A COMPARISON OF TENSOR FASCIAE LATAE AND HIP MUSCLE ACTIVATION DURING THE RUNNING GAIT BETWEEN TRAINED AND CASUAL DISTANCE RUNNERS

A THESIS

Submitted to the Faculty of the School of Graduate Studies and Research
of
California University of Pennsylvania in partial fulfillment of the requirements for the degree of

Master of Science

by
Kurt Otto Buchholz, ATC

Research Advisor, Dr. Shelly DiCesaro

California, Pennsylvania
2014

CALIFORNIA UNIVERSITY of PENNSYLVANIA
CALIFORNIA, PA

THESIS APPROVAL

Graduate Athletic Training Education

We hereby approve the Thesis of

Kurt Otto Buchholz, ATC
Candidate for the degree of Master of Science

Date	Faculty
6-2-14	Shelly DiCesaro Shelly Fetchen DiCesaro, PhD, ATC (Chairperson)
6-2-14	Samuel Cervantes, MS, ATC
6-2-14	Thomas F. West Thomas F. West, PhD, ATC

TABLE OF CONTENTS

Introduction

Due to the high accessibility and the many noted health benefits, running has steadily become one of the most popular modes of exercise.[1-3] With this high rate of participation across many different experience and capability levels, comes a heightened rate of injury as well. Different systemic reviews and epidemiological studies have shown that injury rates can range from 19.4% to 92.4% of all distance runners.[2] This same epidemiological study also noted that injuries to the knee were the predominating injury sustained, with 7.2% to 50.0% of runners experiencing a knee injury.[2] While other studies mirror this statistic,[1,3] they also make a point to say that the leading knee injury is associated with anterior knee pain, specifically patellofemoral pain syndrome.[1-3]

Because lower extremity pain in distance runners is prominent, there have been many investigations into the cause of the pain, as well as potential interventions. With this increased study, numerous sources have recommended further investigation into various aspects of hip strength.[4-6] Studies have shown that strengthening the muscles at the hip can improve proper running kinematics. However, because hip strengthening has been globally recommended, there are now many questions as to proper exercise selection for improving the condition of knee pathologies.[4] By conducting this research, it will be easier to compare and contrast the various strength aspects and muscle involvement between trained distance runners and casual runners. With a clearer picture of the difference between these two groups, it would be possible to see any differences in muscle use and efficiency. This possible information could in turn lead to more focused preventative strengthening exercises and effective rehabilitation programs for endurance runners. This proper exercise selection would in turn be used to target the only hip muscles used in the efficient strides seen in the trained running group, with particular interest in the involvement of the tensor fasciae latae (TFL). An overactive role of this muscle may be present in those experiencing knee pain as well.

Many different methods of research have looked into knee pain from a variety of different viewpoints. While the reasons behind the development of this condition range widely, including age, miles run per week, weight, and foot structure and alignment, there is always room for research.[1-3] For this reason, this research is examining the involvement of hip muscle activation during the running gait while focusing particularly on the TFL.

A plethora of strength assessment research has been conducted using the single leg squat test. This may be due to the ease and accuracy that the test provides when assessing hip and lower kinetic chain strength.[7-9] Being able to determine lower kinetic chain strength is important because the presence of excessive hip adduction and internal rotation, through either weakness or impairment, has been shown to lead to anterior knee pain.[10-13] Being able to identify these impairments and target them with the proper exercises could lead to proper recovery and prevention.

Hip strength is a critical factor in controlling lower leg movement, especially in light of analyzing the running gait and the associated forces. It has also been noted as running velocity increases, the base of support narrows and there is a force of approximately 1.5 to 3.5 times the person's body weight sent through the lower extremity.[10] An analysis of the muscles involved during the running gait has also shown that external rotators are important for both driving the foot forward and preventing excessive knee adduction. Adequate strength is required for proper control of these aspects of the gait cycle as well.

Many different aspects of the lower kinetic chain have been investigated, from pelvic and trunk stability to ankle range of motion, in an attempt to analyze proper running mechanics.[14-16] In order to evaluate knee pain and its etiology, it is also important to look at the joints distal and proximal to it, as they will play a significant role in the kinematics of the knee.

Authors speculate that when runners use a greater percentage of their available pronation, they are more prone to knee pain.[15] Various factors lead to the ankle joint reaching it's maximum range of motion faster, thus if more motion is needed, adaptation must take place at the next joints in the kinetic chain, which manifests in the knee. It is suggested from these findings that this additional knee motion, in a plane of motion that the knee does not operate in, causes anterior knee pain to manifest.[15]

While the ankle joint rotation due to pronation is known to cause internal rotation of the lower extremity,[14] other factors also play into this internal rotation from more proximal joints, specifically at the hip. Control of excessive motion at the hip can occur by the musculature surrounding the hip and knee, and has been shown to help improve running mechanics.[12]

In a further analysis of the effects of various biomechanical factors on the lower closed kinetic chain, Chuter and Janse de Jonge[17] conducted a literature review that investigated the functions of various joints and the injuries that dysfunction can commonly lead to. They suggest that based on the review of available literature, for anterior knee pain and related lower extremity injuries, "hip muscle strengthening and neuromuscular retraining of the lumbopelvic-hip complex should form the basis for rehabilitation … and injury prevention."[17]

Finally, a study by Ferber, Kendall and Farr[6] analyzed the effects of a hip-abductor specific strengthening program on runners' mechanics that had PFPS. Selected from runners presenting at a local clinic with PFPS, participants in this study engaged in a three-week strengthening protocol. After analysis, there was a significant increase in hip-abductor strength, as well as a reported lower level of pain and stride-to-stride knee-joint variability in the runners with PFPS.[6]

In light of various strengthening protocols and recommendations, there is a case for strengthening particular muscles over others, with the end goal of limiting excessive medial knee excursion. This end goal may aid in the reduction of overuse injuries, as well as provide justification for various training and rehabilitation exercises and work-out plans. The purpose of this research is to identify the muscle involvement in trained distance runners and compare it to the muscle involvement in casual runners. The results could establish if there are indeed particular muscles that should be targeted or avoided, such as the TFL, when selecting strengthening exercises for runners.

METHODS

To test the muscle involvement within the hip during running, a specific running protocol was developed and adapted for this study based on similar prior research. Similar instrumentation was also researched and obtained, as well as checked for the validity of its current uses based on previous studies. This section includes the following subsections: research design, subjects, instruments, procedures, hypotheses, and data analysis.

Research Design

This study is an observational experimental design. The independent variable is the experience level of the runner and the dependent variable is the muscle activity as measured through the use of surface electromyography (sEMG) while running on a treadmill. The activity was observed as a percentage of the subjects' maximal voluntary isometric contraction (MVIC). Participants were runners of various capability levels. Through the use of a pretesting screening questionnaire, the participants were divided into two groups, trained and casual. The trained running group was required to report an average weekly mileage of 40 miles per week or more and they were recruited from the university cross country team or the distance program of the track team. This ensured that the runners for the trained group are on a consistent, regimented training program. Runners from the general campus population were also included in this group if they meet the weekly mileage requirement and they were on a regimented training program. The runners recruited for the untrained group were from the campus population who defined themselves as casual runners who run between an average of 5 to 15 miles per week for the last 3 months. Findings were limited to the running population, however the information could provide training insight to casual runners looking to improve their strength or training, as well as for rehabilitation purposes.

Subjects

Subjects (N=20) for this study were recruited from both the campus population and from the National Collegiate Athletics Association (NCAA) Division II cross country and distance track teams at the California University of

Pennsylvania (Cal U). Participants were recruited via a short presentation of the study during either team meetings or health science classes, as well as through word of mouth around campus. No bias was present due to their ability to volunteer at the will of the participant, with no coercion from the researcher or the coaches of the proposed teams.

Inclusion Criteria

- Over 18 years of age
- Free from lower extremity injury for 3 months prior
- Have maintained a consistent level of training for the 3 months prior
- Average a weekly mileage of five to fifteen miles (casual running group) or greater than forty miles (trained running group).

Exclusion Criteria

- Any injury that prevented normal training
- Any injury that has altered normal running mechanics
- Under the age of 18

Preliminary Research

Prior to the testing phase beginning, a preliminary research session was conducted. This session was used as a familiarization session for the researcher to become acquainted with the equipment during a live testing session. Familiarization with the electromyography equipment set-up, treadmill operation, testing procedure and the associated time to complete all of these tasks were the primary goals of this session. For this part of the research, mock participants were petitioned from the graduate and undergraduate athletic training programs at the California University of Pennsylvania. The same pre-participation screening protocol was used prior to having them volunteer and participate in the testing session.

Instruments

The instruments that were used in this study included the pre-participation screening questionnaire (Appendix C3), BioPac MP150 surface electromyography (sEMG)(Biopac, Goletta, California) and the treadmill testing protocol.

Surface Electromyography

Model/Manufacturer:MP150

Serial Number:703A-0000863

The use of sEMG was used to measure the amount of activity in the involved muscles. These muscles included the tensor fasciae latae, the gluteus medius and the gluteus maximus. Electrode pad placement was done in accordance with prior studies and normally accepted and described placement.[18] Prior to electrode placement, the skin was prepared by cleaning the area with an alcohol pad and lightly debriding it with an emery board. This procedure ensured proper pad contact, as this is the recommended method as described by various studies and guides.[18,19] With the inclusion of a ground wire and pad, the system also included pads over the tensor fascia latae, the gluteus medius and the gluteus maximus. Electrode placement for each muscle is described below and is derived from *Cram's Introduction to Surface Electromyography* by Eleanor Criswell.[18]

- Tensor Fasciae Latae
    - Two active pads will be placed two centimeters apart just below the anterior superior iliac spine of the iliac crest.

This placement will place the pads in a parallel line with the muscle fibers.

- Gluteus Medius
    - Two active electrodes will be placed two centimeters apart on the proximal third of the skin between the iliac crest and the greater trochanter. This will place the pads on a parallel line with the muscle fibers. The pads will also be placed anterior to the gluteus maximus.
- Gluteus Maximus
    - For the upper gluteus maximus, two active electrodes will be placed halfway between the greater trochanter of the femur and the sacrum. The two pads are placed 3 cm apart along this line.
    - For the lower gluteus maximus, two active electrodes will be placed in the middle of the muscle belly at a point below the level of the greater trochanter of the femur and at least 1 to 2 inches above the gluteal fold.
- Reference Electrode

- This electrode is a single pad that is used by the sEMG software as a reference for which the incoming active signal is compared to as a means of electronic "noise" reduction. This pad will be placed over a bony landmark, such as the patella or another comfortable landmark on the lower extremity.

Based on research of previous studies pertaining to EMG data collection, the EMG signal was band pass filtered at 10 and 500 Hertz (Hz). The sampling rate was be set at 1000 Hz.[19,21]

Procedures

Upon approval by the Institutional Review Board at the California University of Pennsylvania (Appendix C1), participants for the casual running group were recruited through oral communication at typical centers of activity around the campus and through team. Participants for the trained running group were recruited from the University cross country and distance track teams. The information was presented in an unbiased way to ensure that the participant truly volunteers for the study. The potential participants then filled out a pre-participation screening questionnaire (Appendix C3) to assess their running capability. If they meet the inclusion criteria, they were asked to sign the informed consent form (Appendix C2). The participants were then scheduled a date for data collection. Within the pre-participation screening questionnaire, demographic information was also collected (Appendix C3).

On the testing day, the participant was instructed to wear their typical running clothing. First, they were outfitted with the goniometer on the lateral aspect of their hip. Second, the surface electromyography pads and wires were placed using standard placement protocol. The tensor fasciae latae and the gluteus maximus and medius each had two pads to assess activity, as well as a ground pad. Pads were only placed on the self-identified dominant leg side.

After the pads were placed, a maximal voluntary isometric contraction (MVIC) was obtained. This was conducted in a controlled setting on a treatment table in the athletic training room. This testing was performed by having the subject contract each of the involved muscles with as much force as possible for 3 seconds.[20] This allowed for a data point from which to derive the percentage of muscle contraction during the testing phase of the study. This manually resisted action used to obtain the MVIC was consistent with manual muscle testing techniques currently employed by athletic trainers to isolate and test the strength of each individual muscle and as described by Cram's Introduction to Surface Electromyography by Eleanor Criswell.[18] The MVIC for each of the muscles was obtained as follows.[20]

- Tensor Fasciae Latae
  - The subject will be lying in the supine position with their hip flexed and internally rotated. While holding this position, the researcher will apply a force at the ankle while the subject contracts maximally to obtain the MVIC value.
- Gluteus Medius
  - The subject will be side lying on the side not being tested. The bottom hip and knee can be flexed for more stability. The test leg will then be abducted to half of the available range of motion with the hip in slight extension and external rotation. A downward force will then be applied by the

researcher at the ankle while the participant contracts maximally.

- Gluteus Maximus
  - The subject will be supine with their knee flexed to 90 degrees. This will limit any involvement of the hamstrings during the test action. The researcher will then apply force to the distal femur as the subject maximally contracts their gluteus maximus to extend their hip.

Treadmill Running Procedure

The treadmill running procedure began with a light aerobic warm-up on the treadmill. The participant was allowed to warm-up running on the treadmill at a slow, self-selected pace.[21] This warm-up lasted until the subject self reported that they were "warmed up" and ready to start, or for a maximum of 5 minutes, whichever came first. They were instructed prior to starting the test that their warmed up state should feel similar to how they feel in the middle of a typical training run.

After the subject had completed the warm-up phase, they were transitioned to the testing phase. This transition was continuous with the warm-up, as the only difference was that the speed of the treadmill was increased to a speed and incline that was consistent with mirroring outdoor running.[22] The speed was be set between 2.92 meters per second (6.5 miles per hour) and 5.0 m/s (11.2 mph). The athlete was instructed to run as normally and fluidly as possible. The participant will then run at this speed for 5 minutes. At the end of this 5-minute window, the sEMG and goniometer will record 10 stride lengths.

After the testing phase was complete, the sEMG stopped recording data. The athlete was allowed to cool down if they chose to do so and then they were disconnected from the sEMG recording equipment.

The EMG data was recorded at a 1000 Hz sampling rate. The data was be band pass filtered between 10 and 500 Hz and smoothed at 200 samples per second through the use of the AcqKnowledge software. This data was then normalized to the MVIC activation levels that were analyzed using the same data analysis process.

The data was analyzed by looking at the average electrical activity of the muscle compared to it's MVIC over the course of the ten recorded strides. This could also be broken into average activity while the leg is moving forwards and backwards as defined by the data gathered from the goniometer, however this was not utilized during this study.

The information gathered via the sEMG was used to compare the two groups for potential differences in muscle activity level in the studied musculature.

Hypotheses

The following hypotheses were tested in this study:

1. There will be significantly less activity in the TFL in the trained running group when compared to the untrained/casual running group.
2. Activity of the gluteal muscle group will be significantly higher in the trained running group compared to the untrained/casual running group.

Data Analysis

The data collected was analyzed using SPSS version 18.0 with an alpha level of ≤ 0.05. Data was analyzed using a two sample independent t-test.

RESULTS

The purpose of this study was to investigate and compare the levels of hip muscle activation between casual and trained runners. Subjects were tested using a repeatable running protocol on a treadmill. This protocol consisted of a five-minute warm-up and a five-minute run at their self-selected "typical training pace." Surface electromyography (sEMG) was used to assess the activation levels of the tensor fasciae latae (TFL), the gluteus medius (GMed) and the gluteus maximus (GMax). The following section contains the data collected through the study and is divided into two subsections: Demographic Information and Hypotheses Testing.

Demographic Information

This study consisted of 18 healthy, physically active participants (9 male, 9 female). The two groups were divided into casual and trained running groups. For inclusion within the casual training group, a self-reported weekly average mileage between 5 and 15 miles per week was required. These participants were recruited from the general campus population and university NCAA athletic teams. Inclusion in the trained running group required a self-reported average mileage of any number over 40 miles per week. These participants were also recruited from the general campus population as well as the university NCAA Division II distance track and cross-country teams. Table 1 represents the demographics of all 18 participants.

Table 1. Participant Demographics

	N	Minimum	Maximum	Mean	SD
Age, y	18	18	32	22.50	3.682
Male	9	19	32	21.44	4.035
Female	9	18	29	23.56	3.167

Table 2 represents the demographics within each of the training groups.

Table 2. Participant Demographics by Training Group

	N	Men	Women	Avg Miles/Week	SD
Casual (%)	9 (50)	3 (33)	6 (66)	10.6	3.2766
Trained (%)	9 (50)	6 (66)	3 (33)	59.4	17.2200

Hypothesis Testing

The following hypotheses were tested using the data gathered from the 18 participants. All hypotheses were tested with a level of significance set at $p \leq 0.05$. An independent-samples T test was calculated to compare mean contraction percentages between the groups relative to the hypothesis. The mean contraction percentage was calculated by deriving the mean (in Volts) from ten consecutive strides that were recorded during the end of the five-minute testing phase. The mean voltage of these ten strides was then divided by the maximal voluntary isometric contraction (MVIC) for each respective muscle. This calculation returned the percent of average contraction over the ten strides. These mean percent contractions were derived for all of the participants. Finally, these values were averaged for each training group. During data analysis and hypothesis testing, these averages were the basis of comparison between the two groups and they were compared for each of the muscles involved in their respective hypotheses. The hypotheses are as follows:

Hypothesis 1: There will be significantly less activity in the tensor fasciae latae (TFL) in the trained running group when compared to the untrained/casual running group.

Conclusion: An independent-samples *t* test was calculated comparing the mean TFL activation level of the trained running group to the casual running group. No significant difference was found ($t(2) = -1.87$, $p > .05$). The mean of the trained running group ($m = 167.71$, $sd = 160.835$) was not significantly different from the mean of the casual running group ($m = 61.867$, $sd = 54.874$). This is depicted in table.

Table 3. Average Muscle Activity for TFL during Testing

Group	Mean Activity	SD	t	Sig
Casual, (mean contraction %)	61.87	54.874	-1.868	.080
Trained, (%)	167.71	160.835		

Hypothesis 2: Activity of the gluteal muscle group will be significantly higher in the trained running group compared to the untrained/casual running group.

Conclusion: Independent-samples t tests were calculated comparing the mean gluteus medius (GMed) and gluteus maximus (GMax) activation levels of the trained running group to the casual running group. No significant difference was found for either muscle (GMed: $t(2) = -.929$, $p > .05$; GMax: $t(2) = -1.236$, $p > .05$). The mean of the trained running group (GMed: $m = 84.589$, $sd = 43.890$; GMax: $m = 79.552$, $sd = 48.742$) was not significantly different from the mean of the casual running group (GMed: $m = 62.860$, $sd = 54.786$; GMax: $m = 49.243$, $sd = 55.067$). This can be seen in table.

Table 4. Average Muscle Activity for Gluteal Muscle Group during Testing

Muscle	**Group**	**Mean**	**SD**	**t**	**Sig**
GMed	Casual,(%)	62.86	54.786	-.929	.367
	Trained,(%)	84.59	43.890	-.929	.367
GMax	Casual,(%)	49.24	55.067	-1.236	.234
	Trained,(%)	79.55	48.742	-1.236	.234

% = percent of maximal voluntary isometric contraction (Mean muscle usage)

DISCUSSION

The purpose of this study was to investigate and compare the levels of hip muscle activation between casual and trained runners. The muscles of interest were the tensor fasciae latae, the gluteus medius and the gluteus maximus due to their role in leg control during running gait, as well as their role in injury prevention. The following section is divided into three subsections: Discussion of Results, Conclusions, and Recommendations.

Discussion of Results

The primary purpose of this research was to investigate the hip muscle involvement between trained and casual runners. The rationale behind the two different groups was based on the premise that a large gap in weekly mileage between the two training groups would show any potential difference in muscle activation between the two potentially different training outcomes. This difference in training mileage theorizes that the people who fall into the trained group would have a well-trained and consistent gait cycle. It also theorizes that the participants that fall into the casual training group would not have a consistent muscle activation pattern, leading to a different gait cycle from the trained group.

For this study, the tensor fasciae latae, the gluteus medius and gluteus maximus were investigated for their involvement in the running gait cycle. According to Nicola and Jewison[14] the hip adducts during stance phase and during which, "the abductors and adductors of the hip provide co-contraction stability of the stance leg during single leg support (stance phase)." They also identify the hamstrings and the gluteus maximus as the primary driving force that extends the hip, causing forward propulsion while running. Because of the gluteals role in providing dynamic hip stability and propulsion, they were included in this study. The role of the TFL is identified as an internal rotator and abductor of the hip.[4] It has also been identified that the TFL is able to exert a lateral force on the patella via the IT band. These two actions, hip internal rotation and lateral patellar tacking, are strongly linked to many common running injuries.[4,23,24] For this reason, a specific focus was placed on the involvement of the TFL during this study.

The first hypothesis was based on this rationale, as this hypothesis compared the activation levels of the TFL between the two groups. While it was hypothesized that there would be a lower mean muscle involvement in the trained group as compared to the casual running group, there was no significant difference found between the groups. When looking at the mean contraction percentages between the two groups, the trained group actually had a higher contraction percentage (167% ± 160.8%) than the casual training group (62% ± 54.9%). While the contraction percentage was higher in the trained group, further analysis should be conducted into the timing of this contraction, as it was anecdotally observed that the trained group was only firing the TFL during the stance phase. This was different from the causal group, as it was observed that this group was typically firing the TFL during both the stance and swing phases of gait, leading to a misrepresentation of the data upon analysis. While this type of gait cycle-specific analysis was not the focus of this research, the data and means of analysis exist within the current data and could be used for further research and additional findings. This recommendation is based on visual differences noted by the researcher and no official data analysis was performed in this direction to justify this recommendation.

These results were not consistent with the recommendations of Selkowitz et al,[4] who identified the TFL as primary source of interest for investigation in various exercises. They recommended that "for certain conditions… it would appear appropriate to design rehabilitation programs using therapeutic exercises that promote activity of the GMED and GMAX while minimizing recruitment of the TFL."[4] This recommendation was made on the fact that the TFL, when recruited improperly or at the incorrect time, could lead to the development of many common knee pathologies.

In light of this information, this thesis utilized two different groups, casual and trained runners, to further emphasize and quantify the difference in this contraction pattern. Because of the recommendations that Selkowitz suggested in developing training and rehabilitation programs, a difference in GMed/GMax and TFL contraction percentages between these two groups would have supported these recommendations that runners should train this particular way. Because no difference was found between the two groups, there is no evidence from this thesis to suggest a change in hip strengthening exercises to meet these recommendations.

Similar research by Fredericson and Wolf[23] also stated that a decrease in gluteal muscle strength would lead to compensation by the TFL, most notably during the stance phase of the running gait. This compensation is a contributing factor to "soft tissue tightness and myofascial restrictions."[14] Not only would the resulting TFL tightness cause knee pain and other overuse pathologies, the cause of the TFL compensation, the original weakness found in the gluteus medius and superior gluteus maximus during pelvic stabilization, also is a primary contributor to excessive knee valgus during the running gait. This position is well documented as predisposing the knee to overuse injuries and chronic pain pathologies. For this reason, when this thesis was investigating the average usage of the gluteal muscles during the testing phase, these two muscles were selected.

Based on the aforementioned information, the second hypothesis stated that there would be significantly more activity with the gluteal muscle group in the trained running group as opposed to the casual running group. However, we found no significant difference between contraction percentages between the groups. The mean contraction percentage of the trained group for both the gluteus medius (84.589% ± 43.890%) and the gluteus maximus (79.552% ± 48.742%) were higher, but not significantly higher, than the observed contraction percentage of the casual group (GMed: 62.860% ± 54.786%; GMax: 49.243% ± 55.067%). This is consistent with previous literature, as the gluteal muscle group is the primary source of hip stabilization and hip extension, so a trained runner would be more prone to recruiting these muscles than someone who runs casually, even though a significant difference was not found.[14]

Conclusions

Based on our findings that there was no significant difference in either of the hypotheses, it is not recommended to change training or rehabilitation exercise selection to target GMed and GMax strengthening while minimizing TFL strengthening. There was no significant difference between the groups, however, the difference in means that showed an increase in gluteal muscle group activity in the trained group was consistent with the literature.[14]

Recommendations

While there is no evidence from this study to support a change in exercise selection for hip muscle strengthening and training, the need for strengthening is still relevant due to the high prevalence of lower extremity overuse injuries within the running population. Prior studies show that hip strengthening is effective in improving endurance and lower extremity control of the knee and ankle. Because many overuse injuries are attributed to poor mechanics and fatigue, a hip-strengthening program for distance runners is still highly recommended. Prior research has suggested that there is still room for investigation into this topic, and there could possibly be a benefit to strengthening the gluteal group while minimizing TFL involvement.[4]

REFERENCES

1. Fredericson M, Misra AK. Epidemiology and aetiology of marathon running injuries. Sports Med. 2007;37(4-5):437-9.

2. Van gent RN, Siem D, Van middelkoop M, Van os AG, Bierma-zeinstra SM, Koes BW. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. Br J Sports Med. 2007;41(8):469-80.

3. Taunton JE, Ryan MB, Clement DB, Mckenzie DC, Lloyd-smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. Br J Sports Med. 2002;36(2):95-101.

4. Selkowitz DM, Beneck GJ, Powers CM. Which exercises target the gluteal muscles while minimizing activation of the tensor fascia lata? Electromyographic assessment using fine-wire electrodes. J Orthop Sports Phys Ther. 2013;43(2):54-64.

5. Nakagawa TH, Moriya ET, Maciel CD, Serrão FV. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. J Orthop Sports Phys Ther. 2012;42(6):491-501.

6. Ferber R, Kendall KD, Farr L. Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome. J Athl Train. 2011;46(2):142-9.

7. Kennedy MD, Burrows L, Parent E. Intrarater and Interrarter Reliability of the Single-Leg Squat Test. Athletic Therapy Today. 2010;15(6):32-36.

8. DiMarria MA, Kivengood AL, Uhl TL, Mattacola CG, Malone TR. What Are the Validity of the Single-Leg-Squat Test and Its Relationship to Hip-Abduction Strength? J Sport Rehabil. 2005;14:108-123. © 2005 Human Kinetics Publishers

9. Crossley KM, Zhang WJ, Schache AG, Bryant A, Cowan SM. Performance on the single-leg squat task indicates hip abductor muscle function. Am J Sports Med. 2011;39(4):866-73.

10. Goss DL, Gross MT. A review of mechanics and injury trends among various running styles. US Army Med Dep J. 201;62-71.

11. Bazett-jones DM, Cobb SC, Huddleston WE, O'connor KM, Armstrong BS, Earl-boehm JE. Effect of patellofemoral pain on strength and mechanics after an exhaustive run. Med Sci Sports Exerc. 2013;45(7):1331-9.

12. Ford KR, Taylor-haas JA, Genthe K, Hugentobler J. Relationship between hip strength and trunk motion in college cross-country runners. Med Sci Sports Exerc. 2013;45(6):1125-30.

13. Willy RW, Davis IS. The effect of a hip-strengthening program on mechanics during running and during a single-leg squat. J Orthop Sports Phys Ther. 2011;41(9):625-32.

14. Nicola TL, Jewison DJ. The anatomy and biomechanics of running. Clin Sports Med. 2012;31(2):187-201.

15. Rodrigues P, Tenbroek T, Hamill J. Runners with anterior knee pain use a greater percentage of their available pronation range of motion. J Appl Biomech. 2013;29(2):141-6.

16. Willson JD, Petrowitz I, Butler RJ, Kernozek TW. Male and female gluteal muscle activity and lower extremity kinematics during running. Clin Biomech (Bristol, Avon). 2012;27(10):1052-7.

17. Chuter VH, Janse de jonge XA. Proximal and distal contributions to lower extremity injury: a review of the literature. Gait Posture. 2012;36(1):7-15.

18. Criswell E. Cram's Introduction to Surface Electromyography. Jones & Bartlett Learning; 2011.

19. Kellis E, Zafeiridis A, Amiridis IG. Muscle coactivation before and after the impact phase of running following isokinetic fatigue. J Athl Train. 2011;46(1):11-9.

20. Lee JH, Cynn HS, Choi SA, Yoon TL, Jeong HJ. Effects of different hip rotations on gluteus medius and tensor fasciae latae muscle activity during isometric side-lying hip abduction. J Sport Rehabil. 2013;22(4):301-7.

21. Zong-Yan C, Cheng-Chen H, Chin-Peng S, Chin-Fan L, Yi-An L, Chin-Li L, Mei-Chich H. Comparison of lower limb muscle activation during downhill, level and uphill running. Isokinetics & Exercise Science. 2010;18:163-8.

22. Jones AM, Doust JH. A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. J Sports Sci. 1996;14(4):321-7.

23. Mcbeth JM, Earl-boehm JE, Cobb SC, Huddleston WE. Hip muscle activity during 3 side-lying hip-strengthening exercises in distance runners. J Athl Train. 2012;47(1):15-23.

24. Fredericson M, Wolf C. Iliotibial band syndrome in runners: innovations in treatment. Sports Med. 2005;35(5):451-9.

APPENDICES

APPENDIX A

Review of Literature

REVIEW OF THE LITERATURE

Due to the high accessibility and the many noted health benefits, running has steadily become one of the most popular modes of exercise.[1-3] With this high rate of participation across many different experience and capability levels, comes a heightened rate of injury as well. Systemic reviews and epidemiological studies have shown that injury rates range from 19.4% to 92.4% of all distance runners.[2] This same epidemiological study noted that injuries to the knee were the predominating injury sustained, with 7.2% to 50.0% of runners experiencing a knee injury.[2] While other studies mirror this statisic,[1,3] they also make a point to say that the leading knee injury is associated with anterior knee pain, specifically patellofemoral pain syndrome.[1-3]

Research has looked into this pathology from a variety of different viewpoints. While the reasons behind the development of this condition range widely, including age, miles run per week, weight, and foot structure and alignment, there is always recommended room for research.[1-3] This research has been conducted through various lab and clinical tests, including the single leg squat task. Due to the similarities that this test holds regarding musculature when compared with running, it is seen as a suitable test to assess hip abductor strength. This is important because the presence of hip adduction and internal rotation has been shown to lead to anterior knee pain.[6,9,10,11] Another method commonly used to evaluate knee kinematics and hip muscle involvement is surface electromyography in conjunction with observation of the running gait on a treadmill.

The purpose of this literature review is to assess the current literature pertaining to evaluation, treatment and training procedures regarding hip strength, as this strength has shown a correlation to the presence of anterior knee pain.[19-27]

The Running Gait

Phases of the Running Gait Cycle

In order to analyze the mechanics of the knee during the running gait cycle, it is important to understand the mechanics of the different gait cycles. An understanding of these phases will help put the different phases, and their relative demands, into perspective.

To start, the general phases associated with walking are the stance phase and the swing phase. The stance phase begins when the heel of the foot strikes the ground, loads onto the forefoot, and ends when the toe leaves the ground. The swing phase incorporates the time from when the toe leaves the ground, includes when the foot is swung forward, and ends when the heel makes contact with the ground again.[4]

Some common aspects of both the walking and the running gait cycles include the fact that the stance phase and the swing phase are present in each gait, as well as the fact that the forces from movement load the limb from distal to proximal.[1] This is also important because the kinetic chain is vital to force distribution from ground impact.[4]

Because the kinetic chain is closed during the stance phase, the actions of supination and pronation of the foot have an effect through the entire lower extremity kinetic chain. Pronation causes subtalar eversion, forefoot abduction, ankle dorsiflexion, and internal rotation of the tibia. This internal rotation of the tibia leads to internal rotation of the femur, which manifests in knee flexion and adduction. Overall, force distribution within the lower extremity ends at hip, where stabilizing muscles must also fire properly to prevent unwanted rotation.[4]

However, a key difference between the walking and running gait is the presence of the 'float' phase while running. During this phase, neither foot is in contact with the ground, as one foot is starting the swing phase while the other is coming to the end of the swing phase.[4] Also during the running gait, there is a more narrow base of support. The walking has a greater base of support by about an inch, and as running speed increases, the base of support narrows.[4] It has also been observed that there is a decreased amount of stance phase as velocity increases, resulting in an increased impact force and faster eccentric loading.[4] While there is an increase in this loading force, the distribution varies by running form and style.[5] It has been shown that the greatest amount of force that is placed upon the extremity come from rear-foot, or heel, striking. There is a significant decrease in the amount of force felt through the leg as a person begins to shift to a more mid-foot or fore-foot striking pattern.[5]

Because of these aspects of running, there is an increased demand on all of the structures in lower extremity. It has also been noted as running velocity increases, there is a force of approximately 1.5 to 3.5 times the person's body weight sent through the lower extremity.[6]

In an analysis of the muscles involved during the running gait, the external rotators are important for both driving the foot forward and preventing excessive knee adduction. There is also contribution from the quadriceps, mainly the rectus femoris, to eccentrically contract to load the knee during foot-strike. This is also when the external rotators and the hamstrings are the most active, along with at the end of the swing phase, to drive the leg forward. Additionally, there is a contribution from the gluteus medius as a pelvic stabilizer, especially during the contralateral stance phase.[4]

While this summarizes the involvement of the musculature surrounding the hip and knee, there is also activation of the core, superiorly, and the muscle of the lower leg for dorsiflexion and plantarflexion, as well as propulsion. The primary muscle for propulsion is the gastrocnemius, and it is assisted by other posterior compartment musculature. The muscles of the anterior and lateral compartments are active in dorsiflexion, as well as stabilization of the ankle in the frontal plane.[4]

Biomechanical Problems

Many different aspects of the lower kinetic chain have been investigated, from pelvic and trunk stability to ankle range of motion, in an attempt to analyze proper running mechanics.[4,7,8] In order to evaluate knee pain and its etiology, it is also important to look at the joints distal and proximal to it, as they will play a significant role in the kinematics of the knee.

Starting at the foot, Rodrigues[7] investigated the effect of foot pronation on ankle kinematics. This information could also then be used to help explain tendencies at the knee and hip. The runners were grouped into the uninjured group or the injured group, which consisted of those runners experiencing anterior knee pain. After putting runners through a warm-up protocol, the investigators used a specific device to passively evert the ankle. They everted the ankle in seven different planes of motion, ranging from forty degrees of plantar flexion to maximum dorsiflexion. Following these eversion measurements, motion tracking was used during a five-minute run to analyze foot motion. During analysis, it was shown that injured runners had a higher peak eversion velocity, as well as a smaller eversion buffer. These results indicate that people with anterior knee pain pronate quicker at foot strike, and at the same time, they use a greater percentage of their available motion.[7]

From this information, the authors speculate that when runners use a greater percentage of their available pronation, they are more prone to knee pain. This is due to the reasons that as a joint approaches its end range of motion, the ligaments are placed under greater strain. This leads to a diminished ability to adequately distribute forces through the extremity. Also, with a decreased range of motion, it limits the joint's ability to adapt to changing terrain as well as a healthy ankle would be able to.[7] These factors lead to the ankle joint reaching it's maximum range of motion faster, thus if more motion is needed, adaptation must take place at the next joints in the kinetic chain, which manifests in the knee. It is suggested from these findings that this additional knee motion, in a plane of motion that the knee does not operate in, causes anterior knee pain to manifest.[7]

While the ankle joint rotation due to pronation is known to cause internal rotation of the lower extremity,[4] other factors also play into this internal rotation from more proximal joints, specifically the hip. An internally rotated hip and tibia both cause internal rotation of the knee joint, which primarily moves in the sagittal plane, as opposed to pronation and internal rotation, which forces the knee to operate in the frontal plane. Control of this motion can occur by the musculature surrounding the hip and knee, and has been shown to help improve running mechanics.[10]

In a further analysis of the effects of various biomechanical factors on the lower closed kinetic chain, Chuter and Janse de Jonge[13] conducted a literature review that investigated the functions of various joints and the injuries that dysfunction can commonly lead to. Through their analysis, they agreed that weakness in the muscle groups responsible for hip abduction and external rotation suggested the development of many lower extremity overuse injuries, including anterior knee pain. They suggest that based on the review of available literature, for anterior knee pain and related lower extremity injuries, "hip muscle strengthening and neuromuscular retraining of the lumbopelvic-hip complex should form the basis for rehabilitation… and injury prevention."[13]

Gluteal Muscle Activation Patterns

Due to recent investigations into hip strength and it's relationship to the lower extremity alignment, researchers have looked elsewhere to explain the development of these knee conditions. Because proper kinematics will aid in the prevention of lower extremity injury, some investigators have suggested that not only muscle strength, but also firing patterns and timing of these essential muscles are just as important.[8,13]

Willson et al[8] have looked into this theory on multiple occasions in various different groups. In a study of healthy men and women, they investigated the timing of muscle firing of the gluteus maximus and medius during the running gait. While they were looking for a comparison between the two genders, they were also able to establish various aspects of general muscle timing within each gender. Based on prior research, they established that the primary factor of poor dynamic femur control was mainly caused by fatigue within the hip musculature. This was shown in their research, as they saw a negative correlation between hip abduction strength and hip adduction motion.[8] It was also observed that hip adduction velocity increased over time during a prolonged run.[8] From these results, it was noted that premature fatigue of the gluteus maximus can cause altered hip kinematics, and should be corrected with an endurance based strengthening program.[8,9]

From a gluteal firing and timing point of view, Willson et al[14] also looked at the timing in two different groups of female runners. In a study that compared gluteal muscle firing patterns between female distance runners with and without patellofemoral pain. In an EMG study of the same two gluteal muscles, it was observed that there was a delayed onset of contraction of the gluteus maximus and gluteus medius in runners with patellofemoral pain syndrome. The delay in contraction occurred before footstike in the ipsilateral leg. This delay "was associated with increased hip adduction excursion"[14] and the delay of the gluteus maximus firing was also associated with an increase in internal rotation excursion of the hip.[14] This suggests that runners with anterior knee pain are not preparing their hip musculature for impact with the ground correctly, and as a result could be altering their kinematics.[14]

An observational study by Ford et al[15] also examined abnormal running mechanics in relation to hip strength. However, this research was aimed at assessing trunk motion during the running gait. It was hypothesized that as the isokinetic strength of the hip musculature increased, the amount of motion in the pelvis and thorax would decrease while running. The results of the study proved this in the form of a significant negative correlation between these two variables.[15] Because of the potential relationship indicated by this study between increased hip strength and decreased trunk motion,[15] it lends validity to the viewpoint that increasing hip musculature strength can improve overall running mechanics.

Hip Muscle Activity Observation Through the Use of a Treadmill

The use of surface electromyography in evaluating running mechanics and hip muscle activation has become commonplace.[16-18] While there have been many different methods of data collection have been used for various goals, each with their suggestions for improvement, there has been a normalized procedure for using sEMG to assess muscle activity. With proper placement and attachment, it has been shown to be a reliable source of data collection during an activity with high amounts of movement such as running on a treadmill.[16-18]

Introduction to Surface Electromyography

Surface electromyography is a research tool that is used to measure the amount of electrical activity generated by a muscle when it contracts. This information provides insight into if a muscle is contracting, and if it is, the amount of activity that is present within the muscle. This is accomplished by placing unobtrusive pads on the skin that are connected to a computer that can process the information.[19] In order for this process to be used in a test setting, there needs to be a point of comparison for the test data. Prior to testing any muscle group, a maximal voluntary isometric contraction (MVIC) is obtained by having the participant contract their muscle in an isolated position that allows for the reading to be captured at the strongest point. Then, after a testing protocol is completed, the data is expressed as a percentage of this maximal value.[19]

Use of sEMG on a Treadmill

The use of sEMG on a treadmill allows for the study of muscle activation levels during different speeds and inclines. This has been shown in a study by Cai et al[16] when they investigated the different activation levels of different muscles within the hamstring muscle group. Because of the use of the treadmill, the researchers were able to control the running speed and the degree of the incline or decline. This allowed for a controlled and reproducible environment, as well as a setting where sEMG could be used to assess the amount of contraction within each muscle.

The use of a treadmill in studying muscle activity during running allows for the closest environment to natural running possible. While other tests use various metrics such as squat tests, the use of a treadmill to obtain the muscle activity data will yield results that are easily transferable to making recommendations regarding running.

Running Protocols for sEMG Use

Typical protocols for using sEMG while running on a treadmill include many common components. First, the sEMG pads are attached to the muscles of interest at the recommended and standardized sites, as well as at a bony site for the ground. After this, MVIC data is recorded. After a period of rest, a warm-up protocol is performed. The duration of this can be set in various ways, including a specific amount of time[16] or until the participant self-reports that they feel comfortable[17,18] starting the testing procedure. Finally, the testing protocol is performed.

Researchers have noted that interference of obtaining "clean" data can come from a variety of sources. First, the ground pad may not be attached correctly.[19] Second, the test pads could become loose during the activity. Third, excessive movement or contact with the cords that run from the pads to the computer can cause interference.[17] Measures can be taken to prevent all of these situations, and with careful observation, successful trials can be performed. These methods include, but are not limited to, using tape to secure the pads, using tape to secure the wires, monitoring the attachment of the pads, monitoring the data as it is being collected, and finally filtering the data within the software to exclude values that are known to be associated with interference.[17]

Tensor Fasciae Latae and sEMG

There have been many studies looking at sEMG values from the TFL, which has led to a standardized method of data collection for this muscle.[16-19] With pad placement just below the anterior superior iliac spine and the two pads 2 cm apart running along the muscle, the participant lays supine with their hip in flexion and internal rotation. A force is then applied at the ankle to resist further hip flexion to obtain the MVIC.[19,20]

The use of this information can be applied to using sEMG while the participant runs on the treadmill to observe the amount of activity during the exercise. With proper implementation of the equipment and observing standard protocols, it is possible to obtain clear data from this method of testing and activity.

Current Training Methods

Resistance Training

With this muscle activation pattern in mind, it is also valuable to look at the current training principles being used by distance runners. In order to recommend any possible changes to training mechanics based on a study of the hip musculature, it is important to know how these athletes are currently training. In a review of the current strength training literature, Jones and Bampouras[21] assessed current practice, evaluation methods, and made recommendation for future training within this group of athletes. After inspection of available evidence, it was noted that heavy lifting and resistance training was not a primary focus of most training programs, but literature has recently been showing that when done correctly, there can be no negative effects on aerobic capacity. This led to the recommendation that heavy weight training and plyometrics should be incorporated into normal training programs.[21]

In a further study by Saunders et al,[22] plyometric training was investigated in distance runners. With the implementation of a plyometric training program, runners were able to show an improvement in running efficiency. Respiratory variables were also traced in this study, and this study confirmed the same finding that these variables were not impacted by resistance training.[22] Overall, these studies have shown that the inclusion of weight training and plyometric training have been effective for improving running efficiency in distance runners.[21,22]

Rehabilitation Methods

Because a decrease in hip strength can lead to improper kinematics resulting in overuse injuries, there is a large body of literature that discusses the rehabilitation of overuse injuries in the context of gluteal muscle strengthenining.[23,24] Both studies mentioned here examined various hip abduction exercises for their gluteal muscle involvement, both while looking at possible contribution from the tensor fascia lata. Both studies made note to evaluate the contribution of the tensor fascia lata because of its role as an internal hip rotator. It was a key consideration by the authors because both groups of researchers hypothesized that a reduction of contribution from this muscle during hip abduction would lead to a lower rate and potential for the development of anterior knee pain.[23,24]

In the first study, McBeth et al[23] looked at three different side-lying hip abduction exercises through measuring the EMG activity of anterior hip flexors, gluteus medius and maximus, as well as the contribution from the tensor fascia lata. It was found that the best exercise for strengthening the gluteus medius, with minimal contribution from the tensor fascia lata, is the straight hip abduction exercise.[23] The hip abduction exercise with external rotation of the hip was also found to be an effective exercise for recruiting the gluteus medius, however it also caused significant contraction levels of the tensor fascia lata. The clamshell exercise showed very little gluteal activation with high amounts of anterior hip flexor recruitment.[23]

Selkowitz, Beneck and Powers[24] also looked at hip muscle activation levels among many different hip-strengthening exercises using fine-wire EMG. The use of fine-wire EMG allowed for greater accuracy of identifying specific muscle recruitment, and until this specific study, had not been used for this topic. After conducting a study of a wide variety of exercises for the hip, they made similarly styled recommendations. While considering for tensor fascia lata contribution, the researchers recommend the clam exercise, side-steps (monster walks), side bridges, and quadruped hip extensions (knee flexed and knee extended).[24]

Through the examination of the various hip-strengthening protocols used in both the resistance training and rehabilitation settings, it is important to note that resistance training and plyometric work are effective as a training methods for improving running efficiency,[21,22] and there are therapeutic activities that can be used effectively to target the necessary involved musculature.[23,24] This information can potentially be used as an intervention after an assessment of a poor single-leg test.

Effects of Various Lower Extremity Strength and Alignment on Single-Leg Squat Tests

For the purposes of assessing hip strength, the single leg squat test is used to evaluate strength throughout the movement of the squat. While this study will not be utilizing this test, it maintains its relevance because it assesses the strength of the muscles involved in the treadmill running test that will be used. Many different factors play into the ability to perform a single leg squat correctly, just as these factors also play into how efficiently a person can run. These factors are important to identify, as making a point to either train them or not during a training program will drastically effect the outcome of the plan.

Starting superiorly to the hip joint, Shirey et al[25] investigated the effect of core musculature engagement on lower extremity kinematics during a single-leg squat. The research placed participants into two different groups based on the strength of their lower core musculature. The subjects then performed a single-leg squat with and without verbal cues to contract their core. It was found that intentional contraction of the core during the test led to a significant improvement in lower extremity kinematics during the test.[25] It was recommended that along with hip muscle strengthening, core strengthening may have a great impact on the stability of the pelvis and lower extremity alignment during a single-leg squat.[25]

Other factors that studies have investigated lately[26] have been the relationship of static lower extremity alignment and passive range of motion to performance on the single-leg squat. In a study by Mauntel et al,[26] subjects were placed into groups of either a having medial knee displacement or not during a single leg squat. Analysis of the two groups showed that the group that consistently had medial knee excursion, the subjects lacked a proper coactivation ratio present in the control, implying that the group typically used their adductor muscle group as a means of completing the task.[26] It was speculated that due to the improper contraction pattern between the gluteus maximus and minimus with the adductor muscle group, medial knee displacement occurred.[26]

In a study by Nguyen et al,[12] hip musculature was taken into account for functional knee valgus excursion during a single leg squat. The study compared the strength and activation levels of the gluteus medius and gluteus maximus, relative to static hip alignment factors, to lower extremity joint excursion. This joint excursion factored in hip rotation, knee varus of valgus, and navicular drop. It was shown that, even across many different possible lower extremity alignments, a decreased level of gluteus maximus activation increased hip internal rotation during the squat.[12]

Overall, with all of these possible factors playing into medial knee excursion and the lack of a proper form single-leg squat, Nakagawa et al. investigated the differences between males and females who had and did not have patellofemoral pain syndrome (PFPS). This investigation revealed that both males and females with PFPS showed increased trunk lean, pelvic drop on the non-stance leg, hip adduction and knee abduction during the test.[27] As a result of these characteristics, the researchers also observed decreased hip abductor and external rotator strength.[27] Finally, within the female group with PFPS, it was also observed that they exhibited greater internal rotation of the hip, along with decreased gluteus medius activation, than in their male counterparts.[27]

From this research, it is evident that there are many different factors that contribute to proper form during a single-leg squat test. However, a common theme running through all of the articles is a decreased activation level, either by lack of strength or through improper contraction patterns, resulted in medial knee excursion.

Intervention Programs on Single-Leg Squat Test Performance

Finally, with this knowledge of contributing factors to lower extremity function, various intervention programs have been developed to attempt to correct these issues.

While the interventions have varied, the use of the single-leg squat test is common among research studies focused on identifying the factors leading to the presence of anterior knee pain.

In a study by Wouters et al, a sample of healthy female subjects was evaluated for their performance on the single-leg squat test. The twenty poorest performers, as defined by greatest measured knee deviation medially, were selected to participate in a four-week movement-training program. This program included various functional strengthening exercises, primarily focusing on gluteus medius strengthening, such as lateral step-downs, forward step-ups, resisted shuffles and balanced lunges. At the end of the program, the retest showed a significant decreases in peak hip and knee abduction moments, as well as decreased knee abduction excursion. Also, analysis of the running gait in these females improved.[28]

A study by Willy and Davis also attempted to improve running and squatting mechanics via a hip-strengthening program. The study recruited females who exhibited excessive hip adduction during a walking gait analysis. The participants were placed on a six-week training program that focused on hip external rotator and abductor strengthening, as well as neuromuscular training for the single leg squat. Upon analysis, there was an improvement in hip strength in these motions, as well as in the performance on the single-leg squat. Running mechanics were not significantly impacted, as the authors admitted the exercise selection was not ideal to this end goal.[29] However, the general suggestion that hip strengthening can improve these aspects was founded.

Finally, also as a measure of a strengthening program intervention on lower extremity movement, a study by Ferber, Kendall and Farr analyzed the effects of a hip-abductor specific strengthening program on runners' mechanics that had PFPS. Selected from runners presenting at a local clinic with PFPS, participants engaged in a three-week strengthening protocol. After analysis, there was a significant increase in hip-abductor strength, as well as a reported lower level of pain and stride-to-stride knee-joint variability in the runners with PFPS.[30]

Summary

Overall, the use of surface electromyography and observation while running on a treadmill is commonplace among running mechanics researchers. It has been shown to be reliable and accurate of the involved muscles. Also, the use of the single-leg squat with runners who exhibit abnormal knee mechanics, either with painful symptoms or not, is a common test used to determine mechanics and it is representative of the muscles associated with running. With information from both of these study methods, it is possible to observe running mechanics and muscle strength to determine the difference in activation levels. Finally, in light of various strengthening protocols and recommendations, there is a case for strengthening particular muscle groups over others, with the end goal of limiting excessive medial knee excursion. This end goal could aid in the reduction of overuse injuries, as well as provide training and rehabilitation rational for various exercise plans.

APPENDIX B

THE PROBLEM

Statement of the Problem

Lower extremity pain in distance runners is a common complaint that can vary from mild to severe pain among all levels of runners. The purpose of this research is to investigate the differences in muscle activation in hip musculature between trained endurance runners and casual runners. Research has been conducted relating balance to hip extensor and core strength. However, numerous sources have recommended further investigation into additional aspects of hip strength and it's role during endurance and fatigued settings. Because of these recommendations, this research will look into hip strength for lower extremity control to determine which muscles should play a larger role in the running gait.

Overall, this study will investigate if various muscles surrounding the hip are more or less active in trained endurance runners versus the casual fitness and running population. There is also a special interest in the role of the tensor fasciae latae and its relation to knee kinematics during the running gait. Lastly, while training core strength in relation to balance has been a key rehabilitation goal recently, it is also important to account for the surrounding musculature, especially if it could possibly play a large role in achieving the end goal of a stronger lower kinetic chain. This information would be useful not only for patients involved in lower extremity rehabilitation, but also to athletes looking to further enhance their balance in sports that require either endurance strength for distance running or lower extremity skill.

Limitations of the Study

The following are possible limitations of this study:

1. Familiarity of running on a treadmill and how this possibly affects gait
2. Differences in shoe selection that could alter individual biomechanics
3. Depending on conditioning level, it is possible that at the end of the running protocol during the data collection that the subjects were

Delimitations of the Study

The following are delimitations of this study:

1. Only the TFL, GMed and GMax are being investigated, so other possible muscle contributions to gait will not be measured.

Significance of the Study

This study holds its relevance in endurance-based sports, particularly distance running. By conducting this research, it may be easier to compare and contrast the various strength aspects and muscle involvement between trained distance runners and casual runners. Ideally, the sample of participants tested will not report any current pain with running, so an accurate representation of pain-free leg movement can be established. With a clearer picture of the difference between these two groups, it may be possible to see any differences in muscle use and efficiency. This information can in turn lead to more focused rehabilitation and preventative strengthening for endurance runners and would be relevant to athletic trainers and any coaches involved with strengthening the lower extremity for endurance activities. While the target population would be distance runners, the information has potential to cross over into other endurance based sports, such as soccer or lacrosse, that involve prolonged periods of running, to aid with rehabilitation and strengthening as well.

APPENDIX C

ADDITIONAL METHODS

APPENDIX C1

INFORMED CONSENT FORM

Informed Consent Form
A Comparison of Tensor Fasciae Latae and Hip Muscle Activation in Casual and Trained Distance Runners
With Otto Buchholz LAT, ATC

This research study will be investigating the activation levels of hip muscles during running between casual and trained distance runners. The purpose of this research is to investigate the potential differences in activation levels between these two groups.

You have been selected to participate because of your current training level in regards to how far you typically run each week. This mileage places you into one of two research groups, either casual or trained. You will be asked to report to the athletic training room for one observational research session, lasting no longer than an hour. The investigation will consist of asking you to run for ten minutes on a treadmill while surface electromyography and a goniometer record data. These two instruments are attached to the surface of your body and will not impair your ability to run normally.

Your participation is voluntary. Refusal to participate or withdrawal of your consent or discontinued participation in the study will not result in any penalty or loss of benefits or rights to which you might otherwise be entitled. The principal investigator may at his discretion remove you from the study for any of a number of reasons. In such an event, you will not suffer any penalty or loss of benefits or rights that you might otherwise be entitled.

Your anonymity will be maintained during data analysis and publication/presentation of results by any or all of the following means: (1)You will be assigned a number as names will not be recorded. (2) The researchers will save the data file and/or any video or audio recordings by your number, <u>not</u> by name. (3) Only members of the research group will view collected data in detail. (4) Any physical recordings or files will be stored in a locked drawer in the graduate assistant athletic trainer's office in Hamer Hall, which can only be accessed by authorized researchers. (5) Any electronic records will be stored on CALU servers and only the researchers will have access to the passwords required to view these files.

The testing procedure will consist of a five to ten minute warm-up and a five minute observational running period that will conclude with recording data for ten or more of your stride lengths. The observational running period will be at a speed that is consistent with a typical run. This data will be obtained through the use of surface electromyography (sEMG) and an goniometer. These two pieces of equipment are temporarily attached to your skin in a noninvasive manner with adhesive pads and straps. They will not alter your running mechanics. The use of sEMG is for determining the amount of electrical activity in a muscle group through the adhesive pads that are placed on the skin. The goniometer is used to determine which direction (forwards or backwards) your leg is swinging. After this phase, you will be allowed to cool-down at your discretion.

Foreseeable risks are consistent with the same risks you take while you normally run. These risks include orthopedic injury, such as muscle strains, possible cardiac(heart) issues, and the possibility of falling. The likelihood of any of these events happening is low, as you will not be asked to do anything different from what you normally do when you run on our own. During the preparation for the test, the sEMG pads will be placed on your skin. This process includes light abrasion of your skin with an emery board. There is the risk of some discomfort, such as a light scratching feeling, during this process. The area will be cleansed with an alcohol pad. As the abrasion process will not break the skin, there is no risk of any “sting” or other pain that could be associated with applying an alcohol pad. During the entire observational testing phase, you will be in the presence of at least one licensed athletic trainer who is capable of providing proper instruction to avoid injury, as well as first aid if any of these injuries should occur. This also covers any cardiac emergencies that might occur, as the researcher will provide immediate cardiac care. Should an unforeseeable risk occur, all applicable measures would be taken to ensure the safety and proper care of the participant.

Potential benefits of this research include contributing to general training knowledge and helping improve the understanding of the body during the running gait.

If you have any questions about this study, you should feel free to ask them now or anytime throughout the study by contacting:

Kurt Otto Buchholz, primary researcher at BUC7819@calu.edu

Dr. Shelly DiCesaro, faculty advisor at dicesaro@calu.edu or 724-938-5831

The California University of Pennsylvania Institutional Review Board has approved this research. The approval is effective 4/25/2014 and expires 4/24/2015.

I understand the nature of this study and agree to participate. I realize that by signing this form I give my consent to participate in the described research. I received a copy of this form. I give the principal investigator and his associates permission to present this work in written and/or oral form for teaching or presentation to advance the knowledge of science and/or academic without further permission from me provided that my name or identity is not disclosed. I also verify that I am at least 18 years old.

______________________	________	______________________
Participant Signature	Date	Signature of Witness

APPENDIX C2

INSTITUTIONAL REVIEW BOARD APPROVAL

Institutional Review Board
California University of Pennsylvania
Morgan Hall, Room 310
250 University Avenue
California, PA 15419
instreviewboard@calu.edu
Robert Skwarecki, Ph.D., CCC-SLP, Chair

Dear Kurt Otto Buchholz:

Please consider this email as official notification that your proposal titled "A Comparison of Tensor Fasciae Latae and Hip Muscle Activation between Casual and Trained Distance Runners" (Proposal #13-061) has been approved by the California University of Pennsylvania Institutional Review Board as amended.

The effective date of the approval is 4/25/2014 and the expiration date is 4/24/2015. These dates must appear on the consent form .

Please note that Federal Policy requires that you notify the IRB promptly regarding any of the following:
(1) Any additions or changes in procedures you might wish for your study (additions or changes must be approved by the IRB before they are implemented)
(2) Any events that affect the safety or well-being of subjects
(3) Any modifications of your study or other responses that are necessitated by any events reported in (2).
(4) To continue your research beyond the approval expiration date of 4/24/2015 you must file additional information to be considered for continuing review. Please contact instreviewboard@calu.edu

Please notify the Board when data collection is complete.

Regards,
Robert Skwarecki, Ph.D., CCC-SLP
Chair, Institutional Review Board

APPENDIX 3

PREPARTICIPATION DEMOGRAPHICS COLLECTION SHEET

Pre-participation Demographics Collection Sheet

Gender (Circle): Male or Female

Age: ________

Average weekly mileage for the last 3 months: ________

Years of training/running experience: ________

Dominant leg (Circle): Right of Left

REFERENCES

1. Fredericson M, Misra AK. Epidemiology and aetiology of marathon running injuries. Sports Med. 2007;37(4-5):437-9.

2. Van gent RN, Siem D, Van middelkoop M, Van os AG, Bierma-zeinstra SM, Koes BW. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. Br J Sports Med. 2007;41(8):469-80.

3. Taunton JE, Ryan MB, Clement DB, Mckenzie DC, Lloyd-smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. Br J Sports Med. 2002;36(2):95-101.

4. Nicola TL, Jewison DJ. The anatomy and biomechanics of running. Clin Sports Med. 2012;31(2):187-201.

5. Williams DS, Green DH, Wurzinger B. Changes in lower extremity movement and power absorption during forefoot striking and barefoot running. Int J Sports Phys Ther. 2012;7(5):525-32.

6. Goss DL, Gross MT. A review of mechanics and injury trends among various running styles. US Army Med Dep J. 201;62-71.

7. Rodrigues P, Tenbroek T, Hamill J. Runners with anterior knee pain use a greater percentage of their available pronation range of motion. J Appl Biomech. 2013;29(2):141-6.

8. Willson JD, Petrowitz I, Butler RJ, Kernozek TW. Male and female gluteal muscle activity and lower extremity kinematics during running. Clin Biomech (Bristol, Avon). 2012;27(10):1052-7.

9. Bazett-jones DM, Cobb SC, Huddleston WE, O'connor KM, Armstrong BS, Earl-boehm JE. Effect of patellofemoral pain on strength and mechanics after an exhaustive run. Med Sci Sports Exerc. 2013;45(7):1331-9.

10. Ford KR, Taylor-haas JA, Genthe K, Hugentobler J. Relationship between hip strength and trunk motion in college cross-country runners. Med Sci Sports Exerc. 2013;45(6):1125-30.

11. Willy RW, Davis IS. The effect of a hip-strengthening program on mechanics during running and during a single-leg squat. J Orthop Sports Phys Ther. 2011;41(9):625-32.

12. Nguyen AD, Shultz SJ, Schmitz RJ, Luecht RM, Perrin DH. A preliminary multifactorial approach describing the relationships among lower extremity alignment, hip muscle activation, and lower extremity joint excursion. J Athl Train. 2011;46(3):246-56.

13. Chuter VH, Janse de jonge XA. Proximal and distal contributions to lower extremity injury: a review of the literature. Gait Posture. 2012;36(1):7-15.

14. Willson JD, Kernozek TW, Arndt RL, Reznichek DA, Scott straker J. Gluteal muscle activation during running in females with and without patellofemoral pain syndrome. Clin Biomech (Bristol, Avon). 2011;26(7):735-40.

15. Ford KR, Taylor-haas JA, Genthe K, Hugentobler J. Relationship between hip strength and trunk motion in college cross-country runners. Med Sci Sports Exerc. 2013;45(6):1125-30.

16. Zong-Yan C, Cheng-Chen H, Chin-Peng S, Chin-Fan L, Yi-An L, Chin-Li L, Mei-Chich H. Comparison of lower limb muscle activation during downhill, level and uphill running. Isokinetics & Exercise Science. 2010;18:163-8.

17. Kellis E, Zafeiridis A, Amiridis IG. Muscle coactivation before and after the impact phase of running following isokinetic fatigue. J Athl Train. 2011;46(1):11-9.

18. Higashihara A, Ono T, Kubota J, Okuwaki T, Fukubayashi T. Functional differences in the activity of the hamstring muscles with increasing running speed. J Sports Sci. 2010;28(10):1085-92.

19. Criswell E. Cram's Introduction to Surface Electromyography. Jones & Bartlett Learning; 2011.

20. Lee JH, Cynn HS, Choi SA, Yoon TL, Jeong HJ. Effects of different hip rotations on gluteus medius and tensor fasciae latae muscle activity during isometric

side-lying hip abduction. J Sport Rehabil. 2013;22(4):301-7.

21. Jones P, Bampouras TM. Resistance Training for Distance Running: A Brief Update. Stren And Cond J. 2007;29(1):28-35.

22. Saunders PU, Telford RD, Pyne DB, et al. Short-term plyometric training improves running economy in highly trained middle and long distance runners. J Strength Cond Res. 2006;20(4):947-54.

23. Mcbeth JM, Earl-boehm JE, Cobb SC, Huddleston WE. Hip muscle activity during 3 side-lying hip-strengthening exercises in distance runners. J Athl Train. 2012;47(1):15-23.

24. Selkowitz DM, Beneck GJ, Powers CM. Which exercises target the gluteal muscles while minimizing activation of the tensor fascia lata? Electromyographic assessment using fine-wire electrodes. J Orthop Sports Phys Ther. 2013;43(2):54-64.

25. Shirey M, Hurlbutt M, Johansen N, King GW, Wilkinson SG, Hoover DL. The influence of core musculature engagement on hip and knee kinematics in women during a single leg squat. Int J Sports Phys Ther. 2012;7(1):1-12.

26. Mauntel TC, Begalle RL, Cram TR, et al. The effects of lower extremity muscle activation and passive range of motion on single leg squat performance. J Strength Cond Res. 2013;27(7):1813-23.

27. Nakagawa TH, Moriya ET, Maciel CD, Serrão FV. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. J Orthop Sports Phys Ther. 2012;42(6):491-501.

28. Wouters I, Almonroeder T, Dejarlais B, Laack A, Willson JD, Kernozek TW. Effects of a movement training program on hip and knee joint frontal plane running mechanics. Int J Sports Phys Ther. 2012;7(6):637-46.

29. Willy RW, Davis IS. The effect of a hip-strengthening program on mechanics during running and during a single-leg squat. J Orthop Sports Phys Ther. 2011;41(9):625-32.

30. Ferber R, Kendall KD, Farr L. Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome. J Athl Train. 2011;46(2):142-9.

A Comparison of Tensor Fasciae Latae and Hip Muscle Activation between Trained and Casual Distance Runners

Buchholz KO, DiCesaro SF, Cervantes S, West TF: The School of Graduate Studies and Research, California University of Pennsylvania; California, PA

Context: The sport of distance running is highly popular due to the ease of access to the sport, and with this increase in participation, there has also been an increase in injury rate. Recently there has been research suggesting that there may be a benefit to training the specific hip muscles, the gluteus medius (GMed) the and gluteus maximus (GMax) with specific exercises that also limit the contraction of the tensor fasciae latae (TFL). This particular training pattern has been suggested because it supposedly mimics the muscle use that higher trained runners utilize. Currently there has been a call for investigation into this area of research. **Objective**: The purpose of this study was to investigate and compare the amount of hip muscle recruitment among the TFL, the GMed and the GMax within casual and trained runners. **Design**: Observational experimental design that involved surface electromyography while running. **Setting**: The study protocol was conducted in a laboratory setting. **Participants**: Eighteen physically active runners (male=9, female=9) were recruited from the campus population and the university distance track/cross country programs. **Interventions**: Participants were taken through a ten minute running protocol (5 minute warm-up, 5 minute testing phase) while running on a treadmill. They ran at a speed consistent with replicating traditional outdoor running. At the end of the testing phase, surface electromyography was used to assess hip muscle activation levels over the course of ten stride lengths. **Main Outcome Measures**: TFL, GMed and GMax activation levels were recorded and analyzed. The data were compared between the casual running group (5-15 miles/week) and the trained running group (40+ miles/week) **Results**: There were no significant differences in any of the investigated muscles between the two groups of runners. (TFL: $p = .153$, GMed: $p = .743$, GMax: $p = .824$) **Conclusions**: Based on the findings that there was no significant difference in either of the hypotheses, it is not recommended to change training or rehabilitation exercise selection to target GMed and GMax strengthening while minimizing TFL strengthening. While was no significant difference between the groups, the difference in means that showed an increase in gluteal muscle group activity in the trained group was consistent with the literature. **Word Count:** 400