Effectiveness of Exercise Intervention in Runners with and without Patellofemoral Pain Measured by Functional Movement Screening

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INTRODUCTION: The Functional Movement Screen (FMS) is a tool developed as a standardized pre-participation movement screening to evaluate movement of daily life, used to identify gross movements that are dysfunctional which then need to be corrected, or gross movements that are performed well that can then be further developed. FMS has been used to guide exercise selection to increase sport performance, as well as an injury risk predicting method. Patellofemoral pain is prominent in the running population. The purpose of this study was twofold: (I) Evaluate the effectiveness of a functional movement screen in detecting patellofemoral pain in runners with and without patellofemoral pain; (II) Correct the movement dysfunction with exercise prescription. **METHODS**: 20 participants with patellofemoral pain and 8 participants with no patellofemoral pain were included. The participants underwent an FMS pre-test and based upon their score, were given a home exercise program. The participants were instructed to complete home exercises over a six-week period, then returned for an FMS post-test. Paired samples t-test, Wilcoxon Signed Ranks Test, and McNemar's test were conducted to analyze changes in FMS scores over the course of the home exercise program, separately in the pain and no pain group. **RESULTS**: There was no significant change in composite FMS scores for runners without patellofemoral pain (M=15.7, SD=2.2) after receiving an exercise intervention (M = 17.3, SD = 2.3); $t(5) = -1.976$, $p = 0.105$. There was a significant increase in composite FMS scores for runners with patellofemoral pain (M=15.6, SD=2.0) after receiving an exercise intervention (M = 17.7, SD

= 1.8); $t(14) = -4.571$, $p = <0.001$. **CONCLUSION**: Baseline composite FMS scores were not able to discriminate between participants with or without patellofemoral pain. The exercise intervention was effective in increasing composite FMS scores in participants with patellofemoral pain.

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1.0 Introduction

Functional movement is a term that is often misconstrued as a movement that must replicate a specific activity or sport. However, functional movement should not only be referred to as sport or activity specific. There are gross movement patterns that are performed in sport activity and daily life that are quite similar.[14] Gross movements are fundamental movements learned through life and controlled by large muscle groups. Examples of these gross movement patterns are crawling, walking, and throwing. The term functional movement should be used subjectively on an individual basis because what may be functional for one, may not be functional for another individual. For example, training gait mechanics for a 25-year-old professional athlete would not be as functional as mastering movement patterns that are replicated in their sport. However, training gait for a geriatric patient who is recovering from surgery would be movements that are functional for that individual to then conduct activities of daily life.

A movement screening is oftentimes used as a tool for clinicians to detect deficiencies in gross movement patterns, especially when an injury is present.[12-14] A movement screening is useful in guiding a clinician to determine if an injury creates dysfunctional patterns in the body or if a dysfunctional pattern somewhere else in the body is influencing the injury. Whether it be in a rehabilitation or sports performance setting, the use of a movement screening can guide exercise selection for the individual to then move well with a minimal risk of injury.

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1.1 Functional Movement Screening

1.1.1 Movement Screen

A movement screen that is commonly used is the Functional Movement Screen (FMS) developed by Gray Cook PT, OCS and Lee Burton MS, ATC in 1997. The duo created many screening processes in addition to the FMS, including the Selective Functional Movement Assessment, Y Balance Test, and Fundamental Capacity Screen. The FMS was developed as a standardized movement screening to evaluate how individuals move throughout common movements of daily life.[15] The purpose of initiating a standardized screening process was to identify gross movements that are dysfunctional which then need to be corrected, or gross movements that are performed well that can then be developed more with an added external load.[15] Because of this, exercise programming and selection can be broken down to an individualized approach, so the patient can move better, regardless of the population.

A screening tool, such as the FMS, is useful in a pre-participation evaluation prior to sport or activity. Conducting a movement screening before beginning a sports performance exercise will guide clinicians in detecting what movements to correct and improve on, prior to adding an external load to a muscle and joint. By doing so, this can help reduce the risk of acute injury by improper movement, as well as reduce the risk of a reoccurring injury if a dysfunctional movement is present and detected.[12-14] Sport specific skills may be introduced prior to a movement screening, but a movement dysfunction could be present. Movement dysfunction can lead to compensation and injury, proving the need for a pre-participation movement screening.

Typically, in a pre-participation screening, a medical examination is performed, as well as a very basic level of performance tests. These tests provide objective measurements of the fact that an individual did indeed move, but they do not quantify the quality of the movement.[15] Introducing a movement screening, such as the FMS, can help bridge the gap between activity readiness and quality of movement for said activity. Cook and Burton use the example of two individuals scoring an “above average” score on a sit-up test. Although they both scored in the same category and were deemed equal in quantitative score, the quality of movement may not be assessed. One individual could be completing the movement with compensation of the cervical spine, implying there is dysfunction in the movement which could lead to acute or chronic injury.[15] The other individual may be completing the movement without any compensatory movements and receive the same score. Although they may be judged as equal because of their score during an objective test, movement dysfunction may be present and a screening tool can help reduce the risk of injury, increase performance, and enhance quality of life.[13]

FMS has been proven to be reliable, with good inter-rater reliability and test-retest reliability. In a few studies, practitioners of differing experience conducted and scored the FMS from a videotape of the participants, based upon Cook’s standardized guidelines. All of these studies displayed a moderate to high inter-rater reliability between testers of different experience levels in detecting movement dysfunction, indicating that the FMS is a reliable screening tool.[19,25,26,27,40,57] As per one study, four raters, three novice and one expert, scored the seven FMS movements by watching a video recording of the movements. The results showed that the total mean FMS score between the four raters was 12.6 ± 2.6, which was not significantly different between the raters ($p = 0.26$).[25] The authors concluded on the statement that although there was mostly moderate to high inter-rater reliability between the raters, the level of experience should be considered because the expert rater was more critical in interpreting the scoring criteria, compared to the three novice raters.[25] In addition, two studies evaluated inter-rater reliability by conducting

FMS at a baseline date and the same testing procedure 48 to 72 hours later. The results of these studies supported moderate to good reliability for novice raters. Scores between raters remained consistent during both testing sessions, indicating once again that the FMS is a reliable tool for novice and experienced raters conducting the assessment.[57,64] Two novice raters who underwent 20 hours of FMS training led by four physical therapists and one research assistant conducted a FMS during a baseline test, and a repeated test 48-72 hours later. After conducting both movement screenings, the mean total FMS score between the two novice raters was 15.7 ± 0.2, resulting in the inter-rater agreement of the scores to be ranged from moderate to excellent (κ_w = 0.45–0.82).[64]

1.1.2 Screening Movements

The seven movements included in the FMS are the Deep Squat, Hurdle Step, In-Line Lunge, Shoulder Mobility, Active Straight-Leg Raise, Trunk Stability Push-Up, and Rotary Stability. Of these seven movements, the Deep Squat, In-Line Lunge, and Hurdle Step are deemed functional, while the remaining four are foundational. Foundational patterns are basic mobility patterns that are learned early in life, such as leg raising, reciprocal arm reaching, planking pattern, and reciprocal quadruped pattern like crawling.[15] These four foundational patterns are building blocks for an individual to then complete more advanced functional movements. The functional patterns all require an individual to move into an upright position in which different foot positioning and patterning is utilized in activities of daily life.[15] During movements such as squatting, lunging, and stepping, a symmetrical, asymmetrical, or single leg stance are used in daily activity, all of which requiring stability and mobility. The seven above stated movements are included in this screening because they are all basic movement patterns that are learned through different developmental stages of life but may still encompass dysfunction elsewhere in the body if they are not biomechanically sound.

The Deep Squat is a movement that is used in sports to produce force quickly and explosively and to allow the lower body to absorb force during landing. A sport specific example is to load during a vertical jump in volleyball, then absorb the landing. A squat is also prominent in everyday activity, such as lowering the center of mass to sit down or pick something up off the ground. The Deep Squat reveals if an individual can symmetrically move through a healthy range of motion of the ankles, knees, and hips, while maintaining upper body mobility and stability.[15]

Figure 1 Deep Squat [15]

The Hurdle Step movement pattern requires an individual to move from a double leg position to single leg. In sports, a baseball pitcher must demonstrate this movement pattern by transferring force through a double leg stance to a single leg stance in the windup. In everyday life, the ability to demonstrate double leg to single leg stance is utilized while simply walking up a flight of stairs, stepping over an object on the ground, or climbing a ladder amongst other things.

This movement pattern requires the ability to transition from a balanced double leg stance, to require stability of a single leg stance creating a dynamic challenge. [15]

Figure 2 Hurdle Step [15]

A split stance position, or lunge, is the primary movement during the In-Line Lunge movement pattern. When an athlete changes their base of support to create a stronger position in the sagittal plane, such as changing direction quickly, they are likely in a lunge position. A lunge position may also be utilized while gardening or pushing a heavy object across a room. Lunging is a movement that is used to lower and raise the body from the ground, requiring spinal stability as the lower and upper body segments counterbalance each other to compliment the movement. [15]

Figure 3 In-Line Lunge [15]

Shoulder mobility in sport is crucial for those involving throwing, swinging, and hitting. The opposing action of the arms in throwing a baseball requires mobility of both arms to then create power for the movement. The ability to complete a movement as simple as reaching overhead or putting on a shirt everyday requires shoulder mobility and control. This movement pattern is used to evaluate if moving both arms at once comprises the movement on either side. [15]

Figure 4 Shoulder Mobility [15]

The Active Straight-Leg Raise movement pattern evaluates the reciprocal lower body movement pattern through the hips and spine. While shifting weight and the center of mass through the hips, protecting the spine is important in sports movements such as an Olympic deadlift, as well as everyday movements of general ambulation and bending over to pick up an object. This movement pattern tests lumbo-pelvic control by stabilization of the pelvis and lumbar spine during the testing movement. [15]

Figure 5 Active Straight Leg Raise [15]

The Trunk Stability Push-Up evaluates trunk stability by the resistance of opposing forces through the upper and lower extremities. In sport, this is utilized in almost every movement, with examples such as running, jumping, kettlebell swings, and Olympic lifts. Pushing a lawnmower or carrying grocery bags require an individual to maintain trunk stability to protect the spine and extremities of injury. The Trunk-Stability Push-Up pattern is not intended to evaluate upper body strength, as it is to challenge the trunk's stability during the movement. [15]

Figure 6 Trunk Stability Push-Up [15]

The Rotary Stability movement pattern evaluates a tri-planar movement pattern in resisting rotation to maintain a neutral positioning. When a boxer throws a punch, they are required to coil and uncoil the torso to transfer energy to the extremities without losing postural control. Reaching down to the ground to pick something up with one arm also tests an individual's ability to resist rotation while maintaining postural control. This movement pattern evaluates motor control and stability to see if stability is compromised to complete the task. [15]

Figure 7 Rotary Stability [15]

1.1.3 Screening Process and Scoring

The FMS evaluation tool is comprised of seven fundamental movement patterns that require mobility and stability, as well as three clearing tests that evaluate pain.[13] Because each movement requires a level of stability and mobility, dysfunction will be noticeable if an individual compensates during a movement. Individuals of all competition and sport level may be using compensation methods to unconsciously address their weakness and imbalances, reinforcing poor movement patters that may hinder their performance or lead to injury.[13-14]

To begin this screening, the participant will not go through a warmup. The screening should evaluate a person's natural state of movement that they experience in daily activities. The examiner will only give verbal instruction to the participant with no physical demonstration of the movement patterns. Verbal instruction will give the participant just enough information to understand how to complete the movement without adding feedback that could potentially alter their natural movement pattern. As many as three repetitions may be performed to reduce the likelihood of the participant learning how to complete the movement to remain a true measurement.[15]

Scoring of each movement of the FMS consists of four possibilities. The scores are listed as zero to three, with three being the best score.[13-15] A score of zero is given if pain is elicited anywhere in the body during the movement. A score of one is given if the participant is unable to assume the starting position of the movement or unable to complete the movement pattern. A score of two is given if the participant can complete the movement but must compensate in some form to complete the movement. Lastly, a score of three is given if the participant can complete the movement pattern correctly with no compensatory movement.[13-15] Tests such as the Hurdle Step, In-Line Lunge, Shoulder Mobility, Active Straight-Leg Raise, and Rotary Stability are evaluated bilaterally. To score the above stated tests, both sides will be scored but the side of the lower score will be recorded and counted towards the total.[13-15] However, although only one side will be recorded towards the final score, it is important to note the bilateral difference and imbalances between the two sides. The Shoulder Mobility, Trunk Stability Push-Up, and Rotary Stability tests all include a clearing exam that effects the final score. The clearing tests are graded as positive or negative. If an individual has pain during the clearing exam, that is graded as positive, and no pain means the clearing exam is negative. If a positive clearing exam is present, the score will be zero. The highest possible final score after conducting the seven movement screenings and three clearing exams is 21.

1.2 Screening in Athletes

As movement screening tools have become more utilized, clinicians and researchers alike have found that certain scores or movement specifics on the FMS are indicative of athletes' potential risk of injury and enhanced sport performance. Based upon statistics of many studies conducted, it has been advised as best practice that a score on the FMS of ≤14 leads to a greater risk of injury and a score of >14 leads to minimal risk of injury.[14,17,23,32,33] However, it is important to note that FMS scores have not been shown to be definitely predictive of injury or no injury.

1.2.1 FMS As Injury Risk Predictor

One use of an FMS procedure that is utilized by many clinicians is to evaluate movement prior to beginning competition to help detect the potential risk of injury. When a movement screen is conducted before sport or competition as a pre-participation screening tool, movement dysfunction that may lead to injury can be detected and monitored with an attempt to resolve the dysfunction before the athlete begins sport.[13-15] Although many individual risk factors may contribute to injury, such as previous injury, biomechanics, playing experience, and muscle flexibility amongst others, movement through activity encompasses all of the above risk factors.[32.] One researcher evaluated the effectiveness of predicting injury in American football athletes using the FMS as a movement screening tool. Kiesel discovered that players who scored below a 14 on the FMS screening prior to the beginning of the 2005 NFL season were at an eleven-fold increased risk of injury.[32] Because the FMS evaluates movement based upon mobility and stability, bilateral asymmetries can be evident once examined. In another study, Kiesel evaluated the effect bilateral asymmetries have in the role of risk of potential injury. Supporting the author's other study, results showed that athletes who were found to have at least one asymmetry had a greater time loss from injury, indicating that asymmetries can lead to injury.[33] Further research supports the notion that bilateral asymmetries are one of the primary risk factors for injury.[71] Possible explanations for why bilateral asymmetries elevate the risk of injury include functional immobility and instability of joints, leading to improper proprioception.[14,32,71]

However, although many researchers have found that FMS is a reliable tool in predicting future injury, not all literature is supportive of that. There is conflicting evidence that supports the notion of FMS as not being an effective tool to predict injury. One study was conducted on major junior hockey league athletes. In this study, one FMS certified investigator administered the screening to the athletes before the start of a season and injury data was collected throughout the season for a total of 76 games. The FMS score for those who encountered an injury was 15.0 (+/− 2.21) and for those who were not injured was 14.4 +/− 2.99.[17] participants who scored higher on the FMS missed more game time than those with a low score. This data is contradicting of the notion that a score of ≤14 leads to a greater risk of injury.[14,17,23,32,33] Warren et al evaluated 167 injury free NCAA Division I athletes. They found that the scores of those who sustained injuries (14.3 ± 2.5) and those who did not (14.1 ± 2.4) were not significant enough to demonstrate that a lower FMS score contributes to injury.[67] FMS was not a viable screening tool to detect injuries in a Division I football program, according to Mortensen. 208 athletes were screened prior to beginning their respective football season over a three-year period. Injuries were recorded daily, whether contact or non-contact injuries, by the institution's certified athletic trainers. Through data analysis comparing injury rate and FMS score, the researchers found no significant relation to FMS score and injury rate among the team as a whole, as well as by positional group.[46] The researchers concluded that there was a lack of significant correlation in FMS score and injury risk in Division I collegiate football athletes. Although some studies have supported the use of FMS as an injury predictor tool, there is also conflicting evidence to this claim.

1.2.2 FMS To Improve Sport Performance

Cook explained that stability and mobility are the building blocks of strength and flexibility.[12] That theory is the generalized reasoning as to why the movements he selected for the FMS are such, because they all evaluate either stability or mobility. According to his Optimum Performance Pyramid, good functional movement can translate to the efficacy of power, which can then translate to improved sport performance.[12,58] One study evaluated elite high school baseball players and the relationship of an exercise intervention program on specific sport performance measures, measured by FMS scores. The exercises that were included in the intervention were developed from Cook's FMS training program.[58] The results indicated that strength was improved in the baseball athletes following an exercise intervention program, selected based upon movement dysfunctions found during an FMS evaluation. Hand-grip strength was improved by 12% and bench press was improved by 9% following the intervention.[58] The authors concluded that because of the increase in core stability that was achieved during the exercise intervention, strength was then improved since enhanced core stability can contribute to a greater power output.[58] In elite track and field athletes, the FMS was used and scored as either LoFMS (≤14) or HiFMS (>14). The participants underwent a formal FMS screening prior to the 2011 season, while their best competition marks were compared between the 2010 and 2011 season. The researchers found that athletes who scored in the HiFMS scoring category had significantly greater changes in competition marks between the two seasons, compared to those who scored in the LoFMS category.[9] The researchers concluded from this study that FMS scores may be suggestive of the ability to improve longitudinal sport performance.[9] In regard to golf, one study utilized a golf specific movement screening to test if scores on the screen correlated to golfing performance. Club head speed, side accuracy, peak pelvis rotation speed, ball speed, and swing sequence were recorded as the performance markers. After evaluating the movement screen on 11 participants and testing their performance markers it was found that those who achieved a higher score on the movement screening also had a better composite handicap, ball speed, club head speed, and peak pelvis rotation speed.[59] There was a direct correlation between the golfers who performed better with a higher functional movement screening score. Although using FMS as a tool to evaluate strength and sport performance is relatively novel and understudied compared to the effectiveness of assessing potential risk of injury, it has been proven as a viable tool to utilize in athletes to monitor strength changes.

1.2.3 FMS In Runners

One population that has been impacted from the use of FMS is runners. Biomechanically, running requires mobility, stability, and neuromuscular control.[58] All of the base needs in running economics are evaluated during FMS testing, which is why this population can utilize a movement screening tool to full extent. Dysfunctional gait mechanics, which can be found during a movement screening, may lead to compensation or pain.

Loudon et al were the primary researchers to gather normative values in long distance runners and FMS score. Since their publication, other researchers have used their normative values to predict injuries. In regards to Loudon's findings, they discovered that females generally had greater mobility and flexibility compared to males and participants who were under the age of 40 scored significantly better on the screening.[43] Another important finding was that individuals over the age of 40 displayed much lower balance and neuromuscular control.[43] That implies that through the use of FMS, it was found beneficial for runners over 40 years old to engage in balance-type exercises and training to increase running performance. Of the seven tests used in the FMS, the Deep Squat and Active Straight-Leg Test have been found to be indicative of predicting injury in runners.[28] Runners who had scored below the composite gold-standard score for these two tests, had an injury rate of 37.9%, while those who scored well on the Deep Squat and Active Straight-Leg Raise had an injury rate of 7.3%.[28] Renström reported that poor mobility and neuromuscular control can lead to injury, in which the Deep Squat test assesses mobility of the lower body and core, as well as neuromuscular control through the entire body.[54] Because running requires rapid and forceful contractions of the hamstring muscle group, hamstring flexibility is important for runners to possess. As the Active Straight-Leg Test assesses the ability to maintain a stable pelvis and hamstring flexibility, there is correlation between poor hamstring flexibility potentially leading to an unstable pelvis. The cause and effect of poor hamstring flexibility to poor pelvic stability has been found to lead to injury.[30,63]

Poor hamstring flexibility is also related to anterior knee pain. Hamstring tightness typically causes the knee to naturally be in a slightly flexed position, resulting in a lower output of extensor torque.[39] This requires a higher output from the quadriceps, which leads to increased forces at the patellofemoral joint.[39,58] Runners have been found to display a significant amount of hamstring tightness, which could be one predisposing factor of anterior knee pain in this population. Wang studied lower extremity flexibility in distance runners compared to non-runners. The author concluded through measurements taken with a goniometer, runners displayed a lower range of motion of the posterior muscles, specifically the hamstrings and soleus compared to non-runners.[66] Similarly, 347 runners were evaluated for anterior knee pain and the factors that predisposed them to anterior knee pain. In 40% of the participants, anterior knee pain was present. Bilateral hamstring tightness was found in 42% of the participants, being one of the most frequent intrinsic risk factors for anterior knee pain.[38]

1.2.4 FMS Exercises

Cook lists a table of many exercises that can be used in conjunction with movement deficits that are found during a FMS evaluation. There is no literature describing his rationale for why he chose the exercises for whichever deficit they may benefit. However, other studies support the success of hip, knee, and core exercises for participants with patellofemoral pain.[18,29]

Hip, knee, and core musculature are dynamic stabilizers of the pelvis. If there is malalignment or dysfunction of the pelvis because of weak or tight muscles, abnormal stresses may be put on the lower extremity causing pain.[18]

Rehabilitation programs have been studied to determine the effectiveness of the treatment based upon patient reported levels of pain. Hip and core stability, strengthening, and balance exercises, along with closed chain squat patterns have been proven to be effective in reducing pain, improving strength, and improving function in participants with patellofemoral pain.[18] Furthermore, another study supports the notion of hip, core, and quadricep strengthening to help reduce the effects of patellofemoral pain. Exercises chosen to maximally isolate the hip extensors and external rotators, such as Side-Lying Hip External Rotation Clamshells, have been supported in literature to help reduce the effects of patellofemoral pain.[29]

1.3 Patellofemoral Pain

1.3.1 Injury Epidemiology

Anterior knee pain can arise from many factors. One of the most prominent causes of anterior knee pain is Patellofemoral Pain Syndrome (PFPS). PFPS mostly effects adolescents and individuals under 60 years of age.[22,24] Between 2007-2011 in the United States, the estimated incidence of PFPS out of 30 million patients was 1.75 million patients, or 6%.[24] This condition can be developed in males and females, but females have been reported to be two to ten times more likely to develop this compared to males.[22,24]

Patellofemoral pain is categorized as pain in the peripatellar/retropatellar area that is aggravated with movements that load the patellofemoral joint on a flexed knee.[28] Activities that are common with this condition include running, squatting, and jumping amongst others.

The patellofemoral joint consists of the patella resting in the trochlear notch in the femur, working as a lever during knee extension and flexion.[22] The patella is stabilized by the surrounding quadricep musculature, patellar tendon, and medial patellofemoral ligament, medial patellotibial ligament, and many sheaths of retinaculum to provide support.[22]

Common risk factors of PFPS include female sex, patella maltracking, overuse, activities that load the patellofemoral joint on a flexed knee, quadriceps weakness, and a valgus collapse of the knee.[22,24] When an individual's knee collapses inward towards the center of the body, known as a valgus collapse, lateral forces on the patella are greater. Because of this, patella maltracking is more common, leading to an increased risk of developing PFPS.[22] Similarly, females more commonly display a valgus collapse, in which the hypothesis is that is the reason for their increased risk of PFPS compared to males.[22]

In regard to treatment, physical therapy exercises should be implemented. There is not currently literature that supports best practice of exactly what body segments to improve strength and neuromuscular control with but flexibility, core stabilization exercises, hip, and knee strength should be a priority in rehabilitation.[22]

1.3.2 Patellofemoral Pain in Runners

At the 2013 Patellofemoral Pain Research Retreat, it was discussed that PFP accounted for 25-40% of sports injury clinic visits.[28,69] The incidence of PFPS in runners specifically has been reported at 9-26% respectively.[18,29,69] Pain and injuries in running can occur from a variety of sources. Some of which include extrinsic factors such as running surface and footwear, as well as intrinsic factors such as mobility, anthropometry, and previous injury amongst others.[28,63] With injury comes time off from competition for rehabilitation and restrengthening. Although not specific to PFP, time to recover for running related injuries was tabbed at 10-weeks.[28] With this, it is evident that PFP is prominent in the running population.

1.4 Research Problem

Multiple studies have evaluated the effectiveness of implementing an intervention program based upon FMS scores of children, mixed martial arts athletes, track athletes, and high school baseball athletes among other populations.[1,5,9,58] However, to our knowledge there is no research utilizing a Functional Movement Screen as a tool to guide exercise programming for runners who experience patellofemoral pain, as well as ascertain the effectiveness of the exercise programming by comparing FMS scores before and after intervention.

1.5 Study Purpose

The purpose of this present study is twofold: (I) Evaluate the effectiveness of a functional movement screening in detecting patellofemoral pain in runners with and without patellofemoral pain; (II) Correct the movement dysfunction with exercise prescription

1.6 Specific Aims & Hypothesis

Specific Aim I: Evaluate if functional movement screening can discriminate between runners with and without patellofemoral pain.

Hypothesis I: It is hypothesized that patellofemoral pain will be associated with scores below a "2" on any of the Deep Squat, Hurdle Step, In-Line Lunge, or Active Straight-Leg Raise tests.

Specific Aim II: Evaluate if a 6-week exercise intervention will help correct movement dysfunction based upon FMS scores in runners with and without patellofemoral pain.

Hypothesis II: It is hypothesized that runners in both groups will improve their scores on the FMS after receiving an exercise intervention.

1.7 Study Significance

The significance of this study is that by using a screening process to detect movement dysfunction, exercise intervention can then address pain by correcting gross dysfunction. Clinicians can implement a screening tool prior to their clients training or competing to detect what specific movements need to be biomechanically improved or further developed. This study can be expanded by focusing on a specific population, extending the period of intervention, or specific injury site.

2.0 Methodology

2.1 Experimental Design

The design of Specific Aim I is a cross-sectional study design, whereas the design of Specific Aim II is a one-group before after study conducted separately in two distinct groups (runners with patellofemoral pain and runners without patellofemoral pain).

2.1.1 Independent Variables

Specific Aim I: The independent variable will include the FMS scores of each individual movement. Each of the seven movements will be scored on a scale of 0-3, with a composite score of 0-21.

Specific Aim II: The independent variable will include the exercise intervention.

2.1.2 Dependent Variables

Specific Aim I: The dependent variable will include the presence of patellofemoral pain.

Specific Aim II: The dependent variable will include the FMS scores of each individual movement. Each of the seven movements will be scored on a scale of 0-3, with a composite score of 0-21.

2.2 Subjects

2.2.1 Subject Recruitment

Participants were recruited using advertisement via flyers, University of Pittsburgh approved recruitment platforms, and emails to local running organizations. All participants consented to participate in this study as well. The study was approved by the Institutional Review Board (IRB) at the University of Pittsburgh (STUDY21090047).

2.2.2 Subject Consent

Prior to testing, an overview of Study 21090047, Effectiveness of Exercise Intervention in Runners with and without Patellofemoral Pain Measured by Functional Movement Screening, was delivered to those participating in the study. After the study was explained, potential risks and benefits were explained. Potential participants had an opportunity to ask questions. Before testing began, all participants signed an informed consent form. Participants could choose to withdraw from the study without penalty. Their decision to withdraw had no effect on their current or future relationship with the University of Pittsburgh.

2.2.3 Inclusion Criteria

Participants were included in this study if they are 18 years and older and participate in moderate intensity running for at least 150 minutes per week, vigorous intensity running for at least 75 minutes per week, or a combination of both that generates energy equivalency to either regimen based on the American College of Sports Medicine's guidelines.[2] Participants both with and without anterior knee pain at the time of the study were included.

2.2.4 Exclusion Criteria

Participants were excluded from this study if they have any lower body injury or pain that is not localized to the patellofemoral joint, had lower body surgery within the last 6 months, cannot commit to a 6-week exercise intervention, or received monetary funding or scholarship for running.

2.3 Instrumentation

2.3.1 Functional Movement Screen Kit and Score Sheet

The instrumentation used in this study was the Functional Movement Screen (FMS) Test Kit, developed by Lee Burton and Gray Cook. The equipment that is part of the test kit includes a measuring device, hurdle, and measuring stick. This kit allowed for consistent measurements through all testing procedures.

The scoring sheet from the published FMS manual was used. This sheet has each test divided into raw score, final score, and a comment section. The raw score differentiates left and right sides bilaterally, while the final score denotes the overall score for the test. Qualtrics is an online software program that the primary and co-investigator utilized to record the scoring for each participant. Each participant's non-identifiable identification number was used to record composite score and individual scores of the seven movements during both screening times.

2.3.2 KOOS Survey

The Knee Injury and Arthritis Outcome Score (KOOS-12, KOOS-PF) is a screening tool used to identify the participant's subjective measures of knee pain and quality of life. The survey measures pain, other symptoms, function in activities of daily living, function in sport and recreation, and knee-related quality of life. This tool can be used to measured outcomes of the effectiveness of treatment and rehabilitation.

Upon identification of eligibility and agreement to participate, participants completed the KOOS-12 and KOOS-PF using Qualtrics for both pain and quality of life at the time of the initial evaluation. Pain was categorized as answering "yes" to any of the questions on the KOOS-12 or a numerical number greater than 0 on the KOOS-PF. After reevaluation of the FMS following the 6-week intervention, participants completed a post intervention KOOS-12 and KOOS-PF to evaluate the effectiveness of the intervention on improving pain and QoL. Data was recorded in the same manner as the initial evaluation.

2.4 Testing Process

2.4.1 Pre-Testing Procedures

Participants signed up for an allotted time slot to be tested via an online calendar prior to the first day of testing. Participants reported to University of Pittsburgh's Neuromuscular Research Laboratory in Pittsburgh. Participants were instructed to carry out their activities of daily living, including their current exercise regimen through the duration of this study based on Cook's guidelines that FMS evaluation should be conducted to evaluate a natural state of movement.[14] Each participant was greeted by a member of the research team to complete the check-in process on a university issued tablet. Once the check-in procedure was complete with signed paperwork, participants were instructed by the primary investigator on the procedures of the screening. The screening was conducted by the primary investigator and co-investigator, and all participants were briefed on their results following the testing session.

2.4.2 Testing Procedures

Participants did not go through a warmup. They were verbally instructed on how to complete each movement with no physical demonstration. As many as three repetitions were allotted for each movement to collect the best score but if a score of "3" was achieved prior to the third repetition, no further testing was needed.[15]

During the FMS evaluation, if there was disagreement between raters on the score of each movement, the score that will be recorded was that of the primary investigator's because they are FMS Level 1 Certified.

Each test will be described in full detail in Appendix A FMS Procedures, as per Cook's published protocol.[13-15] To ensure consistency, a script was used for each movement on all participants during both testing sessions.

2.4.3 Post-Testing Procedures

Following completion of the screening, participants were given a physical demonstration of the proper form and mechanics to complete their exercises via a member of the research team. The participants also received a paper copy detailing the exercises needed to be completed. Within 24 hours of their screening, an email was sent to the participant from the primary investigator with videos demonstrating the exercises. Every two weeks, all participants received an email from the primary investigator with a reminder to be completing the at-home exercise program.

2.5 Exercise Selection for Intervention

Participants took part in a 6-week intervention, in which all exercises selected were available for the participants to complete at home with no equipment needed at a commercial gym facility. They were prescribed 7 exercises to complete each day of exercise intervention to be completed 3 days per week, totaling 21 exercises in a week. Compliance of exercise intervention was monitored through a Qualtrics survey that was included in every two-week reminder email.

Exercise prescription matched the needs of deficits found through the screening based on the score of each movement. If no deficits were found, the participant was prescribed the exercise that correlated with a score of "3". For each deficit that was found, exercises were selected to address the deficit as suggested from Cook.[14] Therefore, not every participant was prescribed the exact same exercise selection. For example, every participant who displayed a score of “2” on the In-Line Lunge received the exercise of Half Kneeling Step Up, while every participant who displayed a score of “3” on the In-Line Lunge received the exercise of Single Leg Deadlift Bodyweight. This was conducted for every score on all 7 movements included in the FMS. Included in Appendix B is each exercise to be completed associated with every score on the FMS.

2.6 Statistical Analysis

Descriptive statistics were calculated for all variables (mean, standard deviation, median, interquartile range, proportion as appropriate). Normality was tested using the Shapiro-Wilk Test.

Specific Aim I: The ability of the FMS score to discriminate between runners with and without patellofemoral pain was analyzed. The sensitivity and specificity of the FMS cut off in identifying if the participant does or does not have patellofemoral pain was calculated via composite score. Discriminant validity of FMS in identifying runners with and without patellofemoral pain was assessed by estimating sensitivity and specificity of the movement screen per each individual movement.

Specific Aim II: The change in FMS scores from pre to post exercise was analyzed separately in each group using paired tests or Wilcoxon signed-ranks tests, as appropriate. The percent of runners in whom scores improved was also calculated.

FMS score for each specific movement was characterized by ≤ 2 or >2 based on Cook et al.[12-14] For each task, the change in the category of FMS outcome before and after the intervention was assessed using McNemar’s Test.

Data analysis was conducted using IBM SPSS Statistics Version 28 (IBM Corp; Armonk, NY). Statistical significance will be set *a priori* at $\alpha = .05$, two sided.

3.0 Results

3.1 Subjects

Through recruitment using University of Pittsburgh approved platforms, emails to local running clubs, and flyers posted in local gyms, 129 potential participants expressed interest in the initial screening survey. By means of meeting exclusion criteria, leaving out contact information, or not responding to a follow-up email via the principal investigator, 28 total participants were included in this study.

Table 1 displays subject demographic data. Twenty participants were categorized in the patellofemoral pain group and 8 were categorized in the no patellofemoral pain group based upon their answers to two Knee Injury Arthritis Outcome Score surveys (KOOS-12 & KOOS-PF). Included in this study were 18 females and 10 males. Participants were aged 19-46 years old (26 ± 6.9). Participants were asked to estimate their weekly mileage ran, of which not every subject responded with a number, leaving missing demographic data.

Out of the 28 participants, 21 returned for the post-test, 15 of which in the patellofemoral pain group and 6 participants in the no patellofemoral pain group. For those who did not return, all of which expressed they were no longer interested in the study, or they met exclusion criteria to not be included.

	Patellofemoral Pain (n=20)	No Patellofemoral Pain (n=8)	Total (n=28)
Gender			
Male	8	2	10
Female	12	6	18
Age			
18-29	15	7	22
30-39	0	1	1
40+	2	0	2
Ethnicity			
White	12	7	19
African American	3	0	3
Latino/Hispanic	1	0	1
Asian	1	1	2
Estimated Weekly Miles of Running			
0-10	8	3	11
11-20	6	3	9
21-30	2	1	3
31-40	1	0	1
41+	1	0	1

Table 1 Subject Demographic Data

3.2 Composite FMS Score Discrimination

3.2.1 Logistic Regression

		Pain Self-Reported by Study Subjects		
		Yes	No	
Pain Predicted Using Logistic Regression Model	Yes	20	8	28
	No	0	0	0
		20	8	28

Table 2 Classification Table Displaying Self-Reported Pain and Pain Predicted by Simple Logestic Regression Analysis

Displayed in Table 2 is a classification chart that models the probability of which participants were categorized into the pain group compared to pain self-reported by the participants. The beta coeffecient for the logistic regression was -0.188 and the odds ratio was 0.829 ($p = 0.340$). Although the test was not statistically significant, the direction of the association was as expected. The sensitivity was calculated to be 100% whereas the specificity was calculated to be 12.5%.

3.2.2 ROC Curve

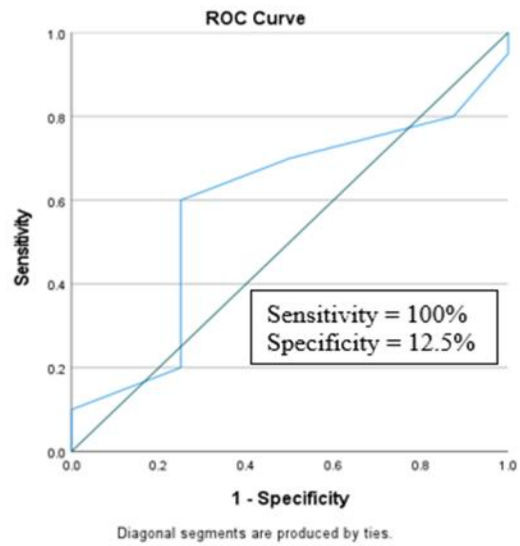

Figure 8 ROC Curve

Figure 8 displayed an ROC Curve demonstrating the sensitivity and specificity of the FMS. For this study, the ability of composite FMS scores to differentiate between subjects with and without patellofemoral pain is low.

Area Under the Curve

Test Result Variable(s): score

Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.591	.120	.461	.355	.826

The test result variable(s): score has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

Table 3 Area Under the Curve

Good discrimination requires the point estimate of the area under the curve to be close to 0.8, whereas this point estimate of the area under the curve in this ROC Curve is 0.591.

Composite FMS score is not a good predictor of presence of knee pain ($p = 0.461$).

3.3 Composite FMS Score

A paired samples t-test was conducted to compare composite FMS score before and after the participants received a 6-week exercise intervention.

Paired Samples Statistics[a]

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	pre	15.67	6	2.160	.882
	post	17.33	6	2.338	.955

a. pain = 0

Table 4 Composite FMS Scores in Runners without Patellofemoral Pain

Paired Samples Test[a]										
		Paired Differences					t	df	Significance	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One-Sided p	Two-Sided p
					Lower	Upper				
Pair 1	pre - post	-1.667	2.066	.843	-3.834	.501	-1.976	5	.053	.105
a. pain = 0										

Table 5 Paired Sample T-Test in Runners without Patellofemoral Pain

Table 4 displayed the average composite FMS scores before and after the exercise intervention in participants without patellofemoral pain. Table 5 showed no significant change in composite FMS scores for runners without patellofemoral pain (M=15.7, SD=2.2) after receiving an exercise intervention (M = 17.3, SD = 2.3); t(5) = -1.976, p = 0.105.

Paired Samples Statistics[a]

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	pre	15.60	15	2.063	.533
	post	17.67	15	1.759	.454

a. pain = 1

Table 6 Composite FMS Scores in Runners with Patellofemoral Pain

Paired Samples Test[a]										
		Paired Differences					t	df	Significance	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One-Sided p	Two-Sided p
					Lower	Upper				
Pair 1	pre - post	-2.067	1.751	.452	-3.036	-1.097	-4.571	14	<.001	<.001
a. pain = 1										

Table 7 Paired Sample T-Test in Runners with Patellofemoral Pain

Table 6 displayed the average composite FMS scores before and after the exercise intervention in participants with patellofemoral pain. Table 7 showed a significant change in composite FMS scores for runners with patellofemoral pain (M=15.6, SD=2.0) after receiving an exercise intervention (M = 17.7, SD = 1.8); t(14) = -4.571, p = <0.001.

3.4 Individual FMS Movement Scores

The likelihood of passing the Deep Squat was not statistically different at baseline (83.3%) as compared to after 6 weeks of an exercise intervention in participants without patellofemoral pain (83.3%), p = 0.050.

The likelihood of passing the Deep Squat was higher at baseline (86.7%) as compared to after 6 weeks of an exercise intervention in participants with patellofemoral pain (80%), p = 0.050.

The likelihood of passing the Hurdle Step was not statistically different at baseline (100%) as compared to after 6 weeks of an exercise intervention in participants without patellofemoral pain (100%), p = 0.050. All participants without patellofemoral pain met the threshold for the Hurdle Step for pre as well as post-test.

The likelihood of passing the Hurdle Step was lower at baseline (93.3%) as compared to after 6 weeks of an exercise intervention in participants with patellofemoral pain (100%), p = 0.050.

The likelihood of passing the In-line Lunge was lower at baseline (83.3%) as compared to after 6 weeks of an exercise intervention in participants without patellofemoral pain (100%), p = 0.050.

The likelihood of passing the In-line Lunge was lower at baseline (93.3%) as compared to after 6 weeks of an exercise intervention in participants without patellofemoral pain (100%), p = 0.050.

The likelihood of passing the Shoulder Mobility was not statistically different at baseline (100%) as compared to after 6 weeks of an exercise intervention in participants without patellofemoral pain (100%), p = 0.050. All participants without patellofemoral pain met the threshold for the Shoulder Mobility for pre as well as post-test.

The likelihood of passing the Shoulder Mobility was not statistically different at baseline (100%) as compared to after 6 weeks of an exercise intervention in participants with patellofemoral pain (100%), p = 0.050. All participants with patellofemoral pain met the threshold for the Shoulder Mobility for pre as well as post-test.

The likelihood of passing the Straight Leg Raise was not statistically different at baseline (100%) as compared to after 6 weeks of an exercise intervention in participants without patellofemoral pain (100%), p = 0.050. All participants without patellofemoral pain met the threshold for the Straight Leg Raise for pre as well as post-test.

The likelihood of passing the Straight Leg Raise was not statistically different at baseline (100%) as compared to after 6 weeks of an exercise intervention in participants with patellofemoral pain (100%), p = 0.050. All participants with patellofemoral pain met the threshold for the Straight Leg Raise for pre as well as post-test.

The likelihood of passing the Trunk Stability Push-Up was lower at baseline (66.7%) as compared to after 6 weeks of an exercise intervention in participants without patellofemoral pain (83.3%), p = 0.050.

The likelihood of passing the Trunk Stability Push-Up was lower at baseline (60%) as compared to after 6 weeks of an exercise intervention in participants with patellofemoral pain (93.3%), p = 0.050.

The likelihood of passing the Rotary Stability was lower at baseline (33.3%) as compared to after 6 weeks of an exercise intervention in participants without patellofemoral pain (83.3%), p = 0.050.

The likelihood of passing the Rotary Stability was lower at baseline (60%) as compared to after 6 weeks of an exercise intervention in participants with patellofemoral pain (86.7%), p = 0.050.

	No Patellofemoral Pain	
FMS Test	% Pre	% Post
1- Deep Squat	5/6=83.3	5/6=83.3
2- Hurdle Step	6/6=100	6/6=100
3- In Line Lunge	5/6=83.3	6/6=100
4- Shoulder Mobility	6/6=100	6/6=100
5- Active Straight Leg Raise	6/6=100	6/6=100
6- Trunk Stability Push Up	4/6=66.7	5/6=83.3
7- Rotary Stability	2/6=33.3	5/6=83.3

Table 8 Individual FMS Movement Score Before and After Exercise Intervention in Runners without Patellofemoral Pain

	Patellofemoral Pain	
FMS Test	% Pre	% Post
1- Deep Squat	13/15=86.7	12/15=80
2- Hurdle Step	14/15=93.3	15/15=100
3- In Line Lunge	14/15=93.3	15/15=100
4- Shoulder Mobility	15/15=100	15/15=100
5- Active Straight Leg Raise	15/15=100	15/15=100
6- Trunk Stability Push Up	9/15=60	14/15=93.3
7- Rotary Stability	9/15=60	13/15=86.7

Table 9 Individual FMS Movement Score Before and After Exercise Intervention in Runners with Patellofemoral Pain

4.0 Discussion

4.1 Specific Aim I Conclusion

In regard to Specific Aim I, our hypothesis was that patellofemoral pain would be associated with scores below a “2” on any of the Deep Squat, Hurdle Step, In-Line Lunge, or Active Straight-Leg Raise tests. We found that FMS score was not a good predictor tool for pain levels. Some participants scored below a “2” in the above listed tests and did not have knee pain, while some participants who identified as having patellofemoral pain scored a “2” or above on those tests. Because the area under the curve in the ROC Curve analysis was 0.591 which is less than 0.8, it was not statistically significant in being able to differentiate pain status based solely on composite FMS score. Also, the p-value rejected the null hypothesis. The ROC Curve is used to display diagnostic ability of the sensitivity (true positive) versus specificity (false positive) and statistically, this curve cannot distinguish positive and negative class points or in this case, individuals with or without patellofemoral pain based on composite FMS score. This result is in agreeance with a previous study conducted by Hotta et al. The found that the cut off composite scores for when injuries started to occur was 14-15/21 and a score ≤14 had a low predictability of injury.[30] A systematic review by Dorrel et al. evaluated the validity of predicting running injuries by using the FMS. Out of the articles they evaluated, FMS had an 85% specificity, but a low sensitivity of 24%, equating to a level of discriminatory slightly above chance to detect injuries.[16]

4.2 Specific Aim II Conclusion

A paired samples t-test was used over Wilcoxon signed ranks test to evaluate the effectiveness of a 6-week exercise intervention because Shapiro-wilk test for normality was not significant. A small sample size influenced it not being significant. Small sample size was partly due to incomplete post-test data from participants dropout.

Our hypothesis of Specific Aim II was that runners in both groups will improve their scores on the FMS after receiving an exercise intervention. For individuals without patellofemoral pain, although composite FMS increased in 83% (5/6) participants who returned for post-testing, the p-value of 0.105 is greater than the alpha value of 0.05 so it is not statistically significant. For participants with patellofemoral pain, the p-value of <0.001 is less than 0.05 so it was statistically significant. It can be concluded that the 6-week exercise intervention was statistically successful in improving composite FMS scores in participants with patellofemoral pain. This finding supports that of other studies, in which mixed martial arts athletes and high school baseball athletes had increased FMS scores after receiving an exercise intervention, compared to their composite scores before intervention.[5,58]

Contrarily, one article evaluated four weeks of an exercise intervention on FMS composite scores of physically active secondary school children. The researchers discovered that the four weeks of exercise intervention had little effect on the composite FMS score, but core stability, assessed with a plank test, was increased although there was no improvement in composite score.[70] Another study which was conducted by Frost et al. discovered that 12 weeks of exercise intervention had no statistical difference in composite FMS scores pre- and post-training in a firefighter population.[21]

4.3 Limitations

This study was not without limitations. Most noticeably, this was a 6-week intervention study, with the intervention dependent upon the participants' compliance. Compliance check-ins were sent to the participants every two weeks for the six-week duration, totaling three compliance surveys for each participant. However, there is no way of knowing if the participants did complete the three sets of 10 repetitions of each exercise, three days per week for six weeks because the exercises were completed at home to their own compliance. There was no oversite from a clinician and participants were not asked to track their exercises.

Also, the intervention was only six weeks in length. One previous study which utilized an exercise intervention to compare pre-test to post-test data included 16 weeks of an exercise intervention.[57] Physiologically, adaptations due to exercise typically take approximately 10 weeks for neurological adaptations, and 12+ weeks for hypertrophic and strength improvements. Although the post-intervention composite FMS scores increased in 80% (17/21) of participants who returned for post-testing in this study, the six-week intervention may not have produced the most potential benefits for the participants included.

Participants were not controlled or limited on their exercise levels outside of the exercise intervention. Participants were asked about their average weekly milage ran at the conclusion of this study (16.2 ±11 miles). As this study recruited runners, many were training for the Pittsburgh marathon during the duration of this study. Some participants said they had transitioned from indoor running on a treadmill to outdoor running on cement, which may have influenced an increase or decrease in patellofemoral pain from the start to conclusion of this study.

Another limitation included the FMS instructions. As previously stated, a verbal script was delivered via the principal investigator for each test, so every test was consistent. The script was verbatim from what Cook and Burton had published.[15] As per the criteria of administering the FMS evaluation, no physical demonstrations or extra verbal cues could be given to the participants as to not potentially alter their natural movement pattern. The instructions included just enough information for the participants to understand how to complete each movement. However, on the first testing session, many participants did not understand some of the instructions. When prompted to move their body into different positions, some participants did not understand the instructions and the examiner could only repeat the instructions on the script without adding extra verbal cues or a physical demonstration. Because some participants could not understand the instructions, their composite score may have been lower because they did not complete the movement correctly. On the post-testing session, many participants performed the tests correctly from the verbal instructions given, and their scores increased demonstrating a possible learning effect. As a research team, we believe more detailed instructions on how to complete the movements would be beneficial, in order for the participants to execute the movement with full understanding.

4.4 Interprofessional Collaboration

This was the first interdisciplinary project in which the School of Health and Rehabilitation Sciences and the School of Nursing at the University of Pittsburgh worked together in research. The principal investigator and the co-investigator worked closely together through the duration of the entire project, identifying a positive collaboration between the two schools. Specifically, contribution between the two schools allowed for completion of the IRB, data collection of all participants, and data analysis of all participants.

This project also served as a demonstration of a novel trust of care between nurse practitioners and athletic trainers. With many professions working in the primary care setting, communication and positive collaboration between professions is imperative for patient care. This project served as a positive collaboration in musculoskeletal intervention and musculoskeletal movement dysfunction. As more clinicians can understand musculoskeletal assessment, specifically the FMS, that will help bridge the gap in communication of pain, injuries, and returning patients to activity amongst others.

As this project was only research based, more collaboration between the school of Health and Rehabilitation Sciences and the School of Nursing is suggested to strengthen the relationship between the two schools even more so. This positive relationship will then transfer over to a positive relationship in the clinical setting, equating to in depth patient care with full understanding from all clinicians.

4.5 Future Research

This study can be further developed with more research. First, a longer exercise intervention would be warranted. As previously mentioned, neurological adaptations occur in approximately 10 weeks of exercise and hypertrophic and strength improvements occur approximately 12+ weeks into exercise. Therefore, an exercise intervention longer than our 6-weeks would be warranted for future research.

Also, consistent running mileage for all participants would be something to recommend for future research. As this study had participants self-report weekly average running milage, there was a wide variety of running volume across participants with a range of 1-50 miles per week

(16.2 ±11). Having the same volume of weekly running miles for each participant would give more consistency to each participant.

Lastly, consistent running terrain would also be something for future research. A few participants began their participation in the wintertime and finished up in late spring. They mentioned at the post-testing session that they had switched from treadmill running to either outdoor street running or outdoor trail running. One constant terrain could allow for future researchers to evaluate kinematics of injuries to that specific terrain, as running on a treadmill, concrete, and trails may have different effects on the mechanics of running form.

4.6 Take Home Points

FMS scores could not differentiate participants with or without patellofemoral pain. Because of the low specificity, FMS composite scores had no relation to level of pain. However, a 6-week exercise intervention was effective in improving composite FMS scores, most notably in participants with patellofemoral pain. This study leads to opportunity for future research in exploring a longer exercise intervention period and controlling more variables about the participants' running protocol.

Appendix A FMS Procedures

1. Deep Squat

Deep Squat Instructions: The individual assumes the starting position by placing his/her feet approximately shoulder width apart and the feet aligned in the sagittal plane. The individual then adjusts their hands on the dowel to assume a 90-degree angle of the elbows with the dowel overhead. Next, the dowel is pressed overhead with the shoulders flexed and abducted, and the elbows extended, so that the dowel is directly overhead. The individual is then instructed to descend as far as they can into a squat position while maintaining an upright torso, keeping the heels and the dowel in position. Hold the descended position for a count of one, and then return to the starting position. As many as three repetitions may be performed. If the criteria for a score of “3” is not achieved, the athlete is then asked to perform the test with a 2x6 block under the heels.[13]

Deep Squat Script: Stand tall with your feet shoulder-width apart and toes pointed forward. Grasp the dowel in both hands and place it on top of your head so your shoulders and elbows are at 90 degrees. Press the dowel so that it is directly above your head. While maintaining an upright torso and keeping your heels and the dowel in position, descend into a squat as deeply as possible. Hold the bottom position for a count of one, and then return to the starting position.[15]

2. Hurdle Step

Hurdle Step Instructions: The individual assumes the starting position by first placing the feet together and aligning the toes touching the base of the hurdle. The hurdle is then adjusted to the height of the athlete's tibial tuberosity. The dowel is grasped with both hands and positioned behind the neck and across the shoulders. The individual is then asked to maintain an upright posture and step over the hurdle, raising the foot toward the shin, and maintaining alignment between the foot, knee, and hip, and touch their heel to the floor (without accepting weight) while maintaining the stance leg in an extended position. The moving leg is then returned to the starting position. The hurdle step should be performed slowly and as many as three times bilaterally. If one repetition is completed bilaterally meeting the criteria provide, a "3"is given.[13]

Hurdle Step Script: Stand tall with your feet together and toes touching the test kit. Grasp the dowel in both hands and place it on top of your head so your shoulders and elbows are at 90 degrees. Then while maintaining hand position, lower dowel to the base of the neck and across the shoulders. While keeping an upright torso, raise the right leg and step over the hurdle, making sure to raise the foot towards the shin and maintain foot alignment vertically with the ankle, knee, and hip. Touch the floor with your heel and return to the starting position while maintaining the same alignment.[15]

3. In-Line Lunge

In-Line Lunge Instructions: The tester attains the individual's tibia length, by either measuring it from the floor to the tibial tuberosity or acquiring it from the height of the string during the hurdle step test. The individual is then asked to place the end of their heel on the end of the board, or a tape measure taped to the floor. The previous tibial measurement is then applied from the end of the toes of the foot on the board and a mark is made. The dowel is placed behind the back touching the head, thoracic spine, and middle of the buttocks. The hand opposite to the front foot should be the hand grasping the dowel at the cervical spine. The other hand grasps the dowel at the lumbar spine. The individual then steps out on the board or tape measure on the floor placing the heel of the opposite foot at the indicated mark. Both toes must point forward, and feet must begin flat. The individual then lowers the back knee enough to touch the surface behind the heel of the front foot, while maintaining an upright posture, and then returns to the starting position. The lunge is performed up to three times bilaterally in a slow controlled fashion. If one repetition is completed successfully then a three is given for that extremity (right or left).[13]

In-Line Lunge Script: Step onto the center of the board with the left foot and your toe on the zero mark. The right heel should be placed according to your tibial measurement. Both toes must be pointing forward with the entire foot in contact with the board. Place the dowel along the spine so it touches the back of your head, your upper back, and your tailbone. While grasping the dowel, your left hand should be in the curve of your neck, and the right hand should be in the curve of your lower back. Maintaining an upright posture so the dowel stays vertical, and you maintain the three points of contact, descend into a lunge position so your left knee touches the center of the board. Then, return to the starting position.[15]

4. Shoulder Mobility

Shoulder Mobility Instructions: The tester first determines the hand length by measuring the distance from the distal wrist crease to the tip of the third digit in inches. The individual is then instructed to make a fist with each hand, placing the thumb inside the fist. They are then asked to assume a maximally adducted, extended, and internally rotated position with one shoulder and a maximally abducted, flexed, and externally rotated position with the other. During the test the hands should remain in a fist, and they should be placed on the back in one smooth motion. The tester then measures the distance between the two closest bony prominences. Perform the shoulder mobility test as many as three times bilaterally.[14]

Shoulder Mobility Script: Stand tall with your feet together and arms hanging comfortably. Make a fist so your fingers are around your thumbs. In one motion, reach the right fist over the head and down your back as far as possible while simultaneously reaching your left fist up your back as far as possible. Do not "creep" your hands closer after the initial placement.[15]

5. Active Straight Leg Raise

Active Straight-Leg Raise Instructions: The individual first assumes the starting position by lying supine with the arms in an anatomical position and head flat on the floor. The tester then identifies mid-point between the anterior superior iliac spine (ASIS) and mid-point of the patella, a dowel is then placed at this position perpendicular to the ground. Next, the individual is instructed to lift the test leg with a dorsiflexed ankle and an extended knee. During the test, the opposite knee should remain in contact with the ground, the toes should remain pointed upward, and the head remain flat on the floor. Once the end range position is achieved, and the malleolus is located past the dowel then the score is recorded per the established criteria. If the malleolus does not pass the dowel, then the dowel is aligned along the medial malleolus of the test leg, perpendicular to the floor and scored per the established criteria. The active straight leg raise test should be performed as many as three times bilaterally.[14]

Active Straight-Leg Script: Lie flat with the back of your knees against the board, feet together with toes pointing up. Place both arms next to your body with the palms facing up. With the left leg remaining straight and the back of the opposite knee maintaining contact with the board, raise your right leg as high as possible.[15]

6. Trunk Stability Push-Up

Trunk Stability Push-Up Instructions: The individual assumes a prone position with the feet together. The hands are then placed shoulder width apart at the appropriate position per the criteria described later. The knees are then fully extended, and the ankles are dorsiflexed. The individual is asked to perform one push-up in this position. The body should be lifted as a unit;

no “lag” should occur in the lumbar spine when performing this push-up. If the individual cannot perform a push-up in this position, the hands are lowered to the appropriate position per the established criteria.[14]

Trunk Stability Script: Lie face down with arms extended overhead at shoulder-width apart. Pull your thumbs down in line with your (forehead for men, chin for women). With your legs together, pull your toes toward the shins. Extend your knees and then lift your elbows slightly off the ground. While maintaining a rigid torso, push your body as one unit into a push-up position.[15]

7. Rotary Stability

Rotary Stability Instructions: The individual assumes the starting position in quadruped with their shoulders and hips at 90 degrees relative to the torso. The knees are positioned at 90 degrees and the ankles should remain dorsiflexed. The individual then flexes the shoulder and extends the same side hip and knee. The leg and hand are only raised enough to clear the floor by approximately 6 inches. The same shoulder is then extended, and the knee flexed enough for the elbow and knee to touch. This is performed bilaterally for up to three repetitions. If a III is not attained, then the individual performs a diagonal pattern using the opposite shoulder and hip in the same manner as described.[14]

Rotary Stability Script: Get down on your hands and knees straddling the board with your thumbs, knees and toes touching the board. Your hands are under your shoulders and your knees are under your hips with your toes pointing backward. At the same time, in one smooth and controlled motion, shift and lift the same side arm and leg. Without touching down, reach back with your hand and touch the outside of the ankle. Then extend that same side leg backward and arm forward, fully extending knee and elbow. Finally reach back to touch the ankle with the hand again, and then return to the starting position. Perform this pattern while keeping the arm and leg moving in-line with board.[15]

Appendix B Exercise Selection

Appendix B.1 Deep Squat

1. Dorsiflexion From Half Kneeling with Pulses[15]

Set-up: Begin in the narrow half kneeling position.

Action: While staying tall, take the front knee and drive it forward. The heel of the front foot should maintain contact with the floor. Find the end range of motion and cycle through a breath.

Return: Return to the start position and repeat.

2. Deadlift Touch the Wall Double Leg[15]

Set-up: Begin standing away about a foot away from a wall, with the feet shoulder width apart. Adjust your stance as wide as necessary.

Action: Keeping the arms against the ribs, reach back with the hips to touch the wall while grasping the kettlebell at the bottom of this position. Inhale and pressurize the abdomen.

Return: While maintaining spinal alignment and arms against the ribs, return to the top position by pushing the feet into the ground and extending the hips until the body forms a vertical line.

3. Toe Touch Squat[15]

Set-Up: Begin with feet shoulder width apart with an object such as a pillow or cushion placed approximately 6 inches in front of toes. Raise the heels with a board or towel roll enough to perform the movement correctly.

Action: Begin by reaching down and pressing into an object, now drop into the squat position. Continue to press into the object going below 90 degrees at the knees. Now raise one hand at a time reaching up into the overhead position.

Return: From this position drive the feet into the ground to stand up out of the squat.

Appendix B.2 Hurdle Step

1. Hip Flexor Stretch with Core Activation[15]

Set-Up: In the half kneeling position, place the dowel in front of the body and maintain a tall spine. Legs are hip width apart.

Action: Engage the glutes and press stick down into the floor to initiate core engagement. Move the front knee forward while maintaining a tall spine and level pelvis.

Return: Return to the start position and relax the arms.

2. Straight Leg Bridge[15]

Set-Up: Lay flat with a ball or foam roll under one leg. Begin under the knee and move the object further away to increase the difficulty. Then bring one knee up as close to the chest as possible and hold it in place with both hands.

Action: Press into the foam roller and lift hips up with the single leg so your body is straight. Lift the hips by pushing into the ground with a straight leg and do not "pull" down with the heel. The leg held to the chest should not change position.

Return: Slowly return back to the ground and relax the leg before performing another rep.

3. Step Up Single Arm Overhead[15]

Set-up: Stand in front of a box, platform, or step that is approximately 12 to 18 inches in height. A lower or higher box is acceptable depending upon ability to execute the move. To specify to the individual that has a passing level of mobility, set the height of the platform so it is even with the tibial tuberosity. Slowly press the arm overhead with the elbow straight. Pack the shoulder down while keeping the arm held vertical to the ceiling and the wrist straight. The opposite arm may hang down at the side or held out away from the body.

Action: Slowly step to place one foot on the platform, placing the foot firmly on the deck while keeping the torso upright and aligning the knee over the second toe. Push off with the trailing leg to raise your body onto the platform placing that foot alongside the leading foot. During this transition, the torso and the tibia will move slightly forward past vertical.

Return: Slowly load the weight of your body into the leading foot, step backwards to place the trailing foot on the floor in its starting position. Allow the body to lean slightly forward during the step-down movement. Repeat for the opposite side or alternate feet during the set and switch hands, if necessary. Always monitor the position of the neck, lumbar spine, knee, ankle, and foot position. The neck remains neutral, spine is tall, knee is aligned over the second toe, and foot and ankle do not collapse in or out.

Appendix B.3 In-Line Lunge

1. Leg Lock Bridge[15]

Setup: Lie on your back and flex the knees with feet flat on the ground. Then bring one knee up toward the chest, at least above the waistline, and hold it in place with both hands.

Action: Press through the heel of the ground-based foot to lift the hips evenly off of the floor until there is a straight line from the shoulders to the hip and knee. Do not let the knee to rotate or fall out to the side during movement.

Return: Once you achieve full extension of the hip and alignment with the shoulder and knee, slowly lower the hip back to the floor.

2. Get-up Half Kneeling to Stand Close Stance Split Stance[15]

Set-up: Start from the Half Kneeling position and place the front foot along a narrow line or as close to directly in line with one another as possible. The heel of the front foot should be almost touching the kneeling knee.

Action: From this position, simply stand up and straighten both legs.

Return: From this position, return down to the starting position.

3. Single Leg Deadlift Body Weight[15]

Set-up: Stand with your feel shoulder width apart and equal pressure through both feet.

Action: Perform the single leg hip hinge by reaching back with the one leg and creating a straight line from the ankle to the ear and maintaining plantarflexion at the end range. Imagine trying to push something away with the back foot while keeping it as straight as possible. Maintain spinal alignment with lat engagement as you drive the static foot into the ground and the knee maintains a five to twenty-degree bend. The shoulders and hips should remain perfectly level and symmetrical.

Return: Return to the starting position by hinging forward.

Appendix B.4 Shoulder Mobility

1. Reach Roll[15]

Set-up: Put your hands in front of shoulders under your shoulders and knees under the hips, and then rock back to your heels with your hips.

Action: Extend and reach the hand/arm and rotate palm up. Hold for three seconds. During the complete movement, the body should be still.

Return: Slowly lower the arm and slide back to the start position. Repeat for the desired number of repetitions and repeat on the other side.

2. Reach Roll Lift[15]

Set-up: Put your hands in front of shoulders under your shoulders and knees under the hips, and then rock back to your heels with your hips.

Action: Extend and reach the hand/arm, rotate palm up, and lift. During the complete movement, the body should be still.

Return: Slowly lower the arm and slide back to the start position. Repeat for the desired number of repetitions and repeat on the other side.

3. Half Kneeling to Standing Rotations[15]

Set-up: Begin in a half kneeling posture by placing one knee down directly under the hip and the other foot should be in line with the knee, this will create the 90/90 position. Depending on the individual, the width of the front foot can be adjusted for balance. The narrower the foot is in relation to the knee, the greater the challenge. Throughout the exercises concentrate on staying as tall as possible creating a straight line from the ear, shoulder, hip, and down knee for proper posture alignment.

Action: Stand up from half kneeling coming into a symmetrical stance with the arm held straight overhead. While the feet remain in place, rotate the trunk both left and right. To protect the shoulder, make sure it is depressed and retracted. Keep the neck relaxed and look with your eyes in the direction you are turning. Maintain neutral alignment and allow yourself to move a little further each time. Note limitations and restrictions to the movement.

Return: Return to the start position by taking one large step back finishing in the half kneeling posture.

Appendix B.5 Active Straight Leg Raise

1. Active Leg Lowering to Bolster[15]

Set-Up: Begin in the supine posture by positioning yourself face up so that your back is on the floor. Place both feet / Achilles on the bolster. Flex your hips to 90 degrees. If 90 degrees is not achieved flex as much as you can while keeping your legs straight.

Action: Once in this position lower one leg to the bolster while maintaining the other legs position. Work to get the heel to touch the bolster with a neutral pelvis.

Return: Return the leg to the start position and repeat the sequence

2. Active Straight Leg Lowering[15]

Set-Up: Begin in the supine posture by positioning yourself face up so that your back is on the floor. Flex your hips to 90 degrees. If 90 degrees is not achieved flex as much as you can while keeping your legs straight.

Action: Once in this position lower one leg to the floor while maintaining the other legs position. Work to get the heel to touch the floor with a neutral pelvis.

Return: Return the leg to the start position and repeat the sequence

3. Get-up Post to High Pelvis Bridge Isolations[15]

Set-up: With arms behind the back, plant both palms on the ground with the fingers pointed backward and off to the side. Bend one leg and extend the other.

Action: Begin to bridge with the leg that is in the flexed position moving the hips up toward the ceiling while also pushing through the heel of the straight leg. At the top position of the bridge, the shoulders and hips should be squarely aligned with no sag.

Return: Slowly lower the hips and return to the set-up position. Perform on both sides to determine if there is a difference between each leg during the bridge pattern.

Appendix B.6 Trunk Stability Push-Up

1. Push-Up Walkout[15]

Set-up: The pushup walkout begins by having the individual standing with feet shoulder width apart and perform a toe touch allowing the knees to bend so you can reach the floor with the hands flat.

Action: Then walk your hands out to a stable plank position, keeping a stable back and not hyperextending. Make sure the surface is a non-slip surface for this exercise.

Return: Maintain a stable plank position, hinge at the hips and walk the hands back toward the feet and return to standing position.

2. Shoulder Tap with Push-Up[15]

Set-up: Begin in a push-up position with both the arms and legs straight and the feet together.

Action: From this position, begin to take one hand to the opposite shoulder and have the palm touch the shoulder. During the exercise, it is important to have minimal rotation from the shoulders and hips.

Return: Repeat for the desired number of repetitions and repeat on the other side.

3. Push-Up with Knee Flexion[15]

Setup: Begin in a push-up position with both the arms and legs straight and the feet together. Maintain a straight line from ankle, knee, hip, shoulder, and ear. Flex one knee so the heel rises, and bottom of the foot faces the ceiling.

Action: From this position, sniff air into abdomen and actively lower yourself into the push-up without letting the shoulders rise towards the ears. Once at the bottom position, push your hands into the ground and return to the top. Make sure that the shoulders, spine, and hips remain in line during the entire movement

Return: Perform for the desired repetitions and repeat on the other side.

Appendix B.7 Rotary Stability

1. Quadruped T-Spine Rotation[15]

Set-up: Get into a quadruped position and sit the buttocks on the heels with the elbows and forearms placed firmly in the floor. Place one hand on your low back, palm facing away from the back.

Action: Look toward and rotate that shoulder toward the ceiling. Return to the starting position and proceed to take the shoulder toward the floor. Keep the post arm firm. Next, place one hand behind the head and on the neck and repeat the exercise leading with the elbow.

Return: Return to the starting position.

2. Quadruped Reach with Neutral Spine[15]

Set-up: Begin in a quadruped position with the hands placed underneath the shoulders and the knees placed underneath the hips. Place a foam roller or other object on the low back and keep it balanced.

Action: Once in this position begin to raise one arm up while rotating the palm upwards.

Return: Return to starting position and do the same with the other arm and note any differences.

3. Quadruped Diagonals with Neutral Spine[15]

Set-up: Begin in a quadruped position with the hands placed underneath the shoulders and the knees placed underneath the hips. Place a foam roller or other object on the low back and keep it balanced.

Action: Once in this position begin to raise one arm and opposite leg up.

Return: Return to starting position and do the same with the other arm and leg and note any differences.

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