will be present to evaluate and treat any such injuries should they occur.

**Compensation:**
There is no compensation for your participation in this study.

**Confidentiality:**
Your identity will be kept confidential to the extent provided by law. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file in my faculty supervisor's office. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

**Voluntary Participation:**
Your participation in this study is completely voluntary. There is no penalty for not participating.

**Right to withdraw from the study:**
You have the right to withdraw from the study at anytime without consequence.

**Whom to contact if you have questions about the study:**
Carol Haskin, Graduate student, Department of Exercise and Sport Sciences
(352) 235-0101

Dr. Michael Power, Ph.D., Assistant Professor, Department of Exercise and Sports Sciences
(352) 392-0584 x1332

**Whom to contact about your rights as a research participant in the study:**
UFIRB Office, Box 112250, University of Florida, Gainesville, FL 32611-2250; Phone number: 392-0433.

**Agreement:**
I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant: ___________________________ Date: ________________

Principal Investigator: ___________________________ Date: ________________
APPENDIX C
DATA SHEET

DATE_____________

ID # ____________

Leg tested  R / L

Size of Brace  S / M / L / XL

Gender M / F

Age _____________

Height __________

Weight __________

1-RM Knee Extension _______________   75% KE ____________

1-RM Leg Press _________________   75% LP _____________

Order of Conditions:
## APPENDIX D
### ANOVA TABLES

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LIST OF REFERENCES


BIOGRAPHICAL SKETCH

I was born on August 2, 1979, in Charlotte, North Carolina to Edward and Julia Haskin. I grew up the younger sister of Eric Franklin on Markwell Drive in Matthews, North Carolina. This is the place where my parents continue to live and I still call home.

I attended Matthews Elementary School and during this time I developed a love of sports by becoming active in tee-ball, coach pitch, and softball, and I also played the piano. I attended Randolph Junior High School from seventh to ninth grade. I began involvement with track in seventh grade and continued my love of softball, and piano. Providence Senior High School is where I spent my tenth through twelfth grade years. I became very active in cross-country, indoor track, outdoor track, and softball during high school. My interest in sports medicine began during this time.

After graduating high school in 1997, I continued my education at the University of North Carolina at Chapel Hill. I began to expand my interest in sports medicine during my sophomore year and was accepted into the Athletic Training Program as a junior. I worked as a student athletic trainer with various men and women’s collegiate teams as well as at a local high school. I graduated from UNC-Chapel Hill in May of 2001 with a Bachelor of Arts degree in exercise and sports science.

I began work on my master’s degree in August of 2001 at the University of Florida. While at UF I worked as a graduate assistant at Hawthorne High School in the local Gainesville area. My quest for a master’s thesis began during this time.