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The Influence of CrossFit Training on Running Mechanics

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THE INFLUENCE OF CROSSFIT TRAINING ON RUNNING MECHANICS

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ABSTRACT

Introduction

40 million Americans run regularly.[1] Contrary to many runner's beliefs, increased strength may be beneficial while not adding body mass. An increase in strength in specific muscles may improve running gait and performance.[9,6] Strength training may also play an important role in preventing common overuse injuries in running[11,12] Depending on the style of strength training, it may also have an enhanced benefit on running economy.[4,16]

Participation in CrossFit is also widely popular, with an increase in participation of 923% in the past ten years.[2] CrossFit is a type of strength training in which most movements performed utilize the hip to generate a majority of the power for successful completion.[8] Muscles of the hip and knee are imperative during many CrossFit movements, but also during running.

Purpose

The purpose of this study is to investigate the influence that CrossFit training has on running mechanics.

Methods

18 recreational runners between the ages of 18-65 were recruited in each of two groups: 9 runners that also participate in CrossFit 3 times per week, and 9 runners that do not do any strength training. Inclusion criteria included running at least 10 miles a week. Participants gave written consent and completed a demographic questionnaire and Physical Activity Readiness Questionnaire. Following consent, InBody (570, InBody USA, Cerritos, CA) bioelectric impedance body composition was collected.

Participants then completed a 5-minute treadmill warm-up. Retro-reflective markers were placed bilaterally on the shoulders and hips and unilaterally on the leg and foot. Data collection was completed over ground along a 10-meter runway with three embedded force platforms (1000 Hz, AMTI Optima, Watertown, MA). Preferred running velocity was then determined. Participants performed two separate conditions; preferred running velocity (C1) and a set velocity of 3.5 m/s (C2). Trials were collected via three-dimensional motion capture system (200 Hz, Vicon, MX and Vantage, Oxfordshire, UK) and photoelectric timing gates. Eight successful trials were collected for each condition.

Participants then performed strength testing of the hip and knee to determine peak torque using the isokinetic dynamometer (Biodex System 3, Biodex Medical Systems Shirley, NY) each consisting of one set of five reps at 120 °/s .

Data Analysis

Following collection, trials were individually processed using Vicon Nexus software (version 2.2.3, Oxfrodshire, UK). Trials were then exported to Visual 3D (version 5, Germantown, MD) and further processed.

Statistics

Kinematic and kinetic variables were analyzed with a 2x2 repeated measures ANOVA. Strength variables were analyzed with independent t-tests. Alpha level was set to 0.05.

Results

There was a significant difference between the CF group and the RO group in all of the strength measures, with the CF group having greater strength. For hip ROM, there were no significant differences between the groups, but there was a significant difference between the conditions

Discussion

Although there were few differences between the two groups, the main finding of this study is that the CrossFit group was significantly stronger than the run-only group. This is of importance because it demonstrates that even though the CrossFit group was stronger, the running mechanics of the two groups were similar.

DEDICATION

Dedicated to the memories of my Papou. Without being inspired by your love of physics I never would have discovered my love of Biomechanics. I will always miss your stories and I am forever grateful I inherited your brains. Lots of hugs.

Also dedicated to my son, Carsen. You came into the world right in the middle of me trying to wrap this project up. We ended up finishing it together. I wouldn’t want it any other way. I love you!

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CHAPTER 1: INTRODUCTION

Participation in recreational running has exploded in recent years with more than 40 million Americans regularly participating in the activity.[1] However, running is not the only activity on the rise. The idea of being strong and having more muscle mass has jutted into the spotlight by means of many activities. It has been brought to the public's attention that having more muscle mass can be beneficial for health and looks. An idea that supports additional muscle mass and is gaining a lot of popularity is the notion of being functionally fit. The idea of being functionally fit is that the athlete is prepared for anything and everything. CrossFit is a strength and conditioning program focused on functional fitness. Participation in CrossFit has increased dramatically in the past ten years with a 923% increase in CrossFit gyms around the world between 2005 and 2015.[2]

Runners typically tend to avoid adding body mass in fear that added mass will slow them down. Therefore, there is a tendency for runners to avoid strength training programs. What many runners do not realize is that muscle mass is a functional addition; the added muscle mass plays a role in movement. Strength training is not always accompanied by an increase in mass. If muscles hypertrophy due to strength training, the additional mass is active mass contributing to the performed movement. Increases in muscular strength improve performance measures in running. Participation in strength training also improves running economy.[3.4] It has been shown that runners who undergo a strength training protocol develop a more efficient running economy.[3,4] Not only are there benefits to the performance properties of running, but to the mechanical aspects as well. Strength training has been shown to enhance running gait mechanics in ways to potentially reduce risk of injury. [5–7]

One of the core ideas behind most movements performed in CrossFit is that the actions are driven by the hips. Whether it be gymnastics style movements or weightlifting, if the movement is hip driven, most of the power to complete the movement is generated at the hips. [8] With this focus on the hip, the muscles of the hip of CrossFitters may be stronger than for those that do not participate in CrossFit, yet this has yet to be empirically studied. Not only are the muscles of the hip important during CrossFit, they are also instrumental in running. The hip extensors are one the main movers and power generators during the stance phase of running. Therefore, the proposed benefits of CrossFit training have the potential to be beneficial for runners.

Purpose of the Study

The purpose of this study was to investigate the influence that CrossFit training has on running mechanics. To complete this goal, runners who either only run or also participate in CrossFit were asked to complete a running protocol in the lab in which kinematic and kinetic variables were assessed. The runners then completed a strength protocol which consisted of isokinetic dynamometry of the hip and knee. Hip and knee flexion and extension peak torque values were assessed.

Research Questions

This study aims to answer two main research questions pertaining to differences in kinematic and kinetic variables between runners who only run and runners who also do CrossFit:

1. Do runners who also participate in CrossFit have more hip and knee flexor and extensor muscle strength than runners that only run?
2. Does CrossFit training contribute to hip power generation in running?

Significance of the Study

Many runners sustain injuries throughout their running career. With the previously mentioned rise in running population any inquiry into possible mechanisms that may prevent or decrease injury rates is significant. Additionally, due to the brevity of the development of CrossFit, there is a lack of peer-reviewed research investigating it. Not only is it relatively new, but it is also extremely popular and growing. Therefore, there is a need for investigations that consider aspects of CrossFit that expand beyond the gym itself.

Statistical Hypotheses

The research questions will be focused upon the following statistical hypotheses. The null (Ho) and alternative (Ha) hypotheses are:

Ho_1: There will be no difference in hip and knee flexor and extensor strength between the two groups.

Ha_1: The CrossFit group will have more hip and knee flexor and extensor strength than the run-only group.

Ho_2: There will be no difference in running kinetics between the two groups.

Ha_2: The CrossFit group will have more active hip power during running demonstrated by greater peak power in the sagittal plane than the run-only group.

Ho_3: There will be no difference in running kinematics between the two groups.

Ha_3: The CrossFit group will have less range of motion in hip and knee angles than the run-only group.

Limitations

A possible limitation of this study is that our population was narrowed due to the selection of inclusion criteria, including participation in running and CrossFit. By selecting CrossFit as a strength training program, assumptions are being made that the differences we saw were because of CrossFit participation. An additional limitation may be the definition used to categorize strength training in this study. CrossFit is categorized as “organized” strength training. The definition of organized strength training is any training done in a class with a teacher. The limitation is that people that do CrossFit do not always do CrossFit in a class. It is possible for people to do CrossFit individually and at a regular gym or even in their own home.

Delimitations

In this study, delimitation is the method used to determine the dominant leg through self-reported means. We asked the participants which leg they would use to kick a soccer ball as that is a common method of dominant leg determination.

CHAPTER 2: LITERATURE REVIEW

Running

Human skeletal muscles produce movement with several muscles and/or groups of muscles that must working together. Lower extremity muscles play an important role in movement production and stabilization. Running gait can be broken down into multiple phases: heel-strike, stance, toe-off, and swing. Heel-strike is the initial contact of the foot with the ground. Stance is the period between heel-strike and toe-off in which the foot in still in contact with the ground. Toe-off is the propulsion phase of stance in which the foot is propelling the body off the ground. Swing is considered the time when the foot is in the air. During running, the muscles of the hip, knee and ankle are of interest. The hip and knee extensor muscle groups are the dominant muscle groups during the stance phase of running.

Increased strength in the hip extensors and abductors has shown to improve particular portions of running gait and running performance.[5,6,9] One role of the hip extensors during heel strike is to absorb and dissipate the impact from landing.[9] Decreased hip extensor strength may decrease the ability of this muscle group to perform the task of impact absorption. Decreased hip abductor strength has important implications in stabilization during the stance phase of running. Greater transverse plane motion is observed with lower hip abductor strength.[6] Additionally, a hypermobile joint is a less stable joint. Increased joint motion is correlated with decreased muscular strength. Specifically, lower hip extensor strength has been correlated with greater frontal plane hip motion.[5]

Running Injuries

In recent years, recreational running has evolved into a sport and activity with high participation rates. In the United States alone, 40 million people regularly run.[1] It is estimated that as many as 65% of runners sustain injuries throughout their running lifetime.[10] Due to the repetitive nature of running, overuse injuries are common. Most of the overuse injuries occur at the knee, with the most common causes of pain being patellofemoral pain syndrome (PFPS) and iliotibial band syndrome (ITBS). [1] The location of PFPS is typically in the anterior portion of the knee, whereas ITBS is located on the lateral portion of the knee. [11,12]

The etiologies of PFPS and ITBS are not entirely understood. There are several factors that may contribute to development of PFPS and these include mal-alignment of the lower extremity, specifically at the patella, overuse, and muscular imbalances.[11] Similar to PFPS, there are multiple factors that could contribute to ITBS development. As stated previously, ITBS is a common consequence of overuse, but particularly running on a track in the same direction or increasing running distance too quickly.[12] This may be due to an imbalance between the two limbs in knee extension and flexion when running in the same direction on a track. It has also been found that there is often an imbalance in knee flexion and extension strength in runners with ITBS.[12] An imbalance in hip adduction and abduction control in the runner's affected limb is also seen with ITBS demonstrated by increased hip adduction moments.[13] Therefore strength appears to be a factor in the development of both ITBS and PFPS.[11,12]

Running Performance

Running performance is a measure often defined by running velocity. There are two main factors that determine running velocity; stride frequency and stride length. Another common metric to determine running performance is to calculate running economy (RE). It is described as oxygen cost for running at a given velocity.[14] RE is a measure of efficiency during running and is primarily used as an indicator of performance and fitness. It is a useful tool when looking to compare differences in performance due to an intervention, such as strength training. It has been shown that strength training has enhanced benefit on RE in long distance runners.[15]

Different styles of strength training may influence RE differently. In a study comparing explosive training versus heavy weight training on RE, there was more of an improvement in RE for the heavy weight training group than for the explosive training group. The explosive training protocol used sets of a twelve-rep maximum in which participants were instructed to perform the concentric portion of the movements as fast as possible. The heavy weight training protocol used 3 sets of a six-rep maximum. The resistance for both groups was increased to maintain the correct number of reps per set. Both groups also participated in regular endurance training. [4] Peak VO2 was higher after the heavy weight training program compared to athletes who completed only the explosive training. Both groups had no change in body mass, but the explosive training group did demonstrate a reduction in body fat.[4] In contrast, another study looking at heavy strength training and RE showed no improvement in peak VO2.[16] Although the two studies showed opposite results in peak VO2, they both demonstrated increases in strength for the heavy weight groups and no change in body mass which is of extreme importance to runners. A runner can partake in heavy weight training and not significantly alter body mass thus discrediting the notion that strength training makes people “too bulky”.

Strength Training

There are many styles of strength training. One way to distinguish different categories of strength training is to describe it as either organized strength training or unorganized strength training. For the purposes discussed here, organized strength training is any type of strength training that takes place in a class lead by an instructor and unorganized strength training is any type of strength training done outside of a class setting. In this case, personal, one-on-one training would fall into the unorganized category because it is done outside of a group class setting. Among the many types of instructor-led classes available to all varieties of consumers, there is a plethora of activities taught. Classes are offered in a wide spectrum of settings, from mainstream to boutique gyms. The curriculum of offered classes is also quite broad.

The American College of Sports Medicine (ACSM) defines resistance training as “a form of physical activity that is designed to improve muscular fitness by exercising a muscle or muscle group against external resistance”.[17] According to the ACSM stance on resistance training for healthy adults, “Maximal power production is required in the movements of sport, work, and daily living”.[18] Greater power production is equivalent to doing the same amount of work in less time or more work in the same amount of time.[18] Following the ACSM’s recommendations, emphasis should be placed on multiple-joint movements to enhance power production.[18] There is a lot of crossover between power production and sports performance.

Most research looking at concurrent resistance/strength and endurance training is done in the form of a training study. There are typically three groups: an endurance group, a strength group, and an endurance and strength group. A study on trained rugby players showed that the strength group had greater increases in strength than the strength and endurance group.[19] Not only did the strength group increase strength measures, but they also maintained endurance performance values. It has also been shown that strength training alone is more beneficial to muscle strength gains than strength training in combination with endurance training.[19]

CrossFit

One type of organized strength training that is on the rise in popularity is CrossFit. CrossFit is a branded strength and conditioning fitness program founded by Greg Glassman. It is self-described as “constantly varied functional movements performed at high intensity”.[20] The CrossFit program describes fitness as the participant being competent in multiple domains including: cardiovascular and respiratory endurance, stamina, strength, flexibility, power, speed, coordination, agility, balance, and accuracy. Not only is CrossFit a strength and conditioning training program, it also created its own journal titled “CrossFit Journal”. This journal is not peer reviewed, but is open-sourced and claims to be “a chronicle of the empirically driven, clinically tested, and community-developed CrossFit program”.[21] Because it is a new fitness regimen, there is limited peer-reviewed science researching CrossFit. Most of the research on CrossFit has previously been published in the CrossFit Journal but the program design of CrossFit is similar to high intensity interval training (HIIT). HIIT utilizes repeating, alternating intervals at moderate and high intensity with a designated rest period. One popular design for a workout utilized in CrossFit and HIIT is the tabata. A tabata style workout consists of 20 seconds of work followed by 10 seconds of rest repeated in four minute blocks.[22] During a tabata-style workout, one study demonstrated that participants could burn between 240 – 360 kcals for the 20-minute workout. The design of many CrossFit workouts is to either do as much as possible within a designated time, or to perform a certain amount of reps as quickly as possible. These workouts are usually done utilizing multiple implements, and rep schemes at a very high intensity and do not always have a designated rest period.

It is thought that HIIT can produce rapid and drastic changes to endurance performance.[23] Participants in HIIT also report that it is more enjoyable than steady-state training.[24] HIIT workouts may allow participants to train at a higher intensity for a shorter amount of time, and still gain similar endurance effects to typical endurance training. Improvements in VO_2 can be seen with HIIT training done at or above the established VO_2 max. These improvements are greater than improvements made due to moderate intensity training.[25] A HIIT protocol has also been shown to improve RE and delay the symptoms of fatigue.[25] A study by Smith et.al looked at the effects of a CrossFit-style training program on aerobic fitness and body composition.[26] They determined that a ten-week training program utilizing a typical CrossFit workout significantly improved aerobic fitness and body composition. Aerobic fitness was determined by VO2 max and body composition was determined utilizing air displacement-plethysmography to determine body fat percentages.[26]

CrossFit prides itself on its functionality. One of the core beliefs of CrossFit training is that it should prepare the athlete for anything and everything. If CrossFit is designed to prepare the user for daily tasks, it could be assumed that it can also prepare you to be a better runner. A lot of the movements that the CrossFit program utilizes emphasize whole body strength generation. Many of these whole body movements place a strong emphasis on using the hip to generate a majority of the power for successful completion.[8] Not only are the muscles of the hip and knee movement imperative during many CrossFit movements, they are also the primary drivers during a running movement.[27] CrossFit training may benefit runners due to improvements in aerobic fitness and increases in strength that may improve running mechanics.

Conclusion

Many aspects of running are affected by strength. Increased levels of muscular strength have shown to improve running gait mechanics, particularly at the hip and ankle. Not only does strength training improve running mechanics, but it also improves running economy and running performance, making runners more efficient. Due to the time demands of endurance training it is important to weigh the benefits and detriments of additional training. Concurrent strength and endurance training has shown to improve both strength and endurance performance values. One method of strength training that may be beneficial to runners is CrossFit. CrossFit emphasizes full body, functional strength and aims to improve every aspect of fitness. The supplementation of strength training to recreational runners' training protocol leads to improvements in mechanics and performance and may prove to be a beneficial addition.

CHAPTER 3: METHODS

Purpose

The purpose of this study is to investigate the influence that CrossFit training has on running mechanics.

Participants

18 recreational runners between the ages of 18-65 years were recruited from the Las Vegas area in each of two groups: 9 runners that participate in CrossFit and 9 runners that do not do any strength training. Inclusion criteria included running at least 10 miles a week for all participants and participating in at least 3 CrossFit classes per week for the CrossFit group (CF). Any individual who reported a lower extremity surgery, or an injury within the past 6 months that resulted in cessation of activity for two or more days, or was pregnant was excluded from the study. Participants were asked to report to the Sports Injury Research Center (SIRC) once, with that visit lasting approximately 1-2 hours.

Procedure

Upon arrival participants were provided with information regarding the study and were given time to ask any questions before granting written consent. Following consent, participants completed a demographic questionnaire and weight and height were recorded. Dominant leg was determined by asking participant which leg they would kick a soccer ball with and was recorded. InBody bioelectric impedance body composition (570, InBody USA, Cerritos, CA) was collected.

Participants were asked to perform a self-directed running warm-up on a treadmill for five minutes. Retro-reflective markers were placed bilaterally on the acromion, anterior superior iliac spine, posterior superior iliac spine, iliac crest. Retro-reflective markers were placed on the side of the body that corresponds with the dominant leg on the greater trochanter, medial and lateral knee, medial and lateral ankle, head of the first toe, base of the first toe and base of the fifth toe. Retro-reflective marker clusters were placed on the thigh, leg, and heel. Data collection was completed over ground along a 10-meter runway with three embedded force platforms (1000 Hz, AMTI Optima, Watertown, MA). Participants were allowed several practice runs on the runway to become familiar with the runway and targeted pace. Subjects were instructed to start in a location that was adjusted by the researchers to allow one footfall on the force platform within the runway. Preferred running velocity was determined by instructing participants to run at a pace that is typical of a training day pace. Eight trials were collected and averaged to determine preferred running velocity. Participants performed two separate conditions; preferred running velocity (C1) and a set velocity of 3.5 m/s (C2). C1 was always collected first to ensure that C2 did not influence the participant's preferred velocity. Trials were collected via three-dimensional motion capture system (200 Hz, Vicon, MX and Vantage, Oxfordshire, UK) and photoelectric timing gates. Eight successful trials were collected for each condition. With a successful trial being defined as the participants striking the force platform with the dominant leg without targeting the force platform while achieving target velocity.

Participants then performed strength testing of the hip and knee to determine peak torque using the isokinetic dynamometer (Biodex System 3, Biodex Medical

Systems Shirley, NY). For the hip measurements, participants were placed in a supine position with the knee flexed for hip flexion and extension. The hip attachment was utilized following manufacturer specifications. Concentric hip flexion and extension of the dominant leg was measured over one set of five reps at 120 °/s. For the knee measurements, participants were seated with the hip at 90. The knee attachment was utilized following manufacturer specifications. Concentric knee flexion and extension of the dominant leg was measured over one set of five reps at 120 °/s.

Data Analysis

Following collection, trials were individually processed using Vicon Nexus software (version 2.2.3, Oxfordshire, UK). Trajectory data were interpolated using a quintic spline, filling gaps up to 20 frames. Trials were then exported to Visual 3D (version 5, Germantown, MD). The data were then filtered using a low pass fourth order zero lag Butterworth filter at 10 Hz for kinematics and 50 Hz for kinetics. Stance phase was determined using vertical ground reaction forces. An ascending and then descending cutoff of 20 Hz was utilized for determination of touch down and toe off.

Hip, knee and ankle joint angles, moments and power were calculated using inverse dynamics throughout the entire stance phase. Hip, knee and ankle joint angles at heel strike were identified in all planes. Hip and knee peak joint velocities, moments and power were identified in all three planes for both joints. Loading rate was identified, as well as peak vertical ground reaction forces. For the isokinetic dynamometry, the maximum torque values of all trials for the hip and all trials for the knee were selected.

Statistics

Kinematic variables of interest included: hip, knee and ankle joint angles at heel strike in all planes; and hip and knee peak angular velocity in all planes. Kinetic variables of interest included: loading rate; peak vertical ground reaction force; and hip and knee peak moments and power in all planes. Averages of individual trials were utilized statistically. The strength variable of interest was the maximum torque value of all trials for the hip and knee per participant. Independent t-tests were used to assess statistical differences between groups. Alpha level was set to 0.05.

CHAPTER 4: RESULTS

Demographic characteristics of the participants are shown in tables 1 & 2. All the participants reported being right leg dominant.

Table 1- Demographics

Group	*Age (years)*	*Height (cm)*	*Mass (kg)*	*% Body Fat*
CF	28.4 ± 4.6	170.1 ± 10.1	74.6 ± 16.2	21.33 ± 7.7
RO	34.9 ± 12.5	167.8 ± 13.7	71.0 ± 16.0	27.2 ± 8.8

*denotes significant difference between groups

Table 2 – Exercise Demographics

Group	*Weekly mileage*	*Preferred Running Velocity (m/s)*	*Years of running*	*Weekly CF Participation (hrs)*	*Years of CF*	*Weekly exercise (hrs)*
CF	11.6 ± 3.6*	3.07 ± 0.4	2.86 ± 2.3	3.83 ± 0.66*	2.28 ± 0.97*	7.44 ± 2.3
RO	24.22 ± 20.7	2.80 ± 0.6	3.83 ± 5.2	0 ± 0	0 ± 0	7.00 ± 3.04

*denotes significant difference from RO group

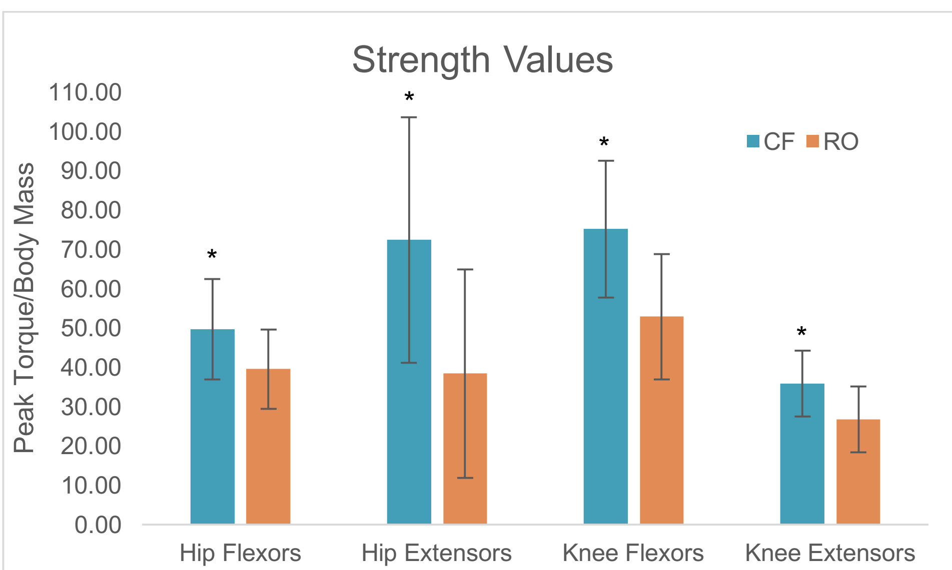

Figure 1. Strength Values - *denotes sgnificant difference between groups

There was a significant difference between the CF group and the RO group in all of the strength measures, with the CF group having greater strength; hip flexors (p-value = 0.04), hip extensors (p-value = 0.01), knee flexors (p-value >0.01), knee extensors (p-value = 0.02) (figure 1). For hip ROM, there were no significant differences between the groups, but there was a significant difference between the conditions (preferred: 42.7± 5.2 Nm; 3.5 m/s: 49.0 ± 6.2 Nm; p-value < 0.01). There were no significant differences between the groups or conditions for hip moments.

CHAPTER 5: DISCUSSION

The purpose of this study was to investigate the influence that CrossFit training has on running mechanics. We were able to accept our hypothesis that the CrossFit group had greater hip and knee flexor and extensor strength than the run-only group. We did not however, support our hypotheses that there would be differences between groups in the variables of interest relative to running mechanics.

Supporting our first hypothesis, we confirmed that runners who also participate in CrossFit exhibited greater strength than runners who do not participate in strength training. The CrossFit group demonstrated significantly greater strength in hip and knee flexion and extension. Specifically, the CrossFit group had 25% greater hip flexor strength, 88% greater hip extensor strength, 42% greater knee flexor strength, and 34% greater knee extensor strength. Although the two groups were exercising approximately the same number of hours each week, the CrossFit group devoted at least half of that time to CrossFit specific classes. Most, but not all, of these classes have a strength training component to them. This likely accounts for the differences in the strength seen between the two groups as the run-only group does not participate in any strength training.

It has been previously determined that concurrent endurance and strength training can increase endurance performance more than endurance training alone. [4] Smith et al found that participating in a CrossFit based training program for ten weeks produced aerobic fitness benefits.[26] While neither of these studies looked at strength values using isokinetic dynamometry, it can be assumed that the participants had some level of increased strength with an added strength training protocol. Running Economy

(RE) is a metric commonly used to determine endurance performance. It has been previously shown that RE is improved with strength training.[15] We did not measure RE in this study, but we did look at running velocity. Running velocity is an additional indicator of running performance, and we can use preferred running velocity as a value to compare between groups. There was no significant difference between the preferred running velocities of the two groups. Preferred velocity has been tied to general health and therefore may indicate that the general health may be similar between the two groups. As seen in our study, concurrent strength and endurance training, as seen with runners who participate in CrossFit, similarly increased strength with no detriment to endurance performance. This supports the concept that CrossFit training does not hinder preferred running velocity in the lab in the groups observed.

An ideal body composition is a primary concern of most runners. Adding heavy weight training can produce advantages in running performance, but does not produce significant negative body composition adaptations in runners. [4,16] In our study, the CrossFit group was stronger, but did not have any significant differences in body mass. In spite of the similarities in muscle mass, they were able to produce greater strength in the muscle groups measured.

Not only does strength play a role in running performance, but also running injuries. Strength may be an important risk factor in the development of prevalent injuries to runners.[11,12] Muscular imbalances may be present in the development of lower extremity injury, specifically PFPS.[11] One measure of muscular balance in the lower extremity is the hamstrings to quadriceps ratio (HQR). Ideally, a healthy ratio is around 0.6, with the hamstrings being 60% as strong as the quadriceps.[28] The findings in the strength data in this study led to a secondary analysis of the HQR for both groups. The HQR was the only piece of strength data that was not in the CrossFit group's favor. The average HQRs were as follows: CF group 0.48, RO group 0.52. Although there was not a significant difference between the HQR of the two groups, the RO HQR was closer to the ideal value of 0.60.

The assessment of the second hypothesis, that the CrossFit group would have more active hip power during running, was modified. The profile of the power waveforms for each subject varied greatly (see figure 2). This may be because power is calculated using inverse dynamics and is dependent on multiple factors. Due to these inconsistencies, it was difficult to choose the appropriate peak to subject to analysis between subjects. The profile of moment waveforms was much more consistent across participants in the two groups and thus was chosen to analyze.

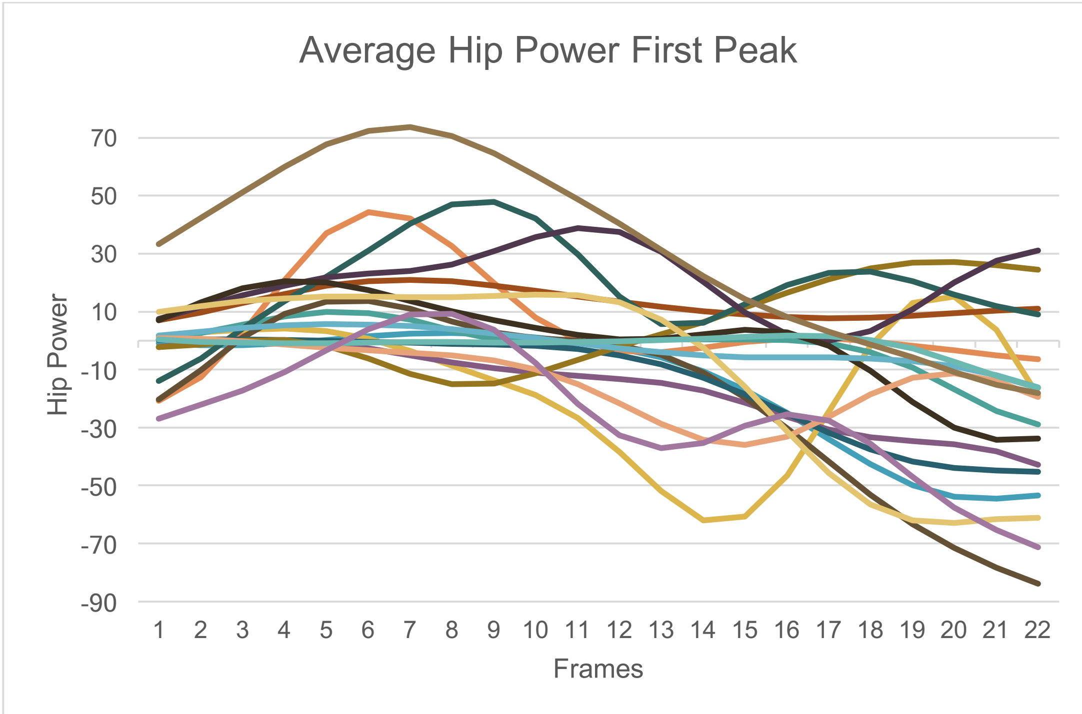

Figure 2. Average Hip Power First Peak

The first maximum hip extensor moment was selected with the intention of analyzing the weight acceptance portion of the running gait. There was no difference in peak hip moments between the two groups. This may be due to the fact that the runners in both were running at sub-maximal efforts. The running velocities may not have been large enough to elicit an appropriate difference in moments between the groups. It may be hypothesized that testing at a faster velocity would stimulate differences between the two groups.

The third hypothesis that the CrossFit group would have less hip and knee range of motion was also rejected. There were no differences in hip or knee range of motion between the two groups. However, significantly greater hip range of motion was observed with the 3.5 m/s condition for both groups. The average preferred running velocity for both groups was 83% as fast as the set velocity condition of 3.5 m/s.

Greater hip range of motion was seen with the increasing velocity of the 3.5 m/s condition. The participants responded to the perturbations in running velocity as expected.[29]

Conclusion

Although there were few differences between the two groups, the main finding of this study is that the CrossFit group was significantly stronger than the run-only group. This is of importance because it demonstrates that even though the CrossFit group was stronger, the running mechanics of the two groups were similar. Therefore, having more strength may not negatively influence running mechanics. Future studies may look into the influence of CrossFit training on running endurance as the current study did not investigate any variables of endurance performance.

REFERENCES

1. Fredericson M, Tenforde AS. Running Injuries. *Phys Med Rehabil Clin N Am*. 2016;27(1):i. doi:10.1016/S1047-9651(15)00100-X.
2. Voci A. crossfit-the-fastest-growing-affiliate-company-of-all-time @ openforum.hbs.org. https://openforum.hbs.org/challenge/understand-digital-transformation-of-business/business-model/crossfit-the-fastest-growing-affiliate-company-of-all-time. Published 2015.
3. Storen O, Helgerud J, Stoa EM, Hoff J. Maximal Strength Training Improves Running Economy in Distance Runners. *Med Sci Sport Exerc*. 2008;40(33):1087-1092. doi:10.1249/MSS.0b013e318168da2f.
4. Guglielmo LGA, Greco CC, Denadai BS. Effects of strength training on running economy. *Int J Sports Med*. 2009;30(1):27-32. doi:10.1055/s-2008-1038792.
5. 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):1125-1130. doi:10.1249/MSS.0b013e3182825aca.
6. Taylor-Haas JA, Hugentobler JA, DiCesare CA, et al. Reduced hip strength is associated with increased hip motion during running in young adult and adolescent male long-distance runners. *Int J Sports Phys Ther*. 2014;9(4):456-467. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4127508&tool=pmcentrez&rendertype=abstract.
7. Snyder KR, Earl JE, O'Connor KM, Ebersole KT. Resistance training is accompanied by increases in hip strength and changes in lower extremity biomechanics during running. *Clin Biomech*. 2009;24(1):26-34. doi:10.1016/j.clinbiomech.2008.09.009.
8. Long Z. The Hip and Athletic Performance. *CrossFit J*. 2015:1-11.
9. Robertson DG. Functions of the leg muscles during the stance phase of running . In: ; 1987.
10. Messier SP, Legault C, Schoenlank CR, Newman JJ, Martin DF, Devita P. Risk factors and mechanisms of knee injury in runners. *Med Sci Sports Exerc*. 2008;40(11):1873-1879. doi:10.1249/MSS.0b013e31817ed272.
11. Thomeé R, Augustsson J, Karlsson J. Patellofemoral pain syndrome. A review of current issues. *Sport Med*. 1999;28(4):245-262. doi:10.2165/00007256-199928040-00003.
12. Fredericson DM, Wolf C. Iliotibial Band Syndrome in Runners. *Sport Med*. 2012;35(5):451-459. doi:10.2165/00007256-200535050-00006.
13. Macmahon JM, Chaudhari AM, Andriacchi TP. BIOMECHANICAL INJURY PREDICTORS FOR MARATHON RUNNERS : STRIDING TOWARDS ILIOTIBIAL BAND SYNDROME INJURY PREVENTION John M. MacMahon, Ajit M. Chaudhari and Thomas P. Andriacchi Stanford Biomotion Laboratory, Stanford

University, Stanford, California. *18 Int Symp Biomech Sport 2000*. 2000:1998-2001.

14. Anderson T. Biomechanics and Running Economy. *Sport Med*. 1996;22(2):76-89.
15. Saunders PU, Pyne DB, Telford RD, Hawley JA. Factors affecting running economy in trained distance runners. *Sport Med*. 2004;34(7):465-485. doi:10.2165/00007256-200434070-00005.
16. Vikmoen O, Raastad T, Seynnes O, Bergstrøm K, Ellefsen S, Rønnestad BR. Effects of Heavy Strength Training on Running Performance and Determinants of Running Performance in Female Endurance Athletes. *PLoS One*. 2016;11(3):e0150799. doi:10.1371/journal.pone.0150799.
17. Resistance training for health and fitness various types of resistances. 2013.
18. Ratamess N, Alvar B, Evetoch T, et al. *Progression Models in Resistance Training for Healthy Adults*.; 2009:687-708. doi:10.1249/MSS.0b013e3181915670.
19. Hennessy L, Watson A. The Interference Effects of Training for Strength and Endruance Simultaneously. *J Strength Cond Res*. 1994;8(1):12-19.
20. Moore K, Wolf R. What is CrossFit ? *CrossFit J*. 2004;(19).
21. Submission Guidelines. http://journal.crossfit.com/submission-guidelines.tpl.
22. Emberts T, Porcari J, Doberstein S, Steffen J, Foster C. Exercise intensity and energy expenditure of a tabata workout. *J Sport Sci Med*. 2013;12(3):612-613.
23. Laursen PB, Jenkins DG. The scientific basis for high-intensity interval training: optimising training programmes and maximising performance in highly trained endurance athletes. *Sport Med*. 2002;32(1):53-73. doi:10.2165/00007256-200232010-00003.
24. Bartlett JD, Close GL, MacLaren DPM, Gregson W, Drust B, Morton JP. High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: implications for exercise adherence. *J Sports Sci*. 2011;29(6):547-553. doi:10.1080/02640414.2010.545427.
25. García-Pinillos F, Soto-Hermoso VM, Latorre-Román PA. How does high-intensity intermittent training affect recreational endurance runners? Acute and chronic adaptations: A systematic review. *J Sport Heal Sci*. 2016;(December). doi:http://dx.doi.org/10.1016/j.jshs.2016.08.010.
26. Smith MM, Sommer AJ, Starkoff BE, Devor ST. Crossfit-based high-intensity power training improves maximal aerobic fitness and body composition. *J Strength Cond Res*. 2013;27(11):3159-3172. doi:10.1519/JSC.0b013e318289e59f.
27. Novacheck T. Review paper: The biomechanics of running. *Gait Posture*. 1998;7:77-95.
28. Coombs R, Garbutt G. DEVELOPMENTS IN THE USE OF THE HAMSTRING / QUADRICEPS RATIO FOR THE ASSESSMENT OF MUSCLE BALANCE. *J*

Sport Sci Med. 2002;(1):56-62.

29. Mann R, Hagy J. Biomechanics of walking, running and sprinting. *Am J Sports Med*. 1979;8(5):345-350.

CURRICULUM VITAE

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EDUCATION

Master of Science in Kinesiology **Summer 2017**
Biomechanics Concentration Advisor: Julia Freedman Silvernail, PhD
University of Nevada, Las Vegas
Thesis: Influence of CrossFit Training on Running Mechanics
GPA 3.96

Bachelor of Science in Nutrition Sciences **May 2015**
Sports Nutrition Concentration
Kinesiology Minor
University of Nevada, Las Vegas
GPA 3.55

PROFESSIONAL EXPERIENCE

ACADEMIC
Graduate Assistant **August 2015 – July 2017**
Department of Kinesiology and Nutrition Sciences, University of Nevada Las Vegas
- Responsible for teaching a 300-level laboratory course
- Develop and update curriculum for Biomechanics Laboratory course

Research Assistant **August 2015 – July 2017**
Biomechanics Laboratory, Sports Injury Research Center, University of Nevada Las Vegas
- Assist with protocol creation, IRB submission, participant recruitment, data collection, and data analysis

COURSES TAUGHT
Department of Kinesiology and Nutrition Sciences, University of Nevada Las Vegas
Graduate Student Instructor
- Kinesiology 346L: Biomechanics Laboratory **August 2015 – July 2017**

CONFERENCE PRESENTATIONS

POSTER PRESENTATIONS

Bradley SD, Wiegand K, Miller KN, Dufek J, Freedman Silvernail J. "Correlation Between Ankle Power and Ankle Strength in Collegiate Cross Country Runners." *American College of Sports Medicine.* Newport Beach, CA. October 2016.

Mangahas A, Russo M, Wiegand K, **Bradley SD** Freedman Silvernail J. "Efficacy of Adhesive Ankle Tape on Restricting Balance Before and After Exercise." *UNLV Office of Undergraduate Research INBRE Poster Presentations.* Las Vegas, NV. August 2016.

Russo M, Mangahas A, Wiegand K, **Bradley SD**, Freedman Silvernail J. "Efficacy of Adhesive Ankle Tape on Restricting Ankle Range of Motion Before and After Exercise." *UNLV Office of Undergraduate Research INBRE Poster Presentations.* Las Vegas, NV. August 2016.

Cardona-Paul S, Wiegand K**, Bradley SD**, Freedman Silvernail J. "The Effect of Footwear and Surface on Walking Velocity and Stride Frequency." *UNLV Office of Undergraduate Research INBRE Poster Presentations.* Las Vegas, NV. August 2016.

Ollano VE, Wiegand K, **Bradley SD**, Freedman Silvernail J, Radzak KN. "Influence of Previous Hamstring Strain Injury on Isokinetic Strength Measures." *Far West Athletic Trainers' Association.* Kailua-Kona, HI. July 2016.

Radzak KN, Wiegand K, **Bradley SD**, Ollano V, Freedman Silvernail J. "Running Gait Biomechanics of Female Collegiate Track Athletes with Previous Hamstring Strain: An Initial Investigation." *National Athletic Trainers' Association Annual Meeting and Clinical Symposia.* Baltimore, MD. June 2016.

Bradley SD, Wiegand K, Miller KN, Dufek J, Freedman Silvernail J. "Quadriceps and Hamstring Strength: A Relationship to Number of Competitive Years on the Cross-Country Team." *American College of Sports Medicine.* Boston, MA. May 2016.

Bradley SD, Wiegand K, Miller KN, Dufek J, Freedman Silvernail J. "Quadriceps and Hamstring Strength: A Relationship to Number of Competitive Years on the Cross-Country Team." *UNLV Interdisciplinary Research & Scholarship Day.* Las Vegas, NV. April 2016.

Ollano V, Wiegand K, **Bradley SD**, Freedman Silvernail J, Radzak K. "Influence of Previous Hamstring Injury on Isokinetic Strength Measures." *Spring Undergraduate Research Forum.* Las Vegas, NV. March 2016.

Bradley SD, Wiegand K, Miller KN, Dufek J, Freedman Silvernail J. "Quadriceps and Hamstring Strength: A Relationship to Number of Competitive Years on the Cross-Country Team." *American College of Sports Medicine.* Newport Beach, CA. October 2015.

AWARDS

UNLV Alumni Graduate Scholarship — August 2016

- Academic Scholarship, Amount: $2500

Graduate and Professional Student Association Sponsorship — May 2016

- Conference Travel Award, Amount: $700

Kinesiology Department Student Travel Award — May 2016

- Conference Travel Award, Amount: $500