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ABSTRACT

The purpose of this study is to determine if instruction and practice in “proper” running form techniques strengthens the hip abductor and hip external rotator muscles and thereby reduce the risk of certain knee injuries such as patellofemoral pain syndrome and iliotibial band syndrome. Four healthy, college-aged female recreational runners completed this study. Subjects were randomly placed into a control and experimental group. Both groups ran within a controlled range of 12-16 miles per week on a treadmill for six weeks, and were measured for hip strength at the first week, third week, and sixth week of the running protocol. Isometric hip abduction and hip external rotation strengths were measured with a hand-held dynamometer. The experimental group received 3-sessions of proper running form instruction. Six separate two-way ANOVA tests were performed to identify changes in hip abductor and hip external rotator strength over time and intervention. Due to the small sample size, no statistically significant results were found, but there was an observed trend in increased hip abduction strength and increased hip muscle strength symmetry in the experimental group. This suggests a need for future studies with a larger sample size.

INTRODUCTION

Running, as it continues to grow as a popular exercise mode, also grows as a topic of interest among researchers and physical rehabilitators. It is predicted that over 50% of recreational runners sustain a running-related injury per year, with half of those injuries occurring at the knee (van Gent et al., 2007; Taunton et al., 2002). Consequently, the large volume of injured persons per year indicates a need for research in determining the etiology of these injuries and methods to prevent and rehabilitate from them.

Of the many running-related knee injuries, the two most prevalent are patellofemoral pain syndrome (PFP) and iliotibial band syndrome (ITBS). Recent research has shown strong evidence correlating hip muscular weakness and incidence of PFP and ITBS, among other knee injuries (Ferber et al., 2011; Fredericson et al., 2000; Ireland et al., 2003). Research has found that both males and females suffering from PFP were significantly weaker in hip abduction and hip external rotation than non-symptomatic individuals, and those suffering from ITBS demonstrated weaker hip abduction in the affected limb versus the unaffected limb (Ferber et al., 2011; Ireland et al., 2003; Fredericson, 2000). It is theorized that weakness in the muscles that control for these hip motions results in excessive internal rotation of the femur, which strains the iliotibial band and tibiofemoral joint (Ireland et al., 2003). This hypothesis is supported by Souza and Powers (2009), who also found significantly higher femoral internal rotation in females with PFP than a control group when performing step-down and running activities.

Additionally, Fredericson et al. (2000) and Ferber et al. (2011) found that 90% of individuals with PFP and ITBS that underwent a 3- to 6-week resistance training protocol for the gluteus medius and minimus experienced partial or complete alleviation in PFP and ITBS pain. Earl and Hoch (2011) found similar results in females with PFP who underwent an 8-week strengthening protocol for the proximal muscle groups; of 19 subjects, 17 improved in symptoms post-rehabilitation and 13 reported a maintained improvement six months later. These studies indicate clinical application for strengthening routines of the hip muscle groups. Therefore, the discovery of various and effective methods of hip strengthening is essential for a widespread reduction in running-related injuries.

One recent method claimed to reduce injury risk is adopting a “proper” running form. The long-standing notion that an individual should run the way most natural-feeling, regardless of technique, is being challenged by the theory that a proper technique exists for running as much as a proper technique exists for golfing and swimming. Numerous methodologies of running form now exist, including barefoot or “minimalist” running, Chi running, Pose running, and the Playmaker’s Good Form Running (GFR®) method. Many of these strategies share common techniques that have become characteristic of proper running form: striking the ground with the midfoot or forefoot, landing with a flexed knee, maintaining a straight posture that leans forward slightly from the ankles, swinging bent arms back-and-forth in a strict sagittal plane motion, maintaining a short stride length, and running with a stride rate of at least 180 steps per minute. These techniques are believed to be more biomechanically efficient than the traditional heel-strike running form and claimed to reduce one’s risk of sustaining running-related injuries (Playmakers, 2011; Pose Tech Corp., 2009; Dreyer, 2009).

Despite these injury-prevention claims, scientific research linking running form techniques and injury rate is still preliminary and remains inconclusive. To date, most research on running form has mainly focused on the effects of individual, isolated techniques (i.e. footstrike) on the lower leg biomechanics. Research thus far has shown landing on the midfoot or forefoot, rather than the heel, decreases the impulse of ground impact forces on the foot, which may reduce the risk of impact-related injuries like stress fractures (Divert et al., 2005; Lieberman et al., 2010). Other research found that increasing one's stride rate by 5 to 10% at a preferred speed decreases the amount of energy absorption in the ankle, knee, and hip joints, which may be linked to a reduced risk of injury (Heiderscheit et al., 2011). Heidersheit et al. (2011) also reported a reduction in peak hip adduction and hip internal rotation, which suggests that altering one's running form to a higher cadence and shorter stride may help prevent knee injuries related to those hip motions. Another study found that a 6-week hip strengthening protocol resulted in lower extremity kinematic changes during running, including reduced hip internal rotation (Snyder et al., 2009). The studies of Heidersheit et al. (2011) and Snyder et al. (2009) suggest that a relationship may exist between hip musculature and running form kinematics.

More evidence is still needed to validate the clinical application of proper running form techniques for injury-prevention and recovery, especially concerning the effect of form alterations on hip musculature and kinematics. To the best of our knowledge, no research has been conducted that observes the effect of altering one's running form on hip muscle strength. If a positive correlation exists between proper running form techniques and hip muscle strength, it would help validate the application of a proper running form as a method for injury prevention and rehabilitation.

Females are reported to have a higher incidence of PFP, ITBS, and other gluteus medius injuries than males, (Taunton et al., 2002). In addition, females display a stronger correlation between hip abductor strength and landing kinematics than males (Jacobs et al., 2007). For these reasons, healthy females were selected as the target population for this study.

Purpose of Research

The purpose of this study is to determine whether instruction and practice in "proper" running form techniques has the potential to decrease the risk of lower extremity injuries, such as PFP and ITBS, by strengthening the hip abductor and hip external rotator muscles. It is hypothesized that female recreational runners who receive instruction and practice proper running techniques during 6 weeks of consistent, controlled mileage running will show a greater increase in hip abductor and hip external rotation strength than a control group of female runners that do not receive instruction. It is also hypothesized that the experimental group will display an increased symmetry in hip muscle strength between the left and right sides.

MATERIALS AND METHODS

Participants

Five college-aged female recreational runners were recruited for this study (mean ± standard deviation: age = 19.8 ± 0.8 years; height = 163.4 ± 4.3 cm; weight = 60.8 ± 7.6 kg). Recruitment methods included emails to Grand Valley State University students, flyers on campus, and through word-of-mouth. To be included in the study, volunteers had to meet the inclusion criteria as evaluated by an electronic questionnaire **(Table 1)**. All qualified participants signed an informed consent form outlining the purpose, procedures, risks, and potential benefits of the study. Participants were randomly assigned to an experimental (E) group and a control (C) group based on their order of signing for the study. Group demographics are given in **Table 3** in the results section.

Table 1. Inclusion criteria met for the study

Criteria	Rationale
Running 10-20 miles per week for at least two weeks immediately prior to the study	Recruiting volunteers already running within the desired range for the study reduces the effects of training or detraining caused by a change in mileage; it minimizes the risk of injury as participants will continue running at an accustomed mileage
Free from all lower extremity and core injuries at least one month prior to the study	Reduces risk of injury onset during the study and eliminates uncontrolled variables related to form-impairing injuries.
Received no official instruction from a coach, clinician, or professional about Good Form Running, Chi Running, and other "proper" form methodologies	Helps ensure that changes in hip strength are caused by practicing "novel" techniques of "proper" form
Be willing to learn and practice a running form different from one's habitual form	All participants must be motivated to practice a new form if placed in the E group
Be willing to abstain from all other consistent (2 or more times per week) physical activities involving the core and legs	Reduces the possibility of results being influenced by uncontrolled variables

Running Routine

Both the E and C groups followed a protocol of running 12 to 16 miles per week on a treadmill for six weeks. Though a runner's form in treadmill running has been shown to differ from overland running (Elliott & Blanksby, 1976), using treadmill running for this study had several advantages: 1) it kept the protocol homogenous for all participants and eliminated the partially uncontrollable variables of course surface type, condition, and elevation; 2) it allowed for easy measurement of mileage, pace, and time; 3) it allowed for consistent training and data recording during the winter months; 4) and allowed for easy video recording to use as visual feedback in running form instruction. These methods are consistent with running store and health clinic methods, many of which evaluate a client's running form using a treadmill.

Pace was self-selected to allow for a normative running experience. Each participant was instructed to record details of each run (time, distance, pace, comments on physical status) in an electronic running journal. The running journal was emailed to the researchers at the end of each week for consistent tracking of mileage. Additionally, the researchers were attentive to physical status comments to identify early signs of injury. In cases where early signs of injury became present, the primary researcher contacted the participant and advised her to temporarily reduce daily mileage and provided stretching instructions to alleviate painful symptoms.

The weekly mileage range of 12-16 miles was chosen because it is achievable for most recreational runners and promotes a running frequency of 3 to 5 days per week, which is a high enough frequency to observe physical adaptations. Participants were discouraged from running more than five miles in a single day in order to maintain a consistent, homogenous running routine between all participants.

All participants were discouraged from engaging consistently (defined as two or more times per week) in other modes of physical activity that could affect hip musculature, including lower body and core resistance training, outdoor running (including races), yoga, intramural sports, hiking, and outdoor games involving running. However, participants were permitted to warm-up with running or any other mode of cardio exercise if the warm-up run was five minutes or less.

Strength Testing

Participants underwent isometric strength testing for hip abduction and hip external rotation at baseline (the week starting the running routine), midline (third week of the routine), and at endline (week after routine completion). All data collection was performed by the same two testers, who showed an inter-rater reliability of 0.71 for hip abduction and 0.95 for external rotation during pilot testing. Participants met the testers in an assessment room in the campus recreation center.

The strength test procedures were adopted with slight modifications from the procedures of Ireland et al. (2003) and Earl and Hoch (2011). These procedures of isometric strength testing are reported to be reliable as they eliminate the effect of tester strength on the hand-held manual muscle tester (MMT). The MMT used to collect data on force output was a MicroFET 2 of Hoggan Health Industries.

To measure isometric hip abduction strength, participants laid in a sidelying position on a plinth table. Pillows and towels were used to abduct the hips into a neutral hip position as determined by an inclinometer near the knee joint. Participants were secured to the table with a buckled lap belt running underneath the table and over the pelvis of the participant (**Figure 1**). Participants grabbed the edge of the table with one hand for further stabilization. The MMT was placed over a mark 5 cm proximal to the lateral femoral epicondyle, and then secured in place using another buckled lap belt running underneath the table and through the strap of the MMT.

A tester placed a hand on the MMT to prevent lateral movement and then instructed participants to abduct the leg upward at maximal contraction for 3 seconds. Force outputs were measured in pounds and converted to kilograms before statistical analysis. Participants performed one practice trial and three experimental trials with 30 seconds of rest between trials. These procedures will be repeated for the opposite hip and leg.

For isometric external rotation strength testing, participants sat up on the table with hips and knees flexed 90 degrees and feet off the floor (**Figure 2**). A buckled lap belt stabilized the thigh of the tested leg to prevent hip flexion, and a rolled towel was placed between the participants' knees to prevent excessive hip adduction motion. Participants sat on their hands and kept a straight posture. Sitting on the hands, rather than grabbing the edge of the table, was found to be a better option since grabbing the edge of the table enabled recruitment of the upper body for contraction. The MMT was secured 5 cm proximal to the medial malleolus with a second lap belt looped around the participant's leg and a stationary object lateral to the participant. The same procedures for hip abduction strength testing were used for external rotation strength testing.

Figure 1. Isometric hip abduction strength test set up

Figure 2. Isometric hip external rotation test set up

Intervention

Participants in the experimental group received three personal, 30-minute form training sessions from the primary researcher in the first, second, and fourth weeks of the protocol. The researcher providing instruction is an Exercise Science student with personal experience in transitioning from traditional running form to the described proper running form. For the instruction sessions, the researcher demonstrated the techniques of proper form to each participant in the experimental group. A condensed list and visual representation of the form is provided in **Table 2** and **Figure 3**. The participant ran on a treadmill in the campus Recreation Center and received verbal feedback. A camera was used to replay video footage for visual feedback and instruction facilitation. Simple drills were used to promote learning, including a drill that consisted of leaning against a wall and lifting the knees to better comprehend the forward lean and knee lifting motion. A checklist of form techniques and useful stretches was given as a reference for each E group participant. Furthermore, the participants in the E group were advised to work on the form gradually, slowly increasing how much of each run was spent practicing the form. It was aimed for each E group participant to be running their full runs in the proper form within the third or fourth week. The distance and time ran during these sessions were not counted towards a participant's weekly mileage because the running was limited and intermittent.

Meanwhile, participants in the C group followed the protocol without receiving any comment or instruction concerning their running form. However, those in the C group were offered the same running form instruction after the completion of the study.

Table 2. A condensed list of the proper running form techniques taught to the E group

• Straight posture with a slight forward lean from the ankles, which utilizes the force of gravity to pull the runner forward
• Head up and looking forward
• Shoulders relaxed and dropped down
• Arms relaxed at the sides, with elbows held at 90 degrees. When running, arms swing forward and back, never crossing the midline of the body.
• Landing on a bent/flexed knee rather than a straight knee
• Short strides with a high cadence (stride rate) of at least 180 steps per minute
• Landing near one's center of gravity (underneath the hips).
• Aiming to land on the middle (midfoot) or front (forefoot) of the foot rather than at the heel (heel strike).
• Lower leg is relaxed

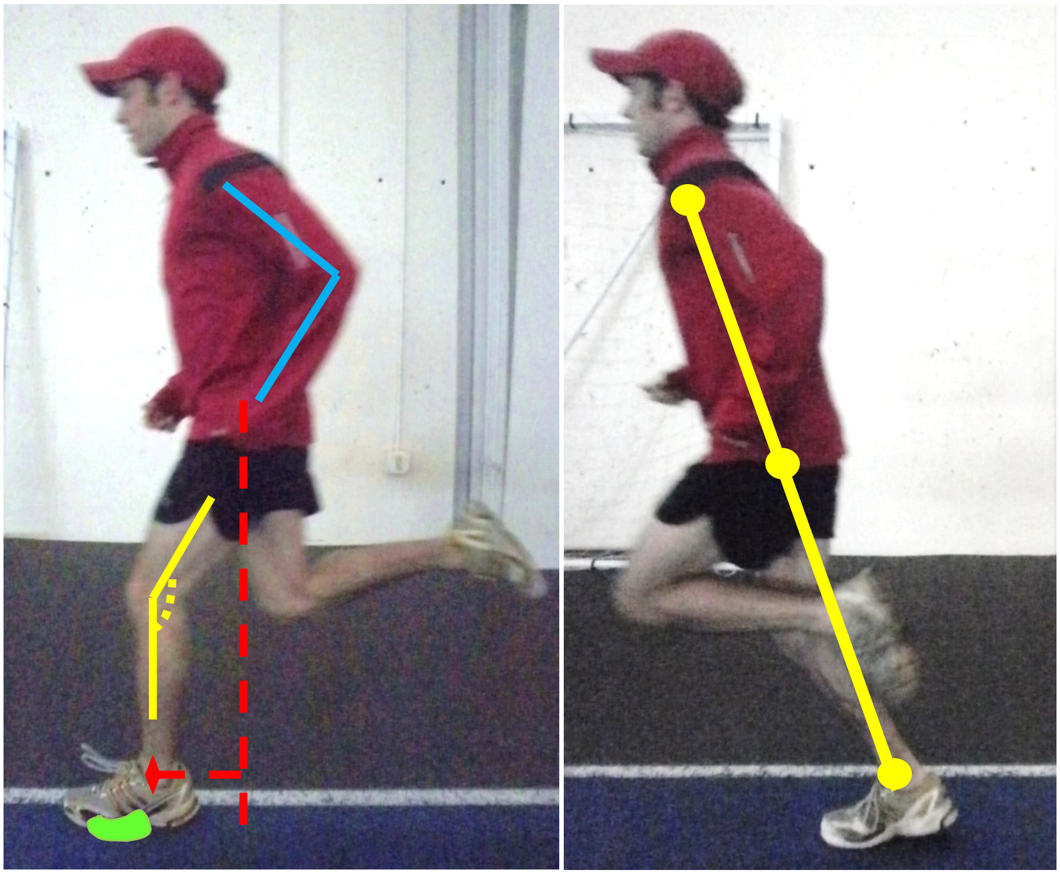

Figure 3. Visual representation of proper running form techniques. At footstrike (A), note the flexed knee, midfoot strike (indicated by the green zone), elbows bent at 90 degrees, and the close proximity of the foot to the hip center (red line). In stance (B), note the straight posture, raised head, and forward lean originating from the ankles (a straight line can be passed through the shoulder, hip, and ankle joints).

Statistical Analysis

Peak force values recorded in pounds during strength testing were converted to kilograms. The independent variables measured were time (Baseline, Midline, Endline) and group (C or E); the dependent variable was the strength of the hip muscles in hip abduction and hip external rotation. Six separate (one for each side and strength test) two-way repeated measure ANOVA tests were performed. A confidence value of 0.95 was set to assess significance.

RESULTS

Participants

Four of the five participants completed the protocol; one participant was dismissed in the fifth week due to excessive calf muscle soreness that hindered her from running the target mileage for two consecutive weeks. The demographics of the C and E group were similar (**Table 3**). The mild difference in average weekly mileage is not believed to have affected results.

Table 3. Participant demographics (Mean ± SD)

Group	Age (years)	Height (cm)	Weight (kg)	Average Weekly Mileage (miles)
C (n = 2)	20.5 ± 0.7	162.3 ± 3.9	64.6 ± 12.2	12.8 ± 1.1
E (n = 2)	19.0 ± 0	166.8 ± 3.9	59.4 ± 5.2	14.8 ± 0.4

As there were only four participants who completed the study, the statistical power of the results was low and yielded no significant differences between groups. However, trends were present that both followed and contradicted the hypotheses.

Hip Abduction: The E group showed an initial decrease in mean force output on both sides from baseline to midline, followed by an increase from midline to endline. A higher force output occurred at endline than at the baseline (**Table 2**). The C group showed a general decrease in force output from baseline to endline. This result is consistent with the hypothesis that the E group would exhibit a greater overall increase in hip strength than the C group.

Table 2. Force output (Mean ± SD) of isometric hip abduction over time per side (R = right, L = left) and group (E = experimental, C = control)

Abduction		**Force Output (kg)**			Significance Between Groups
Side	Group	Baseline	Midline	Endline	
R	E	16.1 ± 5.8	13.8 ± 4.5	17.9 ± 2.8	0.522
	C	16.6 ± 2.6	14.1 ± 3.2	13.3 ± 1.1	
L	E	14.0 ± 1.5	12.6 ± 1.5	17.3 ± 1.2	0.372
	C	14.9 ± 2.4	14.3 ± 3.0	11.8 ± 2.3	

External Rotation: Contrary to the hypothesis, the E group showed a small decrease in mean force output from start to finish (**Table 3**). The C group showed an initial decrease on the right and an initial increase on the left, followed by a return towards baseline values for either side. Thus, the C group remained relatively unchanged overall.

Table 3. Force output (Mean ± SD) of isometric hip external rotation over time per side (R = right, L = left) and group (E = experimental, C = control)

External Rotation		**Force Output (kg)**			Significance Between Groups
Side	Group	Baseline	Midline	Endline	
R	E	6.4 ± 2.1	6.4 ± 3.1	5.7 ± 1.6	0.931
	C	6.5 ± 0.7	5.7 ± 2.6	6.1 ± 3.0	
L	E	6.1 ± 2.3	6.0 ± 2.1	5.6 ± 0.6	0.386
	C	4.4 ± 1.1	5.2 ± 2.9	4.8 ± 3.8	

Symmetry of Hip Strength: Consistent with the hypothesis, the E group showed a decrease in both abduction and external rotation force output difference between sides, indicating a progression towards improved symmetry (**Table 4**). The C group's difference in the abduction and external rotation tests was unchanged between baseline and endline, despite changes seen at midline. This indicates no overall change in symmetry. The difference between groups for abduction was not significant, while the difference between groups for external rotation was significant (*).

Table 4. Symmetry of hip strength as measured by the difference of force output (Mean ± SD) between the left and right side for hip abduction (ABD) and external rotation (ER) over time.

Hip Symmetry		**Difference in Force Output (kg)**			Significance Between Groups
Test	Group	Baseline	Midline	Endline	
ABD	E	2.0 ± 4.7	1.2 ± 4.9	0.6 ± 2.4	0.875
	C	1.7 ± 1.8	0.2 ± 1.4	1.5 ± 2.4	
ER	E	6.1 ± 2.3	6.0 ± 2.1	5.6 ± 0.6	0.026*
	C	4.4 ± 1.1	5.2 ± 2.9	4.8 ± 3.8	

DISCUSSION

The results of this study both supported and contradicted the hypotheses proposed. The E group showed an overall increase in hip abduction force output. This suggests that an increase in strength occurred in the hip abductors and thus supports the hypothesis. The researchers theorize that this strength gain was caused by a greater recruitment of the hip abductors to stabilize the flexed knee at foot contact. The knee joint, when flexed, shows a greater range of motion in the transverse and frontal planes than when the knee is extended. In extension, the knee is supported by the structural integrity of the femur, tibia, and popliteal joint capsule. The participants in the E group were instructed to transition from landing on an extended knee to a flexed knee; thus, they were probably initiating more activation of the hip abductors (such as the gluteus medius, gluteus minimus, and tensor fascia latte) to prevent the knee from jolting into excessive valgus motions. This theory is open for debate, however, as one study has found no difference in gluteus medius activation between subjects despite a significantly higher occurrence of knee valgus in half the subjects during a single leg jump test (Russell, Palmieri, Zinder, & Ingersoll, 2006).

The initial decrease in force output from baseline to midline in the E group could be related to an initial performance drop linked to new skill acquisition; adopting the proper running form is a skill acquisition that requires the retraining of certain musculature. Other explanations may be liable, however, since neuromuscular strength gains are typically observed two weeks into the acquisition of a new skill. Participant motivation to perform the strength tests was probably lowest at midline, as it did not have the “excitement” of beginning or ending the protocol. In addition, running before midline strength tests was not controlled, so participants may have ran before the test and been experiencing some degree of muscular fatigue.

The overall decrease in strength in the C group is also intriguing. They should have experienced no change in hip abduction strength as they had no intervention and little change in running volume. The results suggest that unforeseen changes in the participants’ exercise routines may have occurred. One possibility is those that experienced a drop in force output had switched to treadmill running from circular track running, where the turning may have recruited the hip abductors more heavily.

The observed decrease in external rotation strength in the E group may be due to the shortening of the subjects’ stride length. Longer strides exhibit more transverse movement of the hip in order to extend the leg in front of the body. If the pelvis rotates, then the femur needs to counter-rotate in the external direction to keep the leg upright, forward, and ahead. Shorter strides would exhibit less transverse movement at the hips, and consquently the external rotators would be less activated to rotate the femur. The C group showed no overall change, which is expected as there was little change in their running routine.

The symmetry of hip strength was also focused on in this study because some research suggests that hip strength asymmetry, not just overall muscle weakness, is a factor in knee injuries such as PFP (Robinson & Nee, 2007). The E group showed an increase in symmetry while the C group remained unchanged, possibly suggesting that the form alterations promoted more balanced muscle recruitment. In addition, the group difference for external rotation was found to be significant, suggesting that a difference in symmetry seen between the E and C groups actually existed. Due to the low number of subjects, a post-hoc analysis was not possible to perform between the groups, so it cannot be concluded where the significance occurred; it is possible that the groups were significantly different to start and were not influenced by the intervention.

Many limitations existed in this study. The mileage was self-reported by the subjects, which opens the possibility for uncontrolled error. Other uncontrolled variables may have affected results, including sleep status, motivation, and time of testing. There was also no standardized system to evaluate subjects' running form before and after the protocol, so a subject's level of form adoption was not taken into account for the results. Future studies should utilize a standardized point system that can quantitatively assess a runner's form for comparisons before and after interventions as well as between subjects. This would allow researchers to better attribute proper running form adoption to any kinetic, kinematic, and neuromuscular changes. Other studies should also test external rotation on a long axis with the hip extended, as it better tests the strength of the gluteus maximus, the primary external rotator during running. The external rotation test used in this study measured external rotation strength with the hip in a flexed position, which recruits the smaller external rotators of the hip instead of the gluteus maximus.

Regardless of the results, this study proposes a novel method of testing proper running form over a multi-week period and as a set of combined techniques rather separate techniques (i.e. focusing only on midfoot strike). It is the researchers' hope that this study will provide a model for future studies to modify, perfect, and find conclusive evidence regarding proper running form and its influence on injury risk.

CONCLUSIONS

No statistically significant changes in hip abduction strength and hip external rotation strength were found after a 6-week running and proper form training protocol due to the small sample size. However, there was an observed trend for female recreational runners who received proper form training to have mild strength gains in hip abduction and an increase in hip strength symmetry between the left and right sides. This suggests more research should be conducted with a larger sample size to explore these trends and draw conclusions about proper running form's effect on hip strength.

REFERENCES

Divert, C., Mornieux, G., Baur, H., Mayer, F., & Belli, A. (2005). Mechanical comparison of barefoot and shod running. *International Journal of Sports Medicine*, 26(*7*), 593-598. doi:10.1055/s-2004-821327

Dreyer, D. (2009). *Chi running: A revolutionary approach to effortless, injury-free running.* New York: Fireside

Earl, J. E., & Hoch, A. Z. (2011). A proximal strengthening program improves pain, function, and biomechanics in women with patellofemoral pain syndrome. *American Journal of Sports Medicince,* 39(*1*), 154-163. doi: 10.1177/0363546510379967

Elliott, B. C., & Blanksby, B. A. (1976) A cinematographic analysis of overground and treadmill running by males and females. *Medicine and Science in Sports,* 8*(2)*, 84-87. Retrieved from:http://ukpmc.ac.uk/abstract/MED/957936/reload=0;jsessionid=EZDGgZSqwOVuPMzM4U03.138

Ferber, R., Kendall, K. D., Farr, L. (2011). Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome. *Journal of Athletic Training,* 46(*2*), 142-149. Retrieved from http://www.mendeley.com/research/changes-knee-biomechanics-after-hipabductor-strengthening-protocol-runners-patellofemoral-pain-syndrome/

Fredericson, M., Cookingham, C. L., Chaudhari, A. M., Dowdell, B. C., Oestreicher, N., & Sahrmann, S. A. (2000). Hip abductor weakness in distance runners with iliotibial band syndrome. *Clinical Journal of Sport Medicine*, 10, 169-175. Retrieved from http://www.udel.edu/PT/davis/Hip_strength_PFP.pdf

Heiderscheit, B. C., Chumanov, E. S., Michalski, M. P., Wille, C. M., & Ryan, M. B. (2011). Effects of step rate manipulation on joint mechanics during running. *Medicine and science in sports and exercise*, 43(*2*). doi:10.1249/MSS.0b013e3181ebedf4

Ireland, M. L., Willson, J. D., Ballantyne, B. T., & Davis, I. M. (2003). Hip strength in females with and without patellofemoral pain. *Journal of Orthopedic and Sports Physical Therapy,* 33(*11*), 671-676. Retrieved from http://www.udel.edu/PT/davis/Hip_strength_PFP.pdf

Jacobs, C. A., Uhl, T. L., Mattacola, C. G., Shapiro, R., Rayens, W. S. (2007). Hip abductor function and lower extremity landing kinematics: Sex differences. *Journal of Athletic Training,*42*(1)*, 76-83. Retrieved from: http://www.ncbi.nlm.nih.gov.ezproxy.gvsu.edu/pmc/articles/PMC1896084/pdf/i1062-6050-42-1-76.pdf

Lieberman, D. E., Venkadesan, M., Werbel, W. A., Daoud, A. I., D'Andrea, S., Davis, I. S., Mang'Eni, R.O., & Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature,* 463(*28*). doi:10.1038/nature08723

Playmakers. (2011). Good form running: Four simple steps to good form. Retrieved from http://www.goodformrunning.com/

Pose Tech Corp. (2009). Pose method in running. Retrieved from http://www.posetech.com/pose_method/pose-method-of-running-technique.html

Robinson, R., & Nee, R. (2007). Analysis of hip strength in females seeking physical therapy treatment for unilateral patellofemoral pain syndrome. *Journal of Orthopedic and Sports Physical Therapy,* 37*(5)*. Doi:10.2519/jospt.2007.2439

Russell, K. A., Palmieri, R. M., Zinder, S. M., & Ingersoll, C. D. (2006) Sex differences in valgus knee angle during a single-leg drop jump. *Journal of Athletic Training,* 41*(2),* 166-171. Retrieved from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1472649/

Snyder, K. R., Earl, J. E., O'Conner, K. M., Ebersole, K. T. (2009). Resistance training is accompanied by increases in hip strength and changes in lower extremity biomechanics during running. *Clinical Biomechanics,* 24. Retrieved from http://www.clinbiomech.com/article/S0268-0033%2808%2900279-9/abstract

Souza, R. B. & Powers, C. M. (2009). Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *Journal of Orthopaedic and Sports Physical Therapy,* 39*(1)*, 12-19. Retrieved from http://rehabeducation.com/main/wp-content/uploads/January2009-RR-Souza%5B1%5D.pdf

Taunton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., & Zumbo, B. D. (2002). A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine,* 36, 95-101. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1724490/pdf/v036p00095.pdf

van Gent, R. N., van Middlekoop, M., van Os, A. G., Bierma-Zeinstra, S. M. A., & Koes, B. W. (2007). Incidence and determinants of lower extremity running injuries in long distance runners: A systematic review. *British Journal of Sports Medicine,* 41, 469-480. doi: 10.1136/bjsm.2006.033548