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Fatigue Induced Hip Abductor Strength and Single Leg Drop-Jumps in Recreationally Active Females

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Abstract- Approximately 70% of ACL injuries are a result of non-contact mechanisms such as rapid changes in direction, deceleration, pivoting, and landing. Female athletes are particularly vulnerable to such injuries. Intrinsic factors including: joint laxity, anatomical structure, hormones, strength and fitness deficits, and altered neuromuscular control are all likely to contribute to this trend. PURPOSE: The purpose of this study was to determine the amount of control the hip abductors have on the landing stability of recreationally active females during the landing phase of a single leg drop-jump. METHODS: Fourteen healthy, adult, recreationally active females participated in this study (height=1.71±0.06 meters; Mass=64.5±8.4 kg; age=25.7±4.5 years). Each subject was instructed to perform 3 single leg drop jumps on to a forceplate (sample rate 3000 Hz) on their dominant leg in non-fatigued and fatigued states. The fatigue protocol consisted of a hip abduction one repetition maximum (1RM) of the dominant leg using an Athletic Republic Pro Multi Hip exercise machine followed by maximum repetitions at 75% 1RM until fatigue was achieved (i.e. inability to abduct with full range of motion). The three GRF variables examined were: peak vertical GRF, the range of M/L and range of A/P GRFs as averaged across the three trials for both the pre-fatigued and fatigued states. A series of paired t-tests were used to compare GRF variables in the pre-fatigued and fatigued states. RESULTS: No significant differences were noted in the range of medial/lateral (M/L) (p=0.08) and peak vertical (p=0.39) GRFs during the single leg drop jump task between the fatigued and non-fatigued conditions. The range of anterior/ posterior (A/P) GRFs were significantly lower in the fatigued state (p=0.05) than in the pre-fatigued state. CONCLUSION: Within the parameters of this study hip abductor fatigue did not appear to have a significant impact on the range of medial/lateral (M/L) or peak vertical GRFs during the landing phase of a single leg drop jump. However, range of A/P GRFs were lower while the hip abductors were in a fatigued state.

Keywords- *Anterior Cruciate Ligament, Fatigue, Kinetics, Knee*

I. INTRODUCTION

Anterior cruciate ligament (ACL) injuries are one of the most common injuries found in competitive sports, and can be divided into two categories: contact injury and non-contact injury (1). Contact ACL injuries are caused by direct blow to the lower extremity by an object or opponent (1). Non-contact injuries are caused by intrinsic factors and are often thought to be a result of poor movement patterns (2). Approximately 70% of ACL injuries are noncontact injuries and the most common mechanisms of injury are associated with rapid change in direction, decelerating, jump landings, and pivoting at the knee with a planted foot (2). The anterior cruciate ligament is responsible for stabilizing the knee, preventing, anterior translation of the tibia, and preventing extreme internal rotation of the tibia (3, 4, 5). Excessive stress can be placed on the ACL when an athlete cuts, lands, or pivots in an awkward position, causing the ACL to sprain or rupture (4).

Female athletes, especially those that engage in competitive team sports like soccer, basketball, and volleyball are particularly vulnerable to ACL injuries (1,2,4,6) Since the establishment of Title IX in the Educational Assistance Act, in 1972, the number of females participating in athletics has increased dramatically in the United States. While the ever-growing number of recreational and professional female athletes is certainly exciting, there has also been a dramatic increase in the number of ACL injury occurrences per year (1, 2, 4, 6, 7). The risk of ACL injury is two to nine times greater in female athletes than it is for male athletes participating in the same sport with the same loading and pivoting requirements (8). The exact reason that female athletes experience noncontact ACL injuries at such an alarming rate is still unknown. It is likely that a combination of intrinsic factors including joint laxity, anatomical structure, hormone changes, strength and fitness deficits, and altered neuromuscular control all contribute to this trend (1). While some of these intrinsic contributing factors are unavoidable, such as anatomical structure and hormone fluctuations, there are certainly a few contributing factors that can be improved with training. Improving strength, endurance, neuromuscular control, and biomechanical characteristics of the female athlete have been shown to increase the dynamic stability of the knee and therefore decrease the amount of stress placed on the ACL during physical activity (8, 9, 10, 11, 12)

One movement pattern that is especially prominent and detrimental to the female athlete is known as dynamic knee valgus motion (5, 7, 13). The dynamic knee valgus is a result of knee flexion, hip adduction and internal rotation combined with tibial external rotation and ankle eversion (8). This movement forces the knees toward the midline and places excessive strain on the ACL. It has been suggested that the hip muscles, more specifically, the hip abductors may play a vital role in controlling dynamic knee motion in the frontal plane (10, 13, 14, 18, 19). Therefore, fatigued or weak hip abductors may also contribute to the risky movement patterns of adult female athletes that put them at a higher risk of ACL injury (14). In addition to risky movement patterns, decreased stability during landing and cutting tasks has been shown to be a strong indicator of future injury (4). Strength and conditioning of the hip musculature may help reduce the risk of ACL related injury by stabilizing the knee and reducing unnecessary frontal plane motion (12, 15).

While there has been extensive research comparing the landing mechanics and muscle activation strategies of men and women (3, 5, 13,16), a majority of the existing research focuses on quadriceps to hamstrings strength ratios, force absorption, and landing mechanics in the sagittal plane (5, 16, 17). However, little research has been done on the landing mechanics of females and the function of the hip abductor muscles in lower limb stability during drop-jump tasks. Due to the overwhelming amount of evidence and increased incidence rate of ACL injury in active females, it is critical that we determine a viable way to reduce the risk associated with female sports participation.

Hence, the purpose of this study was to determine the amount of control the hip abductors have on the landing stability of recreationally active females. As differences in landing stability would be reflected in GRF, the current study compared peak vertical GRFs, the range of M/L GRFs, and the range of A/P GRFs upon landing on a forceplate prior to and following a hip abductor fatiguing protocol.

II. Methods

A. Participants

Fourteen healthy, adult, recreationally active females participated in this study. Subject height, mass, and age were: 1.71±0.06 meters, 64.5±8.4 kilograms, and 25.7 ±4.5 years. All participants participated in at least 150 minutes of moderate intensity exercise per week, and reported being free of any lower extremity injuries, or prior lower extremity surgeries. Women with previous lower extremity injuries or pregnancies within the last year, were excluded from participation. Before participants were enrolled in the study, they were verbally informed on the details of the study and were required to read and sign an informed consent document approved by an Institutional Review Board (IRB) for the use of human subjects in research. Likewise, the study was approved by an IRB for the use of human subjects in research

B. Instrumentation

The ground reaction forces (GRFs) were collected with two in-ground force plates Fig. 1. The force plates (AMTI, Model No. BP6001200, Watertown, MA.) were sampled at 3000 Hz and subsequently filtered by a low pass Butterworth filter with a cutoff frequency of 50 Hz. Variables obtained from the force plates included the medial/lateral (M/L), anterior/posterior (A/P), and vertical GRF during the landing phase of the drop jump. Force plates have been found to be a valid instrument with high test-retest reliability (r=0.94) for force and time measurements during single leg vertical jumping tasks as well as drop jump landings, suggesting that forces collected during single leg drop jumps are reliable and repeatable over time (20, 21).

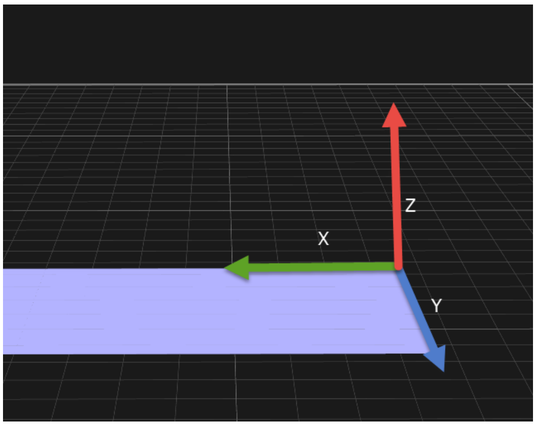

Figure 1. Ground Force Plate Global Coordinate System. X Forces are medial-lateral; Y Forces are anterior-posterior; and Z Forces are vertical for both the left and right force plates.

C. Procedures

Participants were asked to complete two 45 minute testing sessions in the Biomechanics Lab at the Orthopedic Specialty Hospital in Salt Lake City, Utah. During the initial session the subject's height (m), mass (kg), and age were recorded. Each of the participants completed a dynamic warm up including: high knees, butt kickers, shuffling, skipping, and a walking glute stretch at the start of both sessions. After warming up, the participants were introduced to the jumping task. Participants were allowed several practice jumps until they were comfortable with the jump and able to accurately complete the task.

The platform was placed 31cm high directly behind the force plate. An “X” was taped in the center of the platform, and an additional “X” was taped on the force plate in front of the platform. The “X” on the force plate was offset by 7.62 cms (to the right for a right leg dominant subject, and to the left for a left leg dominant subject) from the center of the platform “X” to maintain consistency between jump trials as well as keep a normal stance position between legs. Participants began the test by standing on top of a platform 31 centimeters high, with their feet hip width apart and their nondominant leg in the center of the “X” on the platform. Participants were instructed to 1) stand facing forward, 2) step off the platform (the drop), land on their dominant leg on top of the “X” on the force plate, and 3) immediately perform a maximal single leg vertical jump, landing on the same foot Fig. 2. Participants performed three baseline single leg drop- jump trials on their dominant leg, and temporal GRF were collected upon landing on the force plate.

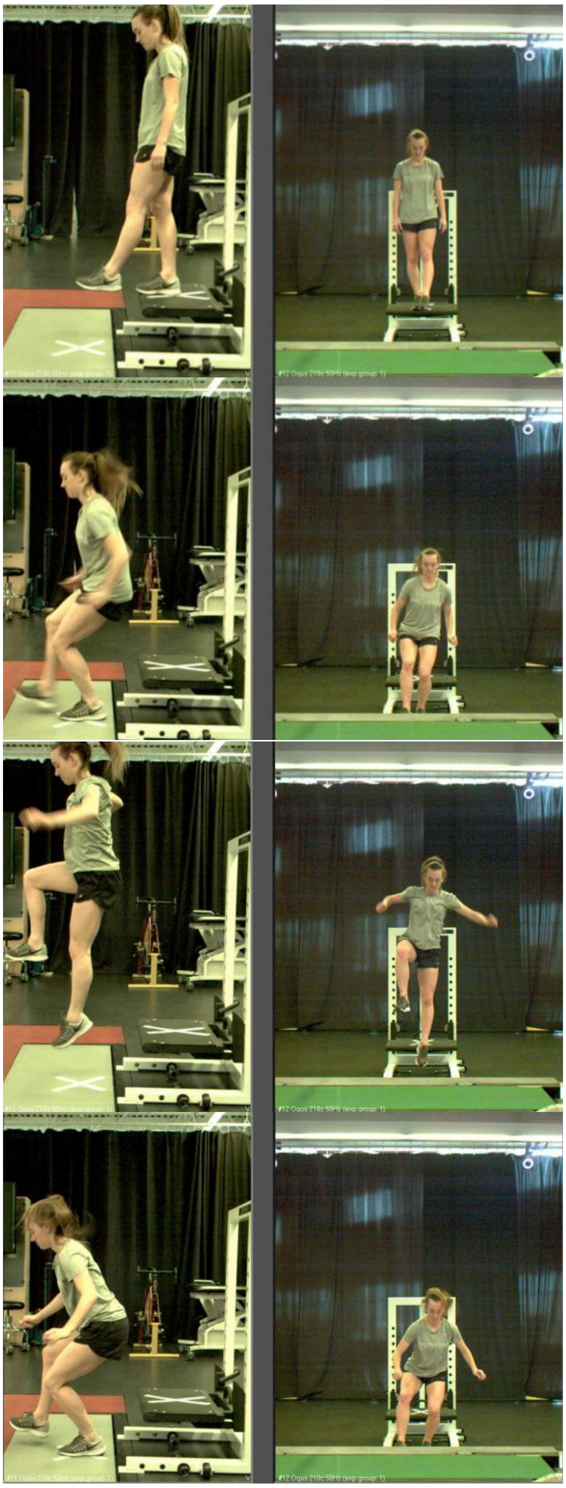

Figure 2. Single Leg Drop Jump

During the second session a hip abductor fatiguing protocol was employed. The fatigue protocol consisted of two tests. The first was a hip abduction one repetition maximum (1RM) on the dominant leg using an Athletic Republic Pro Multi Hip (Tri W-G, Model No. PMH, Valley City, ND) Fig. 3. The second, maximum repetitions at 75% of their 1RM until fatigue was achieved. The Pro Multi Hip was adjusted for the subjects' height, with the greater trochanter aligned with the rotational axis of the machine, and the pad set on the lower one third of the femur, just above the knee. The 1RM was measured by the heaviest repetition a participant could fully abduct and hold for two seconds. Two-three minutes following the 1RM, the participants completed maximal repetitions at 75% of their 1RM until fatigue was achieved. Fatigue was determined by the subject's inability to abduct the weight through the full range of motion, and a rating of perceived exertion (RPE) above seven.

Immediately following the fatigue protocol, participants performed three fatigued single leg drop- jump trials on their dominant leg, and temporal GRFs were collected upon landing on the force plate (identical to the first session).

D. *Calculating Force Range*

GRF range was measured by calculating the magnitude of the difference between the highest and lowest value during the landing phase of the M/L and A/P force (Eq. 1). Peak vertical GRF during the landing phase was also recorded. The landing phase was defined as the deceleration phase of the first landing and was indicated by the first fifty percent of the ground contact time between touch down (TD) and toe off (TO) Fig. 4. These three dependent variables were collected for each of the three drop landing trials and then averaged for both the fatigued and non-fatigued conditions.

$$F_{range} = |F_{ML}max - F_{ML}min| \quad (1)$$

F range is the range in force during deceleration phase of the first landing

F_{ML}*max* is the maximum M/L value during the landing phase

F_{ML}*min* is the minimum M/L value during the landing phase

E. *Statistical Analysis*

The three dependent variables (DVs) analyzed were the peak vertical GRF and the range of M/L, and A/P GRFs upon landing on the forceplate. The DVs were compared between the fatigued and non-fatigued conditions with paired t-tests. An alpha≤0.05 was chosen to denote statistical significance. Statistical analysis was conducted with MS Excel 2013.

Figure 3. Athletic Pro Republic Multi Hip

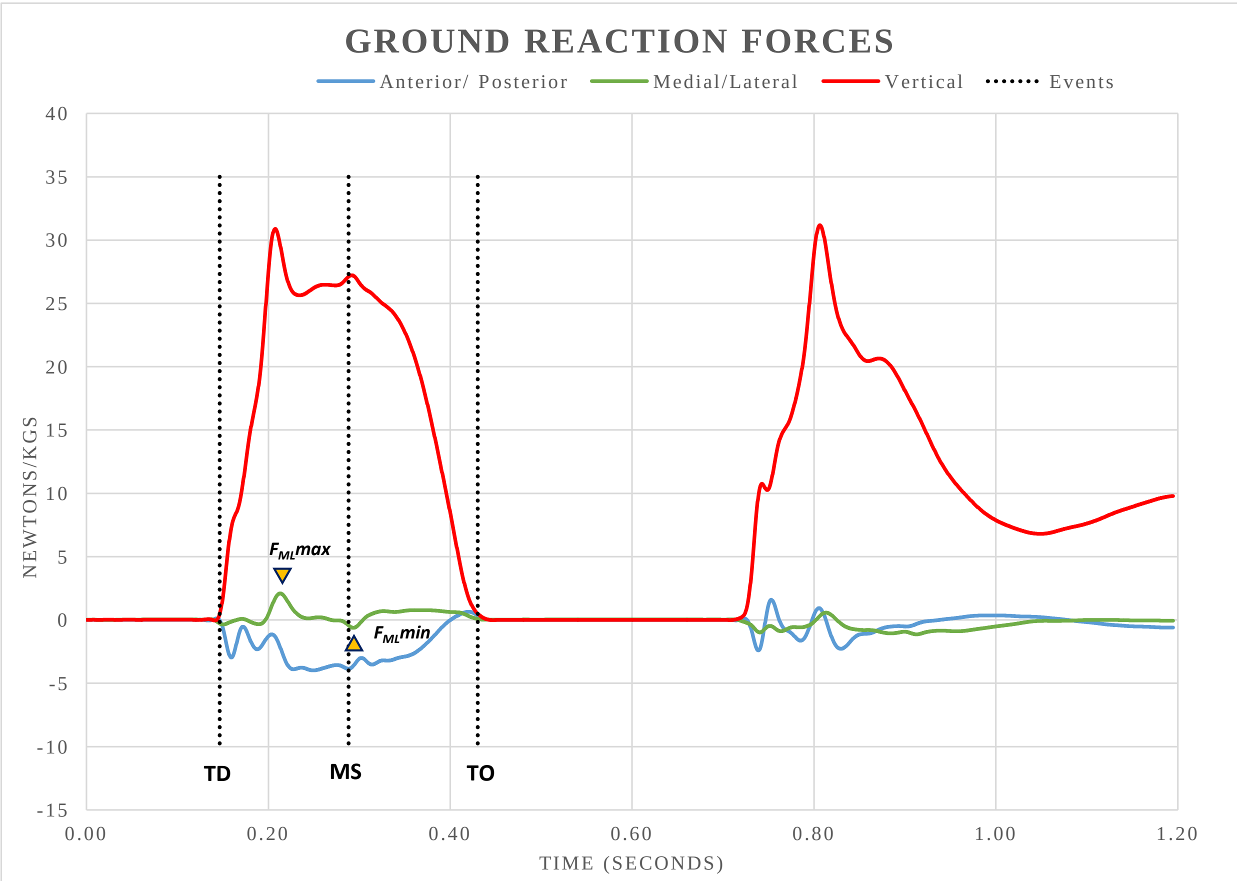

Figure 4. Time history of GRF, Events (TD-Touch down; TO-Toe Off; MS-Mid Stance) and Variables (F_{ML}*max*–Peak medial GRF ; F_{ML}*min*–Peak Lateral GRF

III. Results

Ground reaction forces for fatigued and non-fatigued states are represented in Table 1 where (*) was used to denote significance ($p \leq 0.05$) between the non-fatigue and fatigue states. The table provides mean and standard deviation for medial/lateral GRF range (N), anterior/posterior GRF range (N), and peak vertical (N) GRFs.

A. *Strength and Fatigue Measures*

During the hip abduction one repetition maximum (1RM), the mean maximal strength was 45.5±8.8 kgs, approximately 70% of the average for the participants' body mass. The average number of reps performed at 75% of 1RM was 28.1±10.4 on their dominant leg.

B. *Medial/ Lateral GRF*

The mean M/L force variation during the pre- fatigued landings was 146.4±42.5 N. During the fatigued landings the mean M/L force variation was 149.9±45.6 N. Fatigue did not appear to significantly impact the total range of M/L force during the landing phase of the drop jump task (p=0.34). These results suggest that the hip abductors play little or no role in reducing M/L GRF range during the landing phase of a single leg landing task.

C. *Anterior/Posterior GRF*

The mean A/P force variation during the pre- fatigued landings was 306.5±77.0 N. During the fatigued landings the mean A/P force variation was 282.3±53.2 N. The landing forces in the A/P direction were significantly affected by fatigue during the landing phase ($p \leq 0.05$). The range of A/P GRF was significantly lower in the A/P direction after the fatigue protocol when compared to the pre-fatigue landings. These findings suggest that hip abductor fatigue may affect landing stability in the A/P direction during a single leg landing task.

D. *Vertical GRF*

The mean vertical force variation during the pre- fatigued landings was 1929.4±336.2.5 N. During the fatigued landings the mean peak vertical GRF was 1913.6±275.9 N. The peak vertical GRF was not significantly impacted by hip abductor fatigue (p=0.39). These results suggest that the fatigued hip abductors play little or no role in reducing vertical GRF during the landing phase of a single leg landing task.

TABLE I. Ground Reaction Forces Between Fatigued Conditions

V GRF Pre/fatigue	V GRF Fatigue	A/P GRF Pre/fatigue	A/P GRF Fatigue	M/L GRF Pre/fatigue	M/L GRF Fatigue
1929.4 (±336.2)	1913.6 (±275.9)	306.5 (±77.0)	282.3 (±53.2) *	146.4 (±42.5)	149.9 (±45.6)

Ground reaction forces (GRF) for fatigued and pre-fatigued states. * Significant difference $p \leq 0.05$ between conditions. The table provides GRFs (Newtons) mean ± standard deviation for medial/lateral (M/L), anterior/posterior (A/P), and vertical (V) forces.

IV. Discussion

The purpose of this study was to determine the amount of control the hip abductors have on the landing stability of recreationally active females. The hip abductors main function is to abduct the lower limb or in this case, support the pelvis during unilateral movement. The muscles in charge of this action include the gluteus medius, gluteus minimus, and the tensor fascia lata. Dynamic knee valgus occurs during knee flexion when the hip adducts and internally rotates in combination with tibial external rotation and foot eversion. This position has been referred to as "the position of no return", and can result in unstable landings and increased strain on the ligaments in the knee (4). It has been suggested that decreased hip abductor strength and endurance may manifest itself in decreased knee control at the distal end of the femur (5). Given these facts, one can reasonably assume that that strengthening and conditioning the hip abductors would help bring stability to the distal limb during jumping and cutting tasks. In this study hip abductor weakness was induced by a fatigue protocol to examine whether weak hip abductors result in increased variation of M/L GRF indicating decreased lower limb stability in the M/L plane. Although the original intent of this study was to examine changes in the range of M/L GRF, changes in the range of A/P GRF, and peak vertical GRF were also examined to gain a better understanding as to if fatigued abductors alter GRFs in all three planes upon landing from a single leg drop- jump.

The significant findings in this study are the effects of hip abductor fatigue on the variation of A/P force during a single leg drop jump. A/P force range was significantly lower during the fatigued landings than that of the non- fatigued landings ($p \leq 0.05$). Landing from a jump is one of the most common mechanisms of ACL injury. Therefore, many studies focus on the landing strategies of females (5, 13, 16, 17). In a study comparing the double leg drop landings of male and female recreational athletes, (5) the researchers found that females tend to land more stiffly and with increased frontal plane motion, while males tend absorb landing forces more efficiently. The investigators also found that females landed with higher peak vertical and posterior GRFs, as well as significantly greater peak knee valgus angles during the first phase of landing (5). This study (5) supports our findings that force variation was greater in the A/P direction than M/L and vertical, and significantly altered between non-fatigue and fatigued trials. In another study on landing strategies between males and females (16), Huston et al. found that females land with a significantly straighter knee at 40 and 60 cm heights than their male counterparts. They also found that for every degree of extension, the GRFs were increased by one percent. Together, these studies suggest that greater knee extension at initial contact make it difficult for the female athlete to spread force evenly across the joint and may result in increased stress on the ACL.

Our study displayed a higher range in A/P forces in a non-fatigued state and a lower range of force in the fatigued state. Single leg jumps require increased hip stability to prevent the contra lateral pelvic drop, and the ipsilateral hip from adducting and internally rotating. It is possible that the fatiguing of the hip abductors resulted in a more compliant limb, and absorbed forces using a hip drop mechanism or more knee flexion due to an inability to produce the strength required decelerating on a more extended leg. Because our study did not include kinematic data it is impossible to confirm how A/P force was dissipated during the fatigued jumps.

The ACL is responsible for preventing anterior translation of the tibia and stabilization of the knee. One of the most common mechanisms of ACL injury is a result of landing from a jump on a more extended leg. Typically, this type of landing results in increased GRF. However, the findings of this study showed lower GRF in both the A/P and vertical directions in a fatigued state. Fatigue failed to have a significant impact on the total range in force in the M/L direction. In a study on the effects of fatigue on the drop jump landings of 106 athletic children (68 females and 48 males, ages 10-11 yrs), Briem et al. (3) applied a fatigue protocol consisting of 5 minutes of slide board activities at increasing intensities. Briem et al. discovered that girls displayed higher peak vertical GRF during drop jump landings than boys in general, and that fatigue led to slightly higher GRF than baseline tests. Fatigue also resulted in greater knee flexion at initial contact and less knee flexion at peak ground reaction for girls compared to boys (3). While the goal of the Briem study was to examine general lower leg fatigue and landing mechanics, it is possible that the fatigue protocol used in the Briem study placed extra emphasis on the abductors by using the slide board exercise. While the current study did not find increased vertical GRFs during the fatigued landings, it is possible that the participants used a similar knee flexion strategy at initial impact that may have reduced the vertical GRFs.

Boham et al. (19) demonstrated that a functional fatigue protocol led to significant increase on the A/P GRF of a cutting tasks. Boham et al. also observed an impact on M/L force during the fatigued left cutting task, but similar to the current study, these changes did not reach statistical significance (19). In agreement with Boham et al. study, we also observed significant increase in A/P GRF range.

Several studies have found that hip abductor fatigue alters dynamic knee motion during jumping activities (10, 13, 14, 18, 22). In a study on the differences in hip abductor strength, endurance, and landing mechanics in 30 healthy adult men and women it was found that women had lower hip abductor peak torque as a percentage of body weight, and increased dynamic knee valgus angles upon landing, than the men did during both the pre- and post- jump trials (13). In a prospective study, Khayambashi et al. (10) measured the off season, isometric hip strength of 501 competitive athletes from a variety of sports. During the competitive season, fifteen noncontact ACL injuries were confirmed, and strength measures of those injured were significantly lower than the uninjured athletes. Results showed that isometric hip abduction and external rotation strength independently predicted future noncontact ACL injury status in competitive athletes, and that the chance of injury increased significantly when the subjects' hip abductor strength and external rotator strength fell below 35.4% and 20.3% of body weight respectively (10). Athletes with low levels of proximal hip strength may be at increased risk of ACL injury because they have less control of dynamic knee motion. The mean body mass for the participants of our study was 64.5 (±8.4) kg and the mean maximal strength was 45.5 kg (±8.8), meaning a majority of the participants in our study were able to abduct approximately 70% of their body weight. According to the findings of the Khayambashi study (10), our participants had an adequate level of hip abductor strength and therefore may have had more control of the dynamic motion during landing. This may explain why we did not see a significant increase in M/L force during the fatigued jumps. Mclean et al. (22), found that a unilateral fatigue protocol consisting of single leg squats and landings to failure resulted in significant decreases in knee flexion at initial contact and peak stance, as well as an increase in hip internal rotation and knee abduction angles and moments at peak stance (22). These risky movement mechanics were thought to be the result of a reduced ability to effectively respond to stimuli during the anticipated and unanticipated single-leg landings. The decrease in A/P force variability in our study may be explained by a reduced capacity of the abductors to respond to the landing, requiring the participants to rely more heavily on the flexors and extensors to absorb the forces.

Carcia et al. (14) also found that hip abductor fatigue resulted in increased hip adduction and dynamic knee valgus alignment using electro goniometers. However, Carcia et al. did not observe altered GRFs due to hip abductor fatigue (14). In contrast, Ford et al (7) found no difference in knee flexion angle, but did also find an increased knee abduction moment at initial contact during cutting maneuvers. Ford also mentions that females tend to allow the direction of the GRFs to control the movement of the lower limb (7). By allowing GRFs to dictate movement, female athletes may not adequately distribute forces to the knee and place greater strain on the ligaments. Geiser et al. (18) recruited twenty recreationally active females to determine the role of hip abductor fatigue on different cut, running, and jumping tasks. Using side-lying isokinetic dynamometry and three-dimensional motion analysis system Geiser et al. determined that hip abduction fatigue led to increased frontal plane motion at the knee (18). Interestingly, Geiser found that fatigue led to a more varus knee position at initial contact that transitioned to a more valgus knee position during weight acceptance (18). Each of these studies support that hip abductor fatigue plays a role in lower limb stability during landing tasks and manifests itself in increased varus/ valgus motion at the knee. In the current study, we hypothesized that the transition from a more varus position to a more valgus position would present an increased variance of the M/L forces between initial contact and weight acceptance. While hip abductor fatigue did have a significant effect on the total range of A/P force (p=0.05), M/L force variation was not significantly affected. It is possible that kinematic data would have offered more precise information on the dynamic motion of the knee during landing.

V. CONCLUSIONS

Fatigue appeared to have a small effect on forces variation during a single leg landing task on the dominant leg. A/P force was significantly lower in the fatigued landings. Peak vertical force was also lower during the fatigued landings although this change was not statistically significant. We also noted a small increase in M/L force variation during the fatigued landings, but this change did not reach statistical significance either. Future studies should incorporate 3D motion analysis to better understand lower limb kinematics during the landing phase of single leg jumping tasks. Future studies should also employ different methods of fatigue as well as different unilateral jumping tasks to better understand how hip abductor fatigue alters landing mechanics. The average athlete engages in a variety of running, jumping, landing, change of direction, and deceleration tasks that may induce fatigue during any given practice or game. Many studies have been done on the sagittal plane landing mechanics, quadricep to hamstring strength rations, and muscle fatigue of adult males and females (3, 5, 13, 16, 17), however there is still much to be discovered on the role hip abductor strength plays in the proximal control of frontal plane knee motion and dynamic knee stability in young females. With millions of young females participating in sports worldwide, it is critical that we identify risk factors and injury prevention strategies early on. Therefore, further research on the hip abductors' role in landing stability of this population is warranted.

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