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Research Article

Leg Power Asymmetry with the Onset of Fatigue – A Pilot Study

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Abstract

Background: Non-contact lower-limb injuries are common across skill levels and within both genders for sport. With the incidence of injuries increasing in the second half of the competition and latter portions of tournaments, there is a potential that altered neuromuscular function and biomechanical processes are developing with the onset of fatigue. Additionally, athletes are often required to perform high velocity unilateral movements throughout the duration of the sport. A large imbalance between legs will increase the potential for injury when relied on as the sole source for power production or force dissipation, such as when taking off or landing from a single-leg jump.

Purpose: To quantify the Average Symmetry Index (ASI) between legs when performing single-leg countermovement jumps before and immediately following a 60-second continuous jumping fatigue protocol.

Methods: ASI magnitudes were determined for 5 subjects (3 males and 2 females) while performing 3 maximal single-leg countermovement jumps on each leg. Participants then performed 60 seconds of continuous submaximal double leg jumping, followed immediately by a second bout of 3 maximal single-leg countermovement jumps on each leg. Paired t-tests were used to determine if power output values and ASI magnitudes varied substantially pre- and post the fatiguing bout.

Results: Significant differences were found to be present when comparing the mean power output pre-and post-fatigue for the non-dominant leg ($p = 0.05$) After the 60-second fatiguing bout, subjects' power output in the non-dominant leg was significantly less than prior to the 60-second bout ($p = 0.05$). ASI power output was also found to be significantly higher for the pre-fatigue condition when compared to the post-fatigue ($p = 0.004$). **Conclusions:** The initial findings of this study indicate that there is the potential to be over looking athletes that may truly be in the high risk category as the game or match continues if testing is only conducted in a pre-fatigue condition. Being able to identify such athletes in order to develop training protocols to help minimize asymmetries is essential in optimizing performance while minimizing injury. Future research will investigate additional characteristics previously identified as those that predispose athletes to non-contact lower body injury in pre-and post-fatigue conditions across multiple directions (vertical, horizontal and lateral).

Keywords: Leg Power; Lower Limb Injury; Asymmetry; Single-Leg Jumping

Abbreviations:
ACL: Anterior Cruciate Ligament;
ASI: Average Symmetry Index;

Introduction

Non-contact lower body injuries are extremely common in sports for both males and females. Ankle sprains and anterior cruciate ligament (ACL) sprains and tears often occur when the athlete is decelerating or completing a rapid, unplanned change of direction [1-5]. When dissipating the large deceleration forces while performing a subsequent movement, the athlete may be placed in a comprising position. If the athlete is not able to maintain control throughout such movements (due to neuromuscular imbalances, coordination deficits, previous injuries, etc.) the likelihood of incurring a lower body injury is increased.

There has been a multitude of research investigating the mechanism and characteristics associated with non-contact lower body injuries; specifically with ACL injuries [1,3,4,6,7]. However, the majority of research in this area conducts their assessments on participants that are not in a fatigued state. With the incidence of injuries increasing during the second half play and during the last competitions in tournament-style play in various field sports [8-10], the question that arises is what happens to the non-contact injury characteristics when these athletes participate in their respective sport and begin to tire. Are they still able to perform technically to the level that they had at the beginning of the competition or, more likely have their movement patterns become altered in an attempt to maintain their level of performance even though they are now fatigued, as indicated by Kernozek et al (2008)?

Performance in sport is heavily reliant on high velocity unilateral movements (e.g., running, planting and changing direction, jumping, landing, etc.). An issue arises when one leg is substantially less powerful and possibly less coordinated than the other, yet is still required to perform the same tasks at the same level of proficiency. By quantifying the difference between legs, coaches and practitioners can begin to address the weakness through appropriate training protocols.

One indicator that can be used to ascertain whether one leg is substantially stronger or more powerful than the other leg is a measure of percent difference. For the purposes of this study, the measure of percent difference between legs will be referred to as the Average Symmetry Index (ASI) and calculated using the following equation [12].

ASI = [1-(dominant leg/non-dominant leg)]*100

The ASI magnitude resulting from this equation can then be grouped into categories based on the potential risk for injury (see Table 1). Various researchers comparing ASI magnitudes of injured and un-injured participants have determined that a threshold of 12-15% difference between legs, or an ASI magnitude of 12-15, is associated with an increased risk for injury and should be considered atypical [12-15]. It is important to note that this is a working threshold. For example, if a participant is found to have an ASI magnitude greater than 15%, it does not mean that they are certain to suffer a lower body injury; nor does an ASI magnitude below 12% guarantee a player won't be injured. This threshold is simply used as a guideline to determine those players that are at an increased risk for injury so that a proactive approach can be used to minimize the asymmetry and help that athlete reach their full playing potential.

Table 1. Classification of injury potential based off of ASI magnitude.

ASI Magnitude	Classification
0 – 9.9	Low Risk
10.0 – 14.9	Moderate Risk
≥ 15.0	High Risk

ASI = Average Symmetry Index

This article presents initial findings from a pilot study conducted on a total of 5 participants. While this is a very small sample size, the findings presented offer some insight into the potential for increased risk for non-contact lower body injury as fatigue sets in. A larger study will be performed based off of this initial testing protocol. The first purpose of this preliminary study was to determine if leg power decreased significantly with fatigue. Also of interest to the researcher was whether participants that were initially classified as having normal ASI magnitudes displayed high risk ASI magnitudes immediately following the fatiguing bout.

Methods

This study was conducted as a pilot test for a larger study approved by the human research ethics committee of the Unites States Military Academy looking at the effects of fatigue on leg power asymmetry in the vertical direction. A total of 5 (3 male and 2 female) college-aged students participated in this study. All subjects were involved in intramural sports at the time of testing. A written informed consent was obtained from each subject prior to their participation. None of the participants reported any injuries to the lower body at the time of testing.

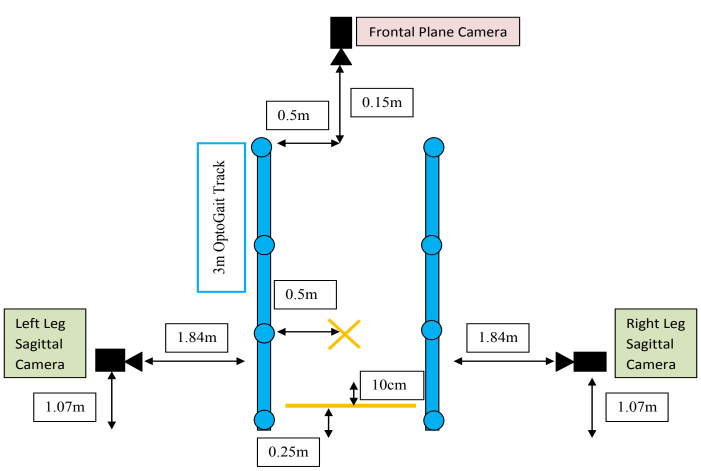
The testing session consisted of 3 single-leg vertical countermovement jumps off of each foot (6 total) which will be used as the "pre-fatigue" condition. Following these initial jumps, each subject performed a 60-second submaximal continuous jumping bout (bilateral jumping) to induce a state of temporary fatigue. Immediately following the 60-second jumping bout, each subject repeated the single leg vertical countermovement trials; which was used as the "post-fatigue" condition. For the purposes of this study, only data concerning the pre- and post-fatigue single leg jumping conditions was used for analysis. Further detail for the entire testing session is provided below.

Upon arrival to the testing session, the age (22.73 ± 1.3 years), height (164.28 ± 10.27 cm) and weight (72.52 ± 15.6 kg) (both without shoes), and leg dominance were recorded for each subject. Leg dominance was determined by the subject's preferred kicking leg [16,17]. All subjects were determined to be right leg-dominant. Each subject then performed a 7-minute standardized warm-up consisting of jogging, skipping for height, skipping for distance, hip flexor lunge stretch, side lunge with adductor stretch, cross-over straight leg stretch, and ankle rotations. Following the warm-up, a brief demonstration and familiarization period for the single-leg countermovement jumps were performed. No more than 3 practice trials were taken by any of the subjects.

Testing Set-up

Testing set-up is illustrated in Figure 1. Two sets of 3m long OptoGait (Microgait Optogait, S.r.l., Bolzano, Italy) track were positioned 1m apart. A starting line was marked on the floor with a 1m long piece of tape 25cm inside the beginning of the testing area. A camera (30 frames/sec) placed 0.15m beyond the end of the track was used to collect frontal plane motion for each trial. Two additional cameras (30 frames/sec) were placed 1.84m from the track on each side (1.07m from the start of the track) to collect sagittal plane motion for the dominant or non-dominant testing leg. When the right leg was being tested, the camera on the right side of the track was collecting footage along with the frontal plane camera. When the left leg was being tested, the camera on the left side of the track was collecting footage along with the frontal plane camera. A large "X" was marked on the floor with tape 0.87m from the starting line (centered between the tracks) and was used to designate the starting point for the 60-second continuous jumping bout.

Figure 1. Diagram of testing set-up.



Single-leg Countermovement Jump (SLCM)

Subjects begin outside of the testing area, facing down the length of the track and standing on the testing leg. For all trials, the non-testing leg was flexed to approximately 90° at the knee and both hands were placed on the hips. Subjects were required to keep both hands on their hips throughout the entirety of the jumping trials so that the jumping performance was representative of their lower body power output. On the investigator's command ("ready – and – go"), the subject performed a single leg hop into the testing area (landing on the testing leg) on the far side of the starting mark followed immediately by a maximal single leg vertical jump, landing on both feet simultaneously. A jump was considered successful if 1) both hands remained on the hips throughout, 2) the non-testing leg did not touch the ground until the final double-leg landing, and 3) balance was maintained for a minimum of 1 second at the end. Twenty seconds of rest separated each trial. Testing order was counterbalanced for each leg, for example subject 1 performed all three trials of the SLCM jumps on the dominant leg first; subject 2 performed all three trials of the SLCM jumps on the non-dominant leg first. Once three successful trials were recorded for each leg, 3 minutes of recovery were taken by each subject prior to completing the 60-second continuous jumping bout. Immediately following the 60-second bout, the SLCM jumps were repeated in the same order as performed prior to the bout.

60-second Continuous Submaximal Jumping Bout

The subject began standing centered above the large "X" in the middle of the testing area with both hands on their hips, facing the frontal plane camera. When ready, the subject began performing consecutive submaximal vertical jumps for 60 seconds.

Of interest to the researchers for this paper was the data from the SLCM trials, both pre- and post-fatiguing bout. The mean power output (see Equation 1) and contact time for each leg was averaged over the three trials pre- and post-fatigue. An ASI measure was also calculated from the averaged data to determine the percent difference in mean power output and contact time between legs before and after a fatiguing bout.

Equation 1. Calculation of power output (W/kg) from the OptoGait™ software; where g = acceleration due to gravity, T_f = flight time, and T_c = contact time.

$$P = \frac{g^2 \bullet T_f \, (T_f + T_c)}{4 \bullet T_c}$$

Data Analysis

Pre-fatigue and post-fatigue values of power output and contact time were compared for both the dominant and non-dominant legs using Paired T-tests. Pre-fatigue and post-fatigue values of ASI were also compared using Paired T-tests. Statistical significance was accepted at the $p < 0.05$ level.

Results

Statistical analysis indicated that the mean pre-fatigue and post-fatigue values of power output of the non-dominant leg were significantly different ($p < 0.05$). Analysis also detected statistically significant differences ($p<0.05$) between the pre-fatigue and post-fatigue values of ASI. Significant differences were not observed in values of contact time and between legs or between pre-and post-fatigue conditions.

Table 2. *P* values for power output and contact time based on the state of fatigue and limb of interest (where applicable).

Variable	*P* value
Power Output	
ASI	*0.04**
Pre/Post (D)	0.147
Pre/Post (ND)	*0.005**
Contact Time	
ASI	0.501
Pre/Post (D)	0.837
Pre/Post (ND)	0.924

**significant difference identified (p<0.05)*

D = dominant leg; ND = non-dominant leg; ASI = Average Symmetry Index

Discussion

As expected, power output was observed to decrease immediately after a 60-second fatiguing bout. Interestingly, only the decrease in power output from the non-dominant leg was significantly different when comparing pre- and post-fatigue conditions. This indicates that the non-dominant leg fatigued more quickly than the dominant leg while performing the double leg task. When performing double leg landings, both legs will be able to absorb and dissipate the impact forces together. Under these circumstances, the decrease in ability of the non-dominant leg will be masked by the work of the dominant leg to complete the task.

In sport, however, players are often required to perform unilateral landings throughout the competition. As the player becomes fatigued over the course of the match or game, the non-dominant leg will still be required to perform single-leg landings under fatigued conditions. The non-dominant leg is now in a compromised position as it may not be able to withstand the load incurred at landing. For example, if the gluteus medius is not able to generate the amount of force required to keep the thigh in line with the hip when fatigued under intense loads, the thigh will begin to adduct towards the midline of the body, causing the knee to move into a valgus position. This alignment is often associated with an increased potential for injury at the knee (e.g. ACL tear or rupture) and is one of the characteristics of the "position of no return" [18].

Assessments that identify characteristics that are linked or associated with increased risk for lower body injury are typically performed when the participants are not fatigued. In most cases, the participants have undergone a 10-15 minute standardized general (and possibly an additional specific) warm-up, followed by a brief familiarization period [4,7,12,14,19,20]. When the subjects are being tested, they are performing the movements (jump take-offs and landings, cutting tasks, etc.) under relatively un-stressed physical conditions. While this information is valuable for identifying those athletes that are naturally predisposed to incurring a lower body injury, it may mask the dangers that begin to present themselves once the participant begins to tire, similar to that experienced throughout the duration of a game or match. It is most concerning when an athlete presents no sign of asymmetries prior to fatigue, but is flagged as high risk (ASI values greater than 15%) when fatigued.

Conclusion

While this brief assessment was a preliminary study to the upcoming investigation focusing on a larger sample population, it indicates that there is the potential to be over looking athletes that may truly be in the high risk category as the game or match continues. Being able to identify such athletes in order to develop training protocols to help minimize asymmetries is essential in optimizing performance while minimizing injury.

Future research in this area will not only address a larger population of both male and female athletes, it will also investigate additional characteristics previously identified as those that predispose athletes to non-contact lower body injury in pre-and post-fatigue conditions. Additionally, unilateral jumping performance (both take-off and landing) will be assessed across multiple directions (vertical, horizontal and lateral) as previous research has indicated that performance across these directions is independent of each other [12]. For example, an athlete performing well in one direction may not perform as equally well in another.

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