4-4-2016

The Effect of Stride Frequency Training on Runners with Patellofemoral Pain

Katelyn Barrett
katbarrett716@gmail.com

"The Effect of Stride Frequency Training on Runners with Patellofemoral Pain"

Katelyn Barrett
Department of Health and Sport Sciences
Otterbein University
Westerville, Ohio 43081

4 April 2016

Submitted in partial fulfillment of the requirements for graduation with Distinction

Advisory Committee:

Shelley Payne, DHS, PT, AT
Distinction Advisor

Advisor's Signature

Joseph Wilkins, MEd, AT, CSCS
Second Reader

Second Reader's Signature

Steffanie Burk, Ph.D.
Distinction Representative

Distinction Rep's Signature

Table of Contents

Abstract

Running is a very popular form of exercise. The most common site of injury for runners is the knee and patellofemoral pain (PFP) is the most common complaint (Taunton et al., 2002). Patellofemoral pain is described as pain around the patella that is worse with activities such as running, squatting, ascending or descending stairs, or sitting for long periods. Much of the recent work with the treatment of patellofemoral pain has involved strengthening of the hip musculature to reduce pain about the knee (Ferber, Noehren, Hamill & Davis, 2010; Souza & Powers, 2009). However, the ability of these strengthening programs to change lower extremity mechanics or sustain long-term pain reduction has been unproven. More recently, researchers have started to examine the impact of "retraining" strategies for runners in an attempt to reduce PFP (Willy, Scholz, & Davis, 2012) and patellofemoral joint forces encountered while running (Lenhart et al., 2014). The purpose of this study was to examine the short term effects of one method of a running "retraining" strategy in runners with PFP. This was a single-subject case study design. The subject completed a pre- and post-training assessment that included a video analysis for stride frequency. The subject also completed a Visual Analog Scale (VAS) and a Lower Extremity Functional Scale (LEFS). After the initial evaluation, the subject completed a training regime of scheduled auditory feedback to increase their running step rate. The training period included 2 sessions per week for 4 weeks. In order to assess the short-term outcomes for PFP in this runner, the subject repeated the VAS and LEFS at the conclusion of the training period. The results of this study supported the hypothesis that increasing a runner's preferred stride frequency by 5% over a 4 week training schedule would decrease their reported PFP as measured by a VAS. Results also showed an increase in reported lower extremity function as measured by the LEFS. The data supports the development of further studies in the topic area of

patellofemoral pain and stride frequency modification. Interventions that are functional in nature and go beyond treatment of PFP at the impairment level may be critical to the development of long-term solutions for PFP within the running community.

Introduction

Running is a popular form of exercise among the general population. The most common site of injury for runners is the knee, with patellofemoral pain being the most common complaint (Taunton et al., 2002). According to the literature, patellofemoral pain (PFP) is defined as pain in the anterior knee due to overuse. Activities that cause pain include ascending and descending stairs, squatting, sitting for long periods of time, running, jumping--anything that increases the patellofemoral joint compressive forces (Witvrouw, et. al., 2014). Much of the recent work with the treatment of patellofemoral pain has involved strengthening of the hip musculature to reduce pain about the knee (Ferber, Noehren, Hamill & Davis, 2010; Souza and Powers, 2009). However, the ability of these strengthening programs to change lower extremity mechanics or sustain long-term pain reduction has been unproven. As a result, more recently, researchers have started to examine the impact of "retraining" strategies for runners in an attempt to reduce PFP (Willy, Scholz, & Davis, 2012) and patellofemoral joint forces (Lenhart et al., 2014). The purpose of this study was to examine the short term effects of one method of a running "retraining" strategy in a runner with PFP. Stride frequency has been established as a contributing factor to increased ground reaction forces through the patellofemoral joint that may contribute to patellofemoral pain (Lenhart et al., 2014).

It is important to evaluate the validity of this training strategy in various populations of runners. It is important to examine if there is a difference in effectiveness of this intervention between recreational and competitive runners. Most studies to this point have not examined recreational runners with varied body types. If found to be beneficial, this type of intervention could be useful in screening recreational runners as they begin running or initiate many of the popular training programs. This information could be used to build prevention programs in the future for runners.

As stated, patellofemoral pain is the most common complaint of injury in runners. There are many examples in the literature of studies that have used quadriceps and hip strengthening in order to reduce PFP; however, there is limited research in the literature about changing running mechanics, such as stride frequency, in order to reduce PFP in runners. An increase in step frequency effectively shortens the stride length of a runner as they train at their preferred running pace. This is thought to decrease the overall effect of patellofemoral joint forces on the knee.

This study was a single-subject case design and therefore, does not allow results to be generalized beyond this case report. However, the data supports the development of further studies in the topic area of patellofemoral pain and stride frequency modification.

Literature Review

Background Information

According to the literature, patellofemoral pain (PFP) is defined as pain in the anterior knee due to overuse. Activities that cause pain include going up and down stairs, squatting, sitting for long periods of time, running, jumping--anything that increases the patellofemoral joint compressive forces (Witvrouw, et. al., 2015). These are some signs of PFP. It is a very common condition, especially in active populations and in the female population when compared to males (Witvrouw, et. al., 2015). Rathleff (2014) stated that activity level plays a major role in PFP due to excessive loading of the patellofemoral joint and/or patellar misalignment. Rathleff (2014) also stated that exercise therapy is a common treatment for adults with PFP, although patient education is also used. Exercise therapy is mainly used to strengthen the muscles that are commonly weak in people with PFP: quadriceps, hip external rotators, hip abductors. Weakness in any of these muscles is often a contributor to PFP. There are multiple factors that go into diagnosing PFP, such as looking for these signs and symptoms mentioned above. Although patellofemoral pain is relatively easy to diagnose, there can be a myriad of different causes, leading to multiple treatment options.

Allied Research

PFP is a multi-factorial condition, meaning there could be any number of causes and treatments for it. One study by Chen & Powers (2014), looked at patellofemoral joint reaction forces (PFJRFs) in those with and without PFP. Along with lower extremity biomechanics, the researchers used an individualized 3D model that included specific anatomical features, retrieved from MRI (Chen & Powers, 2014). This was used to determine the load on the patellofemoral joint during activities (Chen & Powers, 2014). This study found that PFP patients had lower PFJRFs than those without PFP for superior and posterior forces, such as ascending and descending stairs; but higher PFJRFs for lateral forces, such as turning or crouching (Chen & Powers, 2014). The researchers concluded that people with PFP may develop strategies to reduce pain by attempting to decrease loading in the patellofemoral joint (Chen & Powers, 2014). These potential compensatory strategies probably involve the surrounding musculature and the biomechanics, which contribute to PFP symptoms.

A second study by Rathleff (2014) looked at neuromuscular control during stair descent and isometric knee extension strength in adolescents with PFP compared with adolescents without PFP. The study found that the adolescents with PFP had lower isometric knee extension strength compared to those without PFP. These results indicate that exercise therapy should target both neuromuscular control and strength since both are affected in PFP patients (Rathleff, 2014). This study further looked at the pain threshold and found that the pain thresholds were reduced around the knee and lower leg, meaning that PFP patients had altered processing of nocioceptive (pain receptive) information (Rathleff, 2014). This means that early in rehabilitation, exercises that target the knee specifically should be avoided, and general exercises not targeting the knee, self-management and education should be the focus (Rathleff, 2014).

In addition to these studies, Regelski, Ford & Hoch (2015) conducted an extensive literature review and found that majority of studies involving PFP treatments have found that hip strengthening, with or without quadriceps strengthening reduces pain and improves function in patients with PFP. The article also stated that hip weakness has been linked to changes in kinematics in the hip and knee, meaning that hip strengthening is important for rehabilitating patients with PFP to reduce their symptoms and improve their function in their knees and hips. This article shows that the topic of hip versus quadriceps strengthening in PFP treatment is a prevalent topic in existing literature with a common finding being that the hip plays a vital role in PFP rehabilitation.

At this point, many different strategies exist to treat PFP. There has been a lot of research done on hip and quadriceps strengthening, such as the work by Dolak, Silkman, Mckeon, Hosey, Lattermann, & Uhl (2011). However, strengthening programs alone may not have long-lasting effects on the management of PFP. It may be necessary to include movement re-training to further target the reduction of forces through the patellofemoral joint, especially during running. As stated in multiple studies, including a study done by Noehren, Hamill, & Davis (2013), runners with patellofemoral pain oftentimes exhibit increased hip adduction and hip internal rotation. Much of the strengthening protocols for PFP have thus included strengthening of the hip abductors and external rotators as a means to reduce PFP (Ferber, 2015). However, strengthening alone may not be enough.

These altered mechanics may need to be corrected in order to decrease PFP in some runners. When changing poor body mechanics as treatment for PFP in runners, Agresta & Brown (2015) determined that auditory and visual feedback are valid methods. A study done by Willy, Scholz, & Davis (2012) looked at hip mechanics in runners and used a mirror to provide visual feedback. During this study, researchers developed an 8 session training program using mirror and verbal feedback to correct lower extremity alignment during treadmill running in 10 female runners with PFP (Willy, et. al., 2012). Correcting poor hip mechanics in order to reduce PFP in this running population was the focus of this study. The feedback was gradually removed in the final 4 sessions (Willy, et. al., 2012). Results of this study showed that participants maintained proper mechanics even after months without feedback and they reported decreased pain and improved function (Willy, et. al., 2012). This demonstrated that allowing runners to adjust poor hip mechanics through visual and auditory feedback was a valid method for reducing PFP in runners. This is just one of the ways that mechanics can be targeted as treatment for PFP.

Critical Research

One method of treating patellofemoral pain involves re-training running mechanics through increasing stride frequency for those who have a low preferred stride frequency. Heiderscheit, et. al. (2011) found that runners with a low preferred stride frequency tend to land with their foot well out in front of their center of mass at initial contact. This "over-striding" effectively increased the vertical ground reaction forces that are experienced by the runner. Additionally runners that over-stride tend to land with a decreased knee flexion angle at initial contact. This effectively decreases the ability of the quadriceps to dissipate the ground reaction forces about the patellofemoral joint.

Stride frequency is a relatively recent topic of discussion for treating runners with patellofemoral pain. However, multiple studies looking at mechanics in runners have found that an increase in step rate reduces load from forces at the anterior aspect of the knee joint (Lenhart, et. al., 2014). An article by Peterson, Sorensen, and Nielsen (2015) makes a compelling case for increasing stride frequency being a valid treatment option for runners since it may decrease the forces acting on the knee, thus reducing the risk of injury to the anterior aspect of the knee. This study collected data from 16 participants who were recreational runners. Inclusion criteria for this study included presenting a rear-foot running strike pattern, having no injuries in the past 6 months, and having a 5-km distance run time slower than 17.65 km/h. Through this study, the researchers determined if there was an increase in cumulative load at the knee joint as running speed decreased (Petersen, Sorensen & Nielsen, 2015). In order to test this objective, the investigators chose a slow speed (8.02+/-.17 km/h), a medium speed (11.79+/-.21 km/h), and a fast speed (15.78+/-.22 km/h), having each participant run at each speed over a 1000 meter distance (Petersen, Sorensen & Nielsen, 2015). To determine the cumulative load, the investigators used 3-D inverse-dynamics technology along with a force plate (Petersen, Sorensen & Nielsen, 2015). Data was collected after three valid strikes on the force plate and three trials were recorded at each speed for each participant (Petersen, Sorensen & Nielsen, 2015). To calculate the cumulative load, investigators multiplied impulse per stride by the amount of strides needed to complete the 1000 meter distance (Petersen, Sorensen & Nielsen, 2015). At an increased running speed, the decrease in the number of steps taken over a given distance must outweigh the increase in load per step in order for the cumulative load to decrease (Petersen, Sorensen & Nielsen, 2015). The results of this study showed that this is the case. Due to the increased number of strides runners have to take when running at a slower speed over a given distance, the increased cumulative load outweighs the decreased load per stride (Petersen, Sorensen & Nielsen, 2015). In other words, running at higher speeds over a given distance decreases the cumulative load, potentially leading to a lower risk of injury and less PFP in runners who suffer from it. Additionally, Petersen, Sorensen & Nielsen (2015) stated that there is an increase in metabolic demand for each unit of distance a higher speeds of running, meaning that the ability of runners to run long distances decreases with increased speed. This further supports running at higher speeds to decrease the cumulative load, since there would be even less points of contact with the ground when running at higher speeds compared to lower speeds (Petersen, Sorensen & Nielsen, 2015).

A study by Heiderscheit, Chumanov, Michalski, Willie, and Ryan (2011) reiterated the point that increasing a runner's preferred step rate by 10% or greater may reduce the load through the patellofemoral joint and other joints in order to reduce injury risk. From this study, the prevalence of running related injuries, specifically at the patellofemoral joint, is reported to be 56% risk for recreational runners and 90% risk for marathon in training runners (Heiderscheit, et. al., 2011). The prevalence of PFP simply underscores the need for additional studies that examine the application of increasing step frequency in runners of various age, body type and experience as a treatment for PFP.

This group of researchers (Chumanov, Willie, Michalski, & Heiderscheit, 2012) followed up with a study looking at increased step frequency in runners and its effect on neuromuscular activity. They found that when runners ran at an increased step rate 5-10% above their preferred step rate, it could reduce power in movement in order to manage lower extremity injury

(Chumanov, et. al., 2012). This study included 45 injury-free recreational runners and they had them run at their preferred stride frequency, 5% above preferred, and 10% above preferred; and then recorded 3-D motion data, ground reaction force data, and EMG data from the following muscles: rectus femoris, vastus lateralis, medial gastrocnemius, tibialis anterior, medial and lateral hamstrings, and gluteus medius and maximus. Results showed that muscle activity, specifically the gluteus medius and gluteus maximus activity, increased in late swing phase of gait in anticipation of contact with the ground. Due to the anticipatory contraction of these muscles, the authors concluded that this type of muscle activity would be useful in reducing PFP that may be the result of an increased adduction and internal rotation moment about the knee. The results of this study are very informative, but it must be noted that their population included only healthy runners.

Further, a study by Hobra, Sato, Sakaguchi, and Nakazawa (2012) looked at increasing step frequency in running and its effect on vertical ground reaction forces and lower extremity loading variables. The investigators recruited 10 healthy males to run at 2.5 m/s on a treadmill-mounted force platform and measured their lower extremity loading variables at five different step frequencies, controlled using a metronome. These five step frequencies included preferred, 15% below preferred, 30% below preferred, 15 % above preferred, and 30% above preferred. The average preferred step frequency was 163 steps per minute. All subjects were allowed a 3-4 minute warm-up in order to become comfortable with the auditory feedback. Then, each subject ran for 30 seconds at each of the five step frequencies in a random order, with five minute break periods in between each step frequency. The investigators found significant differences in loading variables in each step frequency condition (Hobra, et. al., 2012). Hobra, et. al. (2012) concluded that training at a higher step frequency than the preferred step frequency by runners decreases lower extremity loading variables, and therefore, may be a good method in reducing risk of lower extremity running-related injuries, such as tibial stress fracture or PFP. Additionally the researchers found that each participant performed a step frequency within 5% of the designated metronome frequency, showing that runners adapted to the change in step frequency through auditory feedback via metronome to a significant degree (Hobra, et. al., 2012).

Summary

In conclusion, PFP is a multi-factorial condition, meaning there are many potential contributing factors and causes. Strengthening has been commonly used to treat PFP, focusing on quadriceps and hip strengthening. However, as the literature states, in the running community, PFP could be caused by issues with body mechanics, body structure, or stride length and step frequency. Although much work has been done to examine the effect of increased step frequency and the effect that it may have on the forces experienced at the patellofemoral joint during running, the literature is lacking with reports of how increasing step frequency changes PFP in runners. Therefore, the research question is: will an increase in step frequency decrease a college-aged recreational runner's PFP? The researchers hypothesize that increasing a runner's step frequency by 5-10% over a four week training schedule should reduce his/her PFP. Although there have been studies published recently to support this claim, further research may still be required to support this finding. Additionally, further research may be required to study the long term effects of step frequency training.

Methods

The case study subject was a 19 year old male student at Otterbein University. The subject was recruited by the primary investigator by distributing a recruitment flyer with an inclusion questionnaire (Appendix A) to a classroom of students within the Health and Sport

Sciences Department. Criteria for the inclusion questionnaire on the recruitment flyer was found in the literature, specifically in an article by dos Reis, Correa, Bley, Rabelo, Fukuda& Lucarelli (2015). This criteria included: having anterior knee pain for at least 3 months and pain increasing with 2 or more activities--ascending and descending stairs, squatting, kneeling, jumping, long periods of sitting. Upon completion of the inclusion questionnaire for knee pain, the subject indicated that he had experienced knee pain for three months or longer, and that he experienced pain with ascending stairs, squatting, kneeling on his knees, and sitting for long periods. This indicated that the subject had patellofemoral pain per the established inclusion criteria for this study. The subject also has a history of bilateral ACL sprains (grade II) with no surgical intervention.

The subject had a history of pain in his right knee over his left knee over the past 3-4 years. The subject had approximately one month of physical therapy intervention approximately 4 years ago for his knee pain. The subject ran an average of 15-20 miles per week, running 5 miles in 45-minute increments a few days a week. The subject was instructed to use the 2, 25-minute training sessions each week in place of two typical running days and was otherwise allowed to run outside of training like his typical routine.

At the first meeting, the subject signed an informed consent form. Additionally, the subject completed an initial Visual Analog Scale (VAS) and Lower Extremity Functional Scale (LEFS). The VAS (Appendix B) has been repeatedly used in the literature as way to measure patient perceived pain. The VAS is a horizontal continuum from "no pain" to "very severe pain" and is 100 mm in length. The VAS score is measured in millimeters from the left hand end to the point where the patient marks. The LEFS (Appendix C) is another instrument that has been repeatedly used throughout the literature to measure function in the lower extremities. The LEFS lists 20 activities and patients indicate how much difficulty they have with each activity, from "extreme difficulty or unable to perform" to "no difficulty". Each level of difficulty is indicated by a number from 0 to 4 and these numbers are added in order to produce the LEFS score. A maximum score is 80 on the LEFS.

In order to assess the subject's preferred stride frequency, he was instructed to run at his normal, comfortable pace on the treadmill and a video analysis was completed. As he ran at this self-selected pace, the primary investigator and student investigator each counted the steps taken by one foot for one minute and multiplied the number by two to receive the preferred steps per minute of the subject. The researchers found the subject's preferred stride frequency to be 164 steps/minute. A 5% increase in preferred step frequency was 172 steps/minute for this subject.

The training took place over a 4 week period in the research lab in the Otterbein University Department of Health and Sport Sciences. The instruments used included a Woodway treadmill and an iPad. The iPad was used to provide auditory feedback via a metronome application set to 172 steps/minute. The feedback schedule was similar to the schedule used by Willy, et. al. (2012); however, the 8 sessions were spread over a 4 week period in order to replicate a more typical physical therapy regime. The feedback schedule was as follows:

Week 1: 1 minute on, 1 minute off

Week 2: 1 minute on, 2 minutes off

Week 3: 1 minute on, 4 minutes off

Week 4: 1 minute on, 8 minutes off.

The subject was instructed to match the metronome when introduced and try to continue matching the pace when the metronome was off. During each training session, the subject first completed a warm-up run at a self-selected pace for 5 minutes. Next, the subject was instructed to continue with a self-selected training pace and follow the feedback schedule as indicated for the remaining 20 minutes of training. Investigators did not provide verbal feedback regarding accuracy of matching the 172 steps/minute when the metronome was off. The subject matched the metronome with accuracy each time it was on and did not require verbal feedback. However, observation of the subject noted that he struggled at times to maintain the pace when the metronome was off. The investigator did not provide verbal feedback during that time. The subject was instructed to complete the VAS again at 2 weeks and at the end of the study at 4 weeks. The LEFS was also completed at 4 weeks. The initial VAS and LEFS were compared to the final VAS and LEFS to determine if the 5% increase in preferred stride frequency decreased the pain and increased function in this recreational runner. The VAS at 2 weeks was compared to the initial and final VAS scores to determine how soon the pain started to change.

Results

One student recreational runner responded to the recruitment flyer and inclusion questionnaire, making it a single-subject case study design. This subject completed the study in full over the course of a 4 week training schedule. At the initial visit, the subject signed an informed consent form, completed the initial VAS and initial LEFS. These scores were 4.4 cm (Figure 1) and 57 (Figure 2), respectively. At 2 weeks into the training schedule, the subject completed the VAS again with his score being 1.8 cm (Figure 1). At the end of the 4 week training schedule, the subject completed a final VAS and LEFS. These scores were 0.5 cm (Figure 1) and 71 (Figure 2), respectively.

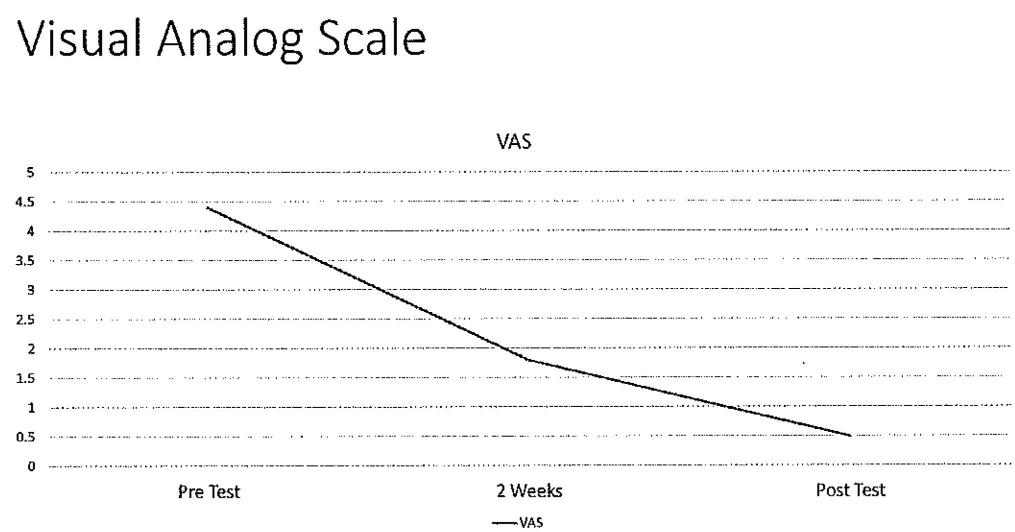

Figure 1: This is a line graph representing the VAS data collected from the subject before the training schedule (pre-test), at 2 weeks into the training schedule, and after the 4 week training schedule (post-test). Over the course of 4 weeks, the subject's VAS scores decreased by 3.9 cm.

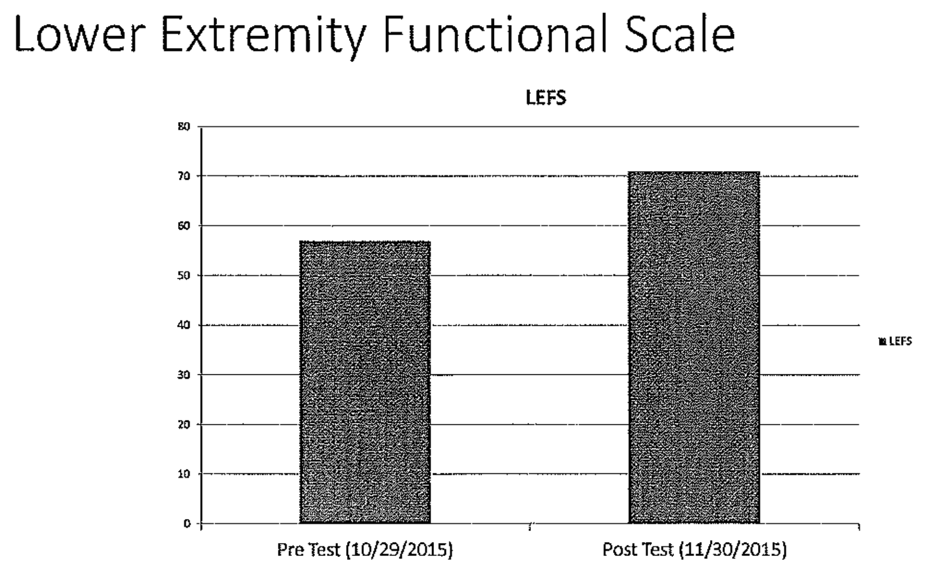

Figure 2: This is a bar graph representing the LEFS data collected from the subject before the 4 week training schedule (pre-test) and after the 4 week training schedule (post-test). Over the course of the 4 week training schedule, the subject's lower extremity function increased by 14 points on the scale, with a final score reported at 71, which is 9 points away from a "perfect" score of 80, which would indicate no difficulty with any of the 20 activities.

Discussion

The results of this study supported the hypothesis that increasing a runner's preferred stride frequency by 5% over a 4 week training schedule would decrease their reported PFP as measured by a VAS. Additionally, the results showed an increase in reported lower extremity function as measured by the LEFS, specifically with usual work and activities, walking between rooms, squatting, lifting an object from the floor, walking two blocks, walking a mile, going up or down 10 stairs, standing or sitting for one hour, running on even or uneven ground, making sharp turns while running fast, and hopping.

The subject of this case study was a male with patellofemoral pain. This is different than the description of most subjects in the literature. Nearly every study cited in this paper included male subjects only when healthy (without PFP) or they included female subjects, with or without PFP. This is most-likely due to the fact that PFP is more common in women (Witvrouw, 2014). In the study by Willy, et. al. (2012), where this study's auditory feedback schedule is supported, the subjects include 10 female runners with PFP between 18 and 40 years of age. In the Heiderscheit, et. al. (2011) study, the subjects included 45 healthy volunteers and 25 were males with a mean age of 32.7. In the study by Hobara, et. al. (2012), which supported the use of the metronome for auditory feedback, subjects included 10 healthy males with an average age of 28. Further research may be needed for male subjects with PFP as well as college-aged students.

The results of this case study support the theory that training a recreational runner with a with PFP at a step frequency 5% above (172 steps/minute) their preferred step frequency using an auditory feedback schedule supported by the literature over the course of 4 weeks will decrease their PFP and increase their function level (Willy, et. al., 2012). The process of using a metronome to provide auditory feedback is supported by the literature as well (Hobara, et. al., 2012). Limitations of the study may include that the results cannot be generalized to the entire recreational running population considering this was a single-subject case study. Also, from observation, the subject was unable to maintain the increased pace when the metronome was off at times, leading researchers to believe that the results may be short-term, since the subject may not be running at the increased stride frequency outside of the lab.

Further research is needed to make the results generalizable. More subjects are needed to test this research theory. Additionally, testing a difference between competitive and recreational runners is an area where more research is needed. Long-term follow-up with subjects could be an area for further research as well. If it is determined that runners need intermittent "retraining", there are step frequency applications that could be used by these runners outside of a research facility. How often and for how long runners require feedback to maintain lower PFP levels has yet to be researched.

Conclusions

The data supports the development of further studies in the topic area of patellofemoral pain and stride frequency modification even if they cannot be generalized beyond this case report. The amount of time required for this patient was minimal to achieve the positive results with regard to decreasing PFP and increasing function. Case studies such as this are important to validate these training strategies within populations suffering from PFP. Interventions that are functional in nature and go beyond treatment of PFP at the impairment level may be critical to the development of long-term solutions for PFP within the running community.

Acknowledgements

The author thanks the Department of Health and Sport Sciences at Otterbein University, Dr. Shelley Payne, Dr. Joe Wilkins, Dr. Steffanie Burk, Dr. David Robertson, Annette Boose, and Dr. Joan Rocks for all assistance provided to complete this research.

References

Agresta C., & Brown A (2015). Gait Retraining for Injured and Healthy Runners Using Augmented Feedback: A Systematic Literature Review. *J Orthop Sports Phys Ther*. 2015;45(8):576-584.

Chen, Y., & Powers, C. (2014). Comparison of Three-Dimensional Patellofemoral Joint Reaction Forces in Persons With and Without Patellofemoral Pain. *Journal of Applied Biomechanics,* 493-500. Retrieved March 24, 2015, from Academic Search Complete.

Chumanov ES, Wille CM, Michalski MP, Heiderscheit BC. Changes in muscle activation patterns when running step rate is increased. Gait Posture. 2012;36:231-235. http://dx.doi.org/10.1016/j.gaitpost.2012.02.023

Dolak, K., Silkman, C., Mckeon, J., Hosey, R., Lattermann, C., & Uhl, T. (2011). Hip Strengthening Prior to Functional Exercises Reduces Pain Sooner Than Quadriceps Strengthening in Females With Patellofemoral Pain Syndrome: A Randomized Clinical

Trial. *Journal of Orthopaedic & Sports Physical Therapy,* 560-570. Retrieved March 24, 2015, from CINAHL.

dos Reis, AC, Correa, JCF, Bley, AS, Rabelo, NDdA, Fukuda, TY, & Lucarelli, PRG. (2015). Kinematic and Kinetic Analysis of the Single-Leg Triple Hop Test in Women With and Without Patellofemoral Pain. Journal of Orthopaedic&Sports Physical Therapy, 45(10), 799-807 9p. doi:10.2519/jospt.2015.5011

Heiderscheit BC, Chumanov ES, Michalski MP, Wille CM, Ryan MB. Effects of step rate manipulation on joint mechanics during running. Med Sci Sports Exerc. 2011;43:296-302. http://dx.doi.org/10.1249/MSS.0b013e3181ebedf4

Hobara H, Sato T, Sakaguchi M, Nakazawa K. Step frequency and lower extremity loading during running. Int J Sports Med. 2012;33:310-313.http://dx.doi.org/10.1055/s-0031-1291232

Ferber R, Noehren B, Hamill J, Davis IS. Competitive female runners with a history of iliotibial band syndrome demonstrate atypical hip and knee kinematics. *J Orthop Sports Phys Ther*. 2010;40:52-58. http://dx.doi.org/10.2519/jospt.2010.3028

Lenhart RL, Thelen DG, Wille CM, Chumanov ES, Heiderscheit BC. Increasing running step rate reduces patellofemoral joint forces. *Med Sci Sports Exerc*. 2014;46(3):557-564.

Noehren B, Hamill J, Davis I. Prospective evidence for a hip etiology in patellofemoral pain. Med Sci Sports Exerc. 2013;45:1120-1124. http://dx.doi.org/10.1249/MSS.0b013e31828249d2

Petersen J, Sorensen H, Nielsen RO. Cumulative Loads Increase at the Knee Joint with Slow-Speed Running Compared to Faster Running: A Biomechanical Study. JOSPT. 2015:45(4):316-322. doi:10.2519/jospt.2015.5469.

Rathleff, MS. (2014). TREATING ADOLESCENT PATELLOFEMORAL PAIN. *Sportex Medicine*, (61), 21-25. Retrieved March 31, 2015, from CINAHL.

Regelski, C., Ford, B., & Hoch, M. (2015). Hip Strengthening Compared With Quadriceps Strengthening in Conservative Treatment of Patients With Patellofemoral Pain: A Critically Appraised Topic. *International Journal of Athletic Therapy & Training*. Retrieved March 24, 2015, from Academic Search Complete.

Souza RB, Powers CM. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *J Orthop Sports Phys Ther*. 2009;39:12-19. http://dx.doi.org/10.2519/jospt.2009.2885

Taunton JE, Ryan MB, Clements DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. *Br J Sports Med*. 2002;36:95-101. http://dx.doi.org/10.1136/bjsm.36.2.95

Willy RW, Scholz JP, Davis IS. Mirror gait retraining for the treatment of patellofemoral pain in female runners. *Clin Biomech (Bristol, Avon)*. 2012;27:1045-1051. http://dw.doi.org/10.1016/j.clinbiomech.2012.07.011

Witvrouw E., Callaghan M., Stefanik J., Noehren B., Bazett-Jones D., Willson J., ... Crossley K. (2014). Patellofemoral pain: Consensus statement from the 3rd International Patellofemoral Pain Research Retreat held in Vancouver, September 2013. *British Journal of Sports Medicine*.

Appendix A: Inclusion Questionnaire

Recruitment Script:

Are you a runner that has experienced knee pain that has limited your running? If so, we would like for you to consider being part of a research study!

We are conducting a research study looking at improving knee pain in runners. You will attend two evaluation sessions that should last no more than 20 minutes. During the course of the study you will complete 3 training sessions per week for a 6 week period. Each training session will last 25 minutes. The information we gain from these tests could be very valuable for providing additional training information for future runners. Your help would be greatly appreciated. If you are interested in participating please email spayne@otterbein.edu.

Questionnaire for Knee Pain:

Please fill out the following questionnaire about your knee:

	YES	NO
Have you had knee pain for 3 months or longer?		
Does your knee hurt when:		
You climb up stairs?		
You go down stairs?		
You squat?		
You kneel on your knees?		
You jump?		
You sit for long periods?		

Appendix B: VAS

INFORMATION POINT:

Visual Analogue Scale (VAS)

A Visual Analogue Scale (VAS) is a measurement instrument that tries to measure a characteristic or attitude that is believed to range across a continuum of values and cannot easily be directly measured. For example, the amount of pain that a patient feels ranges across a continuum from none to an extreme amount of pain. From the patient's perspective this spectrum appears continuous – their pain does not take discrete jumps, as a categorization of none, mild, moderate and severe would suggest. It was to capture this idea of an underlying continuum that the VAS was devised.

Operationally a VAS is usually a horizontal line, 100 mm in length, anchored by word descriptors at each end, as illustrated in Fig. 1. The patient marks on the line the point that they feel represents their perception of their current state. The VAS score is determined by measuring in millimetres from the left hand end of the line to the point that the patient marks.

How severe is your pain today? Place a vertical mark on the line below to indicate how bad you feel your pain is today.

No pain |____| Very severe pain

Figure 1 Effects of the interpersonal, technical and communication skills of the nurse on the effectiveness of treatment.

There are many other ways in which VAS have been presented, including vertical lines and lines with extra descriptors. Wewers & Lowe (1990) provide an informative discussion of the benefits and shortcomings of different styles of VAS.

As such an assessment is clearly highly subjective, these scales are of most value when looking at change within individuals, and are of less value for comparing across a group of individuals at one time point. It could be argued that a VAS is trying to produce interval/ratio data out of subjective values that are at best ordinal. Thus, some caution is required in handling such data. Many researchers prefer to use a method of analysis that is based on the rank ordering of scores rather than their exact values, to avoid reading too much into the precise VAS score.

Further reading

Wewers M.E. & Lowe N.K. (1990) A critical review of visual analogue scales in the measurement of clinical phenomena. *Research in Nursing and Health* 13, 227–236.

NICOLA CRICHTON

Appendix C: LEFS

Instructions

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

Today, *do you* or *would you* have any difficulty at all with:

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