THESIS

THE EFFECT OF FATIGUE ON GROUND REACTION FORCE ASYMMETRIES

IN JUMPS AND HOPS

Submitted by

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ABSTRACT

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INTRODUCTION: Functional movement assessments (FMAs) have gained popularity for screening athletes to determine deficits in movement quality that could increase the risk for injury. Several multi-component FMAs exist, but few use demanding jump tasks for assessment. The two-legged countermovement jump (CMJ) and the single-leg hop (SLH) for distance have been common clinical FMAs to assess for levels of asymmetries in athletes due to their ease of application and similarity to sport play. Injuries occur at greater rates when athletes are fatigued, yet FMAs are often administered when they are fresh. It possible that fatigue and asymmetries interact to increase the injury risk in athletes during athletic tasks. PURPOSE: The goal of this investigation was to analyze the vertical ground reaction forces (GRFv) in the CMJ and SLH and the anterior-posterior GRF (GRFap) in the single-leg landing in young, healthy, recreationally active men and women. It was hypothesized small asymmetries would exist in pre fatigue measures and would decrease in the CMJ as a result of fatigue, but that there would be increases in asymmetry in the SLH landing. Lastly, these measures would be highly repeatable day-to-day. METHODS: Seventeen injury free and recreationally trained subjects (9 men, 8 women) (mean ± SD age: 22.3 ± 2.5 yrs; height 170 ± 9.3 cm; mass 73.4 ± 13.8 kg) performed five maximum effort CMJ pausing to reset one foot on each force platform before performing subsequent jumps. Following this subjects performed three single-leg hops from one force platform to another over a distance of 50 cm (20 in) and make a stable landing. Subjects performed a fatiguing protocol that involved five sets of eight repetitions with 90% of their predetermined eight-repetition maximum (8RM 113 ± 35 % of their body mass). Following fatigue, the subjects repeated the CMJ and SLH landing protocols. The results of the five CMJ were averaged and GRF data on each limb was divided by the total to assess asymmetries in GRFv average and maximum pre and post fatigue. The average of three SLH for

each limb was averaged and divided by bodyweight to normalize asymmetries. Eight subjects were reassessed for repeatability measures. RESULTS: There was evidence of initial asymmetries in the CMJ and SLH landing. The fatigue protocol was validated by a significant reduction in jump height ($p<0.001$), but there were no significant changes in the relative (L-R%) levels of GRFv asymmetries for average ($p=0.437$) or maximum ($p=0.294$). Absolute changes to GRFv asymmetry (|L-R%|) are used to detect the magnitude of asymmetry change that may be lost in side-to-side averages. Absolute GRFv average (|L-R%|) and absolute GRFv maximum (|L-R%|) did not reach statistical significance ($p=0.705$ and $p=0.983$, respectively), indicating that the levels of asymmetry in the CMJ was unchanged by fatigue. Only one measure in the SLH landing reached statistical significance, absolute GRFv maximum (|L-R%|) ($p=0.031$). The CMJ was highly repeatable day-to-day and only two measures had acceptable repeatability in the SLH landing: GRFv maximum pre fatigue (L-R%) ($\alpha=0.746$) and GRFv average post fatigue ($\alpha=0.665$). CONCLUSION: These results suggest that functional asymmetries, though low, were present and remained constant with fatigue in the CMJ. Absolute GRFv maximum (|L-R%|) was the only SLH variable that supported the hypothesis. All other measures did not increase as expected. The CMJ was highly repeatable, but measures in the SLH were not. Repeatable and reliable assessments are important for detecting injury risk in athletes prior to starting a season or returning from injury. Future research is needed to determine the most valuable FMAs for detecting asymmetries and in populations that have higher rates of asymmetry.

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CHAPTER I

INTRODUCTION

Musculoskeletal injuries are an accepted risk by athletes participating in sports. Lower extremity injuries occur in 15% of males and females playing sports at the high school level (McGuine et al., 2017). One of the most common orthopedic surgeries is to the anterior cruciate ligament (ACL) (Mall et al., 2014). Beyond the short- and long-term consequences of an ACL injury, it presents a high economic cost for athletes and organizations (Gottlob & Baker, 2000). Noncontact injuries, those that do not involve another player, account for approximately 70-84% of all ACL tears in soccer (Alentorn-Geli et al., 2009), suggesting that the majority of these injuries could be avoided.

In an attempt to mitigate injury, clinicians have used functional movement assessments (FMAs) to identify risk of injury, clear athletes for return-to-play after injury, and predict performance (S. Chalmers et al., 2018; Samuel Chalmers et al., 2017; Chapman, Laymon, & Arnold, 2014; Kiesel, Plisky, & Voight, 2007; Leeder, Horsley, & Herrington, 2016; Lockie et al., 2015; Minick et al., 2010; Parchmann & McBride, 2011). FMAs typically assess movement quality, which is described as an individual's ability to perform a specific movement task or pattern in an optimal manner (Kritz, Cronin, & Hume, 2009). Poor movement quality is considered to be the result of a disruption in the balance of agonist, antagonist, or synergist muscle function to move and support joints during purposeful movement, resulting in the limited capacity to perform these fundamental movements (Bennett et al., 2017; Hotta et al., 2015). Many FMAs assess asymmetries between the left and right sides of the body as side-to-side differences in athletes have been shown to increase the incidence of injury (Bennett et al., 2017; Hewett et al., 2005; Knapik, Bauman, Jones, Harris, & Vaughan, 1991). Out of eleven popular multi-component FMAs only four have the intended use for general athletic populations, and only two of those use highly demanding jumping tasks for assessment (Bennett et al., 2017). These popular FMAs seek to quantify

movement quality, but there are asymmetries in the forces subjects are exposed to that clinicians and others administering a test may not be able to critically appraise with these FMAs.

While they haven't been incorporated into many of the multi-component FMAs, the two-leg countermovement jump (CMJ) and single-leg hop (SLH) for distance are common individual FMAs and have been the most researched for lower-extremity asymmetries in athletes due to their ease of application and similarity to movement during sport play (Bishop, Turner, Jarvis, Chavda, & Read, 2017). [Note: a hop differentiates itself from a jump in the requirement of the same takeoff and landing leg.] The overall performance of the SLH and two-legged CMJ have been associated with the strength and power of the performer (Augustsson et al., 2006; Impellizerri, Rampinini, Maffiuletti, & Marcona, 2007; Newton et al., 2006; Tomioka, Owings, & Grabiner, 2001a; Tsiokanos, Kellis, Jamurtas, & Kellis, 2002). It is assumed that for best performance and reduced risk, limbs should contribute equally to the height or performance achieved in these tasks. However, ground reaction force (GRF) asymmetries exist in healthy people in both bilateral and unilateral jumps (Challis, 1998; Impellizerri et al., 2007; Lawson, Stephens, Devoe, & Reiser, 2006; Newton et al., 2006; Skelton, Kennedy, & Rutherford, 2002; Stephens, Lawson, DeVoe, & Reiser, 2007; Stephens, Lawson, & Reiser, 2005).

Asymmetries in jumps are task specific (Benjanuvatra, Lay, Alderson, & Blanksby, 2013; Johnston, Butler, Sparling, & Queen, 2015) but in clinical settings are often based on performance outcomes (such as jump height or distance) (Barber, Noyes, Mangine, McCloskey, & Hartman, 1990; Gustavsson et al., 2006; Noyes, Barber, & Mangine, 1991; Orishimo & Kremenic, 2006), rather than on GRFs. Performance asymmetries are also found in SLH and single-leg vertical jumps (Itoh, Kurosaka, Yoshiya, Ichihashi, & Mizuno, 1998; Stephens et al., 2005; van Soest, Roebroeck, Bobbert, Huijing, & van Ingen Schenau, 1985). It is suggested that successful sport participation involves the ability to demonstrate movement quality with single-leg jumping and landing (McKeown, Taylor-McKeown, Woods, & Ball, 2014). Sport movements occur on one leg at a time and the SLH for distance has been specifically validated as an FMA that discriminates between levels of asymmetry (Augustsson et al., 2006; Fitzgerald, Lephart, Hwang, & Wainner, 2001; Gustavsson et al., 2006; Itoh et al., 1998; Johnston

et al., 2015; Noyes et al., 1991; E. Pappas & Carpes, 2012; P. Pappas, Paradisis, & Vagenas, 2015; Swearingen et al., 2011).The numerous classifications of asymmetry and the uncertainty of covariance between jumps warrants further investigation into asymmetries (Bishop et al., 2017; Santamaria & Webster, 2010). Therefore, to get a more complete picture of asymmetry, a battery of tests should be included to account for differences observed in SLHs and CMJs.

The countermovement to toe-off phase in the CMJ will be analyzed. The CMJ has been proven to be reliable and valid for the evaluation of asymmetries (Impellizerri et al., 2007; Jones & Bampouras, 2010). The landing phase will not be analyzed in order to remove task constraints that may artificially promote symmetry (i.e., forcing the subject to jump straight up and down in order to land with one foot on each force platform).

The SLH is preferred to the single-leg vertical jump in the present study due to its ability to evaluate functional performance during the landing phase after an ACL injury (Barber et al., 1990; Itoh et al., 1998; Juris et al., 1997). Interlimb differences in eccentric forces, such as those that dominate the landing phase (when many injuries occur), are relevant to assessing asymmetry and injury risk (Bishop et al., 2017). Several studies have investigated the utility of landing tests as FMAs (Augustsson et al., 2006; Gustavsson et al., 2006; Orishimo & Kremenic, 2006). It has been noticed that asymmetries present differently during the concentric and eccentric phases of a jump (Jordan, Aagaard, & Herzog, 2015), with key differences noted in comparisons between single-leg and double-leg landings (Erik A Wikstrom, Powers, & Tillman, 2004; Yeow, Lee, & Goh, 2011a). In particular, the SLH stresses the ACL maximally at peak vertical GRF (GRFv), suggesting that peak GRFv may predict the risk of non-contact ACL injury (Cerulli, Benoit, Lamontagne, Caraffa, & Liti, 2003). FMAs seeking to mitigate injury risk should include tests that assess rapid deceleration observed in sport, particularly the SLH.

FMAs are usually performed with few repetitions when athletes are not yet fatigued (Augustsson et al., 2006). Most injuries have been observed to occur late in games once fatigue sets in, implicating fatigue as an independent risk factor for injury (Price, Hawkins, Hulse, & Hodson, 2004). Fatigue leads to a reduction in movement coordination (Sparto, Parnianpour, Reinsel, & Simon, 1997), motor control

precision (Parnianpour, Nordin, Kahanovitz, & Frankel, 1988), muscle reaction times (Häkkinen & Komi, 1986), and proprioceptive capabilities (Skinner, Wyatt, Hodgdon, Conard, & Barrack, 1986). All of these could change the outcome of an FMA and the expression of asymmetry. In fact, it has been shown that hop tests have greater discrimination when fatigue is present (Augustsson et al., 2006).

However, little information exists regarding asymmetries and fatigue. The squat, a functional movement closely correlated to the CMJ (Nuzzo, McBride, Cormie, & McCaulley, 2008), has shown to slightly decrease GRFv asymmetries with fatigue in healthy populations (Hodges, Patrick, & Reiser, 2011). The squat exercise models the eccentric-concentric task demands athletes experience. Because it causes minimal disruption to GRFv asymmetries, if any, it is a useful tool inducing fatigue and independently assessing its effects on asymmetries in various FMAs.

Different means of fatigue may elicit different biomechanical effects and/or compensatory strategies (Santamaria & Webster, 2010; Tibone, Antich, Fanton, Moynes, & Perry, 1986). Interpreting the effects of jumps and hops across studies may be inappropriate as some studies have found decreases in GRF and joint flexion during landings (Bruggemann & Arndt, 1994; Christina, White, & Gilchrist, 2001; Madigan & Pidcoe, 2003; Nummela, Rusko, & Mero, 1994) while others have found contradictory results (Bonnard, Sirin, Oddsson, & Thorstensson, 1994; Gollhofer, Komi, Miyashita, & Aura, 1987; J. A. Nyland, Caborn, Shapiro, & Johnson, 1997a; John A. Nyland, Shapiro, Stine, Horn, & Ireland, 1994) To understand the relationship fatigue has on asymmetries it is necessary to induce fatigue with demands that are functionally similar to what athletes are exposed to during sport. Athletes accrue fatigue through functional movements that require high forces and the stretch shortening cycle. FMAs should mimic these task demands too since the ultimate goal of functional assessments is to take research and apply it to testing in the real world. Furthermore, the relationship of asymmetries should be compared across multiple FMA jump tasks to better understand how varying tasks detect asymmetries. Finally, to be incorporated into an FMA for predictive purposes, the movements used should have high day-to-day repeatability.

Statement of Goals

The goal of this investigation was to analyze how fatigue changed the relative and absolute expression of GRF asymmetry in the CMJ and SLH landings in young, healthy, and recreationally active men and women. A secondary goal was to determine the day-to-day repeatability of measures taken in the countermovement jump and single-leg landing.

Hypotheses

We hypothesized that a small asymmetry would exist in healthy individuals (producing or absorbing more force off one leg than the other) prior to fatigue. Based off using the squat as our means of fatigue induction, which has been shown to reduce asymmetries in healthy populations, we hypothesized that GRF asymmetry measures taken in the CMJ would decrease with fatigue. However, fatigue has been shown to increase the sensitivity of hop tests and we hypothesized that the asymmetries would increase in the SLH landings. We hypothesized the evidence of fatigue would exist through a decrease in maximal jump height and measures would be highly repeatable day-to-day.

CHAPTER II

LITERATURE REVIEW

Introduction

Non-contact injuries are a problem in athletics. Currently, functional movement assessments (FMAs) are designed to screen for injuries. Several multi-component musculoskeletal FMAs exist, but very few use highly demanding tasks that athletes will experience as part of sport, namely jumps. Clinicians and researchers have studied jumps and hops as FMAs to discern injury risk and return to play for athletes. It is commonly known that lower limb asymmetries increase risk for lower extremity injuries; therefore, it is important to include jumping and hopping FMAs when assessing for lower extremity asymmetries in athletes [Note: Hopping is different from jumping in that it involves a single-leg takeoff and ipsilateral landing, and typically occurs for horizonal distance]. Most FMAs occur outside the laboratory, and access to force platforms is not readily available. The ultimate goal of FMAs create valid tests for clinical application, yet little is known about lower extremity ground reaction force asymmetries (GRFA) and their significance. Currently, FMAs are performed while athletes are fresh. Most injuries occur at the end of a match when the athletes are fatigued. Therefore, the goal of this literature review will be to examine how jumps and hops are an integral part of FMAs of lower extremity GRFA. Further, it is to discuss how the take-off and landing phases of jumps and hops can highlight asymmetries with fatigue.

Functional Movement Assessments

Functional assessments rose from the functional training boom of the 1990s. The term functional training was popularized when "functional" was a label for training and rehabilitation exercises that are a part of, or focused on, natural movement patterns required throughout activities of daily living (Arnason et al., 2004). Typical functional assessments include squatting, jumping, hinging, lunging, pushing, pulling, balancing, bracing, and mobility tests (Bennett et al., 2017). As a result, functional training seeks

to practice and simulate the situational needs and constraints of real-life activities, including sport events to enhance training effectiveness (Ives & Shelley, 2003). By extension, functional assessments should assess the musculoskeletal, physiological, and cognitive demands of an athlete.

Researchers and clinicians use functional assessments as a screen for future injury, specifically non-contact injuries. Non-contact injuries are significant in the National Collegiate Athlete Association (NCAA), yet research has not provided clear direction with regard to contact and overuse injuries (Warren, Smith, & Chimera, 2015). Because asymmetries exist in healthy individuals as well as those returning from injuries, such as anterior cruciate ligament reconstruction (ACLR), the goal of many functional assessments is to ascertain how asymmetries impact risk. Anterior cruciate ligament (ACL) injury prevention programs have produced equivocal results (Hewett, Lindenfeld, Riccobene, & Noyes, 1999) and the variables responsible for success need to be validated.

FMAs typically assess movement quality, which is described as an individual's ability to perform a specific movement task or pattern in an optimal manner (Kritz et al., 2009). Poor movement quality is considered to be the result of a disruption in the balance of agonist, antagonist, or synergist muscle function to move and support joints during purposeful movement, resulting in movement compensations that reduce physical performance or increase injury risk (Bennett et al., 2017; Hotta et al., 2015). Many FMAs assess asymmetries between the left and right sides of the body as side-to-side differences in athletes have been shown to increase the incidence of injury (Bennett et al., 2017; Hewett et al., 2005; Knapik et al., 1991). Out of eleven popular multi-component FMAs only four have the intended use for general athletic populations, and only two of those use highly demanding jumping tasks for assessment (Bennett et al., 2017). The popular multi-component FMAs have limited capacity to predict injury risk due to the simple scoring methods that lack sensitivity (Bennett et al., 2017). These FMAs seek to quantify movement quality, but there are asymmetries in the forces subjects are exposed to that clinicians and others administering a test may not be able to critically appraise with these FMAs.

Jumps and hops are currently used as functional tests to clear athletes to return to play (Augustsson et al., 2006; Barber et al., 1990; Gustavsson et al., 2006; Noyes et al., 1991). These tests aim

for 85-90% or greater symmetry to pass because musculoskeletal asymmetry is a risk factor for injury (Knapik et al., 1991; Yeung, Suen, & Yeung, 2009). Musculoskeletal injuries have been shown to be occur at the highest rates during competition (Faude, Junge, Kindermann, & Dvorak, 2005). This could be attributed to neuromuscular fatigue leading to a reduced control during cutting, landing, or running (Chappell et al., 2005; Derrick, Dereu, & McLean, 2002; Kernozek, Torry, & Iwasaki, 2008; TSAI, SIGWARD, POLLARD, FLETCHER, & POWERS, 2009). It is reasonable to conclude that FMAs for athletes must have athletic demands in order to gather meaningful data about an athlete's preparedness and injury risk. The need for research investigating asymmetries in jumps and hops is necessary for creating suitable FMAs for athletes.

In studies that have examined FMAs in athletes, significant differences were found between the dominant and non-dominant limbs in peak force and average force during the squat, single- and double-leg vertical jumps, isokinetic extension and flexion at peak torque during a five hop test (Newton et al., 2006). There was a slight negative correlation ($r = -0.62$) between peak GRF asymmetry in single- and double-leg jumps reported which suggests that participants became more symmetric in one task while more asymmetric in the other (Jones & Bampouras, 2010; Newton et al., 2006). Stephens et al. (2007) had similar findings and suggested that the carryover of asymmetries from a unilateral task may not be present in a bilateral task. It has been noted before that asymmetries may be task specific which highlights the need for an FMA with multiple jumps to detect asymmetries (Benjanuvatra et al., 2013).

Sports performance and injury risk are complex and multi-faceted. Attempting to extrapolate an assessment of movement quality does not appear to have a strong correlation to these variables (Bennett et al., 2017). To understand risk a more complete FMA profile must be developed involving the use of jumps and hops and the forces involved.

Jumping Asymmetries

The maximum effort jump is a complex movement that involves the upper and lower extremities coordinating to produce maximum power. Both double- and single-legged jumps and landings have been used to ascertain lower limb asymmetries. For this reason they are used clinically as FMAs to evaluate

performance, return-to-play following injury, and functional strength asymmetries (Impellizerri et al., 2007) . This section explores kinetic determinants of maximal and submaximal jumps, bilateral versus unilateral jumps, and asymmetry in jumps.

In a bilateral countermovement vertical jump (CMJ), the performance is tied to the impulse generated by the lower body before ground-off. The magnitude of the average vertical GRF (GRFv) and the time it is applied are fundamental to jump performance (Brughelli & Cronin, 2008). Performance in single- and double-leg jumps has been linked to the strength and power of the performer (Augustsson & Thomee, 2000; Newton et al., 2006; Tomioka, Owings, & Grabiner, 2001b). In sports, not every jump is maximal nor a bilateral sagittal plane movement. The strategy to execute a submaximal jump differs from a maximal jump. Specifically, submaximal jumps generate the necessary impulse primarily through a larger peak GRF since the ground contact time is shorter (Salles, Baltzopoulos, & Rittweger, 2011). It is plausible that this would alter the muscular function and create differences in asymmetries as interlimb differences may occur as a result of imbalances in specific muscle groups on contralateral sides thereby altering movement strategy. For example, the non-dominant leg has been found to act as a stiffer spring in a single-leg vertical jump and drives asymmetric performance over time (Flanagan & Harrison, 2007).

Maximal jumps involve greater countermovement of the trunk than submaximal jumps (Lees, Vanrenterghem, & De Clercq, 2004; Vanrenterghem, Lees, Lenoir, Aerts, & De Clercq, 2004). The mechanical energy necessary for maximal effort jumps comes from hip and thigh musculature (Fukashiro & Komi, 1987; Rodacki, Fowler, & Bennett, 2002) with the knee joint contributing 49% of the total work done (Hubley & Wells, 1983; Impellizerri et al., 2007). As intensity increases from submaximal to maximal, the data suggest it is the hip extensor musculature that is responsible as the work done at the ankle and knee remain relatively unchanged (Lees et al., 2004). Contributions from the ankle and knee maximized around 50-75% of maximal intensity (Vanrenterghem et al., 2004). The initial expectation with a double-leg vertical jump is that both limbs will contribute equally to the height achieved.

Assessments of bilateral jumps and unilateral hops do not reveal a 50%-50% contribution in most individuals (Lawson et al., 2006; Newton et al., 2006; Stephens et al., 2007). Depending on the style of

jump used, there may be great variance among strategies employed by each limb. For example, when comparing the lead leg in a step-close jump to the same leg in a countermovement jump there are greater maximum and average vertical GRFs in the hip, knee, and ankle with greater minimum angles at the hip, knee, and ankle suggesting it is a fixed joist that is loaded as the trail leg is loaded (Lawson et al., 2006). This differs from a standard countermovement or drop jump and highlights that differences in task demands lead to specific task-asymmetry. In other words, some jumps show greater performance of the dominant limbs while others show bias toward the non-dominant limb (Loffing, Sölter, & Hagemann, 2014).

It is assumed that for best performance and reduced risk, limbs should contribute equally to the height or performance achieved in these tasks. However, ground reaction force (GRF) asymmetries exist in healthy people in both bilateral and unilateral jumps (Challis, 1998; Impellizerri et al., 2007; Lawson et al., 2006; Newton et al., 2006; Skelton et al., 2002; Stephens et al., 2007, 2005). Because of this, our rationale was to determine the effects of GRFA in a battery of FMAs. The first jump we chose was the CMJ since it has been previously validated to determine GRFA (Impellizerri et al., 2007).

One challenge in the evaluation of asymmetry in the laboratory is the standardization of protocol that may not reflect jumps used in athletics. A sport jump is often preceded by a run-up which significantly decreases the take-off time when compared to a CMJ and reflects a more elastic strategy for jumping success (Bobbert, 2001). In soccer, for example, most jumps occur with the intent of heading a ball. This involves an approach to takeoff that rarely occurs in a controlled linear or vertical plane. It has been found that soccer-specific vertical jumps weakly to moderately correlate to a CMJ when considering critical jump variables (Requena et al., 2014). Despite this, it has been found that sporting success requires proficiency in single-leg jumping and landing since most sporting events occur on one leg at a time (McKeown et al., 2014). Since one style of jump may not reveal the breadth of asymmetries in an individual and athletes are required to perform on leg at a time, it is essential to include single-leg tasks in FMAs for athletes.

Single-Leg Landings

Force production is one end of the spectrum when it comes to jumping. In sport, force reduction is associated with landing, deceleration, cutting, and pivoting. In multi-directional women's sports, 60-70% of ACL injuries occur via a non-contact mechanism (Agel, Arendt, & Bershadsky, 2005; Piasecki, Spindler, Warren, Andrish, & Parker, 2003). Great impact forces from landings are considered a risk factor for injuries, particularly to the ACL (Chappell et al., 2005; Chappell, Yu, Kirkendall, & Garrett, 2002; Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; Devita & Skelly, 1992; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). Among the non-contact injuries, jump landings and tasks involving rapid deceleration pose the greatest risk for injury (Boden, Dean, Feagin, & Garrett, 2000; Olsen, Myklebust, Engebretsen, & Bahr, 2004).

Asymmetries found in bilateral jumps may not relate to those asymmetries in unilateral jumps (Benjanuvatra et al., 2013); this provides support to other research groups attempting to find FMAs that are both sensitive and specific to asymmetries (Greenberger & Paterno, 1995; Newton et al., 2006; Ostenberg, Roos, Ekdahl, & Roos, 1998; Petschnig, Baron, & Albrecht, 1998). One in particular, the SLH, is preferred to the single-leg vertical jump in the present study due to its ability to evaluate functional performance during the landing phase after an ACL injury (Barber et al., 1990; Itoh et al., 1998; Juris et al., 1997). Interlimb differences in eccentric forces, such as those that dominate the landing phase (when many injuries occur), are relevant to assessing asymmetry and injury risk (Bishop et al., 2017). A threshold of 10-15% is considered a problematic difference between limbs requiring attention (Hoffman, Ratamess, Klatt, Faigenbaum, & Kang, 2007; McElveen, Riemann, & Davies, 2010; Myer et al., 2011). However, this is loosely defined as those with less than 10% asymmetry may experience injury and those with over 15% asymmetry may not. It is unknown how this threshold stands up outcome measures across jump variations (Meylan et al., 2009) or if it is valid with GRFA. Clinicians are expected to have benchmarks for when an injured athlete should return to play, and as it stands there is no widely established criteria.

The utility of landing tests as FMAs to establish return-to-play clearance for injured athletes because landings are important in the context of both athletic performance and injury risk, (Augustsson et al., 2006; Gustavsson et al., 2006; Orishimo & Kremenic, 2006). However, there are key differences in force absorption in single-leg landings compared to double-leg landings (E A Wikstrom, Tillman, Schenker, & Borsa, 2008; Yeow et al., 2011a). This is relevant to limb-to-limb differences in the lower body post-injury. The double-legged landing is superior in shock absorption and injury minimization of the lower extremity when compared to a single-leg landings (E. Pappas, Hagins, Sheikhzadeh, Nordin, & Rose, 2007). This is due to the landing style which is stiffer with decreased range of motion at all joints in single-leg landings (Devita & Skelly, 1992; Zhang, Bates, & Dufek, 2000). Several key variables more prevalent during single-leg landings have been linked to knee injury (Boden et al., 2000; Hewett et al., 2005) or increased forces on knee ligaments (Markolf, O'Neill, Jackson, & McAllister, 2004): decreased joint power and eccentric work performed in a single-leg landing or landing from a greater height (Yeow, Lee, & Goh, 2011b), decreased knee flexion at initial contact, increased knee valgus, and increased rectus femoris electromyography (EMG) activity (E. Pappas et al., 2007). It's possible that the strategies employed in a single-leg landing utilize static structures for force absorption (Heebner et al., 2017). Based on the available evidence and the fact that athletes perform many movements unilaterally, it is essential to incorporate single-leg landings in the evaluation of athletes as they likely pose the greatest threat.

Single-Leg Hops For Distance

Prospective data from Hewitt et al. (2005) showed that uninjured females who went on to suffer a non-contact ACL injury displayed 20% higher vertical GRF in the drop vertical jump with a 16% shorter stance time. Decreasing stance time and increasing loading creates a larger impulse during a drop jump landing. Asymmetries in landing, especially in single-leg landing can expose athletes to the high tensile forces necessary for ACL rupture (Boden et al., 2000; Hewett et al., 1999).

With respect to ACL testing, the SLH stresses the ACL maximally at peak vertical GRF (GRFv) during landing, suggesting that peak GRFv may predict the risk of non-contact ACL injury (Cerulli et al., 2003). The SLH is used to assess asymmetries, but success in the maximum hop for distance is largely

predicated on the ability to make a stable landing. There is reportedly no significant differences in the GRF between dominant and non-dominant legs in maximum SLH for distance in healthy subjects, however the non-dominant leg has been shown reduced performance (i.e., distance jumped) indicating a disparity in the ability of limbs to absorb force. (Van Der Harst, Gokeler, & Hof, 2007).

The distinction between the dominant and non-dominant leg is often unclear. Studies have identified the dominant leg as the kicking leg (Meylan et al., 2009; Theoharopoulos, Tsitskaris, & Nikopoulou, 2000) the stronger leg (Impellizerri et al., 2007), the foot used to initiate stair climbing (Ceroni, Martin, Delhumeau, & Farpour-Lambert, 2012), the leg used to regain balance after unexpected perturbation (Hewit, Cronin, & Hume, 2012), and the side with the highest single-leg jump height (Ceroni et al., 2012; Stephens et al., 2007, 2005). For injured populations, it is easy to use the uninjured limb as the reference limb when attempting to achieve 85-90% symmetry. Some studies show greater performance on a self-determined non-dominant leg versus a self-determined dominant leg (Aizawa, Hirohata, Ohji, Ohmi, & Yagishita, 2018; Schiltz et al., 2009; Stephens et al., 2007). Regardless, performance seems to be task dependent with respect to which leg is dominant (Fort-Vanmeerhaeghe, Montalvo, Sitjà-Rabert, Kiefer, & Myer, 2015). Still asymmetries have been found the lower extremity in a variety of activities including basketball athletes (Schiltz et al., 2009; Theoharopoulos et al., 2000), volleyball athletes (Lawson et al., 2006), softball athletes (Newton et al., 2006), cycling (F P Carpes, Rossato, Faria, & Bolli Mota, 2007; Felipe P Carpes, Mota, & Faria, 2010), running (Zifchock, Davis, Higginson, Mccaw, & Royer, 2008), and gait (Radzak, Putnam, Tamura, Hetzler, & Stickley, 2017; Sadeghi, Allard Able-Bodied Subjects, & Duhaime, 1997; Sadeghi, Allard, Prince, & Labelle, 2000). Quantification of asymmetries is important in being able to define the meaning of asymmetries and detect those who are at risk. GRF asymmetries are a way to consistently measure asymmetries and compare the results of several studies that may further elucidate the relationships between asymmetry and injury risk.

FMAs are usually performed with few repetitions when athletes are not yet fatigued (Augustsson et al., 2006). Most injuries have been observed to occur late in games once fatigue sets in, implicating

fatigue as an independent risk factor for injury (Price et al., 2004). The next section will explore fatigue

and its relationship to jumps and asymmetries.

Fatigue

Fatigue is any reduction in the force capacity of the total neuromuscular system regardless of the

force required in any given situation (Bigland-Ritchie, 1984). When fatigue is present, one must increase

motor unit recruitment in order to meet task demands or suffer an inability to continue performing the

task at the required level. Beyond a reduction in force producing capabilities, fatigue leads to a reduction

in movement coordination (Sparto et al., 1997), motor control precision (Parnianpour et al., 1988), muscle

reaction times (Häkkinen & Komi, 1986), and proprioceptive capabilities (Skinner et al., 1986). The

combination of reduced force output and muscle activation timing may affect joint stabilization, kinetics,

and kinematics of closed chain movements (Vila-Cha, Carvalho, Machado, Conceicao, & ilas Boas,

2005). Fatigue increases the risk for lower limb injury by decreasing coordination and muscle shock-

absorbing capacity (James, Scheuermann, & Smith, 2010).

From the beginning of exercise, the capacity to generate maximal force declines, and therefore

fatigue beings once exercise starts (Byrne & Eston, 2002). Fatigue accumulates during submaximal tasks

even if task failure is not achieved because new motor units can be recruited to compensate for fatigued

ones (Taylor & Gandevia, 2008). However, fatigue does expand more slowly during submaximal than

maximal contractions (Taylor & Gandevia, 2008). An inability to mitigate or recover from fatigue may be

a reason why fatigue is considered an independent risk factor for injury (Price et al., 2004).

Athletes that are fatigued are more prone to injury and are observed to have limb landing

kinematics that result with increased ACL loading (BELL, TRIGSTED, POST, & WALDEN, 2016;

Jordan et al., 2015). Research using the barbell squat suggest that those with small levels of asymmetry to

begin with become more symmetric or do not change as a result of fatigue (Hodges et al., 2011). Those

with ACLR were shown to decrease their asymmetries in the barbell back squat as a result of fatigue

(Webster, Austin, Feller, Clark, & McClelland, 2015). Those with ACLR have also been shown in

increase symmetry with fatigue in jumping (Jordan et al., 2015). Peddling velocity, and presumably an

increased rate of fatigue accumulation, has been shown to increase symmetry (Felipe P Carpes et al., 2010). Repeated Treadmill sprints have also been shown to fatigue legs at the same rate with no evidence of asymmetry (Girard, Brocherie, Morin, & Millet, 2017) and running has not created alterations in runners (Brown, Zifchock, Hillstrom, & Assistant, 2014), however those with higher levels of performance have been shown to be more symmetrical so caution is advised when interpreting these results (Lehance, Binet, Bury, & Croisier, 2008; Manning & Pickup, 1998).

It is unclear what should happen to GRFA as a result of fatigue. It is generally assumed that the dominant and non-dominant limb will fatigue at different rates thereby affecting the kinetics, kinematics, and performance of the task. For example, the dominant leg could take on higher loads leading to faster fatigue, thereby reducing GRFA. Or the dominant limb could be the more conditioned due to preference and drive GRFA higher. The data above would seem to indicate the asymmetries lessen with fatigue. However, asymmetries are a focal point in many FMAs and Lessi & Radzack indicate that fatigue could increase asymmetries; therefore, it is important to determine whether fatigue is a factor in asymmetries, and if so to what extent (Lessi & Serrão, 2017; Radzak et al., 2017).

It is speculated that the changes in asymmetries may be evident long before excessive amounts of fatigue are accumulated. In one study a series of five squats and a maximal vertical jump were performed until subjects were unable to continue performing at least three squats. The final attempt was considered 100% fatigue. It was found that most changes in kinematic variables occur between 0-50% fatigue states (Borotikar, Newcomer, Koppes, & McLean, 2008; MCLEAN & SAMOREZOV, 2009).

FMAs screen for potential injury risks before someone participates in activities (Cook, Burton, & Hoogenboom, 2006). Athletes suffer non-contact injuries during the later portion of games(Price et al., 2004; Small, McNaughton, Greig, Lohkamp, & Lovell, 2009), therefore it is speculated that FMAs are more sensitive at detect asymmetries when subjects are fatigued (Augustsson et al., 2006). Athletes fatigue from an accumulation of submaximal work or maximal with intermittent breaks through a variety of movements and task demands, thus inducing fatigue for an FMA is a challenge for practitioners looking to assess an entire team under similar fatigue states (Barber-Westin & Noyes, 2017). The

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challenge increases for researchers as different fatigue protocols have led to different fatigue outcomes (James et al., 2010), although one study examined Division 1 athletes and found that both a short and long fatigue protocol produced similar results (Quammen et al., 2012). This was attributed to the high levels of training of the subjects and unanticipated tasks demands.

It is becoming more popular to use competition as a means of fatigue prior to administration of a FMA (Jordan et al., 2015), but the degree of fatigue can vary by athlete and position. Thus, there are no standardized fatigued conditions during which the FMA is performed, possibly nullifying the findings. Athletic exercise (jumps, weight lifting, etc.) offers a more functional assessment of fatigue that is reproducible. High-intensity strength training protocols have been shown to evoke short-term detrimental effects on jump and strength performance (Ahtiainen, Pakarinen, Kraemer, & Häkkinen, 2003; Babault, Desbrosses, Fabre, Michaut, & Pousson, 2006; Byrne, Twist, & Eston, 2004; Cadore et al., 2013; Chatzinikolaou et al., 2010; Häkkinen, 1993). The squat is a functional movement closely correlated to the CMJ (Nuzzo et al., 2008). The squat exercise models the eccentric-concentric task demands athletes experience. Because it causes minimal disruption to GRFv asymmetries, if any, it is a useful tool inducing fatigue and independently assessing its effects on asymmetries in various FMAs.

The utility of some commercial multi-component FMAs for athletes is equivocal (S. Chalmers et al., 2018; Dorrel, Long, Shaffer, & Myer, 2015; Kiesel et al., 2007; Lockie et al., 2015). Using demanding jumping and landing FMAs can raise the risk of performing an assessment. There is a risk ratio to consider during any assessment, but without knowing the manifestations of fatigue an FMA may not have prognostic value. Fatigue may alter knee kinematics and decrease the ability of shock attenuation in the knee joint (Tamura et al., 2016). Among landings there are common performance characteristics that arise due to neuromuscular fatigue such as decreased hip flexion (Chappell et al., 2005; Rozzi, Lephart, & Fu, 1999), decreased knee extensor moment (Chappell et al., 2005), increased knee valgus angles (Chappell et al., 2005), and increased GRFv (Madigan & Pidcoe, 2003; Rozzi et al., 1999). In fatigued drop landings, subjects land with increased knee flexion, ankle plantar flexion, and increased

peak vertical GRF (Brazen, Todd, Ambegaonkar, Wunderlich, & Peterson, 2010). Testing fresh, as is typical of most FMAs, would miss these changes in performance.

Currently there is no known research that has determined how GRFA change with fatigue in a battery of tests. Therefore, it is necessary to induce fatigue in a way that is reproducible and determine the effects on a battery of highly demanding athletic tasks. For FMAs to be most valid, an understanding of GRF asymmetries is important to understand. Thus far the research community is still unsure how fatigue interacts with asymmetries; bringing attention to this matter could have immense value to injury screening.

Summary/Conclusion

As previously discussed, non-contact injuries impact athletes and organizations and come with a high economic cost. Non-contact ACL injuries are very common and the ACLR is one of the most common orthopedic surgeries. FMAs are useful for determining if someone is at risk for injury, particularly those who are recovering from an ACL injury. The CMJ is a popular athletic FMA due to the rapid stretch shortening cycle prevalent in running, cutting, and jumping. The SLH for distance has been a valid FMA due to the stress it places on the ACL. However, these FMAs have largely assessed performance outcomes rather than the kinetics of the asymmetries. Together, these movements allow for a more complete picture of injury screening by assessing the concentric and eccentric phases of athletic movements. Because a majority of athletes suffer injuries under fatigue, it is necessary to determine the effects of fatigue on asymmetries. Several studies have determined that the method of fatigue and/or the task chosen creates variation in the presentation of asymmetries. Many teams use FMAs for injury screening, but current methods are challenging and time consuming. A high-intensity resistance training protocol using the barbell squat, mainly for its similarities to the CMJ and small impact on asymmetries in healthy individuals, was chosen to induce fatigue. The goals of this study are to assess GRFv asymmetries in the CMJ and SLH and GRFap asymmetries in the SLH pre and post fatigue, while assessing day-to-day repeatability. It is hypothesized that small levels of asymmetry will exist in the CMJ but not change with fatigue. It is also hypothesized that asymmetries will increase in the SLH.

CHAPTER III

MATERIALS AND METHODS

Experimental Approach to the Problem

To accomplish the goals of this investigation, a cross-sectional research design was implemented. Prior to conducting the study, human subjects approval was obtained from the Colorado State University Institutional Review Board (Appendix A). Subjects provided written informed consent (Appendix B) and visited the lab up to three times. The first visit involved verification of eligibility, anthropometric measurements, familiarization to the test protocol, obtaining maximum SLH distance on each leg, and determination of eight repetition maximum (8 RM) for the free-weight barbell back squat. During the second visit, subjects completed five maximal vertical jumps followed by three 50 cm single-leg horizontal hops on each leg, and five sets of eight repetitions (5x8) of the squat with 90% of their predetermined 8 RM. Finally, the jump tasks performed prior to squatting were performed again immediately after completing the squat protocol. In both visits, subjects were allowed ample warm-up and stretching opportunities prior to familiarization with the protocol and data collection. The focus of this analysis was on the bilateral asymmetries in the CMJ and the SLH landing protocols pre and post fatigue. An optional third visit to assess for repeatability of measures was completed by eight subjects. T-tests were performed to assess relative differences in asymmetry pre and post-fatigue and Chronbach's alpha was used to determine day-to-day repeatability.

Subjects

Subjects (n=17: 9 men, 8 women) were non-obese (BMI < 30 kg/m^2), healthy individuals aged 18-30 years recruited mainly from the Colorado State University student population. Subjects were recreational athletes that had been involved in resistance training programs whereby the squat had been incorporated for the past eight weeks (at minimum) and were currently involved in weekly sporting activities that utilized jumping activities (basketball, volleyball, racquetball, etc.). Exclusion criteria

included self-reported pain, injury, and soreness at the time of each visit. Any injuries must have healed

at least four weeks prior to participation and those with a history of back and/or lower limb pain, major

previous surgery, bone, joint, or muscular disorder, history of neurological/orthopedic dysfunction, or

pain that would limit the ability to perform the squat or jumps correctly with maximal effort were

excluded. Any subjects with a known reason to perform the activities asymmetrically were also excluded

(e.g., limb length discrepancy, ACL reconstruction, bilateral corrective devices, highly trained in an

asymmetric skill, etc.). Finally, women who were pregnant at the time of investigation were excluded.

All subjects volunteered freely for the study, there was no monetary compensation.

Procedures

Prior to participation, subjects were contacted either over the phone or in person in order to

complete a brief health and activity questionnaire (Appendix C). Two separate visits to the laboratory

were made by all subjects, each lasting approximately one hour per visit. Subjects were instructed to

abstain from heavy exercise of the lower limbs and back for 48 hours before each visit. Caffeine

consumption was limited to normal daily intake and no other ergogenic aids were allowed for

consumption during the day prior to the visit. All testing on individual subjects was conducted at

approximately the same time of day to avoid the effects of diurnal variations in performance. Details of

each of the two visits are outlined below:

Visit 1- Final eligibility of subjects was determined during this visit along with other key

preliminary functions. If not already obtained, the subjects provided written University approved

informed consent (Appendix B). They were given orientation of the laboratory environment by

laboratory staff followed by collection of standing height and body weight. A five-minute warm-up on a

stationary cycle ergometer was required for all subjects before additional physical exercise. Stretching

was allowed and determined by each individual subject with the provision that a stretch performed on one

side of the body must be performed on the other side with similar intensity. The stretching allowed in the

warm-up was to allow each subject to comfortably prepare for maximal exertion. Three to five sub-

maximal vertical jumps with hands on the hips were practiced, followed by determination of a subject's

maximum SLH distance, which included five to six hops per leg. Proper squat form for each subject was evaluated in order to determine if subjects could properly perform the free-weight barbell back squat exercise using guidelines described in the National Strength and Conditioning Association Position Paper (Chandler & Stone, 1991). Visual verification that the squat was performed correctly was made by laboratory staff who also corrected any technique flaws. Subjects were instructed to wear proper athletic clothing and shoes similar to what they would normally wear during exercise and to wear comparable clothes on the following visit. A lifting belt was made available for those in which it was a part of their normal squat routine. In addition to a standard 22 kg Olympic-sized barbell and weight plates, a "cage"-type squat rack was used with safety pins adjusted to the bottom range of barbell travel (Figure 3.1). Determination of each subjects' 8 RM was established and defined as the weight that could be lifted no more than 8 times with acceptable form. To determine the 8 RM, after a squat specific warm-up of one to two light sets, subjects began with a weight assigned by the investigator based on the individual's current weight training program. Subjects completed up to 10 repetitions of that weight, with the barbell placed wherever they felt it to be comfortable on their shoulders, and were then asked to stop. After a three-minute rest, the weight was increased by 2.27 kg (5 lbs). This procedure continued until an 8 RM was determined. If the initial load was too heavy and 8 repetitions could not be completed, the load was reduced accordingly for the next attempt. A 2.54 cm (1 inch) diameter plastic depth bar was positioned behind the subject at the lowest point of their squat to ensure each repetition was performed the same (Figure 3.1). The depth bar was attached to vertical uprights with Velcro. A successful repetition required the subject to touch the depth bar before initiating the up phase of the squat. Two spotters were utilized during all lift attempts, one on each end of the bar. Verbal encouragement was provided for all exercises.

Visit 2- Completed within two weeks after visit one (except for two subjects who were affected by temporary data capture equipment failure). Ground reaction forces were sampled at 1,000 Hz during all tasks of the Jump Protocol and Fatiguing Squat Protocol (described below) with two commercial force-measuring platforms (model 4060-10, Bertec Corp., Columbus, OH) mounted side-by-side and

flush to the surrounding floor. A third identical force platform was positioned similarly to the front of these two platforms to measure the landings of the single-leg hops.

Jump Protocol - After a warm-up similar to their first visit, subjects stood with feet parallel (one foot completely on each force platform with feet approximately shoulder-width, no stagger) and were instructed to look straight ahead, with their head erect and hands on their hips. Performance of one approved trial consisting of five maximum effort vertical jumps, pausing to reset one foot on each force plate and normalizing bodyweight before performing each subsequent jump. Following this, subjects hopped (single-leg take off, same leg landing) from one force platform to another at a distance of 50 cm (~20 inches). The subjects were required to land without an additional bounce, a twisting or shuffling movement of the foot indicating a loss of balance, or the non-working leg touching the ground. Subjects were required to hop from a specified location and land in an approved landing area ranging from 45-55cm (~18-22 inches). Approved trials consisted of landing in the acceptable zone, with the hands on the hips, and until GRF were stable at the subject's body weight. Three approved trials on each leg, alternating right and left legs, were performed. These vertical jumps and horizontal hops were then completed again, immediately following the fatiguing squat protocol.

Fatiguing Squat Protocol - The same equipment, set up, and squat specific warm-up was used as described in the first visit. Research assistants loaded the squat bar with 90% of the subject's previously determined 8 RM. Subjects then performed five sets of eight repetitions with a three-minute rest between each set. A brief pause between repetitions was inserted via verbal coaching to ensure each repetition was completed before the next was initiated. Bilateral GRFs were recorded during the squats. The squat results were previously published (Hodges et al., 2011).

Repeatability Assessment- In order to verify the reliability of this experimental design, eight subjects returned to the lab a third time to establish day-to-day repeatability of the anthropometric measures, single-leg maximum jumps, and symmetry performance of the Jump and Fatiguing Squat Protocol. A minimum of 48 hours from the second visit was required prior to the third visit, with no more than 2 weeks separating the two (expect for one subject who was affected by temporary data capture

equipment failure). The 1RM squat repeatability has been previously established (Hennessy & Watson, 1994; Sewall & Lander, 1991), as have higher repetition maximums of other exercises (Hoeger, Hopkins, Barette, & Hale, 1990) such as the 8RM used in the present study to generate fatigue.

Data Processing and Analysis

Vertical ground reaction forces (GRFv) were low-pass Butterworth (4th-order, recursive) filtered at 10 Hz to remove noise. The hop landings have a highly variable high frequency peak that occurs shortly after initial contact, thus 10 Hz was deemed appropriate for the hop landings too. The average and peak instantaneous GRFv under each foot during the CMJ and SLH landing were analyzed (Figure 3.2, 3.3). GRFap was analyzed for SLH landings (Figure 3.3)

Subjects were required to remain motionless between each jump to ensure that GRFv at the beginning of the analysis were equal to the subject's bodyweight. Analysis of the lower extremity within each jump began during the countermovement and ended at the end of the propulsion phase when the jumper leaves the ground and GRFv drop to zero. The height of each vertical jump was calculated assuming projectile motion and take-off velocity. Take-off velocity was calculated using the impulse-momentum relationship and the total GRFv. Individual foot GRFvs were normalized by taking the total GRFvs and converting it to a percentage. In this way, a perfectly symmetric repetition would yield a value of 50% under each foot for both the average and peak GRFv. GRFv asymmetry level was then calculated as the left GRFv% minus the right GRFv%, so a value of 2%, for example, would indicate 51% on the left foot and 49% on the right foot and -2% would indicate 49% on the left foot and 51% on the right. Given that our subjects were all right handed and the left leg has been shown to be dominant in many single-leg jumping tasks for right handed individuals, we elected to use the left as the reference value in our asymmetry calculation (Loffing et al., 2014).

The results from the five vertical jumps were averaged for both the average and peak instantaneous GRFv asymmetries. Calculation of both the average and peak instantaneous GRFv is important as the average GRFv provides a representation of forces throughout the duration of the jumps while the peak instantaneous GRFv yields the highest forces observed.

The values for the single-leg hops reported were the average of three attempts. Calculation of both the average and peak instantaneous GRFv and GRFap during the landing phase was taken. The asymmetries were normalized by dividing force outputs by the subject's bodyweight. Horizontal distance during the SLH was again calculated assuming projectile motion and use of the impulse-momentum relationship. The GRFap during propulsion was used to calculate horizontal take-off velocity. Hop distance was then determined by multiplying horizontal velocity by time in the air (as determined from the force platforms).

Statistical Analyses

In addition to compiling means and standard deviations for anthropometric and biomechanical data, several higher-level comparisons were performed. Paired t-tests were performed on pre and post fatigue asymmetry measures in GRFv of CMJ and SLH landing and in GRFap of hop landings for both the average and peak instantaneous asymmetries.

Data was grouped in two ways, one based on the left versus right differences, and as an absolute value to ascertain if any directionality existed in asymmetries toward or away from symmetry as a result of fatigue. Finally, intraclass correlations (Chronbach's Alpha) were utilized to establish day-to-day repeatability with those that performed the procedures (maximum single-leg hops, CMJs, and SLH landing protocol) a second time. Statistical tests were conducted in SPSS version 17.0 (SPSS, Inc. Chicago, IL) with significance set at $P < 0.05$.

Figure 3.1: Squat cage positioned over force platforms with visible safety pins and depth bar. Also visible is the 3rd force platform utilized for hoping tests. Note: Spotters normally stood at each end of the bar.
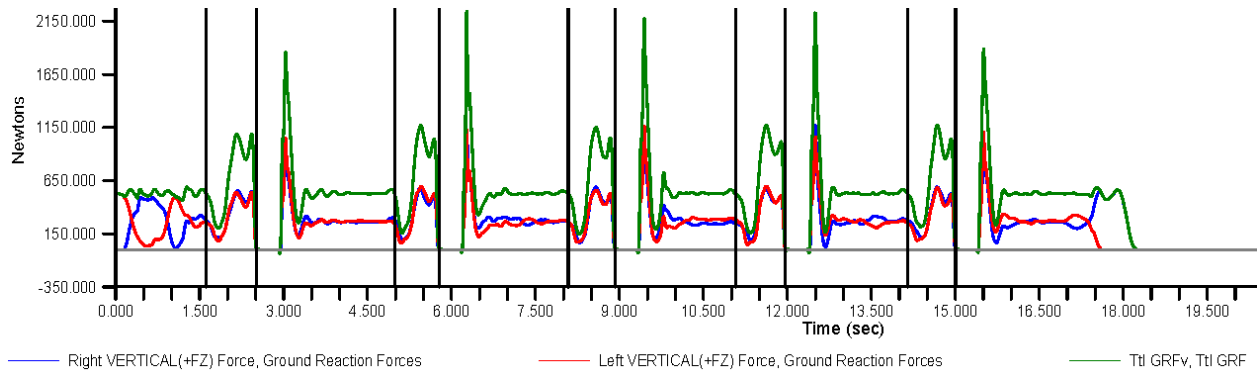

Figure 3.2: Example Total GRFv (green), Left GRFv (red), and Right GRFv (blue) for 5 vertical jumps. Vertical lines identify the countermovement to toe-off used in the analysis for each repetition.
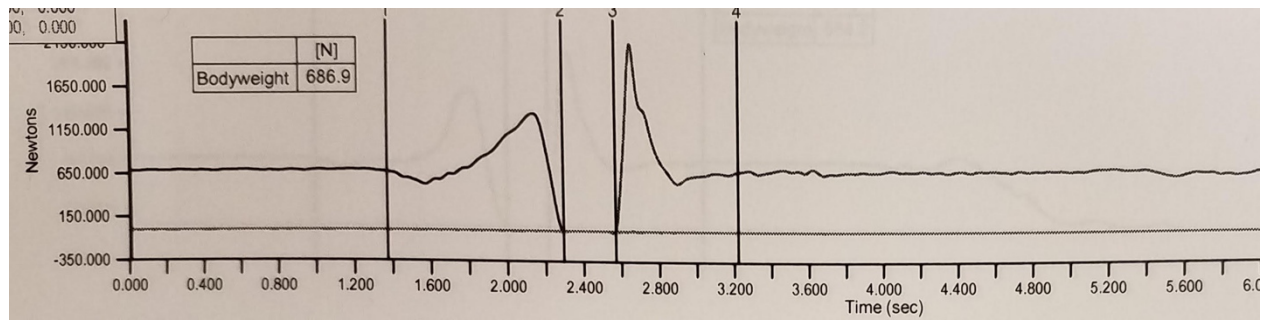
(a)
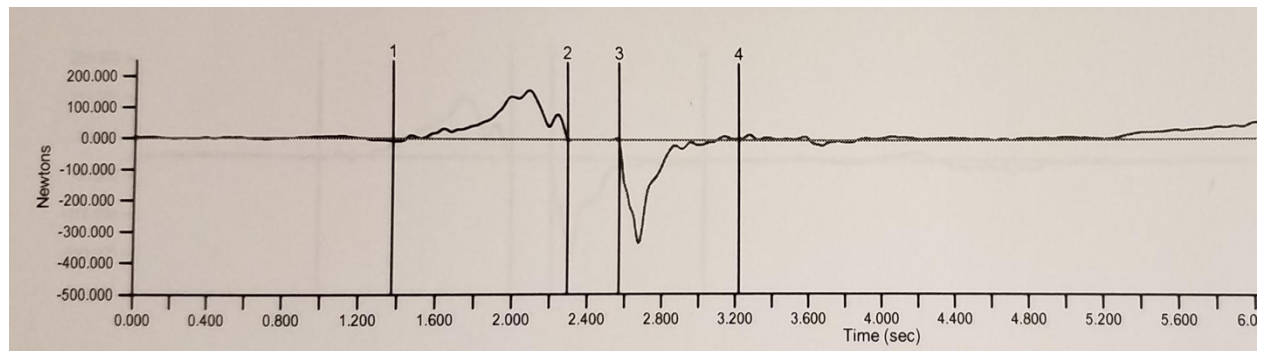
(b)

Figure 3.3: (a) Example for GRFv a single-leg hop task. Vertical lines identify the initiation of the countermovement to toe-off and the landing phases. **(b)** Example of the GRFap during the single-leg hop task. Vertical lines mark the countermovement to toe-off and landing phases.

CHAPTER IV

RESULTS

Subject Characteristics

Seventeen subjects (9 men, 8 women) completed the study (Table 4.1). Of these, four men and

four women returned to complete the third visit to assess repeatability of the measurements. On average,

the subjects' 8 repetition max (RM) was $113 \pm 35\%$ of their body mass. All subjects completed all

repetitions of all sets at 90% of the 8RM during the fatigue protocol. All subjects reported their right leg

and arm as their preferred kicking and throwing arm, respectively. Nine subjects jumped farther on the

left side during their maximum single-leg hops (MSL) on their initial visit and eight jumped farther on the

right. Overall, these measures were highly repeatable (Chronbach's alpha >= 0.928, Table 4.1). One

subject switched dominant sides in the MSL, but only changed the difference between sides by 1.8 cm.

Table 4.1: General Subject Characteristics

	Mean (SD)	alpha
Age (yr)	22.3 (2.5)	
Height(cm)	170.8 (9.3)	0.999
Mass (kg)	73.4 (13.8)	0.996
BMI (kg/m^2)	24.9 (2.8)	0.988
Max Single-Leg Hop Left (cm)	166.6 (35.5)	0.948
Max Single-Leg Hop Right (cm)	166.2 (32.6)	0.948
Max Single-Leg Hop L-R%	0.15 (6.5)	0.928
Max Single-Leg Hop |L-R%|	8.0 (7.9)	

Chronbach's alpha - repeatability assessment, (SD) standard deviation

Ground Reaction Forces & Asymmetries in the Countermovement Jump

Prior to fatigue, fifteen subjects had a right sided bias with respect to the amount of average

GRFv produced and eleven subjects had a right sided bias in the maximum GRFv. Jump height decreased

by 8.9% (0.27m $\pm$ (0.1) pre-fatigue to 0.24m $\pm$ (0.1) post-fatigue) indicating the fatigue protocol produced

changes (p<0001). No subjects changed their dominant leg in the average GRFv due to fatigue. However,

five subjects changed the dominant leg in maximum GRFv with two moving from a dominant right limb

to a dominant left, and three moving from a dominant left limb to a dominant right limb. All five subjects who switched dominant sides for maximum GRFv had less than a 2% total change in peak force; two of the subjects had less than 0.5% change (Figures 4.1 and 4.2).

(a)   (b)
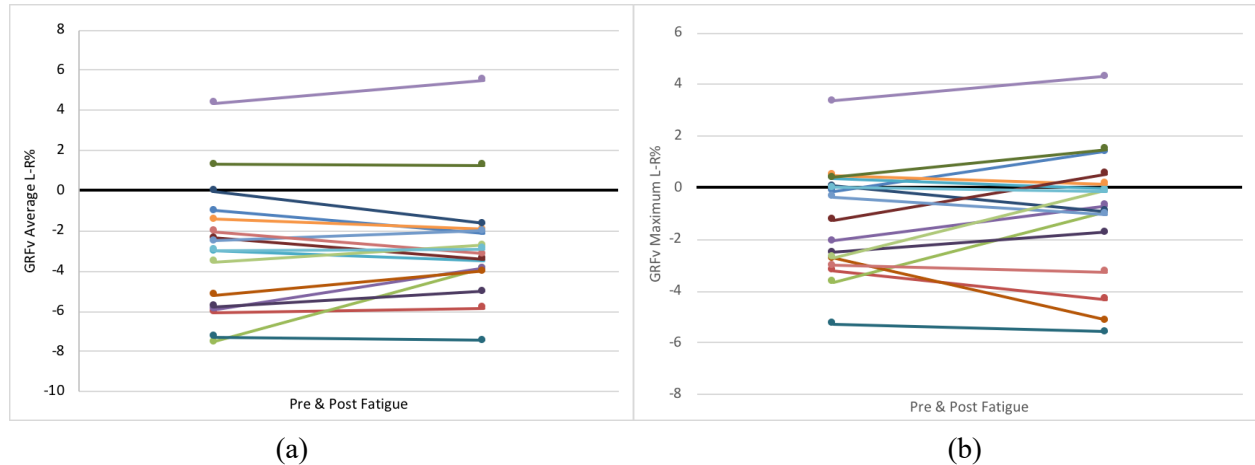
Figure 4.1: Individual relative asymmetries (L-R%) for all subjects in the vertical jump pre- and post-fatigue for (a) average GRFv and (b) maximum GRFv.

With the majority of the subjects placing more weight on their right side both pre and post fatigue, the relative average asymmetry levels were negative (Table 4.2). Furthermore, there were no differences in these asymmetries pre to post fatigue (p=0.437). Similarly, both pre and post conditions in the relative maximum GRFv asymmetries were biased to the right side as well with no differences pre to post fatigue (p=0.294) (Table 4.2).

Table 4.2: Vertical Jump Relative and Absolute GRFv Asymmetries

Mean (SD)	Pre	alpha	Post	alpha	p
GRFv Average L-R%	-2.99 (3.2)	0.952	-2.7 (2.8)	0.929	0.437
GRFv Maximum L-R%	-1.3 (2.1)	0.856	-0.9 (2.5)	0.922	0.294
GRFv Average |L-R%|	3.7 (2.3)		3.5 (1.7)		0.705
GRFv Maximum |L-R%|	1.9 (1.6)		1.9 (1.9)		0.983

Chronbach's alpha - repeatability assessment, (SD) standard deviation, p - significance pre to post fatigue (set to 0.05)
L-R% - relative side-to-side asymmetry as % of total GRFv, |L-R%| absolute asymmetry as % of total GRFv

When categorized based on absolute asymmetry, where a reduction in value would indicate a movement towards being more symmetric, there was no statistical significance for either average GRFv or maximum GRFv asymmetries pre to post fatigue (Table 4.2). (Figure 4.2).
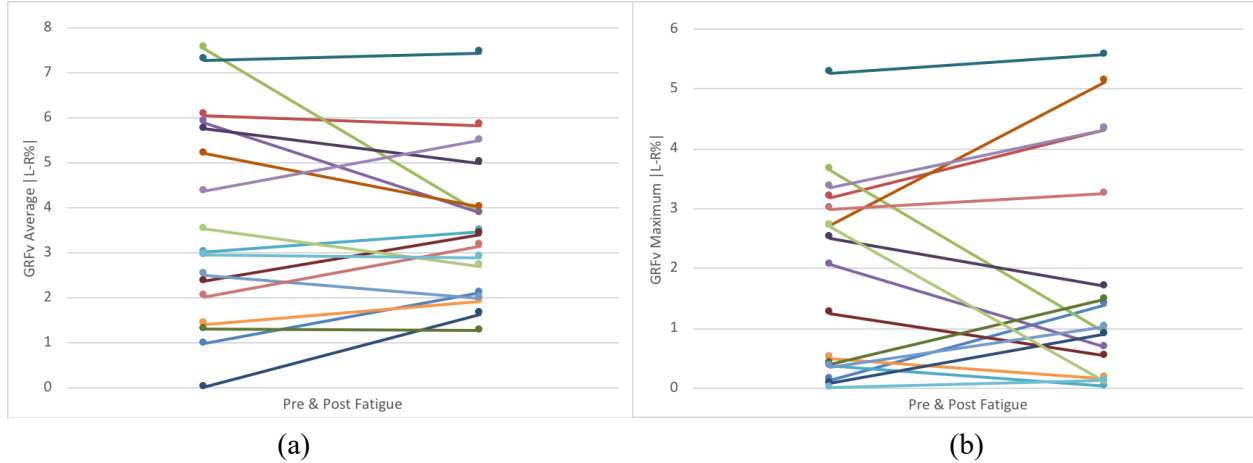
(a) (b)

Figure 4.2: Individual absolute asymmetries (|L-R%|) for all subjects in the vertical jump pre- and post-fatigue for (a) average GRFv and (b) maximum GRFv.

The L-R% asymmetry in the vertical jump showed good repeatability in the pre-conditions for average and maximum and in the post conditions for average and maximum. The repeatability of the jump height showed excellent repeatability for the pre-fatigue and post-fatigue conditions (see Table 4.2).

Ground Reaction Forces & Asymmetries in the Single-Leg Hop Landing

No measures pre to post fatigue were significant for relative asymmetries (L-R%) in either GRFv or GRFap for the SLH landing (Table 4.3). Seven subjects displayed a left sided bias for the pre-fatigue condition in GRFv average and maximum (Table 4.4). Post fatigue eleven subjects showed a left sided bias for GRFv average and eight showed a left sided bias for the GRFv maximum (Figure 4.3).

Table 4.3: Single-Leg Hop Relative and Absolute GRFv and GRFap Asymmetries

Mean (SD)	Pre	alpha	Post	alpha	p
GRFv Average L-R%	-0.9 (3.7)	-0.332	0.7 (4.7)	0.665	0.164
GRFv Maximum L-R%	-0.3 (12.2)	0.746	1.3 (21.1)	0.405	0.702
GRFv Average |L-R%|	3.1 (2.2)		3.7 (2.9)		0.441
GRFv Maximum |L-R%|	10.3 (6.0)		17.5 (10.9)		0.031
GRFap Average L-R%	0.0 (1.5)	-1.583	0.3 (1.6)	-0.005	0.164
GRFap Maximum L-R%	1.1 (3.0)	-0.190	1.2 (3.5)	0.471	0.933
GRFap Average |L-R%|	1.2 (0.9)		1.3 (1.0)		0.703
GRFap Maximum |L-R%|	2.4 (2.1)		3.0 (2.1)		0.437

Chronbach's alpha - repeatability assessment, (SD) standard deviation, p - significance pre to post fatigue (set to 0.05)

L-R% - relative side-to-side asymmetry as % of total GRFv, |L-R%| absolute asymmetry as % of total GRFv

Table 4.4: Change in Dominant Leg in the Single-Leg Hop for Average and Max GRFv and GRFap

	Dominant Left Pre Fatigue	Dominant Left Post Fatigue	Total Subjects Switching Domaint Sides	# Switching Left to Right	#Switching Right to Left
GRFv Average %	7	11	8	2	6
GRFv Maximum %	7	8	5	2	3
GRFap Average %	10	11	7	3	4
GRFap Maximum %	9	11	10	4	6

(a)   (b)

Figure 4.3: Individual relative asymmetries (L-R%) for all subjects in the single-leg hop landing pre- and post-fatigue for (a) average GRFv and (b) maximum GRFv.

Five subjects for the left leg and three subjects for the right leg displayed consistent asymmetries for GRFv average and GRFv maximum in the pre fatigue condition (Figure 4.3). Eight subjects switched dominant limbs in GRFv average yielding the net change of four with more subjects preferring their left limb in the post fatigue conditions (Table 4.4). Five subjects switched sides for dominant limb in GRFv maximum (Table 4.4).

Ten subjects had a left sided bias for GRFap average and nine subjects had a left sided bias for GRFap maximum in the pre fatigue condition (Table 4.4). Post fatigue there were six subjects with a left sided bias in both GRFap average and maximum. Ten subjects switched their dominant limb in GRFap maximum and seven subjects switched their dominant limb in GRFap average (Figure 4.4). Only one subject showed a consistent right sided asymmetry in GRFap average and GRFap maximum in the post-fatigue condition.

(a)   (b)
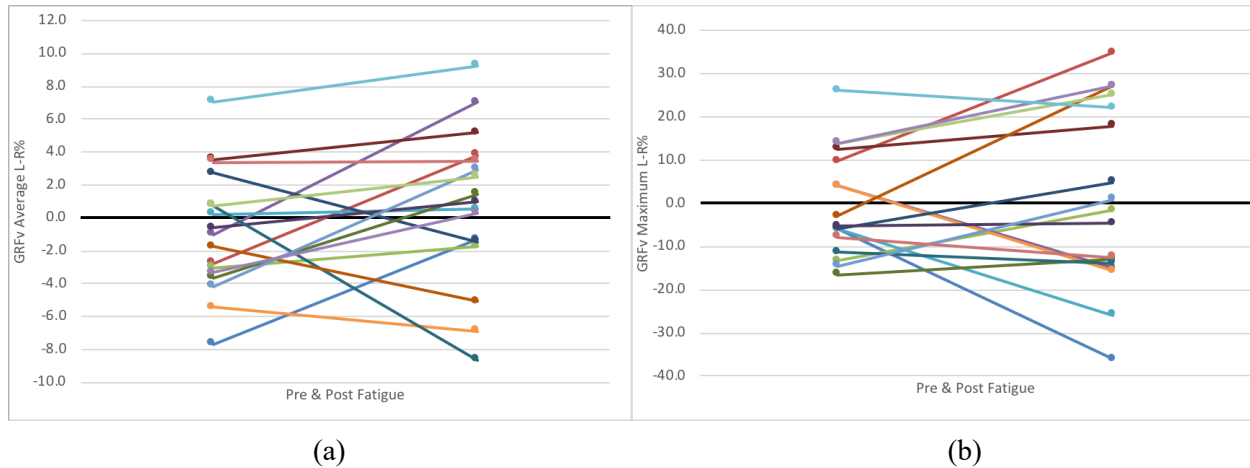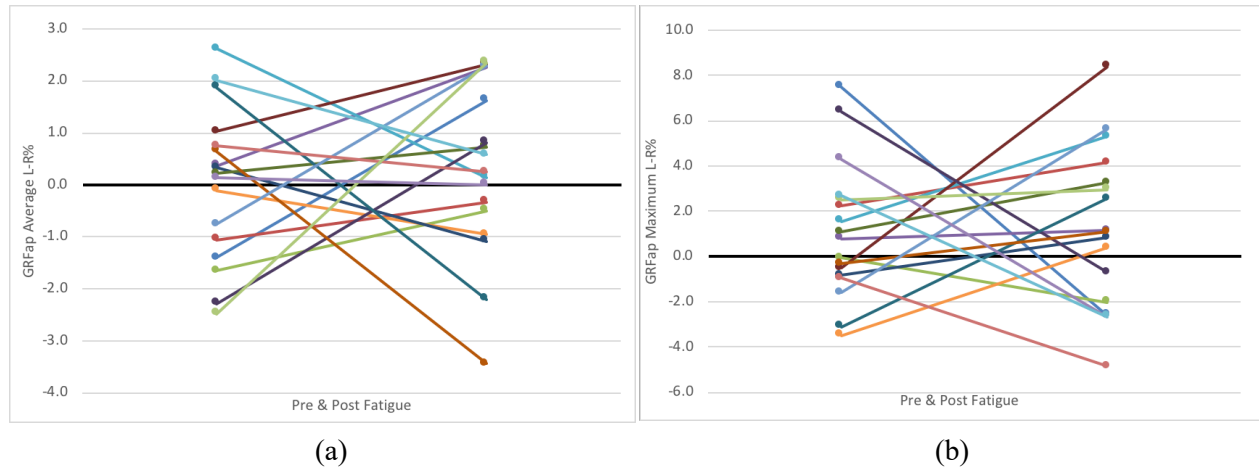
Figure 4.4: Individual relative asymmetries (L-R%) for all subjects in the single-leg hop landing pre- and post-fatigue for (a) average GRFap and (b) maximum GRFap.

Absolute asymmetries increased in all measures but did not reach statistical significance pre to post fatigue except for GRFv maximum (Table 4.3, Figure 4.5, 4.6). Ten individuals, with eight increasing and 2 decreasing, changed their absolute GRFv maximum asymmetry by greater than 10% due to fatigue (Figure 4.5).
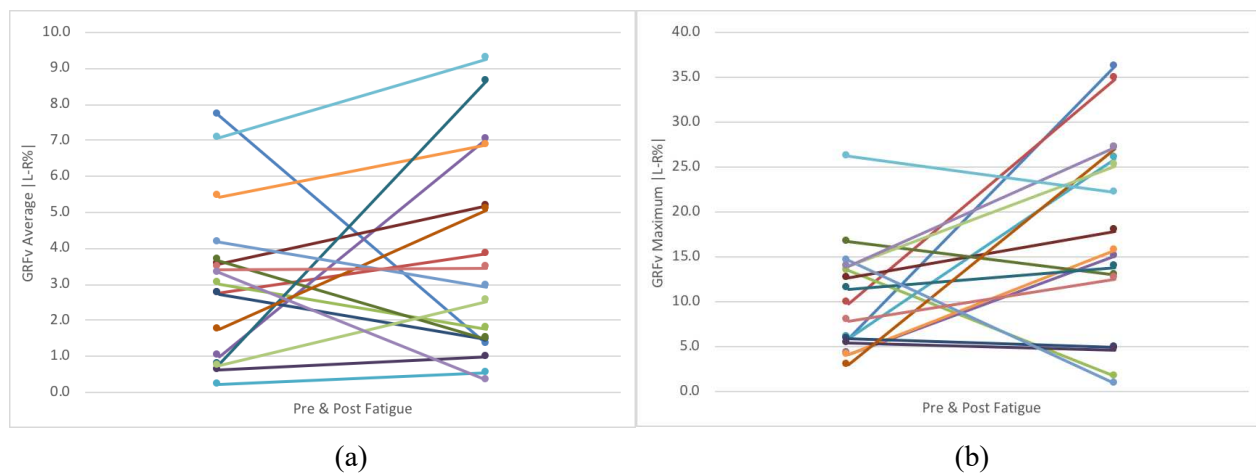

(a)   (b)

Figure 4.5: Individual absolute asymmetries (|L-R|%) for all subjects in the single-leg hop landing pre- and post-fatigue for (a) average GRFv and (b) maximum GRFv.

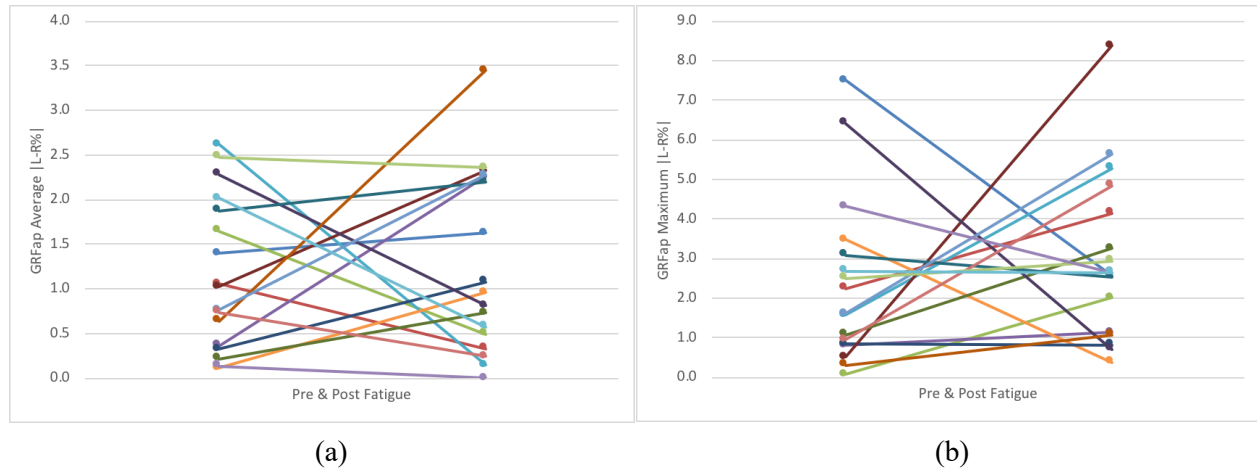(a)   (b)

Figure 4.6: Individual absolute asymmetries (|L-R|%) for all subjects in the single-leg hop landing pre-
and post-fatigue for (a) average GRFap and (b) maximum GRFap.

The L-R% asymmetries in the SLH landing showed poor repeatability for GRFv average in the

pre-fatigue condition and acceptable repeatability in the post-fatigue condition. The L-R% asymmetries in

the single-leg hop landing showed good repeatability for GRFv maximum in pre-fatigue condition and

poor repeatability in the post-fatigue condition for GRFv (Table 4.3).

The L-R% asymmetries in GRFap average in the single-leg hop landing showed poor reliability

for the the pre-conditiong and the post condition. L-R% asymmetries in GRFap maximum also had poor

internal consistency in the pre-fatigue and the post-fatigue conditions (Table 4.5).

Table 4.5: Single-Leg Distance And Landing Time Differences Pre & Post

			Mean (SD)		
Jump Distance	Pre	alpha	Post	alpha	p
L-R Jump Distance	-0.0 (0.0)	0.692	-0.0 (0.0)	0.859	0.568
|L-R|	0.0 (0.0)		0.0 (0.0)		0.581
Landing Time					
L-R Landing Time	-0.0 (0.1)	-1.741	-0.0 (0.1)	0.488	0.318
|L-R| Landing Time	0.1 (0.0)		0.1 (0.1)		0.132

Chronbach's alpha - repeatability assessment, L-R relative side-to-side asymmetry, |L-R| absolute asymmetry

p - significance pre to post fatigue (set to 0.05)

CHAPTER V

DISCUSSION

The goal of this investigation was to analyze how fatigue changed the relative and absolute expression of GRF asymmetry in CMJ and SLH landings in young, healthy, and recreationally active men and women. Functional asymmetries were assessed by individual foot GRFs. Assessments were made based on the average and peak instantaneous GRFv of the average of five countermovement jumps and in the average and peak instantaneous GRFv and GRFap of the average of three landings in a single-leg hop.

It was hypothesized that small levels of asymmetry would exist and that they would decrease with fatigue in the CMJ. We also hypothesized that because fatigue increases the discriminatory power of SLH tests, the asymmetries would increase in the SLH landing task. Furthermore, we hypothesized that fatigue would be evident by a significant decrease in vertical jump height and that measures would be highly repeatable day-to-day. The results of the CMJ did not support the hypothesis fully. Subjects did have small asymmetries, but there was no change as a result of fatigue in average or maximal GRFv. Only one measure, absolute GRFv |L-R%|, increased pre to post fatigue in the SLH was supported by the hypothesis. The repeatability was high for the countermovement jump protocol as previous studies have confirmed, but not for the SLH for any measure except GRFv maximum pre-fatigue.

Countermovement Jumps

Small levels of asymmetries were found in the initial measurements of this healthy population based on GRFv in the jump. This was expected based on previous research which has found asymmetries in the GRFv of subjects during bilateral jumping tasks (Bates, Ford, Myer, & Hewett, 2013; Lawson et al., 2006).

The population had an average absolute GRFv asymmetry in the pre-fatigue condition of the countermovement jump 3.7% ± (2.3). None of these subjects had suffered a previous injury to any joint in the lower extremity that lead to high levels of asymmetry. Despite the low level of asymmetry, subjects

were able to stay consistent with measures on the right side or left side for GRFv average after the fatiguing protocol. These results are reasonable in the light of the relationship between the squat and the countermovement jump. Both require similar muscles for execution (Nuzzo et al., 2008) and it has been shown that subjects either do not change their level or asymmetry or became more symmetrical during the performance of a fatiguing squat protocol (Hodges et al., 2011).

Subjects with ACL reconstruction (ACLR) tend to become more symmetrical as a result of fatigue during a bilateral free weight squat (Webster et al., 2015). This is achieved by an initial shift in the frontal plane over the unaffected knee and leads to increased fatigue in that limb, thereby increasing the loading in the reconstructed knee as fatigue increases. The subjects in the present study were healthy with low levels of asymmetry present to begin with, an no significant changes occurred in the levels of asymmetry in the CMJ as a result of fatigue. We could infer that the ALCR patients are more like our cohort after fatigue than before. What this says about asymmetry or symmertry and fatigue is a topic future studies need to investigate by specifically examining separate cohorts with small and large levels of asymmetry prior to fatigue. Interestingly, it is the uninjured leg that is the most at risk for a tear than a graft re-tear in ACLR patients (Paterno, Rauh, Schmitt, Ford, & Hewett, 2012). This suggests that a move from asymmetry to symmetry may be a risk factor in this population. Currently the effect of fatigue on the GRF asymmetry of a vertical jump in those who have undergone an ACL reconstruction is unknown.

More examination needs to occur with respect to the velocity and/or intensity of functional assessments and limb dominance. Interestingly, subjects put more weight on their non-preferred kicking leg (left, n=13) for barbell squats (Hodges et al., 2011) whereas our subjects favored their right leg in the pre and post fatigue conditions for GRFv average (n=15) and GRFv maximum (n=11 pre, n=12 post). Lawson et al. (2006) found asymmetries present in both step-close jump had some carryover to the CMJ. Their conclusion was that a learned asymmetry in one task may be maintained in a task that does not require the asymmetry. Given that there were no changes in asymmetry it is possible that the squat reinforced equivalent force production from each limb that carried over to the jumping task. Furthermore, it has been shown that (albeit in cycling) that increases in velocity reduce asymmetries. Athletic

maneuvers are not always maximal and future research could investigate asymmetries at varying intensities and speeds within the same FMA.

Using functional exercises as a means of fatigue means there are several muscles required to complete the task. This means the distribution of forces can change to accomplish the task. For example, it has been found that altering the squat mechanics can change the joint torques, and presumably muscle activation and fatigue (Fry, Smith, & Schilling, 2003). However, athletes may not accumulate fatigue in such uniform fashion due to differences in position, task demands, and unpredictable running, cutting, and jumping. Quantifying fatigue remains a challenge as all athletes playing the same game may experience different levels of fatigue.

Future research should investigate the effects of fatigue on the landing phase for asymmetries. Bates et al. (2013) has found that asymmetries are greater in the second landing from a drop-jump (DJ) task than the initial drop from the box. The DJ simulates the mechanics of the stretch-shortening cycle and may mimic athletic movements that are typically sequenced together during competition. In order for FMAs to have widespread utility it is to first understand the presentation of asymmetry across multiple bilateral jumps (e.g., CMJ, squat jump, step-close jump, DJ, etc) and how each of those change with fatigue. Heterogenous cohorts needs to be analyzed, particularly those with large levels of asymmetry or those who have had an injury. Lastly, a cohort needs to be followed longitudinally to see how asymmetries change over time and if there is any prognostic value for CMJ in injury screening.

It has also been shown that stronger athletes reveal less asymmetry than weaker ones (Bailey, Sato, Burnett, & Stone, 2015). Given that our subjects were recreationally trained and had a mean 8RM squat of 113% of their body mass, they may have been protected from revealing asymmetries in these measures. However, subjects in the aforementioned study were Division 1 athletes and the cut offs for strong and weak groups were for the top and bottom 25% of the group, respectively. It is safe to assume that Division 1 athletes are participating in a strength and conditioning program, but it is not the strongest athletes that are necessarily the best. It is uncertain how the 8RM squat of a recreationally active cohort would compare to Division 1 athletes. Furthermore, no connection to injury risk or incidence was

analyzed. Many, but not all, athletes strength train for sport performance. It seems that the magnitude of asymmetry is lessened by the effects of muscular strength. Future studies should examine asymmetries in trained and untrained populations.

It is commonly assumed that the weaker leg of an asymmetric pair is at risk, however the stronger limb has been suggested to be more injured due to the higher forces observed in comparison (Sinsurin, Srisangboriboon, & Vachalathiti, 2017). This would hold true for an ACLR patient who likely has superior strength in the uninjured limb. If the CMJ is found to be a meaningful test for those with higher levels of asymmetry, it could be a safe FMA under fatigue because double leg landings are superior in shock absorption and injury minimization compared to single-leg landings (E. Pappas et al., 2007).

The repeatability of the vertical jump was very high for all measures. This countermovement jump test is simple to execute. The absolute asymmetries in the CMJ were not statistically significant, yet the repeatability was very strong. This is a very important finding and indicates that the CMJ has the discriminatory ability to detect small levels of asymmetry day-to-day. The ability to detect differences with few repetitions and consistency with is an important piece in choosing valid FMAs.

A 10% cutoff is still the standard for meaningful inter-limb asymmetries. Considering that, it is important to note that one study has shown asymmetries were not detected unless 10-12 repetitions of a body weight squat are performed (Sirkis, 2017). The effects of higher repetition sets of jumping on asymmetries is unknown. For asymmetries to be meaningful they must be larger than the intralimb variation that between repetitions. Higher repetition FMAs may have some discriminatory power comparing intra- and interlimb asymmetries.

Single-Leg Hop Landings

The were no statistically significant outcomes in relative (L-R%) GRFv or GRFap for the SLH landing. It was hypothesized that asymmetries would increase as a result of fatigue. Absolute (|L-R%|) GRFv maximum increased significantly. This is important because the relative asymmetries were not statistically significant when the group was averaged. The peak strain on the ACL has been shown to occur *in* vivo at the instant of peak GRFv during a single-leg hopping task (Cerulli et al., 2003).

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Averaging the group data to generalize trends is important, but it can miss individual responses to fatigue. Individual data reveals that absolute asymmetries of GRFv maximum and average pre to post had eleven individuals increase and six decrease their levels of asymmetries in the SLH landing. Absolute GRFap asymmetry had ten increase and seven decrease their maximum values, and nine increase and eight decrease their average values pre to post in the SLH landing. It is interesting to find that ten individuals changed their absolute GRFv maximum asymmetry values by 10% or more given that the absolute GRFv asymmetry was the only SLH value to reach significance. Furthermore, it has been suggested that velocity increases may lead to more symmetrical performances (F P Carpes et al., 2007), albeit this was found in peddling asymmetry of cyclists.

These tests are used by clinicians and examine outcome without regard to GRF, however our study has shown that maximal single-leg hops are highly repeatable. No studies to our knowledge examine the outcome of GRF asymmetries due to fatigue in single-leg hops. Consider that prospective studies have indicated that female athletes who sustained an ACL injury had 20% higher GRFv in a single-leg drop test. Single-leg landings tend to reduce GRFv with fatigue (Santamaria & Webster, 2010), but some studies, like ours, have shown increases (Bonnard et al., 1994; Gollhofer et al., 1987; J. A. Nyland et al., 1997a; J. A. Nyland, Caborn, Shapiro, & Johnson, 1997b). Single-leg hops, like the CMJ, need more research elucidating the effects of varying intensities on asymmetries in SLHs.

Repeatability was weak with all tests in the SLH landing except relative GRFv maximum (L-R%) pre fatigue and relative GRFv (L-R%) average post-fatigue. Because it was a targeted task requiring a specific distance it was possible that the accuracy required led to inconsistencies and altered landing strategies. The novelty may have driven the asymmetries and familiarization with the task may have skewed the repeat measures due to improved performance. Despite any differences in strategy, the absolute differences in jump distance and landing time did not reach statistical significance. This is important because it suggests that regardless of strategy employed the subjects jump similarly side-to-side pre and post fatigue.

Despite the low intensity of the task and a lack of statistical significance, all measures of absolute asymmetry showed increases as a result of fatigue. This is in direct contrast to the measurements of the CMJ did not change. The SLH is a functional assessment that has been shown to be more sensitive with fatigue (Augustsson & Thomee, 2000). However, this outcome may have been specific to the accuracy demands of our SLH landing task. The magnitude of fatigue is a consideration as well. One previous study indicated that all kinematic changes occurred by the 50% fatigue state (defined by labeling the last successful test in the fatigue protocol as 100% fatigue) (Borotikar et al., 2008). Whether this translates to kinetics is unknown, but could be useful in test design where previously injured athletes do not have to be exposed to excessive fatigue to ascertain the effects of fatigue on asymmetries.

Limitations

Limitations of this study include a small sample size and a homogenous population restricted to healthy individuals that were not expected to be highly asymmetric. These restrictions prohibited the ability to assess left-handed/left-footed subjects, analysis of our cohort against those with uninjured subjects higher levels of asymmetry, gender differences, untrained subjects, and those previously injured. Additionally, kinematics and muscle activation data would have allowed for future understanding of the sources of side-to-side differences. Subjects were instructed to refrain from intense lower extremity exercise 48 hours prior to each visit and were taken at their word for self-reported behavior. Further, subjects were deemed acceptable based on their self-reported participation in a lifting program and weekly jump utilization. The comparison of asymmetries is delimited to propulsion measured in a bilateral vertical jump and the landing data of a single-leg jump with a horizontal emphasis. Other forms of jumps and landings were not examined.

Future Studies

Future studies would complement and improve the findings of this study by including more subjects, injured versus non-injured individuals, and trained versus untrained individuals. The study design could also cross examine varying jumps and include kinematic and muscle activation data. A prospective study design could be used to track athletes across a season to see if they sustain an injury

with data collection occurring at the beginning, middle, and end of a season to track the athletes longitudinally. Lastly, a study design could be implemented that correlates the functional assessments to performance outcomes and sporting success.

Conclusions

In conclusion, low levels of average and maximum absolute GRFv asymmetries were found to remain consistent in a CMJ pre and post fatigue. Additionally, the maximum absolute GRFv asymmetries were found to increase in the SLH pre to post fatigue. Although the level of asymmetries were small, the CMJ was able to detect small asymmetries day-to-day. Individual data of the CMJ indicates that the average force output pre and post fatigue was achieved by the same leg. Individual data suggests that High repeatability was found in the vertical jump assessment, but not the fixed distance SLH. Repeatable and reliable assessments are important for detecting injury risk in athletes prior to starting a season or returning from injury. Therefore, it is important to create a battery of FMAs sensitive enough to detect individuals at risk. The squat protocol effectively fatigued the individuals as evidenced by the decrease in jump height. Varying fatigue protocols in the literature must accomplish sufficient fatigue for the effects to be meaningful. Future research is needed to determine the most valuable FMAs for detecting asymmetries and in populations that have higher rates of asymmetry.

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APPENDICES

APPENDIX A

HUMAN SUBJECTS APPROVAL

Research Integrity & Compliance Review Office
Office of the Vice President for Research
321 General Services Building - Campus Delivery 2011
Fort Collins, CO
TEL:#(970) 491-1553
FAX:#(970) 491-2293

NOTICE OF APPROVAL FOR HUMAN RESEARCH

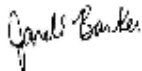|	
DATE:	September 29, 2009
TO:	Reiser, Raoul, Ph.D., Health & Exercise Science
	Israel, Richard, EdD, Health & Exercise Science, Patrick, Ryan, Health & Exercise Science, Hodges, Stephanie, Health & Exercise Science
FROM:	Barker, Janell, CSU IRB 1
PROTOCOL TITLE:	Effect of fatigue on jump and squat asymmetries
FUNDING SOURCE:	NONE
PROTOCOL NUMBER:	09-1358H
APPROVAL PERIOD:	Approval Date: September 29, 2009 Expiration Date: September 24, 2010

The CSU Institutional Review Board (IRB) for the protection of human subjects has reviewed the protocol entitled: Effect of fatigue on jump and squat asymmetries. The project has been approved for the procedures and subjects described in the protocol. This protocol must be reviewed for renewal on a yearly basis for as long as the research remains active. Should the protocol not be renewed before expiration, all activities must cease until the protocol has been re-reviewed.

If approval did not accompany a proposal when it was submitted to a sponsor, it is the PI's responsibility to provide the sponsor with the approval notice.

This approval is issued under Colorado State University's Federal Wide Assurance 00000647 with the Office for Human Research Protections (OHRP). If you have any questions regarding your obligations under CSU's Assurance, please do not hesitate to contact us.

Please direct any questions about the IRB's actions on this project to:

Janell Barker, Senior IRB Coordinator - (970) 491-1655 Janell.Barker@Research.Colostate.edu
Evelyn Swiss, IRB Coordinator - (970) 491-1381 Evelyn.Swiss@Research.Colostate.edu

Barker, Janell

Includes: Approval is for a maximum of 30 participants between the ages of 18-30 using the approved consent form with the CONDITION that the two methods sections are submitted once available and uploaded as an amendment.

Approval Period:	September 29, 2009 through September 24, 2010
Review Type:	EXPEDITED
IRB Number:	00000202

Page: 1

Consent to Participate in a Research Study
Colorado State University

TITLE OF STUDY: Effect of fatigue on jump and squat asymmetries

PRINCIPAL INVESTIGATOR: Raoul F. Reiser, II
Contact Information: 970-491-7980, RFReiser@CAHS.Colostate.edu

WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH? *You are being asked to volunteer for this research because you are a relatively fit healthy adult between the ages of 18-30 years with no current injuries (pain and soreness free for the last month). You must also be free of any current or chronic low-back pain, leg pain, or orthopedic problems. You must be able to perform a series of jumping tasks, as well as multiple sets of your 8 repetition maximum (8RM) free-weight squat.*

WHO IS DOING THE STUDY? *This research is being performed by Raoul F. Reiser II, Ph.D. of the Health and Exercise Science Department. Trained graduate students, undergraduate students, research associates, or research assistants are assisting with the research.*

WHAT IS THE PURPOSE OF THIS STUDY? *It is well documented that asymmetries exist in the lower extremity (i.e., one leg is favored over the other). However, it is not clear if those asymmetries change with fatigue and how fatigue might affect performance. The goal of this investigation is to determine if and how asymmetries change with fatigue.*

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST? *This research project will take place in the Clinical Biomechanics Laboratory located on the 2nd floor of Moby Arena (B wing) on the CSU main campus. Your involvement will last roughly 1 hour each on 2 separate occasions. If you return for repeat visits, to help us determine the reliability of our measures, your involvement will double.*

WHAT WILL I BE ASKED TO DO? *If you agree to participate we will check your jump and squat technique and verify/determine your 8RM on the first visit. On the second visit you will be required to perform a series of jumps pre- and post-fatigue. There will be maximum effort vertical jumps using both feet as well as short single-leg forward hops.   Five sets of 8RM squats will be performed in between the pre- and post-fatigue jumping conditions. While performing all tasks, the forces under your feet will be measured. There are no needles or other devices that will break the skin. We will lead you through a warm-up procedure, have you practice the task at submaximal levels of effort, spot you during the jumps and squats, and give you rest between efforts.*

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY? *You should not volunteer for this study if you do not meet the criteria outlined above. Additionally, if you have any preexisting conditions that would lead you to believe that you are highly asymmetric, you should not participate. If you are a woman, you should not participate if you are pregnant. Regardless of gender, you should also not participate if you have any reason to believe you might be injured by these activities. All physical exertions are controlled by you. The amount you will squat will be based on determination of your 8RM, performed during your first visit.*

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS? *As with all physical activity, there is a risk for injury. The most likely risks associated with this study are muscle strains and pulls as well as muscle fatigue. That fact that you are relatively fit, are familiar with the squat and jump, and that we will spot you and give you plenty of opportunity to stretch and warm-up minimizes these risks.*

You are also given breaks between each squat trials to minimize risk for injury. If at any time you feel uncomfortable, pain, or are excessively tired, you should discontinue effort and tell the investigator. It is not possible to identify all potential risks in research procedures, but the researcher has taken reasonable safeguards to minimize any known and potential, but unknown, risks.

WILL I BENEFIT FROM TAKING PART IN THIS STUDY? *While this study should provide useful information that may in the future provide useful information on lower limb asymmetries and fatigue, there are no current benefits to participation in this study.*

DO I HAVE TO TAKE PART IN THE STUDY? *Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.*
WHAT WILL IT COST ME TO PARTICIPATE? *There are no costs to participate in this study.*

WHO WILL SEE THE INFORMATION THAT I GIVE?   *We will keep private all research records that identify you, to the extent allowed by law.*

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under

lock and key. You should know, however, that there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court. The files containing information about you will be identified with a code, such as "FS01", where FS is short for Fatigue Subject and 01 is a subject number. Upon completion of data collection and verification of results, the list linking your name to the code will be destroyed.

CAN MY TAKING PART IN THE STUDY END EARLY? *Your participation in the study may end early if we are unable to measure ground reaction forces during jumping or squatting tasks. This is usually due to equipment error, but may also occur for unknown reasons. The study may also end early if you experience any pain or discomfort, or are unable to complete the jump and squat protocols.*

WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY? *There is no monetary compensation for your involvement in the study. However, if you are a student in an HES activity course (HES 100O, HES 100N, or HES 332F) your participation qualifies you for "extra credit". Speak with your course instructor for details.*

WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH? *The Colorado Governmental Immunity Act determines and may limit Colorado State University's legal responsibility if an injury happens because of this study. Claims against the University must be filed within 180 days of the injury.*
In light of these laws, you are encouraged to evaluate your own health and disability insurance to determine whether you are covered for any physical injuries or emotional distresses you might sustain by participating in this research, since it may be necessary for you to rely on your individual coverage for any such injuries. Some health care coverages will not cover research-related expenses. If you sustain injuries, which you believe were caused by Colorado State University or its employees, we advise you to consult an attorney.
WHAT IF I HAVE QUESTIONS? *Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigator, Raoul F. Reiser II, Ph.D. at 970-491-6958. If you have any questions about your rights as a volunteer in this research, contact Janell Barker, Human Research Administrator at 970-491-1655. We will give you a copy of this consent form to take with you.*

Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 3 pages.

_____   _____
Signature of person agreeing to take part in the study   Date

_____
Printed name of person agreeing to take part in the study

_____   _____
Name of person providing information to participant   Date

_____
Signature of Research Staff

HEALTH AND ACTIVITY QUESTIONNAIRE

Effect of Fatigue on Jump & Squat Asymmetries
(Fall-Spring 2009-10)

Health & Activity Screening - Coded Cover Sheet
(Separate from the coded screening form, store separately)

Name (Last, First): _____

Address: _____

_____

Phone number: _____

Email: _____

Code #: _____

Acceptable Subject: Yes   or   No

Notes_____

_____

_____

_____

_____

_____

Health & Activity Questionnaire   Date & Time: _____

Code #_____   Sex: **M** or **F**

Are you between the ages of 18-30 years? _____   DOB: /_____/_____

Are you healthy (pain, soreness, and injury free)? _____

Women only: Are you pregnant? _____

Do you have now, or ever had, chronic low-back pain or scoliosis? _____

Do you have any orthopedic or arthritic problems? _____

Do you have any prior injuries or conditions that would cause you to favor one side of the body while performing otherwise symmetric tasks (broken bones, torn muscles and ligaments, a leg-length differential, ACL reconstruction etc.)? _____

_____

Do you use any bilateral corrective devices (heel lift, brace, etc.)?_____

Have you participated in a resistance-training program, which includes a free weight squat for at least the past 8 weeks?   _____

Do you participate in sports that involve jumping on a weekly basis? _____

Are you comfortable exerting high levels of effort from the low back? _____

Are you comfortable jumping or landing with moderate fatigue? _____

Any current or chronic medical conditions (heart disease, diabetes, asthma, allergies, epilepsy, etc.) or medications that would prevent or interfere with maximal physical activity?_____

_____

_____

Please estimate your   Height:_____   Weight:_____

                        Squat 8 RM:_____

Should you be identified as a good match for this project based on your answers, can we schedule a 1 hr block of time for you to come in to the lab? _____

Should you be scheduled for a visit to the lab to participate in the study, will you refrain from major physical activity using the legs 48 hours prior to lab visits and refrain from excessive caffeine and/or ergogenic aids on the days of the lab visit? _____

Should you be asked to participate in this study, do you agree to wear clothing that does not restrict motion (t-shirt, shorts, comfortable shoes, without excessive heel lift, that would be appropriate for squatting and jumping tasks)? _____