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The Effects of Hip Tightness on Running Mechanics and the FMS Deep Squat in DIII Track & Field Runners

Sam Rosario, Augsburg University

Abstract

Running requires rapid hip movements. Increasing running speeds place increased loads on hip flexor and extensor muscles (Schache et al., 2011). It is unclear whether Division III track and field athletes with self-reported hip tightness would present altered sagittal plane hip mechanics while running and functional limitations when performing the Functional Movement Screen (FMS) deep squat. Objective: To investigate the relationship between hip tightness, as measured by the Functional Movement Screen (FMS) deep squat (DS), and running mechanics, as measured by the peak flexion and extension angles in Division III Track & Field athletes. Methods: Ten subjects completed the FMS DS and were filmed from both sides while running on a treadmill at 3 different speeds. Reflective markers were placed on the greater trochanter and lateral epicondyle of the femur. Absolute peak flexion and extension angles were obtained using Dartfish software. Results: DS was not a significant predictor of running mechanics. There were moderate positive correlations between peak hip flexion angles and DS. DS scores of 1 were associated with increased hip flexion ROM and decreased extension, especially on the left side. Runners who reported hip tightness had higher average DS scores. Conclusion: Self-reported hip tightness group showed earlier toe-off and increased flexion ROM during swing phase. Differences between groups are greater in hip extension. Findings also suggest asymmetries in the non-affected side for the tightness group. Future studies could investigate these changes in running mechanics in different planes of motion and injury prevalence in runners with self-reported hip tightness.

Introduction

Running is an activity that requires rapid hip movements. The basic walking gait cycle is marked by the initial contact (IC) of one foot to the ground, loading response (LR), midstance (MS), terminal stance (TS), toe off (TO), then the start of the swing phase at the initial swing (IS), midswing (MS), and terminal swing (TS) marking the end of the first division before IC of the opposing leg’s gait cycle (Novacheck, 1997), as shown in Figure 1. During the swing phase, the hip flexors accelerate the leg forward and during the stance phase, the hip extensors are engaged. According to Novacheck (1997), with proper running mechanics, it is understood that running gait
changes with an increase or decrease in speed and greater involvement of specific muscles with change in speed and intensity. Progression from a stationary position to maximum speed affects contact of the foot to the ground, where the contact moves from the hindfoot toward the forefoot while striking, if progressing from a walk to a run, especially while sprinting. Also, with an increase in speed, time spent in swing increases, stance time decreases, double float\textsuperscript{1} increases, and cycle time shortens.

![Figure 1. Basic running gait cycle](image)

Assessing running mechanics

Souza et al. (2016) suggests that running biomechanics are one of the best methods of testing injury prevention and injury development in runners. In the article, Souza and colleagues sought to provide a methodology for the purpose of analyzing running biomechanics that could have adverse effects on running performance and risk of injury. For starters, having a set pace for a “long run” is preferred for adequate acclimation to the pace and setting while using a treadmill. Having a camera with greater than 60 FPS is preferred. Viewpoints using video-based analysis should have a minimum of 2 orthogonal views, lateral and posterior, and the viewpoint should be reproducible. Markers should be something like bright colored tape, placed onto or as close to the body as possible, such as on compression clothing. Warming up for 6-10 minutes is recommended prior to the beginning of the test stage. This warm up should consist of an initial 6 minute pace at a target speed for proper acclimation. Particular stages within the running cycle should be used for evaluation for more specific focus and precise data collection. For example, the display of the initial contact phase and loading response requires differentiation between video frames while these phases quickly occur. Although there are portions of the running phases that are clear to determine such as the difference between forefoot strike and rear foot strike, being able to accurately determine each phase is essential to providing a reliable analysis.

Hip mechanics at different running speeds

Literature involving biomechanics and the muscles involved in speed increases tend to agree on the importance of muscles in the hip. Increased hip muscle torque and work with increasing speed was represented in Schache (2011) and colleagues study with participants involving 5 male and 3 females (mean age: 27.0 +/- 7.8 yrs) in running based sports, such as track and field and Australian rules football.

\textsuperscript{1} Double float occurs during running gait cycles where there is a period of time that there is no contact of either foot with the ground (Novacheck, 1997).
As speeds increased from 3.50 to 8.95 m/s (7.83 to 20.02 mph, respectively), the hip extensors, hip flexors, and hip abductors contributed the most out of other muscle groups, as measured by three-dimensional kinematics and ground reaction forces. Participants ran on a 110-m synthetic running track (Schache 2011). There were moderate associations that occurred between running speed and the work done at the hip joint during terminal stance (R2 = 0.56) and midswing (R2 = 0.74) (2011). Investigators found the hip extensors contribute most during the second half of swing and the first half of stance, the hip flexors contribute the most after toe off, and the hip abductors, as well as ankle plantarflexors and knee extensors contribute during stance phase generation. The first half of swing was found to have generated an extension torque, knee flexion torque is generated at the first half of swing, and at the last half of swing a knee flexor torque is achieved. During terminal swing there was a substantial increase in work at the hip because of the speed change found by Schache and colleagues of 7.35-fold from 3.50 to 8.95 m*s^-1 (2011). When the running speed changed to 3.50 m*s^-1 the torque magnitude changed with an increase in absolute magnitude by 3.94-fold, 5.02 m*s^-1 4.59-fold, 6.97 m*s^-1 5.94-fold, and 8.95 m*s^-1 3.32-fold (Schache et al., 2011). Despite increased running speed, the peak extension torque and work done at the knee joint during stance were unaffected. However, work done at the ankle joint during stance increased significantly from 3.50-5.02 m/s, but plateaus beyond 5.02 m/s.

Improving running mechanics is an important step to make towards injury prevention, although other factors come into play for progressive improvement. It is unclear whether increased running speed has a positive impact on the amount of energy absorbed upon foot strike while running. In this study by Heiderscheit, 45 healthy adult volunteers (mean age: 32.7 +/- 15.5 yrs) familiar with treadmill running who reported running a minimum of 15 miles/week for at least 3 months prior to the study were included for participation. The participants ran at their preferred speed (~6.5 mph), and proceeded at +/-5% and +/-10% their preferred speed pace by an audible metronome to calculate step length, stance duration, vertical excursion of the center of mass (COM), foot inclination angle at initial contact, and the horizontal distance between the COM and heel at initial contact. Their results found that as step rate increase, step length was shorter with less COM vertical excursion, the impact of transient occurrence was found to decrease, and ~20% and ~34% less energy was absorbed at the knee when preferred step rate increased 5% and 10%, respectively (Heiderscheit, 2011). Heiderscheit also reported a decreased in speed from the preferred pace produced a similar increase in energy absorbed at the knee (2011). In conclusion, there is a significant decrease in the energy absorbed at the hip and knee with a 10% increase in pace beyond preferred running speed.

When gait changes from walking to running, hip range of motion (ROM) can affect the stride length and pelvic movements, showing that different strategies are used based on
how much hip extension is available. Franz et al. (2009) found that, in 73 recreational runners (34 female, 39 male, mean age: 34 years +/- 11yrs) who reported running at least 15 miles per week. The participants were tested at self-selected speeds that with an average range from 1.28 (+/- 0.17) m/s to 3.17 (+/- 0.4) m/s. Hip extension magnitude was only 1% higher in running compared to walking, which may be caused by a difference in hip extension flexibility in the participants. This limitation may cause compensatory movement with more anterior pelvic tilt with stride length increase. A suggested method for improvement in anterior pelvic tilt compensation is with flexibility training to distribute tissue demands while running (Franz et al., 2009). It is not known whether hip extension range of motion would affect running biomechanics in Division III track and field athletes.

### Hip Biomechanics and Range of Motion

Decreased hip ROM can be attributed to many different factors, some not under the control of the affected individual, such as anatomical constraints caused by changes in bone shape at the hip socket or the femoral head and neck. The presence of anatomical differences may lead to compensatory strategies at other joints. For example, adults diagnosed with cam or combined femoroacetabular impingement (FAI) can squat to a depth comparable with the controls, regardless of whether they are constrained or not constrained. However, under the constrained conditions, Diamond et al. reported that FAI patients had greater ipsilateral pelvic rise, maintaining greater hip adduction (Diamond et al., 2016). It is possible that such compensatory movements would be found in other populations with restricted hip ROM, but without a diagnosis of hip FAI.

Altered hip mechanics is a risk factor for injury, as can be seen in individuals suffering from patellofemoral pain (PFP). In a convenience sample of 30 participants (13 males, 17 females, mean age: 34.0 +/- 13.1 yrs), subjects consented to participate that met selected criteria for generalized anterior, anterior/medial knee or retropatellar pain for 1 month or longer due to prolonged sitting, ascending/descending stairs, sports activity, and/or running. In conclusion, significant differences were found between controls and the PFP subjects on both right and left sides. Mean hip extension resulted in 6.8 degrees on both sides for controls, -4.0 L and -4.3 degrees R for mean hip extension, and a mean difference of 10.8 L and 11.1 degrees R. They did not discover significant differences in hip IR or ER ROM, or total rotation between controls and PFP, or within individual groups (Roach 2014).

The importance of a wide ROM is exemplified through the improved performance in those suffering from low ROM capabilities. The participants included in Short’s study consisted of 5 elite male athletes (19-27 years old, mean age: 21.6 years +/-2.87) that underwent manual therapy programs to progress the athletes from a state of pain from diagnosed issues unique to each individual. Short reported that they showed significant improvements in pain reduction, which then allowed
for players to participate more in game (Short 2017). Adding interventions through exercise may assist with lasting ROM development, but may change movement patterns in the individual, but assisting with force distribution in the body (Short et al., 2017).

In addition to hip ROM, hip muscle strength can also affect hip biomechanics. Taylor-Hass and colleagues (2014) studied cohort of 33 male high school and collegiate cross country runners (mean age: 18.3 +/- 1.9yrs) who reported running at least 20 km per week. The study measured running kinematics and peak concentric isokinetic hip abductor and extensor strength at 120 deg/sec using and isokinetic dynamometer within a laboratory setting. Runners with greater hip extensor isokinetic torques had significantly less hip transverse plane ROM (r=-0.39, p=0.012) and runners with greater hip abductor isokinetic torques had significantly less frontal plane hip ROM (r=-0.46, p=0.008). There were no significant relationships between hip isokinetic torques and knee ROM in any of the three planes. Results suggest that the strength of the hip is not linked to frontal or transverse plane knee kinematics, but do indicate that hip abductor and hip extensor weakness is correlated to greater hip adduction during the stance phase of running and hip internal rotation. These movements could indicate compensations at the pelvis and hip and could increase the risk for injury. It is unclear whether Division III track and field athletes with self-reported hip tightness and reduced sagittal plane hip ROM would present functional limitations when performing lower extremity based movement assessments in the Functional Movement Screen (FMS).

**Functional Movement Screen**

The functional movement screen is used to identify imbalances and asymmetries in an individual’s mobility and stability by performing 7 movement patterns: deep squat, hurdle step, in-line lunge, active straight-leg raise, trunk stability push up, rotary stability and shoulder mobility. In the literature reviewed, results suggest that the deep squat (DS) may be a meaningful predictor or injury risk and hip kinematics. In a study done by Kiesel (2009), 62 professional football players participated in an intervention program for 7 weeks during the off-season based off of individual performance on the FMS. Kiesel and colleagues made a significant finding that a score of one on the deep squat put players at five times higher risk for failure, while other factors did not prove to be reliable predictors (2009). Kiesel explains that the FMS DS was an effective measure of mobility and instability because it encapsulates many different parts of the body while attempting the movement, which can assist as an indicator that an individual may be at much higher risk for injury if they perform inadequately, and the movement is the most relevant to the sport of professional football. Similarly, According to Hotta (2015), the deep squat (DS) and active straight leg raise (ASLR) were best in predicting incidence of running injuries instead of predicting injury based off all 7 movement patterns. This would suggest that focusing more on a hip involved movement such as the DS will provide a
better focus for analyzing runners than the FMS as a whole.

Performance on the FMS DS can be attributed to various factors when scoring. For example, Cook et al. (2015) suggests that scores below a three may be associated with limits in dorsiflexion, extension of the thoracic spine, or hip flexion. Normative values for the deep squat (DS) for 45 healthy adult runners, ages 22 to 54 years (24 male, 21 female, mean age: 34.8 +/- 7.7yrs), was 2.0 +/- 0.47 for males and 1.7 +/- 0.48 for females (Agresta et al., 2014). Proper execution of the DS requires adequate ROM and flexibility at hip, shoulder, and thoracic spine, as well as adequate closed chain kinetic dorsiflexion, and stability of the core (Cook et al., 2015).

Other studies in the literature reviewed also highlight the relationship between DS and hip ROM. Butler et al. (2010) compared 28 participants (9 male, 19 female, age range: 18-30) that exercised recreationally or were athletes were divided into 3 groups dependent on their ability to perform the FMS DS test. The group numbers of one through three were representative of their FMS score on the DS. Group one consisted of 4 males and 5 females, group two included 2 males and 7 females, and group three had 3 males and 7 females. Groups 2 and 3 exhibited greater peak hip flexion, greater hip flexion excursion, and greater peak hip extension moments than group 1. There were no significant differences between groups 2 and 3 regarding peak joint angles, joint angle excursion and peak joint moments in the ankle, knee and hip. This study concluded that FMS DS scores have a significant effect on changes in lower extremity performance (Butler, 2010). Similarly, Jenkins et al. (2017) investigated the correlations between passive hip ROM and FMS scores, in participants from several different DII sports including 22 baseball (mean age: 20.0yrs), 10 softball (mean age: 20.1yrs), and 12 cross country (10 male, mean age: 20.7yrs, 2 female, mean age: 19.5yrs). Passive hip flexion on the left side was moderately positively and significantly correlated to DS (r=0.342), right hurdle step (HS) (r=0.301), left in line lunge (ILL) (r=0.422), and right ILL (0.351). Passive hip flexion on the right side was moderately positively and significantly correlated to trunk stability push up (TSPU) (r=0.464). Passive hip flexion on the left side was moderately positively and significantly correlated to the rotary stability left (RSL) (r=0.304). Passive hip extension on the left side was moderately positively and significantly correlated to left active straight leg raise (ASLR) (r=0.427) and right ASLR (r=0.503). There was a moderately positively significant correlation between passive hip extension on the right side to left ASLR (r=0.321). Passive internal rotation on the left side was moderately positively and significantly correlated to left ASLR (r=0.515) and right ASLR (r=0.507). Passive hip internal rotation on the right side was moderately positively and significantly correlated to left shoulder mobility (SM) (r=0.317), left ASLR (r=0.387), and right ASLR (r=0.399). Passive external rotation for the left side was moderately positively significantly correlated to left SML (r=0.480), right SM (r=0.372), left ASLR (r=0.484), and right ASLR (r=0.504). Passive external rotation on
the right side was moderately positively and significantly correlated to left ASLR (r=0.361), and right ASLR (r=0.354). All correlations found from this study were weak to moderate. The strongest correlation was between the FMS active straight leg raise L/R because it is a one-joint exercise employing only the hip joint, but it did not correlate with hip flexion. Another interesting correlation was between the shoulder mobility L/R and external rotation L/R, which provides evidence that hip rotation could impact shoulder mobility. Also noted here was the indirect connection of the FMS and injury risk when considering the implications of ROM to injury, and the usefulness of ROM testing as a tool for assessing weak links in an athlete’s body for injury preventative measures. The FMS results were in agreement with Butler, which was that increased hip ROM or joint mobility generates a higher probability of improving a DS score from a 1 to a 2. The effects of different levels of performance on the FMS deep squat (DS) in DIII Track & Field athletes and their connection to running mechanics at this point is unclear.

Gap in Literature and statement of purpose

This study aims to investigate NCAA DIII Augsburg University Track & Field runners. To our knowledge, the effects of hip tightness on running mechanics and the FMS deep squat has not been studied and can provide insight for future studies related to hip tightness and the FMS, as well as possible future interventions for injury prevention and performance improvement. It is hypothesized that reduced hip range of motion, as measured by the FMS DS, will result in altered running mechanics, as measured by the peak flexion and extension angles. It is hypothesized that self-reported hip tightness has a negative effect on performance in the deep squat and running mechanics in this group. Finally, it is also unclear whether FMS deep squat scores will be lower than the normative values established in the literature for Division III Track & Field runners with hip tightness.

Methods

Subjects

The subjects of this study consisted of 8 men and 2 women currently enrolled in the Augsburg University Track and Field team. They ranged in age from 18 to 22 years of age (mean age = 20.5 yrs +/- 1.75) and were recruited by the investigator via email and directly via text message. Exclusion criteria were lower extremity injuries within the last 6 months or incomplete rehabilitation without medical clearance to return to their respective sport.

Procedure

Participants attended a 45 minute visit to Kennedy Center Physiology Laboratory. Upon arrival, subjects consented to participating in this study. Following the consent process, participants completed FMS testing, which included: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push up, and rotary stability. A level 1 FMS certified tester performed all of the FMS assessments
and scoring, according to the FMS Level 1 manual criteria (Cook et al., 2015). The FMS is scored on a zero to three scale. Zero signifies pain while performing the movement, a one signifies not completing the movement, a two is given if the movement is completed but with some compensation, and a three signifies completing the movement optimally. The FMS deep squat (DS) is the primary focus for this study as it is a movement that places the hips at extreme flexion active range of motion, while maintaining the upper body at a stable position to avoid compensation. The participant being tested on the movement was instructed to stand up straight with feet shoulder width apart, straight forward without their toes pointing outward laterally. The participant was handed the dowel and was to place it above their head with both hands, bringing it down to the top of their head with elbows and shoulders flexed at ninety degrees, then pressing it above their head. While performing the deep squat the participant should keep their torso and the dowel upright while keeping their heels in contact with the floor while descending into a squat as deep as they can. A score of one was given when the tibia and torso were not parallel, the femur was not below horizontal, knees collapsed medially into valgus position, or the dowel was not aligned over feet. A score of two was given if the torso was parallel with the tibia or toward vertical, the femur was below horizontal, no knee valgus was seen, and the dowel was aligned over their feet.

Following the FMS testing, passive hip ROM was measured for purposes of another research project. Finally, participants changed into black compression clothes for video analysis. Reflective markers were placed at the greater trochanter, lateral epicondyle of femur, and the lateral malleolus to determine absolute hip extension and flexion angles.

Participants completed a five minute dynamic warm up of their choice prior to completing the running protocol on a treadmill. Runners’ lower extremities were recorded bilaterally from a sagittal plane view (side view) while running at three different speeds. Two digital video cameras (Panasonic HC-V770 and HC-VX870) at 60Hz on a 1/250 shutter speed were used. The running protocol differed for long distance runners (slower) and sprinters (faster) to accommodate for each individual's ability and comfort level with running at the particular speeds. Participants were allowed to choose if they wanted to complete a slower or faster protocol. One male long distance runner chose to run at the faster pace, and two female sprinters chose to run at the slower pace; however one of the two later felt comfortable enough to complete the maximum speed (12 mph), thus completing four trials instead of three. Long distance runners started at six mph for one minute, then eight mph for thirty seconds, and ten mph for fifteen seconds. Sprinters started at eight mph, then ten mph for thirty seconds, and finally twelve mph for ten seconds. The videos were analyzed using
Dartfish Software, where the absolute hip flexion angles were measured using the horizontal line as a reference to form an angle with the line formed by the marker on the greater trochanter and the one on the lateral epicondyle of the femur, as seen on Figure 1.

![Figure 1. Hip flexion absolute angle](image1)

For hip extension the horizontal line was used as a reference to form an angle with the same femoral markers, as seen on Figure 2.

![Figure 2. Hip extension absolute angle](image2)

This process was completed for 10 consecutive strides/cycles, ensuring no video clips had blurred markers. In the event a marker was not clearly visible, the following frame was used in the analysis. The data were analyzed using Microsoft Excel and R Statistical Software and compared to normative data for runners. Paired t-tests compared average peak hip flexion and extension between low and top speeds, as well as between right and left sides. Single and multiple regression models were used to compare running mechanics and DS.

Results

The participants in this study consisted of 8 males and 2 females, 6 of which were sprinters and 4 were long distance runners. Of the 10 participants, 1 reported knee pain on the right and left side and 3 others had self-reported hip tightness. The mean age of the participants was 20.5 years (SD = 1.75). FMS scores are summarized in Table 7, Appendix A.

Peak flexion angle comparison between low to top speed

There were no significant right and left differences in hip flexion angles at the low speed (p=0.146), or at top speed (p=0.136). The mean peak hip flexion angle at the low speed for the right side was 60.57 degrees (SD = 7.68) and for the left side was 65.12 degrees (SD = 11.76). The mean peak hip flexion angle at the top speed for the right side was 49.29 degrees (SD = 10.04) and for the left side was 54.22 degrees (SD = 13.18). Overall, there was a significant difference in right peak hip flexion angles between low and top speed, with the top speed having significantly lower hip flexion by
22.8% (p<0.001). There was a significant overall difference in left peak flexion from low to high speed of 20%. All peak flexion angles at low and top speeds are summarized in table 1.

Peak extension angle comparison between low to top speed

As was found with flexion, there were no significant right and left differences in peak hip extension angles at the low speed (r=0.143), or at the top speed (r=0.743). Overall, the average right peak extension angle at the low speed was 69.85 degrees (SD = 7.53) and for the left side was 64.26 degrees (SD = 10.34). The average right peak extension angle at the top speed was 63.39 degrees (SD = 8.94) and for the left side was 62.39 degrees (SD = 12.76). There was a significant 10.2% decrease in right hip extension from low to top speed (p<0.005). Peak angles at low and top speeds are summarized in Table 1.

<table>
<thead>
<tr>
<th>DS scores, hip tightness, and running mechanics</th>
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</thead>
<tbody>
<tr>
<td>DS as a predictor of peak hip flexion</td>
</tr>
<tr>
<td>DS was weakly positively correlated to peak right hip flexion at the low speed (r=0.293, p=0.41). DS scores explained only 8% of the variability in right hip flexion at low speed. When adding hip tightness to the regression model between DS and R peak hip flexion at low speed, the model was still not significant (p=0.63) and explained 12% of the variability of right peak hip flexion at low speed. Overall, there were weak correlations between the DS and peak right hip flexion angles at top speed (r=0.341, p=0.33) and DS scores only explained 11% of the variability of right hip peak flexion at top speed. When adding hip tightness to the regression model between DS and R peak hip flexion at top speed, the model was still not significant (p=0.57) and explained 14% of the variability of right hip peak flexion at top speed.</td>
</tr>
<tr>
<td>On the left side, DS was moderately positively correlated to left peak hip flexion at low speed (r=0.56, p=0.09) and explained 31% of the variability in peak left hip flexion. When adding tightness to the left flexion model at low speed, DS was still not a significant predictor (p=0.12) and the model was not significant (p=0.26). It explained 31% of the variability in peak left hip flexion. DS was moderately positively correlated to left peak hip flexion at top speed (r=0.59, p=0.07) and explained 35% of the variability in peak left hip flexion. As shown in Figure 3. When adding tightness to the left flexion model at top speed, DS was still not a significant predictor (p=0.07) and the model was not significant (p=0.15). It explained 41% of the variability in peak left hip flexion. Overall, as hip flexion ROM increased (as marked by lower absolute peak flexion angles), DS scores tended to decrease. The decrease was more pronounced on the left side.</td>
</tr>
</tbody>
</table>
DS as a predictor of peak hip extension

At low speed, there was a weak positive correlation between peak right hip extension angles and DS ($r=0.21$, $p=0.56$) and only explained 4% of the variability in peak right hip extension angles, as shown in Figure 4. When adding hip tightness as a predictor, the model explained 25% of the variability in right hip extension at low speed, but was not significant ($p=0.35$). Tightness was not a significant predictor ($p=0.2$). At top speed, there was no correlation between DS and peak right extension angles ($r=0.04$, $0.9$). When adding hip tightness as a predictor, the model explained 17% of the variability in right hip extension at top speed, but was not significant ($p=0.51$). Tightness was not a significant predictor ($p=0.27$). At top speed, as right hip extension ROM increased, DS scores decreased.

At low speed, there was a weak negative correlation between peak left hip extension angles and DS ($r=-0.21$, $p=0.55$) and only explained 4% of the variability in peak right hip extension angles. When adding hip tightness as a predictor, the model explained 25% of the variability in left hip extension at low speed, but was not significant ($p=0.36$). Tightness was not a significant predictor ($p=0.21$). DS was not a significant predictor of left hip extension at top speed either ($r = -0.14$, $p=0.68$) and only explained 2% of variability. When adding hip tightness as a predictor, the model explained 35% of the variability in left hip extension at top speed. Tightness was not a significant predictor ($p=0.09$). For the left side, as hip extension ROM increased (as marked by lower absolute peak flexion angles), DS scores increased.
Figure 5. Scatterplot of Left peak hip extension at top speed as modeled by DS

Self-reported hip tightness group vs. normal group: hip flexion at different speeds

The mean peak hip flexion angle for the right side at the low speed for individuals with self-reported hip tightness was 58.9 degrees (SD = 1.86) and 61.28 degrees (SD = 9.24) for individuals with normal hips. Mean right peak hip flexion at low speed was 3.89% higher for the normal group. At the top speed, mean right peak hip flexion angle was 47.3 degrees (SD = 6.96) for individuals with self-reported hip tightness and 50.13 degrees (SD = 11.51). Mean right peak hip flexion at top speed was 5.59% higher for the normal group.

For the left side, the mean peak hip flexion angle at the low speed for individuals with self-reported hip tightness was 66.91 degrees (SD = 16.31) and 64.35 degrees (SD = 10.79) for individuals with normal hips. Mean left peak hip flexion at low speed was 3.97% lower for the normal group. At the top speed, mean left peak hip flexion angle was 51.02 degrees (SD = 3.83) for individuals with self-reported hip tightness and 55.60 degrees (SD = 15.76). Mean left peak hip flexion at top speed was 8.24% higher for the normal group.

As speeds increased, right peak hip extension angles for individuals with self-reported hip tightness decreased by 19.6% and by 18.2% for individuals in the normal group, indicating greater hip flexion ROM during swing phase. On the left side, peak hip flexion angles for individuals with self-reported hip tightness decreased by 23.7% and by 13.6% for individuals in the normal group, indicating greater ROM during the swing phase for both groups with an increase in speed.

Self-reported hip tightness group vs. normal group: hip extension at different speeds

The mean peak hip extension angles for the right side at the low speed for individuals with self-reported hip tightness was 75.1 degrees (SD=5.25), and at the top speed was 68.8 degrees (SD=5.41). The peak hip extension angle for the right side at the low speed was 8.39% larger for the tightness group than when running at the top speed.

The mean peak hip extension angles for the left side at the low speed for individuals with self-reported hip tightness was 70.65 degrees (SD=8.48), and at the top speed was 72.69 degrees (SD=3.44). The peak hip extension angle for the left side at the low speed was 2.9% less for the tightness group than when running at the top speed.

As speeds increased, right peak hip extension angles for individuals with self-reported hip tightness decreased by 8.4% and by 9.6% for individuals in the normal group, indicating greater hip extension ROM before toeing-off. On the left side, peak hip extension angles for individuals with self-reported hip tightness increased by 2.9% and decreased by 5.8% for individuals in the normal group, indicating lower ROM and earlier toe-off just for the tightness group.
Running mechanics comparison between different DS scores

Research conducted by Butler et al. (2010) separated participants according to their scores on the deep squat. Utilizing similar methodology, we found individuals who scored a 1 in the DS had 28% lower left peak hip flexion angles at the low speed than group 2, 26.9% lower peak flexion angles than those who scored a 3, and 28.5% lower peak flexion angles compared to the 2 and 3 averaged flexion score. Individuals who scored a 1 were found to have 15.8% lower right peak hip flexion angles at the low speed than those who scored a 2, and 11.7% lower flexion angles compared to the 2 and 3 averaged score. Individuals who scored a 1 had 41.5% lower left peak hip flexion angles at the top speed than those who scored a 2, 37.1% lower flexion angles than those who scored a 3, and 39.4% lower flexion angles compared to the 2 and 3 averaged score. Results are summarized in Table 2 and 3.

<table>
<thead>
<tr>
<th>DS score</th>
<th>(L) P. Fl. Low</th>
<th>(L) P. Fl. Top</th>
<th>(R) P. Fl. Low</th>
<th>(R) P. Fl. Top</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53.16</td>
<td>39.29</td>
<td>49.73</td>
<td>34.86</td>
</tr>
<tr>
<td>2</td>
<td>63.16</td>
<td>52.51</td>
<td>69.10</td>
<td>59.59</td>
</tr>
<tr>
<td>3</td>
<td>57.25</td>
<td>46.79</td>
<td>68.03</td>
<td>55.41</td>
</tr>
</tbody>
</table>

Note: DS = Deep squat, (L) = left, (R) = right, P = peak, Fl = flexion

Table 2: Mean peak flexion angles at low and high speeds grouped by DS scores.

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<thead>
<tr>
<th>Hip flexion</th>
<th>Low</th>
<th>Top</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>-28.5%</td>
<td>-39.4%</td>
</tr>
<tr>
<td>Right</td>
<td>-11.7%</td>
<td>-20.6%</td>
</tr>
</tbody>
</table>

Note: Low = low speed, Top = top speed. Percent differences were comparing the DS score of 1 to an average score in that category (e.g. Hip flexion left side at low speed) to those who scored a 2 and those who scored a 3.

Table 3: Percent differences of deep squat scores of 1 versus an averaged DS score of 2 and 3.

<table>
<thead>
<tr>
<th>DS score</th>
<th>(L) P. Ext. Low</th>
<th>(L) P. Ext. Top</th>
<th>(R) P. Ext. Low</th>
<th>(R) P. Ext. Top</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69.83</td>
<td>65.10</td>
<td>71.78</td>
<td>69.73</td>
</tr>
<tr>
<td>2</td>
<td>68.73</td>
<td>62.13</td>
<td>65.58</td>
<td>59.58</td>
</tr>
<tr>
<td>3</td>
<td>77.71</td>
<td>68.83</td>
<td>60.87</td>
<td>67.34</td>
</tr>
</tbody>
</table>

Note: DS = deep squat, (L) = left, (R) = right, P = peak, Ext = extension

For extension results we also found 11.6% lower right peak hip extension angles on the right side from individuals who scored a 1 to those who scored a 2, and 10.1% lower extension angles than those who scored a 3. Individuals who scored a 1 had 9.38% lower right peak hip extension angles at top speed than those who scored a 2. Individuals who scored a 1 had 14.2% greater left hip extension angles at the low speed than those who scored a 2, 15.2% greater extension angles compared to those who scored a 3, and 14.7% greater extension angles compared to the 2 and 3 averaged extension score. Results are summarized in Table 4 and 5.

<table>
<thead>
<tr>
<th>DS score</th>
<th>(L) P. Ext. Low</th>
<th>(L) P. Ext. Top</th>
<th>(R) P. Ext. Low</th>
<th>(R) P. Ext. Top</th>
</tr>
</thead>
<tbody>
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</tr>
</tbody>
</table>

Note: DS = deep squat, (L) = left, (R) = right, P = peak, Ext = extension

Table 4: Mean peak extension angles at low and high speeds grouped by DS scores.
Table 5: Percent differences of deep squat scores of 1 versus an averaged DS score of 2 and 3.

DS scores, hip tightness, and normative values

Overall, there was a very low correlation between self-reported hip tightness and DS scores ($r = 0.12$). Normative values related to the deep squat (DS) in Agresta et al.‘s study for males was 2.0 (SD=0.47) (percent difference= 0%) and for females 1.7 (SD=0.48) (percent difference=1%) (2014). The participants in our study are in agreement with Agresta. The mean DS score for males was 2.0 (SD=1), and the mean DS score for females was 1.5 (SD=0.5). All deep squat scores, SD and percent differences from normative values are summarized in table 6.

Contradicting the initial hypothesis that individuals with self-reported hip tightness would score lower in the DS, individuals with self-reported hip tightness scored on average 2 (SD = 0), while normal individuals scored on average 1.86 (SD = 0.69). The normal group mean score was 7.14% lower than the self-reported hip tightness group and 0.54% greater than the normative value for males.

Table 6: Mean deep squat (DS) scores and standard deviation (SD) as compared to normative scores by Agresta et al. (2014).

<table>
<thead>
<tr>
<th></th>
<th>DS mean</th>
<th>SD</th>
<th>% dif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normative</td>
<td>1.85</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>Self-reported tight</td>
<td>2.0</td>
<td>0</td>
<td>7.5%</td>
</tr>
<tr>
<td>Normal group</td>
<td>1.86</td>
<td>0.68</td>
<td>0.54%</td>
</tr>
</tbody>
</table>

Note: DS = Deep Squat, SD = Standard Deviation, % dif. = percent difference

Discussion

This study hypothesized that reduced hip range of motion, as measured by the FMS DS, would result in altered running mechanics, as measured by the peak flexion and extension angles, and that self-reported hip tightness would have an effect on performance in the DS and running mechanics in this group. Finally, it is also hypothesized that FMS DS scores would be lower than the normative values established in the literature for Division III Track & Field runners with hip tightness.

Self-reported hip tightness effect on DS performance

Overall, there was a low correlation ($r=0.12$) between self-reported hip tightness and DS scores. When comparing individuals who scored 1 on the FMS DS to athletes who scored 2 or 3, mean right peak flexion at the top speed was lower by 10 degrees for athletes that scored a 1 versus athletes who scored a 2 or 3 (39.29 degrees to 49.29 degrees, respectively), and mean left peak flexion at the top speed being roughly 20 degrees less than the average for athletes who scored a 2 or 3 (34.86 degrees to 54.22 degrees, respectively), suggesting that individuals that scored lower in the DS had greater hip flexion ROM. These findings are not in line with results from Butler and colleagues (2010), in recreationally active participants and athletes ages 18-30. In their study, individuals who scored a 1 on the DS had less active peak hip flexion angles than those who scored a 2 or a 3. This contradicts the findings of
our study, as we found that those who scored a 1 on the DS had more hip flexion ROM, but less hip extension ROM. Given that the participants in this study were all high performing, young, and healthy individuals and that DS scores are affected by more than just hip mobility, it is possible that other underlying issues affected the performance of the DS for the athletes in the present study. When comparing groups, the average deep squat score for individuals with self-reported hip tightness was a 2, and those who did not report hip tightness had an average of 1.86 (SD=0.69). This contradicts our hypothesis that self-reported hip tightness has an effect on performance in the deep squat in this group, as the average DS score for participants with self-reported hip tightness scored slightly higher than the average DS score for the entire group. Based on Butler's findings, the DS only reflects reduced hip peak flexion for scores of 1. There was no difference in peak hip flexion between scores of 2 and 3. This may explain the fact that the tightness group did not perform differently than the normal group. It is important to remember that even though these individuals reported tightness, they are young, healthy, high performing athletes.

Self-reported hip tightness effect on running mechanics

Our results partially confirmed our hypothesis that decreased range of motion, as measured by the FMS DS, would result in altered running mechanics, as measured by peak flexion and extension angles. The findings of the present study suggest that with greater hip flexion ROM, DS scores were lower, and that with greater left hip extension ROM, DS scores were greater. However, we found no relationship between right hip extension and the DS at top speed, and there was no significance between the DS and running mechanics for this population in this study. Even though the findings in the present study were not significant, the magnitude of the correlation coefficient between right peak flexion and DS were in line with Jenkins and colleagues (2017), who found a significant moderate positive correlation between passive flexion on the left side with the DS (p=0.342). One distinction to make between our findings and Jenkin's is that we analyzed active hip flexion, while Jenkins analyzed passive hip flexion. The results of a study by Schache and colleagues (2011) also supports the findings of our study, as they had found that the hip extensor and knee flexor muscles during terminal swing demonstrated the most dramatic increase in biomechanical load when running speed increased in intensity. In the present study, we found that, as participants ran faster, the hip angles got smaller, suggesting that there is an increase in average swing angles while running as speeds increase. This study did not measure hip acceleration, so we cannot infer whether there was an increased hip flexor torque with an increase in running speed, but there was an increase in angular displacement.

We also found that, in general, individuals with self-reported hip tightness tended to flex more and normal people tended to extend more. This suggests that there are changes between toe off and mid-swing between the groups. This finding confirms
our hypothesis that the running mechanics of the group with self-reported hip tightness would differ from the normal group. Findings by Roach et al. (2014) suggest that runners who experience limited hip extension may develop shortening of anterior hip muscles such as the hip flexor, and with the converse also being a possibility where hip extension may decrease due to shortening in anterior hip musculature. Roach explains that possible repercussions for these deficits may limit one’s ability to generate full potential power in the gluteus maximus, as well as a decrease in efficiency in the anterior hip muscles and potential for overuse.

The results of Lindsay et al. (2014) found that the mean stride interval decreased significantly with increasing speed, which confirms the findings of our study, as there is an increase in peak hip flexion and extension angles when running at a faster pace, meaning that the ROM of the hip increases with an increase in speed. The limitations that runners may experience due to hip tightness and decreased ROM during stride are points for possible future intervention. Short et al. (2017) suggests that adding interventions through exercise may assist with lasting ROM development, but may change movement patterns in the individual. These changes may take adjustment and cause alteration in performance, but they are in turn assisting with force distribution in the body, which can help prevent potential injuries from occurring.

Heiderscheit and colleagues (2011) studied the difference in stride speed on joint manipulation with 45 healthy adults (mean age: 32.7, +/- 15.5yrs) familiar with treadmill running, who reported running a minimum of 15 miles/week for at least 3 months prior to the study. The results found that increasing step rate by 5-10% from their preferred step rate caused the impact transient occurrence to decrease, and ~20% and ~34% less energy was absorbed at the knee. With the increase in speed, there was also a decrease in step length, and the hip achieved less peak flexion (p<0.01). This method of running could help change the magnitude of compensations made by athletes whose longer stride length may be causing greater load concentrations at their lumbar spine rather than at the hip.

DS scores compared to normative values

Individuals with self-reported hip tightness scored an average of 2.0 on the DS (SD=0). The tightness group compared to the normal non-tightness average scored higher with the normal scoring 1.86 (SD=0.69), and still scored higher when compared to normative scores from Agresta et al. (2014), which were averaged at 1.85 (SD=0.48). These findings were in partial confirmation of our hypothesis that the participants in our study would be in line with normative values. However, we expected individuals with self-reported hip tightness to score lower than normative scores, but the tightness group scored above average. These differences in comparisons to the normative values are likely due to differences in populations. Our participants were young competitive runners, while those
included in the normative values were recreational runners who ranged from 22-54 years old. Prior research done by Cook et al. (2015) suggested scores below a three may be associated with limits in dorsiflexion, extension of the thoracic spine, or with hip flexion. A DS score of 3 requires sufficient ROM and flexibility at the hip, shoulder, and thoracic spine, as well as sufficient closed kinetic dorsiflexion, and core strength (Cook et al. 2015). Another potential explanation for our results can be supported by a meta-analysis on a phenomenon called “Butt wink” by Somerset (2018). Butt wink is the instance where one attempts a deep squat, but is limited due to several factors such as tight gluteal muscles (piriformis and adductor magnus), tight hamstrings, excessive hip socket depth, and acetabulum orientation. The main takeaway point here is that hip tightness may not be the cause for low DS scores, and in fact the inability to perform the deep squat can be attributed to inherent anatomical formations such as hip socket depth or acetabulum orientation limiting ROM indefinitely. However, the DS is an example of an extreme hip ROM not required during running at any speed. It is possible that some runners can perform adequately despite a low score in the FMS DS. Future research on running mechanics could incorporate other FMS test like the active straight leg raise (ASLR), which may provide additional insight on hip ROM and performance.

Limitations

Some of the limitations of this study included, firstly, that we focused only on the deep squat, which represents the greatest hip flexion range of motion, requires multiple parts of the body such as the ankle, knee, and hip to perform, and was one of the best FMS movements as an indicator of injury risk according to Hotta et al. (2015). However, there was not any significant correlations between the DS and running mechanics in this study. Also, we have looked at the hip only in the sagittal plane, which is limited to hip flexion and extension, but not IR/ER, abduction/adduction. It may be that there are meaningful variables that were not looked at for this study, so future studies could look at other planes or other FMS tests. There is a wide range of running strategies, which include movements outside out the sagittal plane and movements at other joints in the kinetic chain where future studies could account for these differences.

Measurement limitations

Overall, the FMS DS was not a good predictor of active hip extension or flexion while running. This may be due to the nature of the scoring of the FMS (not a continuous numbering scale), since there is a large range of abilities that fit within a score of 2, for example. Another factor to consider is that, while running, the peak flexion ROM is lower than the peak flexion angles required to successfully complete the DS with a score of 2 or 3; therefore it is possible that, even for individuals with low DS scores, their hip flexion active ROM is sufficient to successfully run their events. However, when comparing individuals who scored a 1 on the deep squat to averaged angles in those who scored a 2 and those who scored a
we found there were considerable differences between right and left side hip flexion and extension angles. The percent differences for hip flexion at the low and top speed between the right and left side were almost 17% and 19% lower in the left side flexion angles from the DS score of 1 to the average scores of DS 2 and 3. Our findings are in line with Butler et al. (2010), as they found that there are significant differences in the hip flexion and extension moments between subjects who scored a 1 on the deep squat to those who scored a 2 or a 3, where those who scored lower had less flexion and extension moments at the hip.

The use of a treadmill in a lab setting could raise questions as to whether this protocol is representative of the demands experiences by DIII track and field athletes. In this study, participants ran at 3 different speeds, limited at a 12 mph max pace. Higashihara et al. (2017) reported mean peak running speeds at maximum exertion at 21.296 +/- 0.514 mph, and although speeds this fast are representative of maximum exertion, they are impractical as a maintenance speed during a race and during video analysis, since they could not be sustained over a longer period of time. For running analysis purposes, the speeds in this study were determined by adapting the speeds in Schache et al. (2011) and by consulting with head coaches to better suit the abilities of the participants. Another possible question regarding the use of a treadmill is whether it causes running mechanics changes from overground running. Results reported by Lindsay et al. (2014) suggest that treadmill running compared to overground running resulted in stronger correlations and consistent stride timing dynamics, due to features unique to treadmill running, such as the dimensions of a treadmill, speed regulation, and a straight path, which cause less degrees of freedom available for a difference in gait regulation. The perceived environment running on a treadmill places a higher demand on voluntary control on the runner, which sets the experience apart from regular running gait (Lindsay, 2014). These observations would suggest treadmill running is a superior environment for research testing during biomechanical analysis, especially for the purposes of this study.

Sample size

There were only 10 runners included in this study, where 6 were sprinters, 3 were long distance, 1 was a thrower, and 2 of the 10 runners were female. These imbalances in the sample do not evenly encapsulate the diversity of runners; normative scores by Agresta et al. (2014) found there were differences between performance on the DS between males and females, where females tended to score lower than males. If there was a greater sample of females, it is possible this relationship could have had an effect on our correlations between the DS and running mechanics.

One limitation of the present study is the small sample size. After conducting a post-hoc power analysis, we found right peak hip flexion at the low speed to have a small effect size of 0.36 and top speed to have an effect size of 0.29, with a 0.12 and 0.11 statistical power achieved, respectively. To find statistical
significance at 0.8 power for these conditions would require 234 and 342 subjects. For left peak flexion at the low speed we found a small effect size of 0.19 and 0.4 at the top speed, where there was a 0.08 and 0.13 statistical power achieved, respectively. To find statistical significance for these conditions at 0.8 power, would require 862 and 186 subjects, respectively. The somewhat large number of subjects needed to find significance and smaller effect sizes, suggests that there is not a large difference in this hip flexion in Division III track and field runners.

For right peak hip extension at the low speed with an effect size of 1.11 and 1.06 at top speed, where there was a 0.43 and 0.41 statistical power achieved, respectively, to find statistical significance for these conditions which would require 26 and 28 subjects. For left peak hip extension at the low speed we found large effect sizes of 0.96 and 1.56 at the top speed, where there was a 0.36 and 0.66 statistical power achieved, respectively, to find statistical significance for these conditions which would require 34 and 14 subjects. The smaller sample sizes needed to achieve 0.8 power and larger effect sizes suggest that the differences in peak extension are more prominent than the ones in flexion size in Division III track and field runners and should be investigated further in future studies.

Implications

A proper sprint involves accelerating through 30-40 meters to reduce the amount of time running upright, which requires more energy, and is difficult to sustain. During acceleration, hip flexion ROM is much greater while driving the knees up and forward, propelling the body forward when pushing hard off the ground with each step. After acceleration, top end running is most efficient when continuing to drive the knees to roughly 90 degrees (flexion), and when making initial contact the foot should strike directly under the body, causing vertical lift, moving the body to double float which allows for an easier drive forward, and less braking forces when striking the ground. With limited ROM during swing, acceleration is more difficult, likely forcing the runner to erect their body sooner, later compensating for loss in acceleration by increasing stride length, which the forces from longer and lower strides increase risk of injury as the energy required is greater, and the braking forces from stepping in front of the hip puts strain on the body and slows the runner down.

Conclusion

Our results were in partial confirmation with our hypotheses. The self-reported hip tightness group had higher FMS DS scores than normal group, but the DS was not a significant predictor of peak hip flexion or extension while running. The self-reported hip tightness group showed altered running mechanics, marked by early toe-off, or less hip extension, and lower hip flexion angles during the swing phase on both sides. Overall, DS scores were in line with the normative values, but the self-reported hip tightness group was above the normative values.

Future studies could investigate these changes in running mechanics in
different planes of motion and also the injury prevalence in runners with self-reported hip tightness.

Bibliography


Gait & Posture, 29(3), 494-498.


