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INTERLIMB ASYMMETRIES FOLLOWING HIGH AND LOW EXTERNAL TRAINING LOADS IN COLLEGIATE BASKETBALL PLAYERS

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INTERLIMB ASYMMETRIES FOLLOWING HIGH AND LOW EXTERNAL TRAINING LOADS IN COLLEGIATE BASKETBALL PLAYERS

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Table of Contents

List of Tables

List of Figures

Abstract

Interlimb asymmetry refers to the performance of an extremity in relation to the other. This imbalance between limbs has often been considered a risk factor for injury, as well as a dynamic performance inhibitor. However, limited evidence exists on the prevalence of acute development of asymmetry from external load prescription. **PURPOSE:** The primary purpose of the present study was to evaluate functional performance differences in asymmetry pre-, immediately post-, and 24h post-basketball specific training. The secondary purpose was to evaluate the significance of sex differences in asymmetry pre-, immediately post-, and 24h post-basketball specific training. **METHODS:** A convenience sample of 20 (males = 12; females = 8) NCAA Division I collegiate basketball players were enrolled in the present study. The 1st visit consisted of a consent and familiarization, the 2nd and 4th consisted of pre-post countermovement jump (CMJ) testing, along with randomized cross-over designed basketball practice load prescription, while the 3rd and 5th visit consisted of solely a warmup and (CMJ) test. The 2nd and 4th visits consisted of a randomized training load, hereafter referred to as the "High" or "Low" conditions. **RESULTS:** Only Eccentric Mean Force displayed significance (p = 0.004) between training loads, across time points for Change Scores. There were no significant sex differences between condition and time, however small effect sizes were identified for Asymmetry Scores with Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Peak Force, Force at Zero Velocity, Force at Peak Power, and Takeoff Peak Force Pre to Post- and Post to 24hPost- for females (*d* = 0.20-0.49), while males exhibited trivial effects (*d* < 0.20). Additionally, we saw large effects within males and females in Change Scores (*d* > 0.80), with Concentric Impulse, Concentric Mean Force, Eccentric Mean Force, Force at Peak Power, and Takeoff Peak Force Pre to Post- in males, while females revealed small (*d* = 0.20-0.49) to moderate (*d* = 0.50-0.79) effects. **CONCLUSIONS**: It

appears that Eccentric Mean Force may be a valuable metric to detect acute changes in asymmetry during the CMJ following offseason basketball specific training. Additionally important to note, practitioners may note sex differences in asymmetry change following offseason specific basketball training. These findings may also be exacerbated in different training phases throughout the year, in conjunction with increased intensities and training loads.

Chapter I: Introduction

The primary purpose of training for sport is to initiate a cascade of specific physiological responses in hopes of inducing supercompensation (peaking) of physical performance, through intra- and extracellular mechanisms such as mTOR pathway activation, AMPK activation, alterations in cortical activation, and many more (Cunanan et al., 2018). Often times, athlete success in competition is largely predicated on the physical performance attributes of speed, explosive strength, change of direction (COD), and combinations of anaerobic and aerobic power, in addition to a high level of sport-specific skill. In order to maximize these qualities alongside prevention of overtraining or stress-induced injury, strenuous training regimens are implemented by practitioners with the ideology of improving performance capacities in conjunction with maintenance of fatigue. Maintaining low levels of fatigue, particularly in collegiate athletes, is inherently difficult as these athletes are exposed to a combination of both mental and physical stressors (Wilson et al., 2005), such as examinations, social stressors, sport specific activity, etc. Previous research in collegiate athletes has indicated that high academic stress (i.e. campus-wide exam periods) significantly increases the number of physical injury restrictions (Mann et al., 2016). Additionally, physical stressors such as individualized training sessions, strength training and conditioning, sport specific practices, and gameplay itself, also contribute to fatigue accumulation with numerous studies demonstrating the inverse relationship between performance outcomes and neuromuscular fatigue (Gathercole et al., 2015; Heishman et al., 2018; Heishman et al., 2020; Cormack et al., 2008). Although the origin of fatigue in collegiate athletes appears to be multifaceted, the impact of fatigue accumulation on sports performance has motivated sports scientists and strength and conditioning practitioners to determine ways to better monitor athlete fatigue and performance (Halson et al., 2014; Heishman et al., 2018).

External training load refers to the mechanical work completed by the athlete (Heishman et al., 2018), placing stress on the musculoskeletal system (joints, bones, tendons, ligaments, muscles, etc.). This can be measured in a multitude of ways, such as power output, velocity, Time-Motion Analysis, and measures of neuromuscular function (Halson et al., 2014). An example of measuring power output is seen often in cycling, by measuring work rate (watts) over the duration of the activity. While Time-Motion Analysis, as well as wearable microsensors, such as Global and Local Positioning Systems, have previously been utilized to measure training loads in the team setting to monitor training loads, wearable microsensors known as inertial measurement units (IMUs) are becoming increasingly common among indoor-team sports, such as basketball and hockey (Holme et al., 2015; Halson et al., 2014; Fox et al., 2018; Heishman et al., 2018). IMUs incorporate tri-axial accelerometer, gyroscope and magnetometer data to capture the athletes' movement signature during the intermittent, reactive, and multi-directional movements of team sport (Holme et al., 2015; Fox et al., 2017; Heishman et al., 2018). Practitioners, along with medical and coaching staff, collaborate to manage total work performed in order to administer load when necessary, and minimize unwanted fatigue.

The countermovement jump (CMJ) is commonly utilized in the applied performance setting to evaluate acute fatigue and longitudinal changes in performance. The CMJ uses a dynamic eccentric muscle action, or "stretch", followed by rapid concentric muscle action, utilizing the stretch-shortening cycle in order to increase force production. This is thought to be a powerful monitoring tool in the model of neuromuscular fatigue, due to the heavy metabolic and neural contributors of the stretch-shortening cycle, particularly in conjunction with likewise mechanisms exhausted following sport specific training (Cormack et al., 2008; Komi, 2000). Traditionally, CMJ performance has been determined from examining jump height from commercially available devices such as the Vertek or Just Jump Mat. More recently, it has become common for CMJ performance to be evaluated using force plate technology. Force plates are often limited to laboratory and elite sports settings (i.e. NCAA, NBA, etc.), however, access to force plate technology allows practitioners to evaluate the CMJ beyond gross output performance parameters, such as jump height. The reliability of CMJ performance and the protocol used to examine CMJ performance have been outlined previously, suggesting that certain measures are reliable, and the jump protocol should be determined based off the measures of interest and the training phase (Heishman et al., 2018). In addition to displaying reliable measures, the minimal time requirement and non-invasive implementation makes this an attractive measure for basketball athletes. Interestingly, advances in technology continue to be facilitated, such that some force plates can now come equipped with dual cells (i.e. one for the right leg and one for the left leg). The dual cell force plate setup has the ability to measure the traditional and alternative CMJ variables for each leg and allow sports scientists and practitioners to examine differences between the right and left leg and evaluate inter-limb asymmetry.

Inter-limb asymmetry refers to comparing the performance of one limb with respect to the other and have been measured with a variety of techniques (Bishop et al., 2017). These methods include isokinetic dynamometry (Lockie et al., 2012) and functional approaches such as the single-leg CMJ (SLCMJ)(Bishop et al., 2017, 2018, 2019; Hoffman et al., ; Bromley et al., 2019), various hop tests for distance (Dos Santos et al., 2017; Stephens et al., 2007; Schiltz et al., 2009), isometric mid-thigh pull (Bailey et al., 2013, 2015), and isometric back squat (Bazyler et al., 2014). Isokinetic dynamometry is the most widely used method used to test asymmetries. However, the arthrokinematics and contraction speeds of isokinetic testing vary greatly from the dynamic closed-chain movements experienced during sport activities, such as basketball (Impellizzeri et al., 2007). Prior literature has outlined the inability of isokinetic assessments to show bilateral asymmetries alone, which suggests that more sport-specific assessments may quantitate asymmetries more effectively (Menzel et al., 2013). Therefore, efforts have been focused on developing more functional assessments (i.e. single-leg CMJ, hop tests, and CMJ) to quantify lower inter-limb asymmetries (Bromley et al., 2018; Bishop et al., 2017).

In contrast to the isokinetic approach of testing asymmetries, the single-leg CMJ (SLCMJ), single leg hop tests, and CMJ serve as alternative assessments that more closely resemble movement of sport. These methods are dynamic, closed-chained functional assessments, that incorporate the stretch-shortening cycle during explosive multi-joint movement (Impellizzeri et al., 2007; Komi et al., 2000). The SLCMJ provides the advantage of allowing individual assessment of the eccentric, isometric, and concentric performance individually when performed on a force plate. The single leg hop test has the advantages of cost effectiveness and easy accessibility for measuring performance, however this assessment only provides a gross output of performance (distance jumped). Although the advantages of SLCMJ and single leg hop test over isokinetic testing are clear in a field-based testing battery, the SLCMJ and hop tests also present limitations. These assessments require high levels of balance and coordination, which may confound the analysis of performance. Additionally, athletes returning to play post-injury may not be able to express their true level of performance on the injured limb due to kinesiophobia, or the fear of movement resulting from previous trauma. Therefore, some work in the literature has navigated toward the use of the bilateral CMJ as a performance assessment to evaluate inter-limb asymmetries (Heishman et al., 2019).

Assessing and monitoring inter-limb asymmetries has become increasingly popular among practitioners and clinicians to provide insight into athletic performance, injury prevention, as well as guiding return-to-play and return-to-performance protocols following an injury (Heishman et al., 2019; Bishop et al., 2017; Taberner et al., 2019). More specifically, inter-limb force asymmetries in excess of 10 percent have been associated with decreases in jump height and reductions in change-of-direction speed, both key components of basketball play (Bell et al., 2014; Hoffman et al., 2007; Bishop et al., 2019; Bishop et al., 2017). Inter-limb asymmetry values exceeding 15 percent have been associated with an elevated injury risk (Impellizzeri et al., 2007), while inter-limb asymmetries less than 10% have traditionally been utilized as a standard in guiding and evaluating the success of a rehabilitation program following an injury (Krytsis et al., 2015). In addition to the use of inter-limb asymmetries to evaluate injury risk and guide return-to-play protocols following injury, more contemporary work has looked to inter-limb asymmetries as an indicator of fatigue following training. Recent work by Bromley et al. (2018) explored inter-limb asymmetries following a competitive match and observed significant increases in inter-limb asymmetries immediately following a soccer match, trending back to baseline values at 48 to 72 hours post-match. Therefore, short-term accumulation of neuromuscular fatigue potentially contributes to alterations in movement mechanics up to a 72 hour window post-match, inherently decreasing performance and magnifying injury risk during that window.

Previous literature examining lower limb asymmetry is abundant in soccer, volleyball, rugby, and American football athletes (Bromley et al., 2018; Stephens et al., 2007; Lonergan et al., 2018; Impellizzerri et al., 2007; Bell et al., 2015; Bishop et al., 2018; Hoffman et al., 2007; Young et al., 2011), whereas literature respective to the sport of basketball is lacking. Only a few studies have evaluated interlimb asymmetry in professional or collegiate basketball athletes (Heishman et al., 2019; Schiltz et al., 2009; Fort-Vanmeerhaeghe et al., 2016). Furthermore, sex comparisons of jump asymmetry have been shown to display larger asymmetry in jump height variables in women’s basketball players compared to men. This asymmetry is also associated with a larger injury rate, as well as an increased incidence rate of anterior cruciate ligament injury (Lonergan et al., 2018). Previous data has also revealed that women commonly show deficits in strength, postural control, and coordination compared to their male counterparts (Fort-Vanmeerhaeghe et al., 2016). Although little data is available, the apparent sex differences in jump asymmetry following acute fatigue warrants more research in this area.

While previous literature has identified the influence of inter-limb asymmetries on performance and injury risk, limited evidence exists specifically examining the influence of varying external training loads on inter-limb asymmetries, nor evaluating the critical time points of asymmetrical fluctuations following sport specific training. Furthermore, sex comparisons of jump asymmetry have been shown to display larger asymmetry in jump height variables in women’s basketball players compared to men. This increased asymmetry among women is also associated with a larger injury rate, as well as the larger incidence rate of anterior cruciate ligament injury among women (Hewitt et al., 2006; Paterno et al., 2010), potentially due to deficits in strength, postural control, and coordination between sexes (Fort-Vanmeerhaeghe et al., 2016). Although these sex differences are documented, prior research has yet to examine the influence of sex on inter-limb asymmetries following various training loads. Cumulatively, asymmetry tracking and monitoring may be particularly insightful to the population of basketball athletes. This information can provide valuable insights regarding the training demands of individual athletes, optimizing athletic performance, reducing injury risk, guiding return-to-play rehabilitation, and may be potentially useful in revealing acute fatigue.

Purpose of the Study

The primary purpose of this investigation was to evaluate countermovement jump performance interlimb asymmetry following prescription of high and low training loads pre-, immediately post-, and 24-h post-session. A secondary purpose of this experiment was to evaluate sex differences in asymmetry changes with training load.

Research Questions

1. Are there significant differences in lower-limb asymmetries during the countermovement jump pre-, immediately post-, or 24-hours following exposures of high and low load sport-specific basketball training?
2. Are there significant sex differences in lower-limb asymmetries during the countermovement jump pre-, immediately post-, or 24-hours following exposures of high and low load sport-specific basketball training

Research Hypotheses

1. It was hypothesized that the trend in asymmetry will increase with high training load immediately post-training, similar to the findings of Bromley et al. (2018).
2. It was hypothesized that lower-limb asymmetries will be significantly larger in women than in men, as seen previously by Fort-Vanmeerhaeghe et al. (2016).

Significance of the Study

Inter-limb asymmetries play a role in optimizing athletic performance, reducing injury risk, guiding return-to-play rehabilitation, and are potentially useful in revealing acute fatigue. Identifying the athlete inter-limb asymmetry responses to varying external training loads will offer unique insights to practitioners and clinicians. These findings may support the improvement of programming appropriate training regimens to optimization athlete performance through the reduction of asymmetries, especially during phases of intense training with increased training loads. Additionally, understanding the time-course of changes in asymmetries following varying training loads may be useful in informing clinicians about critical time-frames with increase injury risk or how to implement rehabilitation programs to mitigate asymmetries, ultimately to return athletes back to the court more safely.

Delimitations

1. The participants will be members of the University of Oklahoma Men's and Women's Basketball squads.
2. Participants will be between 18 and 26 years of age.
3. Participants will be free of recent musculoskeletal injury.

Limitations

1. Participants enrolled in this study will be of a convenience sample of collegiate basketball players at the University of Oklahoma.
2. These results will only be generalizable to men's and women's collegiate basketball players.
3. Results are measuring acute changes in interlimb asymmetry basketball specific training load, and therefore are not generalizable to longitudinal changes due to training.
4. Dietary compliance will not be controlled.

Assumptions

1. Participants will give maximal effort on CMJ testing.
2. Participants will answer questionnaires truthfully.
3. Participants will abide by normal dietary intake set forth by the team's sport nutritionist.

Operational Definitions

1. **Concentric Impulse** (N•s) – force exerted during the concentric phase multiplied by the time taken during the phase (Heishman et al., 2019).
2. **Concentric Mean Force** (N) – the average force exerted during the concentric phase (Heishman et al., 2019).
3. **Concentric Peak Force** (N) – the greatest force exerted during the concentric phase (Heishman et al., 2019).
4. **Countermovement Jump** (CMJ) - a form of vertical jump in which the participant starts tall and drops to a self-selected depth before maximally vertically displacing in the air (Heishman et al., 2018).
5. **Eccentric Braking RFD** [N•s^{-1}] : Rate of force development from the minimum force at the start of the active braking phase to zero velocity at the end of the eccentric phase (Heishman et al., 2019).
6. **Eccentric Deceleration RFD** [N•s^{-1}] : Eccentric rate of force development from the maximum negative velocity to zero velocity at the end of the eccentric phase (Heishman et al., 2019).
7. **Eccentric Mean Force** (N) – Average force during the eccentric phase from the onset of movement to zero velocity (Heishman et al., 2019).
8. **Eccentric Peak Force** (N) – Peak force over the eccentric phase (Heishman et al., 2019).
9. **External Load** - the assessment of mechanical or locomotive work completed by the athlete (Boyd et al., 2011; Halson et al., 2014; Heishman et al., 2018).
10. **Force @ Peak Power** (N) – Force exerted at the point of peak power (Heishman et al., 2019).

11. **Force @ Zero Velocity** (N) – Combined force when velocity = 0 (Heishman et al., 2019).
12. **Inertial Measurement Analysis** (IMA) - instant one-step movement effort; distinct acceleration micro-movement events generated during sudden explosive movement bouts, such as accelerations, decelerations, and change of direction (CoD) movements and expressed as the number of occurrences (counts) (Heishman et al., 2018).
13. **Interlimb Asymmetry** – comparison of performance between bilateral extremities (Bishop et al., 2018).
14. **PlayerLoad** (PL) - a vector of magnitude, expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the 3 orthogonal planes and divided by the scaling factor of 100 and is expressed in arbitrary units (au) (Barrett et al., 2014; Boyd et al., 2011; Heishman et al., 2018; Rowell et al., 2017; Van Iterson et al., 2017).
15. **Takeoff Peak Force** (N) – Peak force over the takeoff phase (Heishman et al., 2019).

Chapter II: Literature Review

The purpose of this investigation was to examine lower extremity interlimb asymmetry following exposures of high and low external training loads of basketball specific training in a cohort of NCAA Division 1 collegiate basketball athletes. This synopsis of the literature examines the body of research on bilateral limb asymmetry, external training load monitoring, neuromuscular fatigue, and the influence of load prescription on asymmetry. The search for literature was performed via search engines such as PubMed, SportDiscus, Google Scholar, and CINAHL Complete. Keywords and phrases included “interlimb asymmetry” and “bilateral asymmetry”, “external load monitoring”, in conjunction with “injury”, “countermovement jump”, “performance”, “return-to-play”, and “monitoring”.

Interlimb Asymmetry

Interlimb asymmetry has been characterized as the relative difference in strength between two limbs (Impellizzerri et al., 2007). This may consist of a musculoskeletal imbalance, such as differences in lean tissue (Bell et al., 2015), neuromuscular interlimb deficit, such as lateralized motor control (Sainburg et al., 2016), and bone length (Auerbach and Ruff, 2006). Therefore, this definition pertaining to strength could be a bit simplistic and a contemporary view of asymmetry. Maloney (2018) identifies sport-specific asymmetry as a shift in unilateral deficiency due to “task-specific”, high mechanical load demands developed over repetition and large durations. It may be assumed that bilateral imbalances do not occur, however it is abundant in the literature that lower-limb asymmetry is common, and often accompanied with an inverse effect on athletic performance and risk of injury. Evaluating interlimb imbalances has also been shown to demonstrate changes following sport (Bromley et al., 2019), similar to findings of athlete performance across proportional timelines (Heishamn et al., 2018, 2020; Gathercole et al., 2015; Cormack et al., 2008).

Therefore, the use of asymmetry monitoring may be deemed logical in quantifying acute neuromuscular fatigue, as well as create benchmarks for return-to-play for sport.

Asymmetry is an important topic of research, as interlimb imbalances provide insight into performance, injury risk (Hart et al. 2019), and in the rehabilitative setting, return to play or performance. Asymmetry of ~10% or greater has been shown to have negative effects on jump height (Bell et al., 2014), and slower change of direction (Hoffman et al., 2007). Bailey et al. (2013) revealed significant negative associations with peak force asymmetries during the isometric mid-thigh pull and jump height, as well as peak power ($r = 0.28\text{-}0.52$); $p < 0.05$). Another work by Bailey et al. (2015) demonstrated significant differences in asymmetry between to median split strength groups, where the weaker group exhibited significantly larger peak force ($d = 0.82$) and RFD ($d = 0.90$) asymmetries ($p < 0.05$ for both measures). Bazyler et al. (2014) showed similar findings between median split strong and weak groups, as peak force was significantly larger during the isometric squat at 90° ($p = 0.045$) and 120° ($p = 0.007$) for the weaker group. However, conflicting findings were shown by Sato and Heise (2012) with the effects of standing weight distribution on 1RM (relative to BW) back squat. These findings showed no significant differences in squat performance between "symmetrical" and "asymmetrical" groups.

Specificity of sport plays a large role in accumulating imbalances. For example, in the sport of soccer, the dominant limb used to shoot goals with is more often used for that kicking motion, whereas the non-dominant limb is used as a "gather" step where massive absorption of eccentric forces must occur prior to striking the ball. In the sport of basketball, right hand-dominant athletes have a similar outcome where the right limb is often used as a "gather" and the left is used as a propulsive mechanism prior to take-off for a layup or dunk. Another example proposed by Bishop et al. (2018) is the heavy unilateral lunge in fencing. Due to the nature of the sport, often times the forward placed limb in fencing has much larger cross-sectional area, specifically of the quadriceps and hamstrings, due to the large eccentric forces absorbed during the forward lunge. In summary, there are vast amounts of overshadowed unilateral accelerations and decelerations of high mechanical stress in these sports that may accumulate bilateral imbalances of the lower extremities over time.

Previous research has highlighted a range of >15% limb asymmetry as being “flagged” at greater risk of injury (Impellizzerri et al., 2007). Similarly, other studies have used the value of ~10% as threshold of “risk” in the realm of ACL rehabilitation research (Lonergan et al., 2018). Previous lower limb injury is also associated with asymmetry of the lower limb (Hart et al., 2019), and previous injury is often the strongest risk factor of future injury. Additionally, lower limb injury magnifies the likelihood of future lower limb injury by 2-3 times (Hart et al., 2019). Following injury or trauma to the musculoskeletal system, the limbs develop deficits often enabled by a compensatory pattern in the movement gait. Once a re-injury occurs, rehabilitation of the re-injury automatically increases in duration compared to the original injury, resulting in larger time loss from team sport activity (Ekstrand et al., 2011). In conjunction, some have also shown that incomplete rehabilitation from injury increases the likelihood of a compensatory gait pattern, eliciting a bilateral imbalance in time (Rannama et al., 2015; Impellizzeri et al., 2007). Consistently in the body of the literature, these values are presented vaguely, meaning further investigation is needed in order to establish concrete benchmarks of injury risk.

Assessing/Computing Asymmetry

Previous research has utilized a multitude of different methods for evaluating asymmetry, such as isokinetic dynamometry, and functional tests, such as the CMJ, SL CMJ, and various hop tests. The use of isokinetic dynamometry is the most recurring method, and heavily used in a laboratory setting. There is a variety of hop tests that have been used to evaluate asymmetry in the horizontal plane, such as a single hop, triple hop, and the crossover hop (Bishop et al., 2018; Dos Santos et al., 2017). The SLCMJ is very popular in the applied setting, as a time-efficient, non-invasive tool that has been shown to have reproducible results (Bishop et al., 2018; Hoffman et al., 2007; Bromley et al., 2019; Fort-Vanmeerhaeghe et al., 2016). However, this type of jump may have results that are hidden due to the instability factors of single-leg explosiveness (Heishman et al., 2019; Benjanuvatra et al., 2013). The bilateral CMJ is increasingly becoming a more common method, and the methods of assessment are becoming more and more clever. Initially, the CMJ was used on a single-cell force platform with one limb on and one limb off the force plate, both limbs on level surface (Impellizzerri et al., 2007). As modern technology further advances, the dual-cell force platform is becoming increasingly more common, and has been recently recurring in the literature. Furthermore, the reliability of CMJ performance has been evaluated with and without an arm swing during a bilateral CMJ (Heishman et al., 2018). The bilateral CMJ has been shown to be moderately to highly reproducible intra- and inter-day, and may provide more valid results as the specificity to sport is increased (Heishman et al., 2019). These results also showed that CMJ asymmetry was further elucidated during the CMJ NAS.

Previous literature has also characterized asymmetry in many different ways. Many studies have evaluated the dominant vs. non-dominant limb (Fort-Vanmeerhaeghe et al., 2016), right vs. left, injured vs. non-injured, anterior cruciate ligament-reconstruction vs. non-injured (Lonergan et al., 2018), preferred vs. non-preferred, and stronger vs. weaker. This broadness of view demonstrates the specificity to the research question the investigator is attempting to answer, and is therefore challenging to duplicate study designs. Laterality, or lateral limb preference (often referred as “skill dominant” limb) and force dominant limb preference have been shown to have poor agreement. Lake et al. examined asymmetries, finding that there were insignificant differences in GRF asymmetries when categorizing as the preferential limb, however there were significant asymmetries when categorized as the GRF dominant limb versus the weaker limb ($p < 0.05$). Newton et al. found similar results, with insignificant asymmetries during the back squat, bilateral and unilateral CMJ, and 5 hop test when categorized as right and left limbs. However, significant asymmetries were found in all circumstances when categorized as the force dominant and nondominant limbs.

Quantifying asymmetry is very broad in the literature, showing many different equations to calculate percent limb differences. It appears that most authors select a formula by citing from previous literature, however, Bishop et al. (2016) reported that small differences in equations may have a drastic difference on the outcome measure. Therefore, it is important to understand the calculation methods of asymmetry, and between-works interpretations of results need be accompanied by this understanding that outcomes vary in magnitude based upon the equation used. Previous work from Exell et al. shows there is an “artificial inflation” of results between equations, by using the example of the maximum symmetry value found in the study using the symmetry angle equation (93.23%) with its subsequent symmetry index counterpart, which equates to 1872.82% (Exell et al., 2012).

Previous works have shown the multitude of different equations to quantify between-limb differences, and categorized them with respect to the bilateral or unilateral nature of the testing battery (both Bishop articles). When performing the bilateral CMJ, it is important to use a calculation that gives the respective limb of interest (dominant, right, preferred, etc.) as a percentage of the whole. This is because the sum of the ground reaction forces (GRF) between limbs is dependent on the variation of between-limb GRF. Therefore, such an equation would include the difference between limbs divided by the whole, or the sum of the limbs, as seen in the Bilateral Asymmetry Index-1 (BAI-1), used in prior investigations (Bishop et al., 2019; Kobayashi et al., 2010). Additionally, Exell et al. (2012) concludes that the asymmetry outcome is only a "true" asymmetry if the between-limbs difference is greater than the intralimb variability. Ultimately, it is important to have a foundational understanding of the equation used, and to maintain a singular equation for inter-session comparisons of asymmetry.

Monitoring External Training Load

External training load (eTL) refers to the mechanical stress placed on the musculoskeletal system (muscles, bones, tendons, ligaments, etc.) during exercise. This mechanical stress is objectively quantified via several different methods, which is important for the management of fatigue, as well as prescription of training loads during training plans and periodization (Halson et al., 2014; Heishman et al., 2018).

Various systems are increasingly utilized among team sports to capture external training load, which is often reactive, intermittent and chaotic in nature. Early innovations implemented time-motion analysis, however, these methods require lengthy and time consuming data analysis (Halson et al., 2014). Extensive amounts of the literature in eTL monitoring have consisted of Global Positioning Systems (GPS) and Local Positioning Systems (LPS) in order to triangulate athletes' position on the playing field and gather particular workload metrics (Cummins et al., 2013; Halson et al., 2014; Coutts and Duffield, 2010; Jennings et al., 2010). GPS monitoring in itself contains potential limitations, such as the inability to monitor indoors, and potential lack of accuracy in events with decreased playing area/field size (Duffield et al., 2010). LPS then appears attractive in the field of indoor team sports monitoring, though the systems lack mobility/portability, and often expsensive. Inertial Measuremetn Units (IMU) appear to be an attractive options for monitoring external load among indoor sports (Fox et al., 2017; Heishman et al., 2018). These micro-sensors include an accelerometer, gyroscope, and magnetometer, which work together to detect the magnitude and orientation of movement in all three orthogonal planes. IMUs are often worn in a supportive garment, accurately designed to be placed at the athletes center of mass and are often positioned in a supportive garment between the scapulae, near the 7th thoracic vertebra, which does not inhibit or influence the athlete's motin during play (Heishman et al., 2017, 2018; McLean et al., 2018). Accelerometers detect linear accelerations, and furthermore quantify the intensity of a movement, expressed in G-forces, whereas gyroscopes are used as a measure of change in orientation (Yang and Hsu, 2010), measured by the angular velocity of one or multiple axes. Although not technically classified as a microsensor, the IMU also incorporated a magnetometer to complemented and enhance the orientation of the unit with respect to the "magnetic north" (Holme, 2015).

IMU-based systems typically offer commercially available software with proprietary algorithms that transform the raw collected data into various useable workload metrics. Some companies allow "live" feedback to improve athlete development in sport-specific practice sessions by monitoring and reporting the mechanical demands of the session (Holme, 2015; Fox et al., 2017). The most common parameter found in the literature and most frequently used among applied performance practitioners is PlayerLoad^{TM}. PlayerLoad^{TM} is expressed in arbitrary units, and is the square root of the sum of squared instantaneous rate of change in each orthogonal plane, divided by 100 (scaling factor) (Boyd et al., 2011; Heishman et al., 2018), often thought to be a strong identifier of training volume during a sport specific session. The equation for PlayerLoad^{TM}, in three dimensions, is as follows:

$$\text{PlayerLoad™} = \sqrt{\frac{(a_{Y1} - a_{Y-1})^2 + (a_{X1} - a_{X-1})^2 + a_{Z1} - a_{Z-1})^2}{100}}$$

Note: *a_Y = anteroposterior acceleration; a_X = mediolateral acceleration; a_Z = vertical acceleration*

Workload metrics are similarly computed by other manufacturers, however, the Catapult Systems IMU utilizes a sampling rate of 1000Hz, with large sensitivity compared to traditional GPS units, with sampling rates of 10Hz (Heishman et al., 2018; Boyd et al., 2011). PlayerLoad^{TM} (PL) is heavily researched, and has shown strong validity and reliability in team sport quantification of eTL (Boyd et al., 2011; Barnett et al., 2014; Van Iterson et al., 2017). In addition, a commonly utilized session intensity index is represented as PL/min (Heishman et al., 2020), by dividing the accumulated PL by time.

External Training Load and Performance

Various studies have shown the influence of training load on acute neuromuscular load prescription on countermovement jump (CMJ) performance (Gathercole et al., 2015; Heishman et al., 2018, 2020; Cormack et al., 2007), noting negative correlations between workload and jump performance. Rowell et al. examined CMJ performance in Australian Football athletes, noting that high accumulation of PlayerLoad^{TM} was strongly associated with decreased CMJ performance for up to 42 hours post-intervention. Heishman et al. (2018) examined the training load effects on CMJ performance and over the preseason phase in basketball athletes, noting increases in external training loads were significantly associated with decreased CMJ jump height 24h post-session. Additionally, the jump height metric showed a gradual decrease in CMJ performance throught the entire preseason period. Similarly, Ferioli et al. (2018) found peak power was negatively associated with increased training loads in professional basketball players. These findings consistently suggest there are subsequent interactions between the increased prescription of training loads and degradation in CMJ performance.

Muscle Fatigue

Fatigue is defined as an inability to maintain an expected value of muscle contraction or force (Halson et al., 2014). Furthermore, and more recently, physiological fatigue has often been categorized as exercise-induced impairment of performance (Knicker et al., 2011). Though muscle fatigue is multi-faceted and complex, several different mechanisms and sites play into fatigue. Enoka and Duchateau (2008) state that neuromuscular fatigue is quantifiable by measuring the decrement in force produced during prolonged high intensity exercise, via electromyography. Additionally, Enoka summarizes multiple different sources of reduced force capability due to fatigue: limitation in excitation-contraction coupling, metabolic alterations within the intracellular milieu, metabolic substrate depletion, limited neuromuscular propagation, and ischemic or acidotic conditions.

Limitations in excitation-contraction coupling has been shown to contribute to muscle fatigue (Allen et al., 2008). Once the centrally mediated action potential reaches the neuromuscular junction, acetylcholine is released into the cleft, allowing the signal to propogate to the working musculature. The membrane potential of the muscle cells is largely predicated by the up- and down-regulation of Na^+ and K^+ into and out of the skeletal muscle cells. Once the action potential travels down the t-tubules and into the sarcoplasmic reticulum, ryanodine receptors sense the voltage change, opening the voltage-gated Ca^{2+} channels, setting off a cascade of Ca^{2+} release into the sarcolemma. This ryanodine receptor loop has been heavily researched as a potential inhibitor of excitation-contraction coupling. Once the Ca^{2+} reaches the cross-bridges of the active musculature, Ca^{2+} binds to troponin, causing a shift in tropomyosin, exposing the myosin binding site for myosin to form a cross-bridge. This resultant cross-bridge cycling and recycling is the known nechanism of muscle contraction. However, Ca^{2+} buffering is regulated on calmodulin and ATP to release from the cross-bridge, and therefore could influence the accumulation of metabolic by-product contributing to fatigue.

An extraordinary feature of the physiological energy systems is the utilization and resynthesis of fuel in order to replenish ATP. However, at high intensities of exercise, ATP is consumed at a high rate, producing large amounts of ADP and P_i. ATP is resynthesized via anaerobic glycogenolysis and the aerobic catabolism of glycogen, glucose, or lipids. Once anaerobic glycogenolysis is initiated, though this pathway resynthesizes ATP, the metabolic accumulation of acidotic elements are known to be associated with muscle fatigue (Allen et al., 2008), ultimately influencing force production. The knowledge of fatigue is of importance for medical or sport professionals in order to properly mitigate fatigue, furthermore chronic decrement in athlete performance.

Chapter III: Methodology

The purpose of this investigation was to assess inter-limb asymmetry changes upon application of training load immediately post-, 24 hours post-training load application in National Collegiate Athletic Association (NCAA) Division 1 men's and women's intercollegiate basketball players.

Study Design

The study consisted of a randomized cross-over design used to evaluate CMJ asymmetry changes following a high- and low-load sport-specific practice session. Subjects included a cohort of NCAA Division 1 Men's and Women's Basketball players at the University of Oklahoma. Training load administration (high- and low-load approximations) was predetermined by the previous year's analyses of sport-specific training load, tracked by a *Catapult Sport OptimEye T6 Inertial Movement Unit* (Catapult Innovations, Melbourne, VIC, Australia) by *Catapult* load monitoring systems. This study consisted of 5 total visits, with details as follows: visit 1 – consent and familiarization to countermovement jump testing; visit 2 – pre-practice CMJ test, followed by a session of high or low external training load, followed by immediately-post practice CMJ testing; and visit 3 – 24-hours post-training CMJ testing. There was a minimum 1-week washout period, proceeded by visit 4 – pre-practice CMJ testing, followed by reciprocated high or low external training load from visit 2, followed by immediately-post practice CMJ testing; visit 5 – 24-hours post-practice CMJ testing, as shown in *Figure 1.*

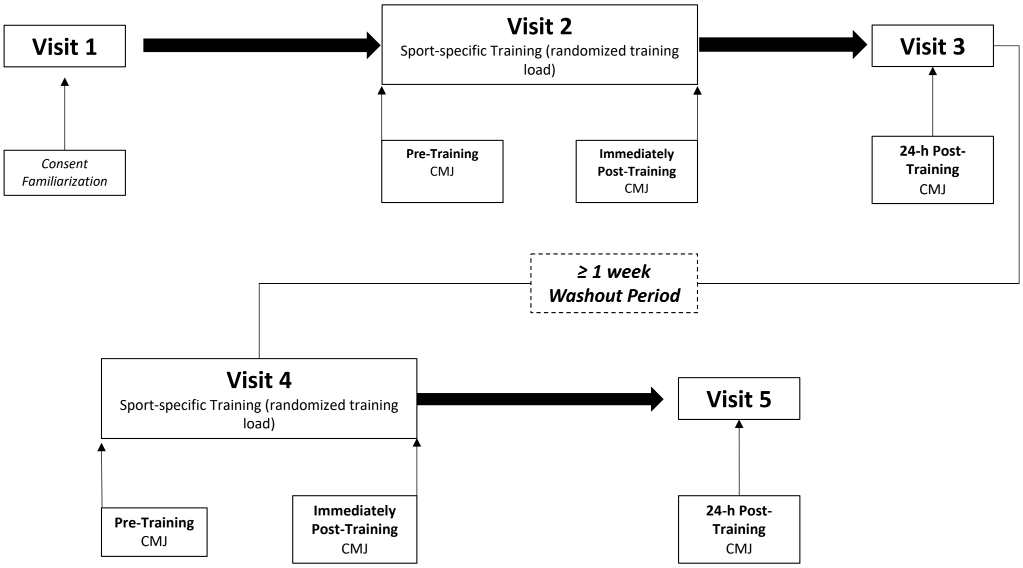


Figure 1. A schematic giving a visual representation of the research design.

Visit 1 lasted approximately 60 minutes. Visit 2 lasted approximately 150 minutes, while visits 3-5 lasted approximately 30 minutes each. Variables of interest were collected at approximately the same time of day for all CMJ procedures, as seen previously (Heishman et al., 2017).

Participants

A convenience sample of 20 NCAA Division 1 collegiate basketball players (males = 12; females = 8) were enrolled from the University of Oklahoma men's and women's basketball programs to participate in this study. Four participants were later excluded due to missing data points during analysis, as the results will reflect a sample of 12 males, and 4 females. Each participant provided informed consent prior to participating in the study. Furthermore, participants were informed that their participation in this investigation would have no bearing on their status as a member of the basketball squad and that they were free to withdraw from participating in the investigation at any point without penalty.

Inclusion Criteria

1. Participants included men and women between the ages of 18 and 26 years that were current members of University of Oklahoma Varsity basketball teams.
2. Men and women free of any musculoskeletal injuries at the time of testing and healthy for participation.

Exclusion Criteria

1. Individuals that were not members of the University's Varsity basketball programs.
2. Men or women who had experienced a recent musculoskeletal injury, surgery, or other medical reasons restricting their participation in team training sessions.
3. Men and women not cleared to fully participate in team practice.

Questionnaires and Documentation

Informed Consent

Each participant was informed of the inherent risk and benefits of the study and provided written informed consent before participating in the research. The research project was approved from the Institutional Review Board (IRB) at the University of Oklahoma.

Health Insurance Portability and Accountability Act

The Health Insurance portability and Accountability Act (HIPAA) informed the participant of the potential use of protected health information acquired during the project.

Sport Specific Health Status Questionnaire

The health status questionnaire gathered information pertaining to the health, wellness and previous medical history, assisting in the determination of participant inclusion. The questionnaire included a series of questions related to age, demographics, medical history, exercise habits, family medical history, medications, and smoking behavior.

Menstrual History Questionnaire

The menstrual history questionnaire was given to female subjects, including a variety of questions pertaining to menstrual cycle characteristics. These questions were broken down into two sections: A) current menstrual status and B) previous menstrual status, including questions related to present menstrual status, length of menstrual cycle, and irregular or missing periods, as well as questions related to menarche and hormonal abnormalities. In addition, the questionnaire gathered information regarding the use of contraceptives, such as the type, dosage, and duration of use.

Physical Activity Readiness Questionnaire

The physical activity readiness questionnaire (PAR-Q) acted as the initial screening tool before engaging in physical activity. The questionnaire included a series of questions determining the participant's capacity to engage in physical activity. If a participant responds 'yes' to any of the questions, clearance by the University's Sports Medicine staff would have been sought out prior to participation.

Anthropometric Measurements

Body height and weight was measured during visit 2. Body height was measured to the nearest cm using a wall stadiometer. Participants placed their back against the wall with their heel together and head position at a 90-degree angle looking forward, followed by a deep inhalation before recording. Body weight was measured to the neared 0.1 kg with the ForceDecks FD4000 Dual Force Platforms (ForceDecks, London, UK) prior to each countermovement jump test. Body height was measured without shoes and weight was measured with the participants wearing their shoes to increase feasibility of assessment.

External Load Monitoring during Practice Training Session

Participants wore a garment containing a Catapult Sport OptimEye T6 Inertial Movement Unit (IMU) (Catapult Innovations, Melbourne, VIC, Australia), which was used to quantify the biomechanical load of the practice session. The data was analyzed via the Catapult software (Openfield, Catapult, Innovations, Melbourne, VIC, Australia). Load monitoring began once the subject took the floor at the start of practice. The assessment of load was monitored "Live" during the practice session, to provide feedback on load accumulation and determine the cessation of the subject's practice se

Countermovement Jump Testing

Countermovement Jump (CMJ) testing was performed on the ForceDecks FD4000 Dual Force Platforms hardware (ForceDecks, London, UK), with a sample rate of 1000Hz, as described by previous research (Heishman et al., 2018). Asymmetry variables were calculated and produced via the ForceDecks software (ForceDecks, London, UK), which has also been described by previous literature (Heishman et al., 2019).

A standardized warmup protocol was implemented, consisting of dynamic stretches and skipping/locomotion, with increasing intensity for the duration of the protocol prior to the CMJ testing. In order to limit excess accumulation of training load and as the subjects will already be "warmed-up" from participating in the practice bout, subjects did not perform this protocol prior to immediate-post-practice CMJ testing.

When performing the CMJ, subjects started in the tall standing position, with feet placed hip width to shoulder width apart and hands on hips. *ForceDecks* software (ForceDecks, London, UK) provided the subject with a visual representation of weight distribution and were calibrated to equal distribution between limbs on the force cells. Subjects were instructed to choose a self-selected depth, followed by a maximal effort vertical jump, and land in an athletic position on the force cells. Three trials were performed, with a clear reset between each trial. If the subject's hands broke contact with their hips at any time during the jump or they exhibit excessive knee or hip flexion once airborne, the jump was ruled invalid and repeated. If the subject did not land adequately near the center of each plate, or lost balance upon landing, the trial was ruled invalid and repeated. Consistent instructions and verbal cues were provided to all participants during each CMJ trial to limit the impact of instructions on the CMJ performance characteristics (Young et al., 1995). Practice attire was worn during each trial and participants wore wear the same shoes for each session. In addition, verbal encouragement was provided to promote maximal effort during each jump attempt.

Asymmetry Quantification

Raw data from each individual limb was captured during each CMJ. Asymmetry variables were collected via the ForceDecks software (ForceDecks, London, UK), respective to the independent limbs with ForceDecks Dual Cell Platforms (ForceDecks, London, UK). After individual limb variables were computed by the ForceDecks software, data was exported and inter-limb asymmetries were calculated using the Bilateral Asymmetry Index-1 formula found below in Microsoft Excel, similar to previous literature (Bishop et al., 2018).

$$BAI\text{-}1 = \frac{DL-NDL}{DL+NDL} * 100$$

Note: BAI-1 = Bilateral Asymmetry Index-1. Negative values indicate direction of asymmetry to the non-dominant limb.

Change scores were then calculated for each of the three time points using the following equation, one the asymmetry score was derived:

$$\text{Change Score } (\mathbf{\Delta}) = T_2\text{-}T_1$$

Note: T = Time Point. Change scores are presented as Post-Pre, 24hPost-Pre, and 24hPost-Post, respectively.

Limb Dominance Raw Scores were then examined using the gross Force values for each limb. Comparisons were tested between dominant and nondominant limbs.

Statistical Analyses

Statistical analyses were performed using SPSS, Version 24 (SPSS INC., Chicago, IL). Descriptive statistics are reported as either mean ± standard deviation or mean (standard error). Initially, data normality was confirmed using the descriptive and graphical information, including skewness and kurtosis, supplemented by Shapiro-Wilk test statistic.

A 3-way (Sex [male, female] x Condition [high load, low load) x Time [pre-, immediately post-, 24-hours post-exercise]) repeated measures (RM) analysis of variance (ANOVA) was used to assess Sex, Condition, and Time main effects, as well as the interaction between Sex, Condition, and Time for each variable, in terms of the asymmetry score, as well as change scores and raw score values. If a significant Sex X Time or Sex X Condition interaction was observed, the model was decomposed into a separate two-way RM ANOVA with Bonferroni correction to test the simple effects. A one-way repeated measures ANOVA will be used if significant condition by time interactions are observed. Pearson's Correlation was used to assess the relationships between Change Scores and Playerload, as well as Change Scores and sRPE to quantify the magnitude and direction of changes in asymmetry to training loads. Statistical significance will be set at $\alpha \leq 0.05$. According to an a-priori G*Power (G*Power, version 3.1.9.2) analysis, for condition effects, a sample size of 14 participants (n=14) is required to achieve a power ≥ 0.8, based off an effect size = 0.25 and an alpha level set at $\alpha = 0.05$.

Chapter IV: Results & Discussion

Anthropometrics and Subjective Results

Baseline measurement differences of anthropometrics were analyzed using descriptive statistics over both conditions, consisting of body weight, height, and biological age. Subjective questionnaire results, immediately post-practice rating of perceived exertion (RPE), and condition effects (eTL parameters) are also reported as descriptive statistics.

Nineteen Division I NCAA collegiate basketball players (Male: *n* = 12, age = 20.3 ± 1.2 years, height = 201.7 ± 7.5 cm, body weight = 97.5 ± 9.8kg; Female: *n* = 4, age = 20.2 ± 0.2 years, height = 178.1 ± 3.9 cm, body weight = 82.3 ± 5.2kg) participated in the present study. Though twenty participants were enrolled, one subject was excluded from the study due to musculoskeletal injury during activity not related to the study. Anthropometrics are shown in **Table 1**.

Table 1. Subject Anthropometric Characteristics by Sex (Mean ± SD).

Variable	Male (n = 12)	Female (n = 4)
Age (years)	20.3 ± 1.2	20.2 ± 0.2
Height (cm)	201.7 ± 7.5	178.1 ± 3.9
Body Weight (kg)	97.5 ± 9.8	82.3 ± 5.2

Subjective recovery questionnaire results, reported as Mean ± SD, are as follows: Hours of sleep (Male = 6.4 ± 1.7; Female = 6.0 ± 1.1), Quality of Sleep (Male: 3.6 ± 0.6; Female = 3.7 ± 0.7), Hours of Outside Activity (Male = 1.7 ± 0.7; Female = 2.0 ± 1.8), Intensity of Outside Activity (Male = 5.3 ± 2.3; Female = 3.9 ± 3.1) Fatigue (Male = 3.0 ± 0.7; Female = 3.0 ± 0.5), Soreness (Male = 2.8 ± 0.6; Female = 3.2 ± 0.7), Stress (Male = 3.9 ± 0.8; Female = 3.4 ± 1.2), Mood (Male = 4.3 ± 0.5; Female = 4.2 ± 0.4), as shown in **Table 2**.

Table 2. Descriptive Statistics between Sexes of Subjective Questionnaire Results (Mean ± SD).

Variable	Male (n = 12)	Female (n = 4)
Hours Sleep	6.4 ± 1.7	6.0 ± 1.1
Sleep Quality (1-10)	3.6 ± 0.6	3.7 ± 0.7
Outside Activity	1.7 ± 0.7	2.0 ± 1.8
Activity Intensity (1-10)	5.3 ± 2.3	3.9 ± 3.1
Fatigue*	3.0 ± 0.7	3.0 ± 0.5
Soreness*	2.8 ± 0.6	3.2 ± 0.7
Stress*	3.9 ± 0.8	3.4 ± 1.2
Mood*	4.3 ± 0.5	4.2 ± 0.4

Descriptive statistics presented as Mean ± Standard Deviation. * = Likert scale answers: 1 = poor, 5 = best.

External Training Load Results

Descriptive statistics of External Training Load (eTL) variables of interest are presented in **Table 3**. There were significant Sex*Condition differences for Duration between conditions (Low: $p < 0.001$; High: $p < 0.001$), as well as PL/min, however, no significant differences in PL with 'Low' condition ($p > 0.05$). There were significant Sex*Condition interactions between the aforementioned variables, as well as main effects for Sex and Condition.

Table 3. Sex*Condition Interactions of eTL variables.

Variable	Male (N=12)		Female (N=4)	
	Low eTL	High eTL	Low eTL	High eTL
Duration (min)	86.6 ± 0.5	86.4 ± 0.5	70.0 ± 0.0	67.4 ± 0.8
PL (au)	410.5 ± 125.4	458.3 ± 78.7	389.8 ± 59.8	465.5 ± 72.4
PL/min (au/min)	4.7 ± 1.4	5.3 ± 0.9	5.2 ± 1.1	6.6 ± 0.9
RPE	5.5 ± 2.2	5.6 ± 1.9	5.8 ± 1.3	3.8 ± 0.5
sRPE	476.3 ± 194.5	490.0 ± 171.6	402.5 ± 88.1	252.0 ± 32.1

Descriptive statistics presented as Mean ± Standard Deviation.PL = PlayerLoad™; PL/min = PlayerLoad™ per minute; RPE = Rating of Perceived Exertion; sRPE = Session Rating of Perceived Exertion; au = arbitrary units.

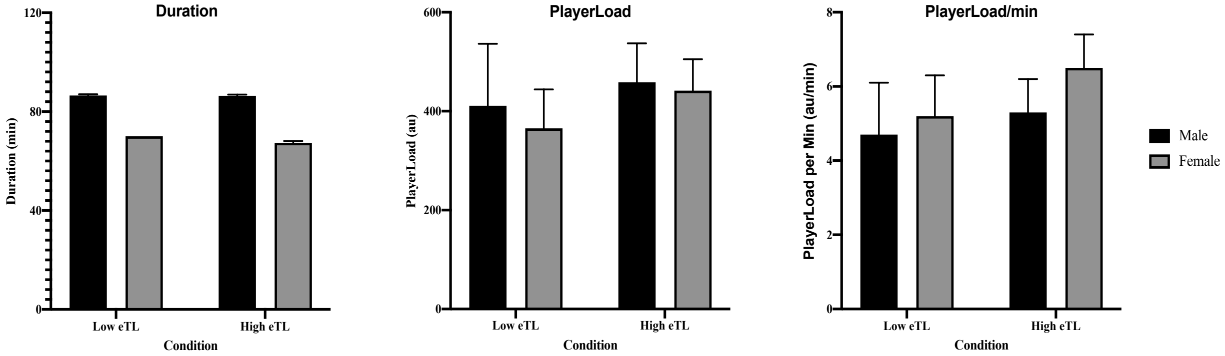


Figure 2. eTL Parameters between Sex and Condition. Represented as Mean ± SD.

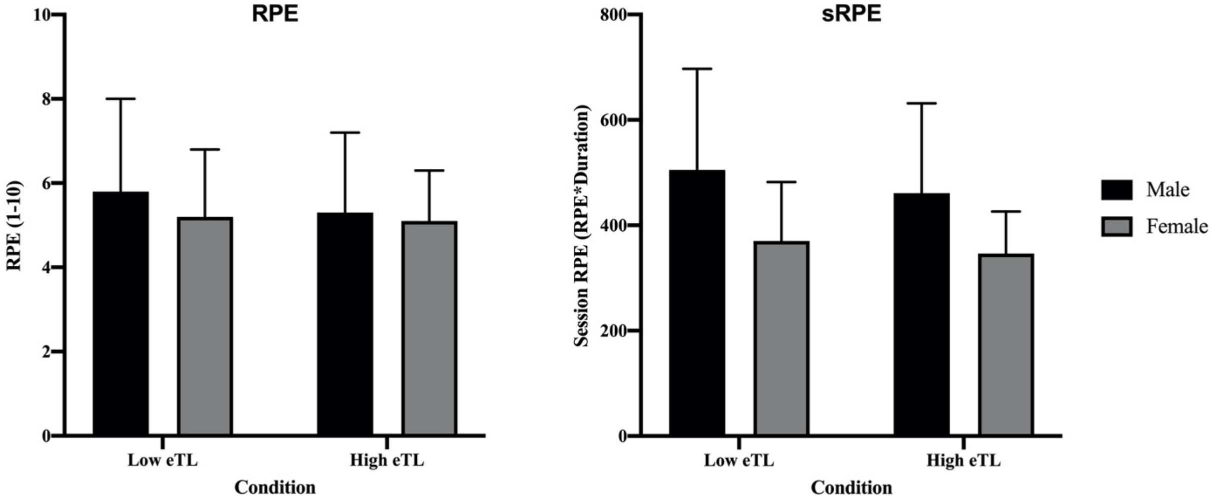


Figure 3. RPE and Session RPE between Sex and Condition. Represented as Mean ± SD.

There was a significant Sex*Condition interaction with Duration, as the males appeared to participate a significantly longer duration compared to the females over both the High (Males = 86.4(0.5) min.; Females = 67.4(0.8) min.; $p < 0.001$) and Low (Males = 86.6(0.5) min.; Females = 70.0(0.0) min.; $p < 0.001$) conditions. There was no significant Sex*Condition interaction for PL ($p = 0.261$). There was a significant main effect for Condition in Duration (High = 76.9(0.1) min; Low = 78.3(0.1) min, $p < 0.001$). Though the Duration was decreased for the High eTL Condition, there was a significantly greater PL (High = 449.9(17.5) au; Low = 388.0(26.4) au, $p < 0.001$) than the Low eTL condition. These interactions are shown in **Figures 2** and **Figure 3**. There was a significant Sex main effect for Duration (Men = 86.5(0.1) min; Women = 68.7(0.1) min, $p < 0.001$), though PL (Men = 434.4(26.2) au; Women = 403.5(34.3) au; p = 0.485) did not reach statistical significance. There was no significant Sex × Condition interaction (p = 0.473, ηp2 = 0.031), nor significant Condition (p = 0.314, d = 0.36) or Sex (p = 0.629, d = 0.23) main effects for differences in RPE. In parallel, there were no significant Sex*Condition interactions (p = 0.534, ηp2 = 0.023), nor significant main effects for differences by Condition (p = 0.314, d = 0.43) or Sex in sRPE (p = 0.062, d = 0.95). Means ± SD of Rating of Perceived Exertion (RPE) and Session RPE (sRPE – computed by multiplying session duration by session RPE) are shown in **Table 3**.

Countermovement Jump Results

BAI-1 Asymmetry Score Results

There were no significant Sex*Condition*Time interactions for any of the asymmetry variables ($p > 0.05$). As outlined in **Table 4**, as well as **Figures 4** and **5**, there were no significant Condition*Time interactions for any Asymmetry Score variable, including Concentric Impulse (p = 0.136; $\eta_p^2 = 0.133$), Concentric Mean Force (p = 0.144; $\eta_p^2 = 0.129$), Concentric, Peak Force (p = 0.252; $\eta_p^2 = 0.094$), Eccentric Braking RFD (p = 0.854; $\eta_p^2 = 0.011$), Eccentric Deceleration RFD (p = 0.604; $\eta_p^2 = 0.035$), Eccentric Mean Force (p = 0.082; $\eta_p^2 = 0.163$), Eccentric Peak Force (p = 0.369; $\eta_p^2 = 0.069$), Force at Zero Velocity (p = 0.295; $\eta_p^2 = 0.083$), Force at Peak Power (p = 0.383; $\eta_p^2 = 0.066$), or Takeoff Peak Force (p = 0.291; $\eta_p^2 = 0.084$).

All Low eTL effects were interpreted as trivial (p = 0.141-0.843; $d < 0.20$) for all three time points, however Concentric Impulse ($d = 0.25$), Concentric Mean Force ($d = 0.25$), Concentric Peak Force ($d = 0.26$), Eccentric Mean Force ($d = 0.24$), Eccentric Peak Force ($d = 0.24$), Force @ Zero Velocity ($d = 0.23$), Force @ Peak Power ($d = 0.31$), and Takeoff Peak Force ($d = 0.26$) demonstrated small effects for High eTL Pre-to-Post-, Eccentric Deceleration RFD ($d = 0.30$)

showed small effect for High eTL Pre-to-24hPost-, and Concentric Impulse (*d* = 0.29), Concentric Mean Force (*d* = 0.28), Concentric Peak Force (*d* = 0.24), Eccentric Mean Force (*d* = 0.27), Force @ Peak Power (*d* = 0.29), and Takeoff Peak Force (*d* = 0.23) revealed a small effect for High eTL Post-24hPost-.

Table 4. Condition*Time Interactions of Asymmetry Score Variables.

							Effect (*d*)					
	Low eTL			**High eTL**			**Low eTL**			**High eTL**		
Variable	**Pre**	**Post**	**24hPost**	**Pre**	**Post**	**24hPost**	**Pre to Post**	**Post to 24hPost**	**Pre to 24hPost**	**Pre to Post**	**Post to 24hPost**	**Pre to 24hPost**
Concentric Impulse (%)	0.7(1.7)	1.2(2.3)	1.1(1.8)	1.6(1.6)	3.7(2.3)	1.3(1.8)	0.07	0.05	0.02	0.25	0.05	0.29
Concentric Mean Force (%)	0.7(1.7)	1.3(2.2)	1.1(1.8)	1.6(1.6)	3.6(2.3)	1.3(1.8)	0.07	0.05	0.03	0.25	0.05	0.28
Concentric Peak Force (%)	0.3(1.7)	0.9(1.9)	0.9(1.9)	0.7(1.5)	2.4(1.7)	0.7(1.7)	0.07	0.07	0.00	0.26	0.00	0.24
Eccentric Braking RFD (%)	1.2(3.0)	1.5(4.3)	2.2(3.8)	2.0(3.3)	3.3(3.9)	2.2(3.4)	0.02	0.07	0.04	0.09	0.01	0.08
Eccentric Deceleration RFD (%)	-0.4(4.0)	-0.2(4.8)	1.0(4.0)	-1.3(3.4)	1.2(4.2)	2.9(3.6)	0.01	0.09	0.07	0.16	0.30	0.11
Eccentric Mean Force (%)	1.1(2.3)	1.1(2.5)	1.5(2.4)	2.2(2.1)	4.5(2.7)	1.8(2.2)	0.00	0.04	0.04	0.24	0.04	0.27
Eccentric Peak Force (%)	0.2(2.6)	1.3(3.3)	1.3(2.9)	1.4(2.4)	4.2(3.4)	2.4(2.6)	0.09	0.10	0.00	0.24	0.10	0.14
Force @ Zero Velocity (%)	0.2(2.6)	1.4(3.3)	1.7(2.9)	1.5(2.4)	4.3(3.4)	2.4(2.7)	0.10	0.13	0.03	0.23	0.09	0.15
Force @ Peak Power (%)	0.3(0.9)	0.5(1.4)	0.1(1.0)	0.6(0.7)	1.9(1.2)	0.6(1.0)	0.04	-0.06	0.09	0.31	0.02	0.29
Takeoff Peak Force (%)	0.5(1.7)	0.8(1.9)	0.5(2.0)	0.7(1.5)	2.4(1.8)	0.7(1.7)	0.04	0.00	0.03	0.26	0.01	0.23

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development; eTL= External Training Load.

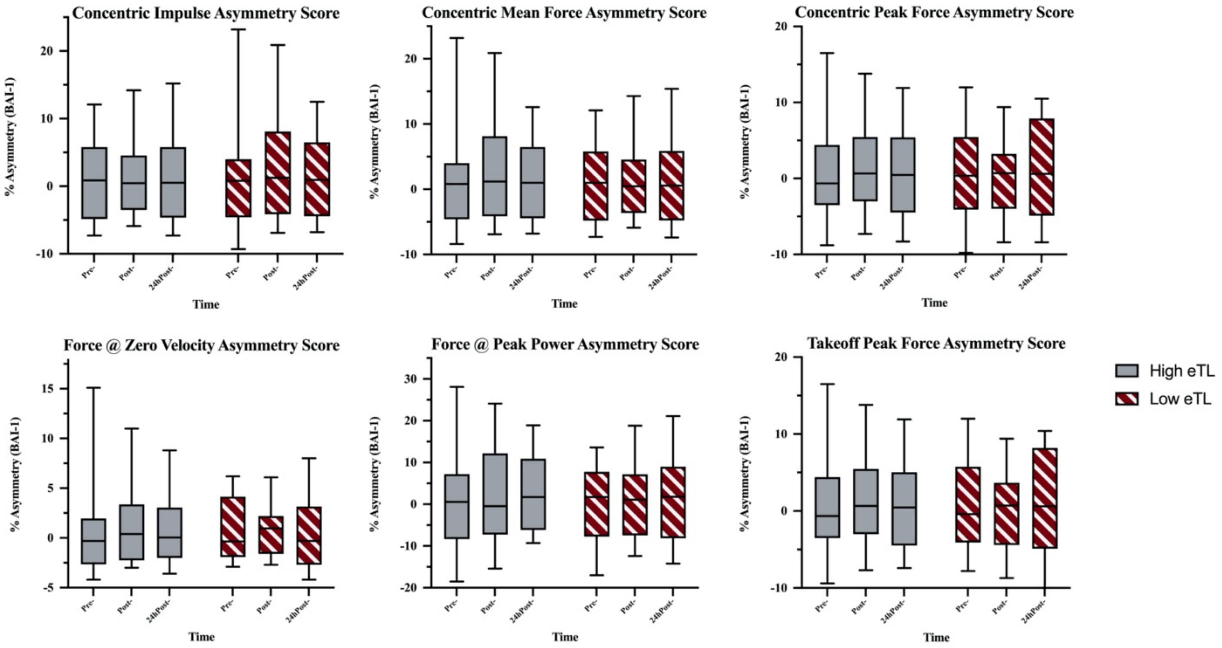


Figure 4. Condition*Time Interactions of Asymmetry Score Variables

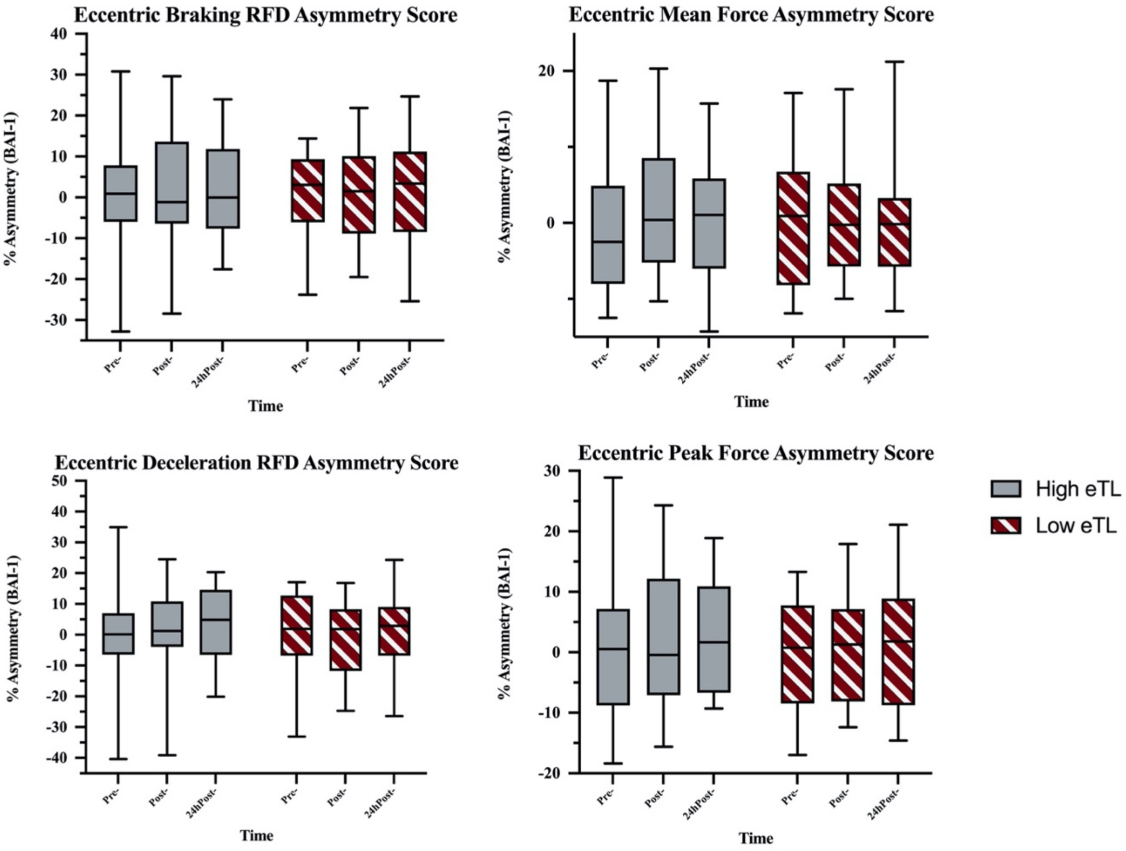


Figure 5. Condition*Time Interactions of Asymmetry Score Variables

There were no significant Sex*Time interactions for any Asymmetry Score variables, including Concentric Impulse (p = 0.39; $\eta_p^2 = 0.065$), Concentric Mean Force (p = 0.386; $\eta_p^2 =$ 0.066), Concentric Peak Force (p = 0.43; $\eta_p^2 = 0.058$), Eccentric Braking RFD (p = 0.729; $\eta_p^2 =$ 0.022), Eccentric Deceleration RFD (p = 0.818; $\eta_p^2 = 0.014$), Eccentric Mean Force (p = 0.126; η_p^2 = 0.138), Eccentric Peak Force (p = 0.569; $\eta_p^2 = 0.039$), Force at Zero Velocity (p = 0.618; $\eta_p^2 =$ 0.034), Force at Peak Power (p = 0.534; $\eta_p^2 = 0.044$), or Takeoff Peak Force (p =0.543; $\eta_p^2 =$ 0.043). These interactions are presented in **Table 5**. Females demonstrated small effects Pre-to-Post- for Concentric Impulse (*d* = 0.28), Concentric Mean Force (*d* = 0.28), Concentric Peak Force (*d* = 0.34), Eccentric Mean Force (*d* = 0.28), Eccentric Peak Force (*d* = 0.24), Force @ Zero Velocity (*d* = 0.27), Force @ Peak Power (*d* = 0.33), and Takeoff Peak Force (*d* = 0.28), a small effect Pre-to-24hPost- for Eccentric Deceleration RFD (*d* = 0.32), and small effects Post-to-24hPost- for Concentric Impulse (*d* = 0.33), Concentric Mean Force (*d* = 0.33), Concentric Peak Force (*d* = 0.24), Eccentric Mean Force (*d* = 0.34), Force @ Peak Power (*d* = 0.39), and Takeoff Peak Force (*d* = 0.25), while all other values for these time points were interpreted as trivial (*d* < 0.20). Males showed trivial effects for all Asymmetry Score variables for all time points (*d* < 0.20).

Table 5. Asymmetry Scores for Men and Women Across Time Points.

	Sex						**Effect (*d*)**					
	Female (n = 4)			**Male (n = 12)**			**Female (n = 4)**			**Male (n = 12)**		
Variable	**Pre**	**Post**	**24hPost**	**Pre**	**Post**	**24hPost**	**Pre to Post**	**Post to 24hPost**	**Pre to 24hPost**	**Pre to Post**	**Post to 24hPost**	**Pre to 24hPost**
Concentric Impulse (%)	1.5(2.8)	3.4(3.9)	1.1(3.1)	0.8(1.6)	1.5(2.2)	1.3(1.8)	0.28	0.08	0.33	0.10	0.08	0.03
Concentric Mean Force (%)	1.6(2.8)	3.4(3.8)	1.1(3.1)	0.8(1.6)	1.5(2.2)	1.3(1.8)	0.28	0.08	0.33	0.11	0.08	0.03
Concentric Peak Force (%)	0.5(2.8)	2.5(3.1)	1.0(3.1)	0.5(1.6)	0.8(1.8)	0.6(1.8)	0.34	0.09	0.24	0.05	0.01	0.04
Eccentric Braking RFD (%)	3.5(5.2)	4.7(6.8)	3.2(6.2)	-0.2(3.0)	0.2(3.9)	1.1(3.5)	0.10	0.03	0.11	0.04	0.13	0.08
Eccentric Deceleration RFD (%)	-1.6(6.3)	0.7(7.5)	2.3(6.3)	-0.0(3.6)	0.1(4.3)	1.6(3.6)	0.18	0.32	0.11	0.02	0.13	0.10
Eccentric Mean Force (%)	4.6(3.7)	6.8(4.4)	4.0(3.9)	-1.2(2.1)	-1.1(2.5)	-0.6(2.2)	0.28	0.08	0.34	0.00	0.08	0.07
Eccentric Peak Force (%)	2.5(4.2)	5.0(5.7)	2.9(4.8)	-0.8(2.4)	0.5(3.3)	0.8(2.7)	0.24	0.04	0.19	0.14	0.19	0.03
Force @ Zero Velocity (%)	2.3(4.3)	5.0(5.7)	3.2(4.8)	-0.6(2.4)	0.6(3.3)	0.9(2.8)	0.27	0.10	0.17	0.12	0.17	0.03
Force @ Peak Power (%)	0.3(1.4)	1.5(2.1)	0.0(1.7)	0.7(0.8)	0.9(1.2)	0.7(0.9)	0.33	0.10	0.39	0.07	0.00	0.06
Takeoff Peak Force (%)	0.7(2.8)	2.4(3.1)	0.8(3.2)	0.4(1.6)	0.7(1.8)	0.4(1.8)	0.28	0.02	0.25	0.05	0.00	0.05

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development.

There were no significant Condition*Sex interactions for the Asymmetry Score variables, including Concentric Impulse ($p = 0.317$; $\eta^2 = 0.071$), Concentric Mean Force ($p = 0.276$; $\eta^2 = 0.084$), Concentric Peak Force ($p = 0.103$; $\eta^2 = 0.179$), Eccentric Braking RFD ($p = 0.33$; $\eta^2 = 0.068$), Eccentric Deceleration RFD ($p = 0.853$; $\eta^2 = 0.003$), Eccentric Mean Force ($p = 0.76$; $\eta^2 = 0.007$), Eccentric Peak Force ($p = 0.442$; $\eta^2 = 0.043$), Force at Zero Velocity ($p = 0.565$; $\eta^2 = 0.024$), Force at Peak Power ($p = 0.294$; $\eta^2 = 0.078$), or Takeoff Peak Force ($p = 0.08$; $\eta^2 = 0.203$). These interactions are presented in **Table 6**. Males demonstrated trivial effect ($d < 0.20$) between conditions for all Asymmetry Score variables, whereas Females showed small effect for Concentric Impulse ($d = 0.27$), Concentric Mean Force ($d = 0.26$), Concentric Peak Force ($d = 0.24$), Eccentric Mean Force ($d = 0.23$), Eccentric Peak Force ($d = 0.23$), Force @ Zero Velocity ($d = 0.21$), Force @ Peak Power ($d = 0.34$), and Takeoff Peak Force ($d = 0.26$) between conditions.

Table 6. Asymmetry Scores for Men and Women Between Conditions.

	Male (n = 12)			**Female (n = 4)**		
Variable	**Low eTL**	**High eTL**	**Effect (*d*)**	**Low eTL**	**High eTL**	**Effect (*d*)**
Concentric Impulse (%)	0.9(1.9)	1.5(1.8)	0.09	1.2(3.3)	2.9(3.2)	0.27
Concentric Mean Force (%)	0.9(1.9)	1.5(1.8)	0.08	1.2(3.3)	2.9(3.2)	0.26
Concentric Peak Force (%)	0.8(1.8)	0.5(1.6)	0.04	0.6(3.1)	2.1(2.8)	0.24
Eccentric Braking RFD (%)	0.4(3.5)	0.2(3.3)	0.01	2.9(6.1)	4.7(5.7)	0.15
Eccentric Deceleration RFD (%)	0.0(3.9)	1.1(3.5)	0.09	0.1(6.9)	0.7(6.2)	0.04
Eccentric Mean Force (%)	-1.7(2.3)	-0.3(2.3)	0.17	4.2(4.0)	6.1(3.9)	0.23
Eccentric Peak Force (%)	-0.3(2.9)	0.7(2.7)	0.11	2.3(5.0)	4.6(4.8)	0.23
Force @ Zero Velocity (%)	-0.2(2.8)	0.9(2.8)	0.12	2.5(4.9)	4.6(4.8)	0.21
Force @ Peak Power (%)	0.6(1.0)	0.9(0.9)	0.08	0.0(1.8)	1.2(1.6)	0.34
Takeoff Peak Force (%)	0.7(1.8)	0.4(1.6)	0.04	0.5(3.2)	2.1(2.8)	0.26

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development.

There were no significant Time main effects for any of the Asymmetry Score variables, including Concentric Impulse ($p = 0.198$; $\eta^2 = 0.115$), Concentric Mean Force ($p = 0.175$; $\eta^2 = 0.126$), Concentric Peak Force ($p = 0.234$; $\eta^2 = 0.1$), Eccentric Braking RFD ($p = 0.868$; $\eta^2 = 0.001$), Eccentric Deceleration RFD ($p = 0.361$; $\eta^2 = 0.066$), Eccentric Mean Force ($p = 0.288$; $\eta^2 = 0.085$), Eccentric Peak Force ($p = 0.236$; $\eta^2 = 0.099$), Force at Zero Velocity ($p = 0.209$; $\eta^2 = 0.109$), Force at Peak Power ($p = 0.289$; $\eta^2 = 0.085$), and Takeoff Peak Force ($p = 0.278$; $\eta^2 = 0.086$), as shown in **Table 7**. Subjects showed trivial effects ($d < 0.20$) for all Asymmetry Score variables Pre-to Post-. Eccentric Deceleration RFD showed small effect ($d = 0.20$) Pre-to-24hPost-, and Force @ Peak Power showed small effect ($d = 0.20$) Post-to24hPost-, while all others showed trivial effect ($d < 0.20$).

Table 7. Time Effects of Asymmetry Score Variables.

Variable	Pre	Post	24hPost	Pre to Post	Post to 24hPost	Pre to 24hPost
Concentric Impulse (%)	1.2(1.6)	2.5(2.2)	1.2(1.8)	0.16	0.00	0.16
Concentric Mean Force (%)	1.2(1.6)	2.5(2.2)	1.2(1.8)	0.17	0.00	0.16
Concentric Peak Force (%)	0.5(1.6)	1.7(1.8)	0.8(1.8)	0.17	0.04	0.12
Eccentric Braking RFD (%)	1.6(3.0)	2.4(3.9)	2.2(3.5)	0.06	0.04	0.02
Eccentric Deceleration RFD (%)	-0.8(3.6)	0.4(4.3)	1.9(3.6)	0.08	0.20	0.09
Eccentric Mean Force (%)	1.7(2.1)	2.8(2.5)	1.6(2.2)	0.12	0.00	0.12
Eccentric Peak Force (%)	0.8(2.4)	2.8(3.3)	1.9(2.7)	0.17	0.10	0.07
Force @ Zero Velocity (%)	0.8(2.4)	2.8(3.3)	2.1(2.8)	0.17	0.11	0.06
Force @ Peak Power (%)	0.5(0.8)	1.2(1.2)	0.3(0.9)	0.17	0.04	0.20
Takeoff Peak Force (%)	0.6(1.6)	1.6(1.8)	0.6(1.8)	0.14	0.01	0.13

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development. Δ1 = Pre-Post; Δ2 = Pre-24hPost; Δ3 = Post-24hPost.

There were no significant Sex main effects among any of the Asymmetry Score variables, including Concentric Impulse (Men = 1.221(1.873)%, Women = 2.073(3.243)%, p = 0.823, *d* = 0.131), Concentric Mean Force (Men = 1.262(1.872)%, Women = 2.075(3.242)%, p = 0.831, *d* = 0.125), Concentric Peak Force (Men = 0.671(1.715)%, Women = 1.397(2.97)%, p = 0.835, *d* = 0.122), Eccentric Braking RFD (Men = 0.372(3.418)%, Women = 3.864(5.92)%, p = 0.617, *d* = 0.295), Eccentric Deceleration RFD (Men = 0.582(3.71)%, Women = 0.464(6.426)%, p = 0.988, *d* = 0.009), Eccentric Mean Force (Men = -1.013(2.285)%, Women = 5.17(3.958)%, p = 0.198, *d* = 0.781), Eccentric Peak Force (Men = 0.192(2.809)%, Women = 3.532(4.865)%, p = 0.562, *d* = 0.343), Force at Zero Velocity (Men = 0.333(2.822)%, Women = 3.582(4.887)%, p = 0.574, *d* = 0.332), Force at Peak Power (Men = 0.793(0.983)%, Women = 0.616(1.702)%, p = 0.93, *d* = 0.052), and Takeoff Peak Force (Men = 0.589(1.741)%, Women = 1.358(3.016)%, p = 0.828, *d* = 0.127), as shown in **Table 8**. Eccentric Mean Force demonstrated medium effect (*d* = 0.78) between sexes, Eccentric Braking RFD (*d* = 0.29), Eccentric Peak Force (*d* = 0.34), and Force @ Zero Velocity (*d* = 0.33) revealed small effect, while all others remain trivial (*d* < 0.20).

Table 8. Sex Effects of Asymmetry Score Variables.

Variable	Men (n = 12)	Women (n = 4)	p-value	Effect (*d*)
Concentric Impulse (%)	1.2(1.8)	2.0(3.2)	0.82	0.13
Concentric Mean Force (%)	1.2(1.8)	2.0(3.2)	0.83	0.12
Concentric Peak Force (%)	0.6(1.7)	1.4(2.9)	0.83	0.12
Eccentric Braking RFD (%)	0.3(3.4)	3.8(5.9)	0.61	0.29
Eccentric Deceleration RFD (%)	0.5(3.7)	0.4(6.4)	0.98	0.01
Eccentric Mean Force (%)	-1.0(2.2)	5.1(3.9)	0.19	0.78
Eccentric Peak Force (%)	0.1(2.8)	3.5(4.8)	0.56	0.34
Force @ Zero Velocity (%)	0.3(2.8)	3.5(4.8)	0.57	0.33
Force @ Peak Power (%)	0.7(0.9)	0.6(1.7)	0.93	0.05
Takeoff Peak Force (%)	0.5(1.7)	1.3(3.0)	0.82	0.13

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development.

There were no significant main effects between conditions for Concentric Impulse (p = 0.432; $\eta_p^2 = 0.045$), Concentric Mean Force (p = 0.476; $\eta_p^2 = 0.037$), Concentric Peak Force (p = 0.619; $\eta_p^2 = 0.018$), Eccentric Braking RFD (p = 0.782; $\eta_p^2 = 0.006$), Eccentric Deceleration RFD (p = 0.428; $\eta_p^2 = 0.045$), Eccentric Mean Force (p = 0.642; $\eta_p^2 = 0.016$), Eccentric Peak Force (p = 0.984; $\eta_p^2 = 0$), Force at Zero Velocity (p = 0.68; $\eta_p^2 = 0.013$), Force at Peak Power (p = 0.804; $\eta_p^2 = 0.005$), or Takeoff Peak Force (p = 0.954; $\eta_p^2 = 0$). These effects are presented in **Table 9**. All of the Asymmetry Score variables showed trivial effect between Conditions (*d* < 0.20).

Table 9. Condition Effects of Asymmetry Score Variables.

Variable	Low eTL	High eTL	Effect (*d*)
Concentric Impulse (%)	1.0(1.9)	2.2(1.8)	0.16
Concentric Mean Force (%)	1.1(1.9)	2.2(1.8)	0.15
Concentric Peak Force (%)	0.7(1.8)	1.3(1.6)	0.09
Eccentric Braking RFD (%)	1.7(3.5)	2.5(3.3)	0.06
Eccentric Deceleration RFD (%)	0.1(3.9)	0.9(3.5)	0.06
Eccentric Mean Force (%)	1.2(2.3)	2.8(2.3)	0.18
Eccentric Peak Force (%)	1.0(2.9)	2.7(2.7)	0.15
Force @ Zero Velocity (%)	1.1(2.8)	2.7(2.8)	0.14
Force @ Peak Power (%)	0.3(1.0)	1.0(0.9)	0.18
Takeoff Peak Force (%)	0.6(1.8)	1.3(1.6)	0.10

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development.

Change Score Results

There were no significant Sex*Condition*Time interactions for any of the Change Score variables, including Concentric Impulse ($p = 0.387$; $\eta^2 = 0.066$), Concentric Mean Force ($p = 0.3$; $\eta^2 = 0.082$), Concentric Peak Force ($p = 0.475$; $\eta^2 = 0.052$), Eccentric Braking RFD ($p = 0.849$; $\eta^2 = 0.012$), Eccentric Deceleration RFD ($p = 0.953$; $\eta^2 = 0.003$), Eccentric Mean Force ($p = 0.845$; $\eta^2 = 0.012$), Eccentric Peak Force ($p = 0.616$; $\eta^2 = 0.034$), Force at Zero Velocity ($p = 0.581$; $\eta^2 = 0.038$), Force at Peak Power ($p = 0.118$; $\eta^2 = 0.142$), or Takeoff Peak Force ($p = 0.585$; $\eta^2 = 0.038$).

There were no significant Condition*Sex interactions for the Change Score variables: Concentric Impulse ($p = 0.065$; $\eta^2 = 0.223$), Concentric Mean Force ($p = 0.072$; $\eta^2 = 0.213$), Concentric Peak Force ($p = 0.123$; $\eta^2 = 0.161$), Eccentric Braking RFD ($p = 0.221$; $\eta^2 = 0.105$), Eccentric Deceleration RFD ($p = 0.618$; $\eta^2 = 0.018$), Eccentric Mean Force ($p = 0.352$; $\eta^2 = 0.062$), Eccentric Peak Force ($p = 0.34$; $\eta^2 = 0.065$), Force at Zero Velocity ($p = 0.092$; $\eta^2 = 0.189$), Force at Peak Power ($p = 0.224$; $\eta^2 = 0.104$), Takeoff Peak Force ($p = 0.457$; $\eta^2 = 0.04$). These interactions are shown in **Table 10**. Males demonstrated medium effect between Conditions for Concentric Impulse ($d = 0.61$), Concentric Mean Force ($d = 0.62$), Concentric Peak Force ($d = 0.51$), Eccentric Deceleration RFD ($d = 0.63$), Force @ Zero Velocity ($d = 0.62$) and Force @ Peak Power ($d = 0.76$), while Eccentric Braking RFD ($d = 0.42$), Eccentric Mean Force ($d = 0.22$), Eccentric Peak Force ($d = 0.42$), and Takeoff Peak Force ($d = 0.38$) showed small effect. Females revealed large effects for Concentric Peak Force ($d = 0.95$), medium effect for Eccentric Deceleration RFD ($d = 0.56$), and small effects for Concentric Impulse ($d = 0.48$), Concentric Mean Force ($d = 0.48$), Eccentric Braking RFD ($d = 0.27$), Force @ Peak Power ($d = 0.43$), and Takeoff Peak Force ($d = 0.39$).

Table 10. Change Scores of Men and Women Between Conditions.

	Males (n = 12)			**Females (n = 4)**		
Variable	**Low Mean(SE)**	**High Mean(SE)**	**Effect *(d)***	**Low Mean(SE)**	**High Mean(SE)**	**Effect *(d)***
Concentric Impulse (%)	-0.0(0.2)	0.7(0.4)	0.61	0.5(0.4)	-1.1(0.7)	0.48
Concentric Mean Force (%)	-0.0(0.2)	0.7(0.4)	0.62	0.5(0.4)	-1.1(0.7)	0.45
Concentric Peak Force (%)	-0.3(0.3)	0.4(0.5)	0.51	1.0(0.5)	-0.3(0.8)	0.95
Eccentric Braking RFD (%)	0.0(1.1)	1.9(1.3)	0.42	1.2(1.9)	-1.6(2.3)	0.27
Eccentric Deceleration RFD (%)	-0.3(1.6)	2.6(0.9)	0.63	2.3(2.9)	3.0(1.7)	0.56
Eccentric Mean Force (%)	0.1(0.8)	0.6(0.5)	0.22	0.3(1.4)	-1.1(0.8)	0.10
Eccentric Peak Force (%)	0.7(0.6)	1.6(0.5)	0.42	0.7(1.0)	-0.1(1.0)	0.02
Force @ Zero Velocity (%)	0.4(0.5)	1.6(0.5)	0.62	1.5(0.9)	-0.3(1.0)	0.59
Force @ Peak Power (%)	-0.3(0.1)	0.3(0.3)	0.76	0.0(0.3)	-0.4(0.6)	0.43
Takeoff Peak Force (%)	-0.2(0.4)	0.3(0.4)	0.38	0.3(0.7)	-0.1(0.8)	0.39

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; d = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development.

Only Eccentric Mean Force (p = 0.015; $\eta^2 = 0.308$) displayed a significant Condition*Time interaction, while all other variables were not significant: Concentric Impulse (p = 0.113; $\eta^2 = 0.166$), Concentric Mean Force (p = 0.107; $\eta^2 = 0.169$), Concentric Peak Force (p = 0.14; $\eta^2 = 0.144$), Eccentric Braking RFD (p = 0.692; $\eta^2 = 0.014$), Eccentric Deceleration RFD (p = 0.658; $\eta^2 = 0.021$), Eccentric Peak Force (p = 0.213; $\eta^2 = 0.108$), Force at Zero Velocity (p = 0.182; $\eta^2 = 0.122$), Force at Peak Power (p = 0.239; $\eta^2 = 0.098$), Takeoff Peak Force (p = 0.139; $\eta^2 = 0.144$). Condition* Time interactions are shown in **Table 11**, as well as **Figures 6** and **7**. Only trivial effects were shown Pre-to-Post- for Low eTL for all Change Scores ($d < 0.20$), small effects for Concentric Mean Force ($d = 0.20$), Force @ Peak Power ($d = 0.20$) Pre-to-24hPost-, and small effects for Concentric Mean Force ($d = 0.22$), Eccentric Peak Force ($d = 0.25$), and Force @ Zero Velocity ($d = 0.28$) Post-to-24hPost-. Medium effects were shown for the High eTL Condition Pre-to-Post- for Concentric Impulse ($d = 0.75$), Concentric Mean Force ($d = 0.75$), Concentric Peak Force ($d = 0.60$), Eccentric Mean Force ($d = 0.71$), Force @ Peak Power ($d = 0.52$), and Takeoff Peak Force ($d = 0.59$). Large effects were revealed Pre-to-24hPost- for Concentric Impulse ($d = 1.05$), Concentric Mean Force ($d = 1.04$), Concentric Peak Force ($d = 1.00$), Eccentric Mean Force ($d = 1.09$), Force @ Zero Velocity ($d = 0.80$), and Takeoff Peak Force ($d = 0.97$), with medium effects in Eccentric Peak Force ($d = 0.78$) and Force @ Peak Power ($d = 0.76$). Medium effects were shown Post-to-24hPost- for Concentric Impulse ($d = 0.55$), Concentric Mean Force ($d = 0.54$), Eccentric Mean Force ($d = 0.58$), Eccentric Peak Force ($d = 0.61$), and Force @ Zero Velocity ($d = 0.59$), while small effects were observed in Concentric Peak Force ($d = 0.48$), Force @ Peak Power ($d = 0.41$), and Takeoff Peak Force ($d = 0.\ 49$).

Table 11. Change Scores Between Conditions and Time Points.

	Low eTL						**High eTL**					
	Mean(SE)			**Effect (*d*)**			**Mean(SE)**			**Effect (*d*)**		
Variable	**Δ_1 = Post-Pre**	**Δ_2 = 24hPost-Pre**	**Δ_3 = 24hPost-Post**	***d* Δ_1**	***d* Δ_2**	***d* Δ_3**	**Δ_1 = Post-Pre**	**Δ_2 = 24hPost-Pre**	**Δ_3 = 24hPost-Post**	***d* Δ_1**	***d* Δ_2**	***d* Δ_3**
Concentric Impulse (%)	0.5(1.2)	0.3(0.3)	-0.1(1.0)	0.04	0.15	0.18	2.0(0.9)	-0.3(0.6)	-2.3(1.1)	0.75	1.05	0.55
Concentric Mean Force (%)	0.6(1.2)	0.3(0.3)	-0.2(0.9)	0.07	0.20	0.22	2.0(0.9)	-0.3(0.6)	-2.3(1.1)	0.75	1.04	0.54
Concentric Peak Force (%)	0.5(1.0)	0.5(0.5)	-0.0(0.9)	0.00	0.14	0.18	1.7(0.6)	0.0(0.7)	-1.7(1.0)	0.60	1.00	0.48
Eccentric Braking RFD (%)	0.2(2.9)	0.9(1.7)	0.6(1.9)	0.07	0.04	0.04	1.3(2.4)	0.2(2.0)	-1.1(2.4)	0.13	0.26	0.15
Eccentric Deceleration RFD (%)	0.1(3.5)	1.4(2.5)	1.3(2.2)	0.11	0.10	0.02	2.5(2.0)	4.2(1.4)	1.6(2.7)	0.24	0.09	0.29
Eccentric Mean Force (%)	-0.0(1.0)	0.3(1.2)	0.4(1.1)	0.09	0.11	0.01	2.3(1.1)	-0.3(0.7)	-2.7(1.2)	0.71	1.09	0.58
Eccentric Peak Force (%)	1.0(1.7)	1.0(0.9)	0.0(1.2)	0.00	0.18	0.25	2.8(1.5)	1.0(0.8)	-1.7(1.4)	0.35	0.78	0.61
Force @ Zero Velocity (%)	1.1(1.6)	1.5(0.8)	0.3(1.2)	0.06	0.14	0.28	2.8(1.5)	0.9(0.8)	-1.8(1.4)	0.38	0.80	0.59
Force @ Peak Power (%)	0.1(0.8)	-0.2(0.2)	-0.4(0.6)	0.17	0.20	0.09	1.2(0.7)	-0.0(0.5)	-1.3(0.9)	0.52	0.76	0.41
Takeoff Peak Force (%)	0.2(1.0)	0.0(0.6)	-0.2(0.9)	0.07	0.12	0.08	1.7(0.6)	0.0(0.7)	-1.6(1.0)	0.59	0.97	0.49

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development. Δ1 = Pre-Post; Δ2 = Pre-24hPost; Δ3 = Post-24hPost.

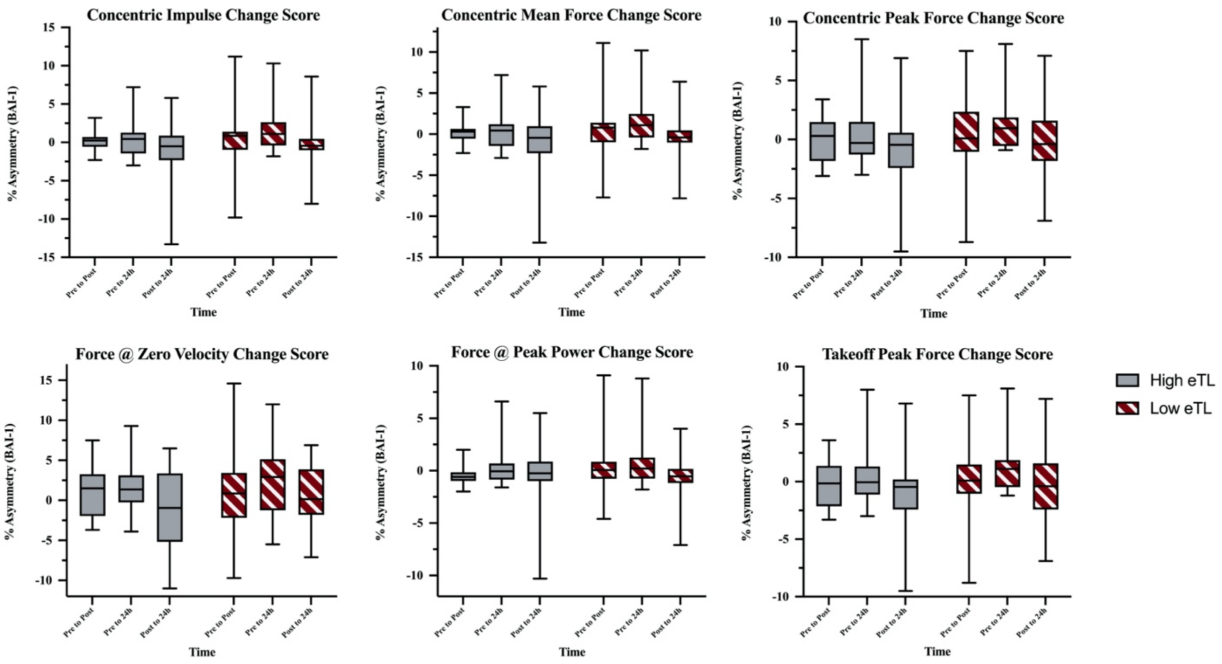


Figure 6. Condition*Time Interactions of Change Score Variables

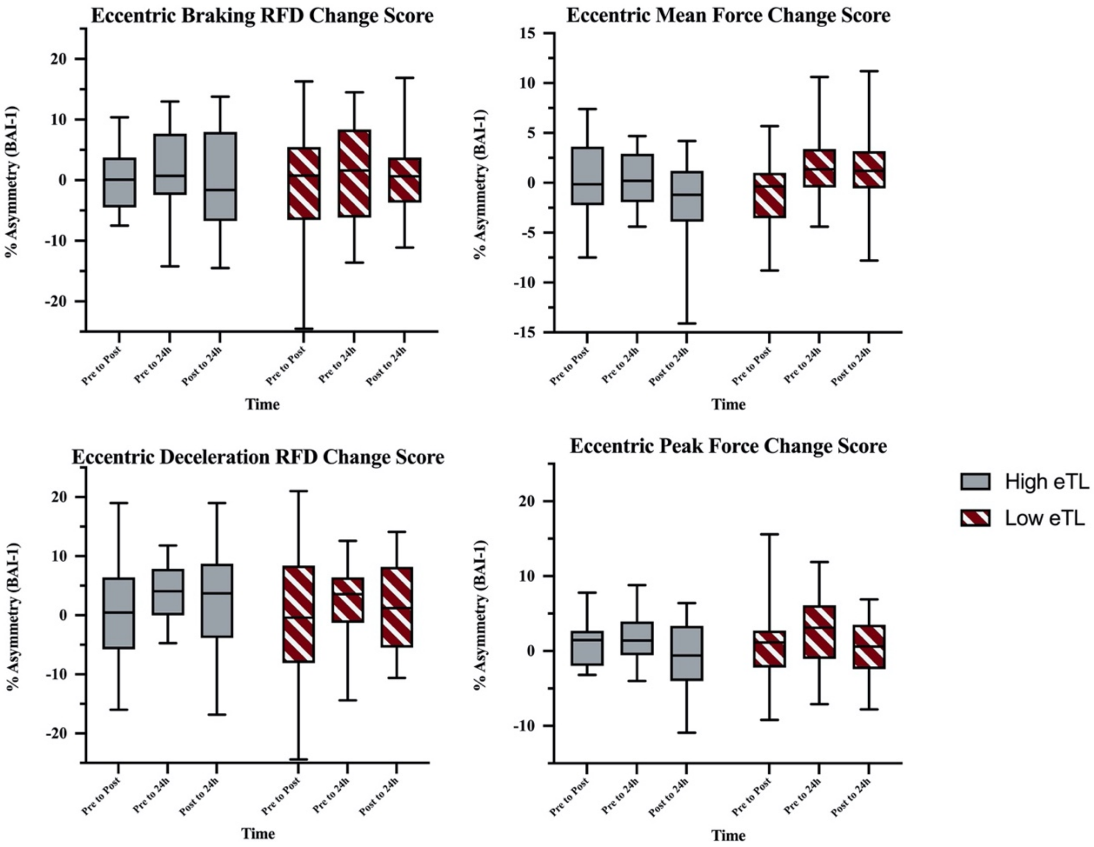


Figure 7. Condition*Time Interactions of Change Score Variables

There were no significant Sex*Time interactions for the Change Score variables: Concentric Impulse (p = 0.442; η_p^2 = 0.057), Concentric Mean Force (p = 0.441; η_p^2 = 0.057), Concentric Peak Force (p = 0.392; η_p^2 = 0.065), Eccentric Braking RFD (p = 0.778; η_p^2 = 0.018), Eccentric Deceleration RFD (p = 0.931; η_p^2 = 0.005), Eccentric Mean Force (p = 0.086; η_p^2 = 0.161), Eccentric Peak Force (p = 0.635; η_p^2 = 0.032), Force at Zero Velocity (p = 0.607; η_p^2 = 0.035), Force at Peak Power (p = 0.528; η_p^2 = 0.045), and Takeoff Peak Force (p = 0.488; η_p^2 = 0.05). Sex*Time interactions are shown in **Table 12**. Males demonstrated large effects for Concentric Impulse (*d* = 0.98), Concentric Mean Force (*d* = 1.02), Eccentric Mean Force (*d* = 1.18), Force @ Peak Power (*d* = 0.86), and Takeoff Peak Force (*d* = 0.80), while medium effects were shown in Concentric Peak Force (*d* = 0.79), Eccentric Peak Force (*d* = 0.55), and Force @ Zero Velocity (*d* = 0.51), small effects were shown in Eccentric Braking RFD (*d* = 0.26) and Eccentric Deceleration RFD (*d* = 0.23) Pre-to-Post-, large effects for Concentric Impulse (*d* = 1.31), Concentric Mean Force (*d* = 1.36), Concentric Peak Force (*d* = 1.30), Eccentric Mean Force (*d* = 1.63), Eccentric Peak Force (*d* = 1.01), Force @ Zero Velocity (*d* = 1.03), Force @ Peak Power (*d* = 1.13), and Takeoff Peak Force Pre-to-24hPost-, and large effect in Concentric Impulse (*d* = 0.81), Concentric Mean Force (*d* = 0.83), Concentric Peak Force (*d* = 0.85), and Force @ Zero Velocity (*d* = 0.85), medium effect in Eccentric Mean Force (*d* = 0.77), Eccentric Peak Force (*d* = 0.78), Force @ Peak Power (*d* = 0.66), and Takeoff Peak Force (*d* = 0.71), and small effect in Eccentric Braking RFD (*d* = 0.24), and Eccentric Deceleration RFD (*d* = 0.40) Post-to-24hPost-. Females showed medium effect in Eccentric Braking RFD (*d* = 0.54), small effects in Eccentric Deceleration RFD (*d* = 0.43), Eccentric Peak Force (*d* = 0.48), and Force @ Zero Velocity (*d* = 0.42) Pre-to-Post-, while large effect was shown in Concentric Impulse (*d* = 0.90), Concentric Mean Force (*d* = 0.93), Concentric Peak Force (*d* = 1.05), Eccentric Mean Force (*d* = 1.08), Force

@ Peak Power (*d* = 0.97), and Takeoff Peak Force (*d* = 0.99), medium effect in Eccentric Peak Force (*d* = 0.67) and Force @ Zero Velocity (*d* = 0.70), and small effect in Eccentric Deceleration RFD (*d* = 0.49) Pre-to-24hPost-, as well as large effect Post-to24hPost- in Concentric Impulse (*d* = 1.58), Concentric Mean Force (*d* = 1.61), Concentric Peak Force (*d* = 1.34), Eccentric Braking RFD (*d* = 1.25), Eccentric Deceleration RFD (*d* = 1.11), Eccentric Mean Force (*d* = 1.39), Eccentric Peak Force (*d* = 1.52), Force @ Zero Velocity (*d* = 1.43), Force @ Peak Power (*d* = 1.57), and Takeoff Peak Force (*d* = 1.32).

Table 12. Change Scores Between Men and Women Across Time Points.

	Males (n = 12)						**Females (n = 4)**					
	Mean(SE)			**Effect (*d*)**			**Mean(SE)**			**Effect (*d*)**		
Variable	**Δ Pre to Post**	**Δ Post to 24hPost**	**Δ Pre to 24hPost**	***d*** Δ_1	***d*** Δ_2	***d*** Δ_3	**Δ Pre to Post**	**Δ Post to 24hPost**	**Δ Pre to 24hPost**	***d*** Δ_1	***d*** Δ_2	***d*** Δ_3
Concentric Impulse (%)	0.7(0.9)	0.5(0.2)	-0.1(0.9)	0.98	1.31	0.81	1.9(1.6)	-0.4(0.4)	-2.3(1.6)	0.33	0.90	1.58
Concentric Mean Force (%)	0.7(0.9)	0.5(0.2)	-0.2(0.8)	1.02	1.36	0.83	1.8(1.5)	-0.4(0.4)	-2.3(1.5)	0.33	0.93	1.61
Concentric Peak Force (%)	0.2(0.6)	0.0(0.4)	-0.2(0.8)	0.79	1.30	0.85	2.0(1.1)	0.5(0.6)	-1.5(1.5)	0.19	1.05	1.34
Eccentric Braking RFD (%)	0.5(1.9)	1.4(1.2)	0.9(1.5)	0.26	0.44	0.24	1.1(3.3)	-0.3(2.2)	-1.4(2.6)	0.54	0.51	1.25
Eccentric Deceleration RFD (%)	0.2(2.4)	1.7(1.1)	1.4(2.2)	0.23	0.11	0.40	2.4(4.2)	4.0(2.0)	1.5(3.8)	0.43	0.49	1.11
Eccentric Mean Force (%)	0.0(0.7)	0.5(0.6)	0.5(1.0)	1.18	1.63	0.77	2.2(1.3)	-0.6(1.0)	-2.8(1.7)	0.27	1.08	1.39
Eccentric Peak Force (%)	1.4(1.4)	1.7(0.5)	0.3(1.1)	0.55	1.01	0.78	2.4(2.4)	0.3(1.0)	-2.0(1.9)	0.48	0.67	1.52
Force @ Zero Velocity (%)	1.2(1.3)	1.5(0.5)	0.2(1.1)	0.51	1.03	0.85	2.7(2.3)	0.9(0.9)	-1.8(2.0)	0.42	0.70	1.43
Force @ Peak Power (%)	0.2(0.6)	-0.0(0.2)	-0.2(0.7)	0.86	1.13	0.66	1.2(1.2)	-0.3(0.3)	-1.5(1.2)	0.30	0.97	1.57
Takeoff Peak Force (%)	0.3(0.7)	0.0(0.4)	-0.2(0.8)	0.80	1.19	0.71	1.6(1.2)	0.1(0.7)	-1.5(1.5)	0.22	0.99	1.32

Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development. $\Delta 1$ = Pre-Post; $\Delta 2$ = Pre-24hPost; $\Delta 3$ = Post-24hPost.

There were no significant Sex effects for any of the Change Score variables: Concentric Impulse ($p = 0.069$; $\eta_p^2 = 0.218$), Concentric Mean Force ($p = 0.071$; $\eta_p^2 = 0.214$), Concentric Peak Force ($p = 0.582$; $\eta_p^2 = 0.022$), Eccentric Braking RFD ($p = 0.499$; $\eta_p^2 = 0.033$), Eccentric Deceleration RFD ($p = 0.347$; $\eta_p^2 = 0.063$), Eccentric Mean Force ($p = 0.355$; $\eta_p^2 = 0.061$), Eccentric Peak Force ($p = 0.26$; $\eta_p^2 = 0.09$), Force at Zero Velocity ($p = 0.569$; $\eta_p^2 = 0.024$), Force at Peak Power ($p = 0.505$; $\eta_p^2 = 0.032$), Takeoff Peak Force ($p = 0.92$; $\eta_p^2 = 0.001$). However, Concentric Impulse (*d* = 1.13) and Concentric Mean Force (*d* = 1.12) demonstrated large effects of Change Score on Sex, while Eccentric Deceleration RFD (*d* = 0.56), Eccentric Mean Force (*d* = 0.55), and Eccentric Peak Force (*d* = 0.67) showed medium effect, Concentric Peak Force (*d* = 0.32), Eccentric Braking RFD (*d* = 0.40), Force at Zero Velocity (*d* = 0.33), and Force at Peak Power (*d* = 0.39) showed small effect, and Takeoff Peak Force (*d* = 0.59) showed a trivial effect, as shown in **Table 13**.

Table 13. Sex Effects of Change Score Variables.

Variable	Men (n = 12)	Women (n = 4)	Effect (*d*)
Concentric Impulse (%)	0.3(0.1)	-0.3(0.2)	1.13
Concentric Mean Force (%)	0.3(0.1)	-0.3(0.2)	1.12
Concentric Peak Force (%)	0.0(0.2)	0.3(0.4)	0.32
Eccentric Braking RFD (%)	0.9(0.8)	-0.2(1.4)	0.40
Eccentric Deceleration RFD (%)	1.1(0.7)	2.6(1.3)	0.56
Eccentric Mean Force (%)	0.3(0.4)	-0.4(0.7)	0.55
Eccentric Peak Force (%)	1.1(0.3)	0.2(0.6)	0.67
Force @ Zero Velocity (%)	1.0(0.3)	0.6(0.6)	0.33
Force @ Peak Power (%)	-0.1(0.1)	-0.2(0.2)	0.39
Takeoff Peak Force (%)	0.0(0.2)	0.0(0.4)	0.06

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development.

There were no significant Condition main effects for any of the Change Score variables: Concentric Impulse ($p = 0.432$; $\eta_p^2 = 0.045$), Concentric Mean Force ($p = 0.476$; $\eta_p^2 = 0.037$), Concentric Peak Force ($p = 0.619$; $\eta_p^2 = 0.018$), Eccentric Braking RFD ($p = 0.782$; $\eta_p^2 = 0.006$), Eccentric Deceleration RFD ($p = 0.428$; $\eta_p^2 = 0.045$), Eccentric Mean Force ($p = 0.642$; $\eta_p^2 = 0.016$), Eccentric Peak Force ($p = 0.984$; $\eta_p^2 = 0.00$), Force at Zero Velocity ($p = 0.68$; $\eta_p^2 = 0.013$), Force at Peak Power ($p = 0.804$; $\eta_p^2 = 0.005$), Takeoff Peak Force ($p = 0.954$; $\eta_p^2 = 0.00$). Condition effects are illustrated in **Table 14**. Small effects were observed between Conditions for Concentric Impulse (*d* = 0.36), Concentric Mean Force (*d* = 0.32), Eccentric Peak Force (*d* = 0.20), and Eccentric Deceleration RFD (*d* = 0.33), while all other effects were interpreted as trivial (*d* < 0.20).

Table 14. Condition Effects of Change Score Variables.

Variable	Low eTL	High eTL	Effect (*d*)
Concentric Impulse (%)	0.2(0.2)	-0.2(0.4)	0.36
Concentric Mean Force (%)	0.2(0.2)	-0.2(0.4)	0.32
Concentric Peak Force (%)	0.3(0.3)	0.0(0.5)	0.20
Eccentric Braking RFD (%)	0.6(1.1)	0.1(1.3)	0.10
Eccentric Deceleration RFD (%)	0.9(1.6)	2.8(0.9)	0.33
Eccentric Mean Force (%)	0.2(0.8)	-0.2(0.5)	0.19
Eccentric Peak Force (%)	0.7(0.6)	0.7(0.5)	0.01
Force @ Zero Velocity (%)	0.9(0.5)	0.6(0.5)	0.16
Force @ Peak Power (%)	-0.1(0.2)	-0.0(0.3)	0.11
Takeoff Peak Force (%)	0.0(0.4)	0.0(0.4)	0.02

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development.

There were no significant Time effects for any of the Change Score variables: Concentric Impulse ($p = 0.19$; $\eta_p^2 = 0.119$), Concentric Mean Force ($p = 0.167$; $\eta_p^2 = 0.132$), Concentric Peak Force ($p = 0.208$; $\eta_p^2 = 0.111$), Eccentric Braking RFD ($p = 0.76$; $\eta_p^2 = 0.008$), Eccentric Deceleration RFD ($p = 0.735$; $\eta_p^2 = 0.009$), Eccentric Mean Force ($p = 0.208$; $\eta_p^2 = 0.111$), Eccentric Peak Force ($p = 0.276$; $\eta_p^2 = 0.084$), Force at Zero Velocity ($p = 0.273$; $\eta_p^2 = 0.086$), Force at Peak Power ($p = 0.265$; $\eta_p^2 = 0.088$), Takeoff Peak Force ($p = 0.234$; $\eta_p^2 = 0.1$). Additionally, pairwise comparisons showed no significant differences in any of the Change Score asymmetry variables ($p > 0.05$).

When comparing Change Scores Pre- to Post- Concentric Impulse (d = 0.46), Concentric Mean Force (*d* = 0.49), Concentric Peak Force (*d* = 0.49), Eccentric Mean Force (*d* = 0.41), Eccentric Peak Force (*d* = 0.20), Force at Peak Power (*d* = 0.43), and Takeoff Peak Force (*d* = 0.41) demonstrated small effects, while Eccentric Braking RFD (*d* = 0.04), Eccentric Deceleration

RFD (*d* = 0.19), and Force at Zero Velocity (*d* = 0.19) showed trivial effects. When comparing Change Scores across Time Point 2 (**Δ_2 = 24hPost-Pre**) Concentric Impulse (*d* = 0.69), Concentric Mean Force (*d* = 0.72), Concentric Peak Force (*d* = 0.64), Eccentric Mean Force (*d* = 0.63), Eccentric Peak Force (*d* = 0.55), Force at Zero Velocity (*d* = 0.55), Force at Peak Power (*d* = 0.58), and Takeoff Peak Force (*d* = 0.61) demonstrated medium effects, while Eccentric Braking RFD (*d* = 0.16) and Eccentric Deceleration RFD (*d* = 0.02) showed trivial effects. When comparing Change Scores across Time Point 3 (**Δ_3 = 24hPost-Post**), Concentric Mean Force (*d* = 0.50), Eccentric Peak Force (*d* = 0.54), and Force at Zero Velocity (*d* = 0.54) demonstrated medium effects, while Concentric Impulse (*d* = 0.48), Concentric Peak Force (*d* = 0.42), Eccentric Mean Force (*d* = 0.34), Force at Peak Power (*d* = 0.34), and Takeoff Peak Force (*d* = 0.36) showed small effects, and Eccentric Braking RFD (*d* = 0.15) and Eccentric Deceleration RFD (*d* = 0.19) showed trivial effects, as shown in **Table 15**.

Table 15. Time Effects of Change Score Variables.

				Effect (*d*)		
Variable	**Δ_1 = Post-Pre**	**Δ_2 = 24hPost-Pre**	**Δ_3 = 24hPost-Post**	***d* Δ_1**	***d* Δ_2**	***d* Δ_3**
Concentric Impulse (%)	1.3(0.9)	0.0(0.2)	-1.2(0.9)	0.46	0.69	0.48
Concentric Mean Force (%)	1.3(0.9)	0.0(0.2)	-1.2(0.8)	0.49	0.72	0.50
Concentric Peak Force (%)	1.1(0.6)	0.2(0.4)	-0.8(0.8)	0.39	0.64	0.42
Eccentric Braking RFD (%)	0.8(1.9)	0.5(1.2)	-0.2(1.5)	0.04	0.16	0.15
Eccentric Deceleration RFD (%)	1.3(2.4)	2.8(1.1)	1.5(2.2)	0.19	0.02	0.19
Eccentric Mean Force (%)	1.1(0.7)	-0.0(0.6)	-1.1(1.0)	0.41	0.63	0.34
Eccentric Peak Force (%)	1.9(1.4)	1.0(0.5)	-0.8(1.1)	0.20	0.55	0.54
Force @ Zero Velocity (%)	1.9(1.3)	1.2(0.5)	-0.7(1.1)	0.19	0.55	0.54
Force @ Peak Power (%)	0.7(0.6)	-0.1(0.2)	-0.8(0.7)	0.43	0.58	0.34
Takeoff Peak Force (%)	1.0(0.7)	0.0(0.4)	-0.9(0.8)	0.41	0.61	0.36

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). RFD = rate of force development. Δ1 = Pre-Post; Δ2 = Pre-24hPost; Δ3 = Post-24hPost.

Pearson's correlation results showed significant relationships Pre-to-Post in Males (n = 12) during the High Condition between PL and Force @ Peak Power (r = 0.613; p = 0.034), sRPE and Eccentric Mean Force (r = 0.738; p = 0.006), Pre-to-24h between PL and Eccentric Mean Force (r = 0.585; p = 0.046), while all other relationships did not reach statistical significance for the High condition (p > 0.05). These results are presented in **Table 16**.

Table 16. Change Score Correlation Matrix of High Condition.

	Male (n = 12)				**Female (n = 4)**			
	PlayerLoad™		**sRPE**		**PlayerLoad™**		**sRPE**	
	Pre-Post	**Pre-24h**	**Pre-Post**	**Pre-24h**	**Pre-Post**	**Pre-24h**	**Pre-Post**	**Pre-24h**
Concentric Impulse	0.059	-0.082	-0.433	0.01	-0.021	-0.821	0.644	0.425
Concentric Mean Force	0.048	-0.087	-0.436	0.005	-0.015	-0.797	0.639	0.384
Concentric Peak Force	0.169	-0.2	-0.323	0.146	0.009	-0.788	0.614	0.422
Eccentric Braking RFD	-0.128	-0.277	0.092	-0.38	0.521	0.351	0.108	0.104
Eccentric Deceleration RFD	-0.19	-0.257	-0.004	0.097	0.232	-0.205	-0.468	0.656
Eccentric Mean Force	0.208	.585*	-.738**	-0.168	0.281	0.398	0.359	-0.892
Eccentric Peak Force	-0.222	-0.126	-0.414	-0.113	0.03	-0.169	0.549	0.247
Force @ Zero Velocity	-0.271	-0.269	-0.403	-0.086	-0.003	-0.332	0.581	0.449
Force @ Peak Power	.613*	-0.035	-0.429	0.11	0.11	-0.793	0.545	0.329
Takeoff Peak Force	0.2	-0.153	-0.347	0.144	0.022	-0.474	0.604	-0.022

Results are presented as Pearson's correlation coefficient (r). * = $p > 0.05$. ** = $p > 0.01$.

Correlation results for the Low condition revealed significant relationships in females Pre-to-Post between sRPE and Eccentric Mean Force (r = -0.987; p = 0.013), Eccentric Peak Force (r = -0.975; p = 0.025), and Force @ Peak Power (r = -0.974; p = 0.026). Significant relationships were also identified Pre-to-24h in females between PL and Eccentric Peak Force (r = -0.982; p = 0.018) and Takeoff Peak Force (r = -0.954; p = 0.046), as well as sRPE and Concentric Impulse (r = -0.979; p = 0.021), and Concentric Mean Force (r = -0.973; p = 0.027), though all other associations did not reach statistical significance (p > 0.05). These results are shown in **Table 17**.

Table 17. Change Score Correlation Matrix of Low Condition.

	Male (n = 12)				**Female (n = 4)**			
	PlayerLoad™		**sRPE**		**PlayerLoad™**		**sRPE**	
	Pre-Post	**Pre-24h**	**Pre-Post**	**Pre-24h**	**Pre-Post**	**Pre-24h**	**Pre-Post**	**Pre-24h**
Concentric Impulse	0.008	-0.113	-0.047	-0.179	0.643	0.222	-0.766	-.979*
Concentric Mean Force	0.02	-0.111	-0.052	-0.165	0.691	0.063	-0.78	-.973*
Concentric Peak Force	0.236	-0.11	0.1	0.187	0.804	0.912	0.278	0.235
Eccentric Braking RFD	0.116	0.051	0.093	0.11	0.433	0.413	0.748	0.32
Eccentric Deceleration RFD	0.232	0.279	-0.049	-0.061	0.567	0.637	0.703	0.066
Eccentric Mean Force	-0.071	0.183	0.083	0.095	0.192	-0.691	-.987*	0.66
Eccentric Peak Force	0.147	0.154	0.044	-0.069	0.058	-.982*	-.975*	0.253
Force @ Zero Velocity	0.134	0.129	0.108	0.227	0.857	0.527	-0.625	0.73
Force @ Peak Power	0.146	0.073	-0.081	-0.159	0.194	-0.215	-.974*	-0.918
Takeoff Peak Force	0.228	-0.109	0.088	0.19	0.196	-.954*	0.436	-0.107

Results are presented as Pearson's correlation coefficient (r). * = p > 0.05. ** = p > 0.01.

Limb Dominance Results

There were no significant differences between sexes for any of the Raw Score variables (p > 0.05 for all). There was a significant Limb*Time*Condition interaction for Eccentric Mean Force (p = 0.045; η_p^2=0.187), though Concentric Impulse (p = 0.463; η_p^2=0.05), Concentric Mean Force (p = 0.432; η_p^2=0.054), Concentric Peak Force (p = 0.673; η_p^2=0.026), Eccentric Braking RFD (p = 0.875; η_p^2=0.009), Eccentric Deceleration RFD (p = 0.731; η_p^2=0.021), Eccentric Peak Force (p = 0.308; η_p^2=0.075), Force at Zero Velocity (p = 0.282; η_p^2=0.081), Force at Peak Power (p = 0.461; η_p^2=0.05), and Takeoff Peak Force (p = 0.342; η_p^2=0.069) did not reach statistical significance. There was a significant difference in Eccentric Mean Force Pre- to Post- for the High eTL exposure in the nondominant limb (11.4 ± 4.2N; p = 0.049).

There were no significant Time*Condition interactions for any of the Raw Score variables, including Concentric Impulse (p = 0.699; η_p^2 = 0.024), Concentric Mean Force (p = 0.395; η_p^2 = 0.06), Concentric Peak Force (p = 0.227; η_p^2 = 0.094), Eccentric Braking RFD (p = 0.522; η_p^2 =

0.042), Eccentric Deceleration RFD (p = 0.257; $\eta_p^2 = 0.087$), Eccentric Mean Force (p = 0.139; $\eta_p^2 = 0.123$), Eccentric Peak Force (p = 0.299; $\eta_p^2 = 0.077$), Force at Zero Velocity (p = 0.226; $\eta_p^2 = 0.094$), Force at Peak Power (p = 0.528; $\eta_p^2 = 0.042$), or Takeoff Peak Force (p = 0.281; $\eta_p^2 = 0.081$), as shown in **Table 16**. A small effect was shown between Conditions Pre- for Concentric Impulse ($d = 0.27$), while all other Raw Scores revealed trivial effects. Small effects were shown between Conditions Post- for Eccentric Braking RFD ($d = 0.23$), Eccentric Deceleration RFD ($d = 0.20$), and Force @ Zero Velocity ($d = 0.20$), while all other Raw Score variables remained trivial ($d < 0.20$). Only trivial effects were shown between Conditions for all Raw Score variables 24hPost- ($d < 0.20$).

Table 18. Time*Condition Interaction of Raw Score Variables.

	Pre-			Post-			24h-Post		
Variable	**Low eTL Mean(SE)**	**High eTL Mean(SE)**	**Effect *(d)***	**Low eTL Mean(SE)**	**High eTL Mean(SE)**	**Effect *(d)***	**Low eTL Mean(SE)**	**High eTL Mean(SE)**	**Effect *(d)***
Concentric Impulse (N·s)	258.0(27.8)	235.2(10.3)	0.27	242.0(19.4)	229.8(10.0)	0.19	232.6(9.9)	230.0(10.0)	0.06
Concentric Mean Force (N)	966.0(38.0)	968.7(33.5)	0.01	975.5(42.6)	947.7(37.1)	0.17	977.6(39.0)	969.9(34.4)	0.05
Concentric Peak Force (N)	1241.1(47.8)	1239.8(50.1)	0.00	1275.5(58.1)	1238.7(52.8)	0.16	1248.0(50.3)	1244.5(46.8)	0.01
Eccentric Braking RFD (N/s)	3807.3(514.4)	3722.6(474.9)	0.04	3971.5(553.8)	3494.4(455.9)	0.23	4113.6(504.0)	3847.0(357.5)	0.15
Eccentric Deceleration RFD (N/s)	4777.8(745.4)	4879.7(755.7)	0.03	5064.7(807.6)	4403.6(774.1)	0.20	5198.7(702.6)	4822.4(577.3)	0.14
Eccentric Mean Force (N)	456.8(13.9)	455.1(14.3)	0.02	452.2(14.0)	453.2(13.5)	0.01	454.9(14.3)	459.0(14.4)	0.07
Eccentric Peak Force (N)	1108.8(62.6)	1129.7(62.0)	0.08	1119.5(68.6)	1067.5(63.6)	0.19	1155.6(57.5)	1142.2(53.8)	0.06
Force @ Zero Velocity (N)	1098.8(62.1)	1118.4(61.3)	0.07	1115.8(69.1)	1062.6(63.5)	0.20	1144.0(58.0)	1130.9(52.4)	0.05
Force @ Peak Power (N)	1067.9(40.1)	1058.6(34.9)	0.06	1097.2(45.2)	1072.4(38.1)	0.14	1067.6(41.3)	1055.0(36.8)	0.08
Takeoff Peak Force (N)	1246.8(47.3)	1245.0(50.9)	0.00	1277.7(57.5)	1240.5(52.9)	0.16	1254.0(48.8)	1250.5(47.0)	0.01

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). N = Newtons; N·s = Newton seconds; N/s = Newtons per second; RFD = rate of force development.

There was a significant Limb*Condition interaction for Eccentric Mean Force ($p = 0.035$; $\eta_p^2 = 0.263$), however, Concentric Impulse ($p = 0.058$; $\eta_p^2 = 0.219$), Concentric Mean Force ($p = 0.103$; $\eta_p^2 = 0.167$), Concentric Peak Force ($p = 0.842$; $\eta_p^2 = 0.003$), Eccentric Braking RFD ($p = 0.817$; $\eta_p^2 = 0.004$), Eccentric Deceleration RFD ($p = 0.51$; $\eta_p^2 = 0.029$), Eccentric Peak Force ($p = 0.089$; $\eta_p^2 = 0.181$), Force at Zero Velocity ($p = 0.084$; $\eta_p^2 = 0.186$), Force at Peak Power ($p = 0.155$; $\eta_p^2 = 0.13$), and Takeoff Peak Force ($p = 0.725$; $\eta_p^2 = 0.008$) did not reach statistical significance. There were significant differences between Conditions for the Dominant Limb in Eccentric Mean Force ($p = 0.016$), as shown in **Table 17**. A small effect was shown between Conditions for the Nondominant limb for Concentric Impulse (*d* = 0.27), while all other Raw Score variables remain trivial (*d* < 0.20). Additionally, a small effect was observed between Conditions for the Dominant limb for Concentric Impulse (*d* = 0.20), while all other Raw Score variables showed trivial effect. Eccentric Mean Force showed a significant difference for the Dominant Limb between Conditions (-7.4(2.7N); $p = 0.016$).

Table 19. Limb*Condition Interaction of Raw Score Variables.

Variable	Nondominant Low eTL Mean(SE)	High eTL Mean(SE)	Effect (*d*)	Dominant Low eTL Mean(SE)	High eTL Mean(SE)	Effect (*d*)
Concentric Impulse (N·s)	243.2(16.9)	227.9(11.2)	0.27	245.2(14.3)	235.5(9.8)	0.20
Concentric Mean Force (N)	961.7(39.0)	944.0(35.6)	0.12	984.3(42.9)	980.2(38.4)	0.03
Concentric Peak Force (N)	1240.2(47.0)	1225.2(44.5)	0.08	1269.5(61.4)	1256.9(57.5)	0.05
Eccentric Braking RFD (N/s)	3906.6(481.3)	3644.0(406.7)	0.15	4021.7(548.4)	3731.9(419.9)	0.15
Eccentric Deceleration RFD (N/s)	5024.5(738.0)	4667.3(679.7)	0.13	5003.0(748.7)	4736.5(686.6)	0.09
Eccentric Mean Force (N)	456.1(17.2)	450.8(17.9)	0.07	453.2(15.9)	460.7(15.2)	0.12
Eccentric Peak Force (N)	1121.6(59.3)	1094.2(57.0)	0.12	1134.3(72.1)	1132.0(66.3)	0.01
Force @ Zero Velocity (N)	1111.8(59.1)	1083.6(56.8)	0.12	1127.3(72.7)	1124.3(66.1)	0.01
Force @ Peak Power (N)	1072.3(42.6)	1051.0(36.0)	0.13	1082.8(43.0)	1073.0(38.2)	0.06
Takeoff Peak Force (N)	1247.7(46.7)	1231.4(44.6)	0.09	1271.3(60.7)	1259.3(58.0)	0.05

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; d = Cohen's d, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). N = Newtons; N·s = Newton seconds; N/s = Newtons per second; RFD = rate of force development.

There were no significant Limb*Time interactions for Raw Score variables, including Concentric Impulse ($p = 0.624$; $\eta_p^2 = 0.031$), Concentric Mean Force ($p = 0.397$; $\eta_p^2 = 0.06$), Concentric Peak Force ($p = 0.555$; $\eta_p^2 = 0.039$), Eccentric Braking RFD ($p = 0.832$; $\eta_p^2 = 0.012$), Eccentric Deceleration RFD ($p = 0.429$; $\eta_p^2 = 0.055$), Eccentric Mean Force ($p = 0.724$; $\eta_p^2 = 0.021$), Eccentric Peak Force ($p = 0.287$; $\eta_p^2 = 0.08$), Force at Zero Velocity ($p = 0.306$; $\eta_p^2 = 0.076$), Force at Peak Power ($p = 0.609$; $\eta_p^2 = 0.033$), and Takeoff Peak Force ($p = 0.725$; $\eta_p^2 = 0.021$). These interactions are shown in **Table 18**, as well as **Figures 8-11**. Trivial effects were demonstrated for Dominant and Nondominant Limbs Pre-to-Post- for all Raw Score variables ($d < 0.20$). Small effects were observed for the Nondominant Limb Pre-to-24hPost- for Concentric Impulse ($d = 0.27$), and the Dominant Limb Pre-to-24hPost- for Concentric Impulse ($d = 0.26$), while all other variables remained trivial ($d < 0.20$). Small effects were observed for the Nondominant Limb Post-to-24hPost- for Eccentric Peak Force ($d = 0.23$) and Force @ Zero Velocity ($d = 0.20$), while the Dominant Limb showed small effects for Eccentric Peak Force ($d = 0.20$) Post-to-24hPost-, while all other variables remained trivial ($d < 0.20$).

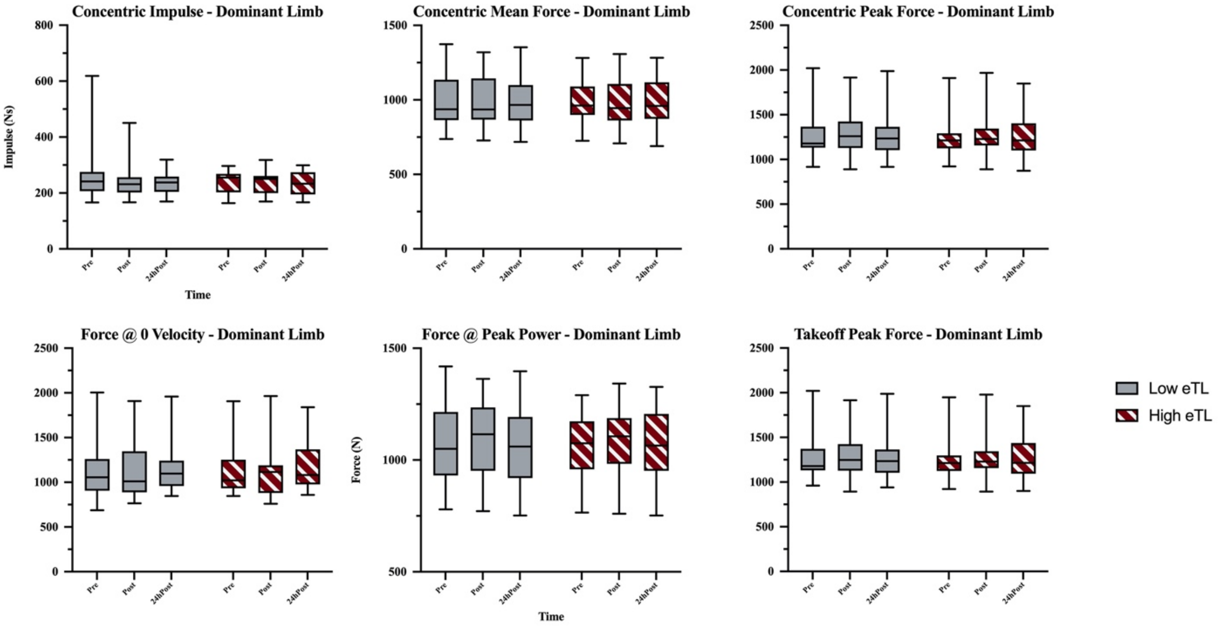


Figure 8. Dominant Limb Condition*Time Interactions of Limb Dominance Raw Variables

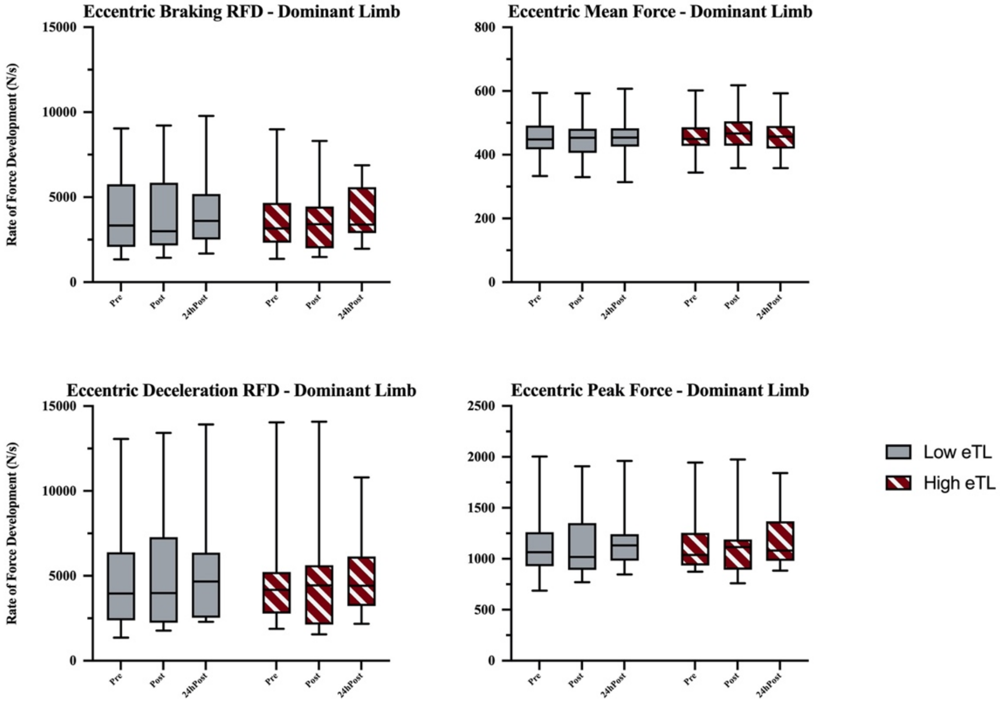


Figure 9. Dominant Limb Condition*Time Interactions of Limb Dominance Raw Variables

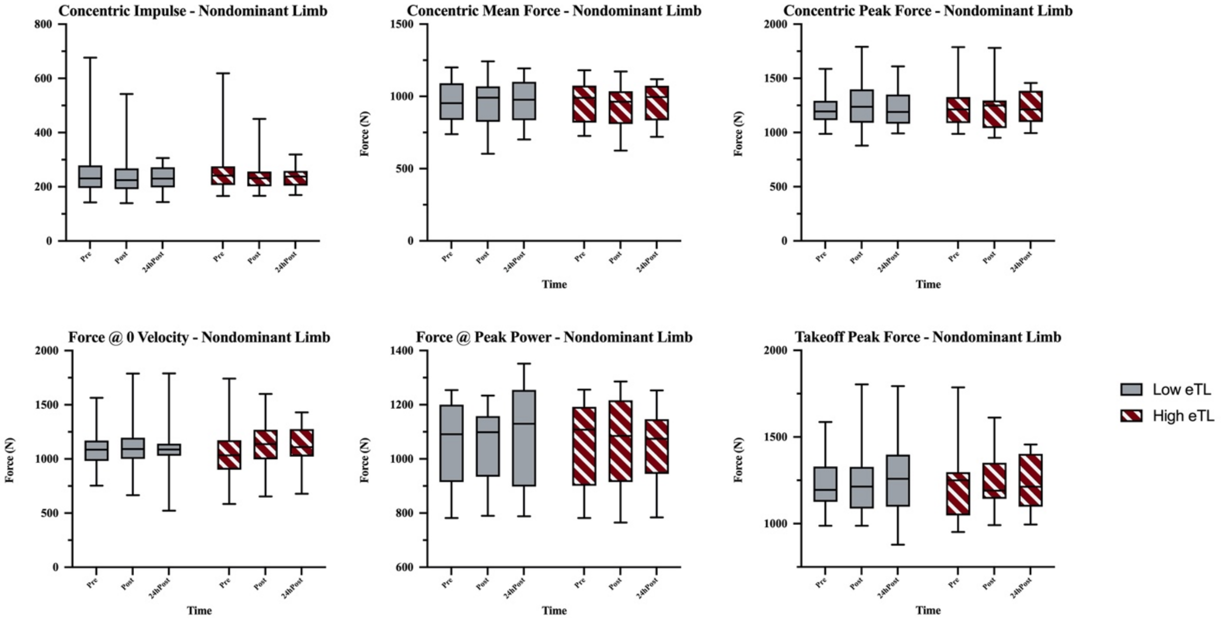


Figure 10. Nondominant Limb Condition*Time Interactions of Limb Dominance Raw Variables

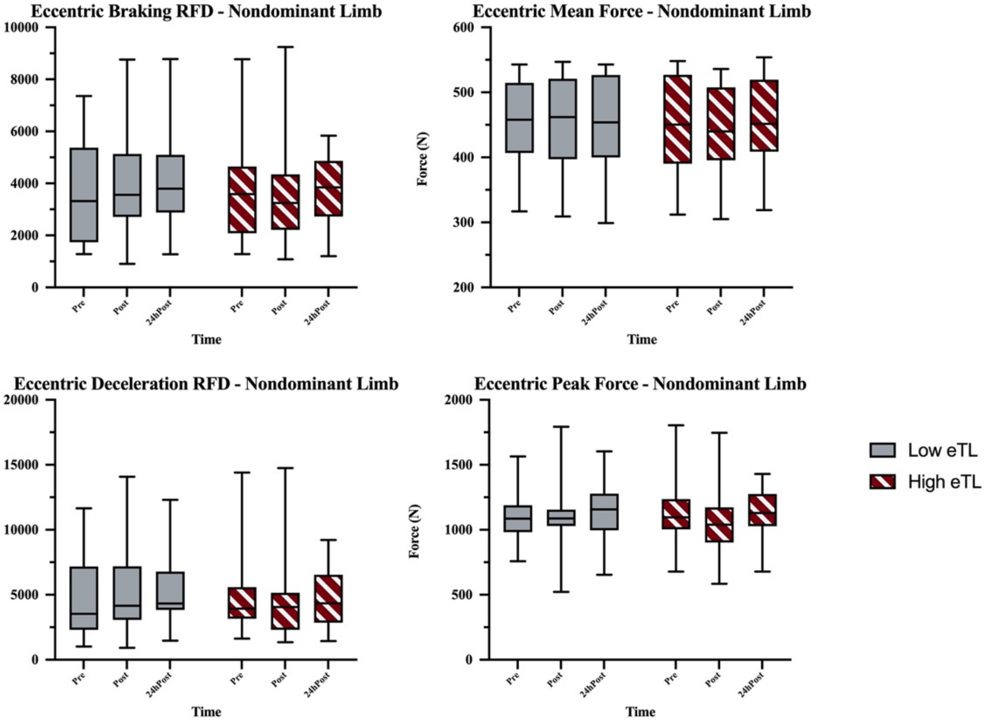


Figure 11. Nondominant Limb Condition*Time Interactions of Limb Dominance Raw Variables

Table 20. Limb*Time Interactions of Raw Score Variables.

	Nondominant						**Dominant**					
	Mean(SE)			**Effect (*d*)**			**Mean(SE)**			**Effect (*d*)**		
Variable	**Δ_1 = Post-Pre**	**Δ_2 = 24hPost-Pre**	**Δ_3 = 24hPost-Post**	***d* Δ_1**	***d* Δ_2**	***d* Δ_3**	**Δ_1 = Post-Pre**	**Δ_2 = 24hPost-Pre**	**Δ_3 = 24hPost-Post**	***d* Δ_1**	***d* Δ_2**	***d* Δ_3**
Concentric Impulse (N·s)	245.3(18.8)	232.6(16.0)	228.7(10.7)	0.18	0.27	0.07	247.9(16.0)	239.1(12.5)	233.9(10.0)	0.15	0.26	0.11
Concentric Mean Force (N)	956.1(33.9)	942.5(42.4)	960.0(35.7)	0.09	0.03	0.11	978.6(39.8)	980.7(41.6)	987.5(41.4)	0.01	0.05	0.04
Concentric Peak Force (N)	1229.8(42.1)	1237.5(53.8)	1230.8(40.4)	0.04	0.01	0.04	1251.1(58.8)	1276.7(60.2)	1261.8(59.8)	0.11	0.04	0.06
Eccentric Braking RFD (N/s)	3722.5(437.9)	3695.2(480.7)	3908.2(400.0)	0.01	0.11	0.12	3807.4(503.9)	3770.6(489.5)	4052.4(452.1)	0.02	0.13	0.15
Eccentric Deceleration RFD (N/s)	4872.2(723.7)	4730.8(785.0)	4934.8(609.1)	0.05	0.02	0.07	4785.3(725.4)	4737.5(772.3)	5086.3(658.9)	0.02	0.11	0.12
Eccentric Mean Force (N)	455.5(17.1)	449.6(17.8)	455.3(17.8)	0.08	0.00	0.08	456.5(15.5)	455.8(16.1)	458.5(15.2)	0.01	0.03	0.04
Eccentric Peak Force (N)	1115.6(55.0)	1076.5(66.1)	1131.8(54.4)	0.16	0.07	0.23	1122.9(71.4)	1110.5(71.7)	1166.0(65.8)	0.04	0.16	0.20
Force @ Zero Velocity (N)	1103.0(55.2)	1071.3(66.1)	1118.7(53.8)	0.13	0.07	0.20	1114.1(71.1)	1107.1(71.9)	1156.1(66.0)	0.02	0.15	0.18
Force @ Peak Power (N)	1056.4(36.9)	1073.6(43.4)	1055.0(37.4)	0.11	0.01	0.11	1070.2(39.0)	1096.0(41.9)	1067.6(40.8)	0.16	0.02	0.17
Takeoff Peak Force (N)	1235.5(42.1)	1242.6(53.7)	1240.5(40.2)	0.04	0.03	0.01	1256.4(59.0)	1275.5(60.3)	1264.1(59.5)	0.08	0.03	0.05

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). N = Newtons; N·s = Newton seconds; N/s = Newtons per second; RFD = rate of force development. Δ1 = Pre-Post; Δ2 = Pre-24hPost; Δ3 = Post-24hPost.

There were no significant Condition main effects for any of the Raw Score variables, including Concentric Impulse ($p = 0.184$; $\eta_p^2 = 0.115$), Concentric Mean Force ($p = 0.35$; $\eta_p^2 = 0.058$), Concentric Peak Force ($p = 0.4$; $\eta_p^2 = 0.048$), Eccentric Braking RFD($p = 0.315$; $\eta_p^2 = 0.067$), Eccentric Deceleration RFD ($p = 0.29$; $\eta_p^2 = 0.074$), Eccentric Mean Force ($p = 0.378$; $\eta_p^2 = 0.052$), Eccentric Peak Force ($p = 0.442$; $\eta_p^2 = 0.04$), Force at Zero Velocity ($p = 0.429$; $\eta_p^2 = 0.042$), Force at Peak Power ($p = 0.17$; $\eta_p^2 = 0.122$), Takeoff Peak Force ($p = 0.375$; $\eta_p^2 = 0.053$). Condition effects are shown in **Table 19**. A small effect was observed between Conditions for the Raw Score variables in Concentric Impulse ($d = 0.24$), while all other variables remained trivial ($d < 0.20$).

Table 21. Condition Effects of Raw Score Variables.

Variable	Low eTL	High eTL	Effect (*d*)
Concentric Impulse (N·s)	244.2(15.2)	231.7(9.9)	0.24
Concentric Mean Force (N)	973.0(38.4)	962.1(34.3)	0.08
Concentric Peak Force (N)	1254.9(51.3)	1241.0(48.9)	0.07
Eccentric Braking RFD (N/s)	3964.1(504.6)	3688.0(404.8)	0.15
Eccentric Deceleration RFD (N/s)	5013.7(732.5)	4701.9(675.7)	0.11
Eccentric Mean Force (N)	454.6(14.1)	455.8(14.0)	0.02
Eccentric Peak Force (N)	1128.0(60.9)	1113.16(57.0)	0.06
Force @ Zero Velocity (N)	1119.5(61.2)	1104.0(56.8)	0.07
Force @ Peak Power (N)	1077.6(41.8)	1062.0(36.3)	0.10
Takeoff Peak Force (N)	1259.5(50.5)	1245.3(49.0)	0.07

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). N = Newtons; N·s = Newton seconds; N/s = Newtons per second; RFD = rate of force development.

There were significant Time main effects for Eccentric Mean Force ($p = 0.011$; $\eta_p^2 = 0.259$), Eccentric Peak Force ($p = 0.03$; $\eta_p^2 = 0.208$), and Force at Peak Power ($p = 0.002$; $\eta_p^2 = 0.333$), though Concentric Impulse ($p = 0.431$; $\eta_p^2 = 0.055$), Concentric Mean Force ($p = 0.573$; $\eta_p^2 = 0.036$), Concentric Peak Force ($p = 0.466$; $\eta_p^2 = 0.05$), Eccentric Braking RFD ($p = 0.382$; $\eta_p^2 = 0.062$), Eccentric Deceleration RFD ($p = 0.529$; $\eta_p^2 = 0.042$), Force at Zero Velocity ($p = 0.065$; $\eta_p^2 = 0.167$), and Takeoff Peak Force ($p = 0.64$; $\eta_p^2 = 0.029$) did not reach statistical significance. There were significant differences in Eccentric Mean Force Pre-Post (3.2(1.1)N; $p = 0.040$), and Post-24hPost (-4.2(1.4)N; $p = 0.027$), and Force at Peak Power Pre-Post (-21.5(7.7)N; $p = 0.044$), Post-24hPost (23.4(6.3)N; $p = 0.007$). There were no significant differences between time points for Eccentric Peak Force ($p = 0.057$-0.590). Time effects are shown in **Table 20**. Only trivial effects were observed Pre-to-Post- for all of the Raw Score variables ($d < 0.20$). A small effect was observed Pre-to-24hPost- for Concentric Impulse ($d = 0.27$), while all others remained trivial for this time point (*d* < 0.20). A small effect was seen Post-to-24hPost- for Eccentric Peak Force (*d* = 0.23) and Force @ Zero Velocity (*d* = 0.20), while all other variables remained trivial (*d* < 0.20).

Table 22. Time Effects of Raw Score Variables.

Variable	Pre-	Post-	24hPost-	Effect (*d*)		
				d Δ_1	***d*** Δ_2	***d*** Δ_3
Concentric Impulse (N·s)	246.6(17.1)	235.9(13.7)	231.3(9.8)	0.17	0.27	0.10
Concentric Mean Force (N)	967.3(34.7)	961.6(38.8)	973.7(36.1)	0.04	0.05	0.08
Concentric Peak Force (N)	1240.4(48.2)	1257.1(54.5)	1246.3(47.2)	0.08	0.03	0.05
Eccentric Braking RFD (N/s)	3765.0(463.6)	3732.9(476.2)	3980.3(411.9)	0.02	0.12	0.14
Eccentric Deceleration RFD (N/s)	4828.7(715.1)	4734.2(770.5)	5010.5(620.2)	0.03	0.07	0.10
Eccentric Mean Force (N)	456.0(14.1)	452.7(13.8)	456.9(14.3)	0.06	0.02	0.07
Eccentric Peak Force (N)	1119.2(59.5)	1093.5(63.7)	1148.9(54.5)	0.10	0.13	0.23
Force @ Zero Velocity (N)	1108.6(59.6)	1089.2(63.8)	1137.4(54.2)	0.08	0.13	0.20
Force @ Peak Power (N)	1063.3(37.3)	1084.8(41.3)	1061.3(38.2)	0.14	0.01	0.15
Takeoff Peak Force (N)	1245.9(48.2)	1259.1(54.3)	1252.3(46.5)	0.06	0.03	0.03

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). N = Newtons; N·s = Newton seconds; N/s = Newtons per second; RFD = rate of force development. Δ1 = Pre-Post; Δ2 = Pre-24hPost; Δ3 = Post-24hPost.

There were no significant Limb main effects for any of the Raw Score variables, including Concentric Impulse (p = 0.518; $\eta_p^2 = 0.028$), Concentric Mean Force (p = 0.308; $\eta_p^2 = 0.069$), Concentric Peak Force (p = 0.39; $\eta_p^2 = 0.05$), Eccentric Braking RFD (p = 0.589; $\eta_p^2 = 0.02$), Eccentric Deceleration RFD (p = 0.915; $\eta_p^2 = 0.001$), Eccentric Mean Force (p = 0.844; $\eta_p^2 = 0.003$), Eccentric Peak Force (p = 0.615; $\eta_p^2 = 0.017$), Force at Zero Velocity (p = 0.575; $\eta_p^2 = 0.021$), Force at Peak Power (p = 0.348; $\eta_p^2 = 0.059$), and Takeoff Peak Force (p = 0.483; $\eta_p^2 =$

0.033). Limb effects are shown below in **Table 21**. Only trivial effects were observed between Limb Dominance for all Raw Score variables (*d* < 0.20).

Table 23. Limb Dominance Effects of Raw Score Variables.

Variable	Nondominant	Dominant	Effect (*d*)
Concentric Impulse (N·s)	235.5(13.5)	240.3(11.6)	0.09
Concentric Mean Force (N)	952.9(36.8)	982.3(40.3)	0.19
Concentric Peak Force (N)	1232.7(44.7)	1263.2(59.0)	0.15
Eccentric Braking RFD (N/s)	3775.3(428.5)	3876.8(465.3)	0.06
Eccentric Deceleration RFD (N/s)	4845.9(693.7)	4869.7(703.8)	0.01
Eccentric Mean Force (N)	453.5(17.4)	456.9(15.5)	0.05
Eccentric Peak Force (N)	1107.9(57.2)	1133.1(68.7)	0.10
Force @ Zero Velocity (N)	1097.7(57.0)	1125.8(68.8)	0.11
Force @ Peak Power (N)	1061.7(39.0)	1077.9(40.4)	0.10
Takeoff Peak Force (N)	1239.5(44.6)	1265.3(59.0)	0.12

Results are presented as Mean(Standard Error). Statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). N = Newtons; N·s = Newton seconds; N/s = Newtons per second; RFD = rate of force development.

Summary of Findings

*Sex*Condition*Time Interactions*

There were no significant Sex*Condition*Time interactions for any of the asymmetry variables ($p > 0.05$). There were no significant Condition*Time interactions for any Asymmetry Score variable. Concentric Impulse ($d = 0.25$), Concentric Mean Force ($d = 0.25$), Concentric Peak Force ($d = 0.26$), Eccentric Mean Force ($d = 0.24$), Eccentric Peak Force ($d = 0.24$), Force @ Zero Velocity ($d = 0.23$), Force @ Peak Power ($d = 0.31$), and Takeoff Peak Force ($d = 0.26$) demonstrated small effects for High eTL Pre-to-Post-, Eccentric Deceleration RFD ($d = 0.30$) showed small effect for High eTL Pre-to-24hPost-, and Concentric Impulse ($d = 0.29$), Concentric Mean Force ($d = 0.28$), Concentric Peak Force ($d = 0.24$), Eccentric Mean Force ($d = 0.27$), Force @ Peak Power ($d = 0.29$), and Takeoff Peak Force ($d = 0.23$) revealed a small effect for High eTL Post-24hPost-. There were no significant Sex*Condition*Time interactions for any of the Change Score variables or Raw Score variables.

*Sex*Condition Interactions*

There was a significant Sex*Condition interaction with Duration, as the males appeared to participate a significantly longer duration compared to the females over both the High (Males = 86.4(0.5) min.; Females = 67.4(0.8) min.; $p < 0.001$) and Low (Males = 86.5(0.5) min.; Females = 70.0(0.0) min.; $p < 0.001$) conditions, however, there was no significant Sex*Condition interaction for PL ($p = 0.261$). Though the Duration was decreased for the High eTL Condition, there was a significantly greater PL (High = 449.9(17.5) au; Low = 388.0(26.4) au, $p < 0.001$) than the Low eTL condition.

There were no significant Condition*Sex interactions for the Asymmetry Score variables. Males demonstrated trivial effect ($d < 0.20$) between conditions for all Asymmetry Score variables, whereas Females showed small effect for Concentric Impulse (*d* = 0.27), Concentric Mean Force (*d* = 0.26), Concentric Peak Force (*d* = 0.24), Eccentric Mean Force (*d* = 0.23), Eccentric Peak Force (*d* = 0.23), Force @ Zero Velocity (*d* = 0.21), Force @ Peak Power (*d* = 0.34), and Takeoff Peak Force (*d* = 0.26) between conditions.

There were no significant Condition*Sex interactions for the Change Score variables. Males demonstrated medium effect between Conditions for Concentric Impulse (*d* = 0.61), Concentric Mean Force (*d* = 0.62), Concentric Peak Force (*d* = 0.51), Eccentric Deceleration RFD (*d* = 0.63), Force @ Zero Velocity (*d* = 0.62) and Force @ Peak Power (*d* = 0.76), while Eccentric Braking RFD (*d* = 0.42), Eccentric Mean Force (*d* = 0.22), Eccentric Peak Force (*d* = 0.42), and Takeoff Peak Force (*d* = 0.38) showed small effect. Females revealed large effects for Concentric Peak Force (*d* = 0.95), medium effect for Eccentric Deceleration RFD (*d* = 0.56), and small effects for Concentric Impulse (*d* = 0.48), Concentric Mean Force (*d* = 0.48), Eccentric Braking RFD (*d* = 0.27), Force @ Peak Power (*d* = 0.43), and Takeoff Peak Force (*d* = 0.39).

Condition*Time Interactions

Only Eccentric Mean Force (p = 0.015; $\eta^2 = 0.308$) displayed a significant Condition*Time interaction, while all other variables were not significant for the Change Scores. Only trivial effects were shown Pre-to-Post- for Low eTL for all Change Scores (*d* < 0.20), whereas small effects were found for Concentric Mean Force (*d* = 0.20), Force @ Peak Power (*d* = 0.20) Pre-to-24hPost-, and small effects for Concentric Mean Force (*d* = 0.22), Eccentric Peak Force (*d* = 0.25), and Force @ Zero Velocity (*d* = 0.28) Post-to-24hPost-. Medium effects were shown for the High eTL Condition Pre-to-Post- for Concentric Impulse (*d* = 0.75), Concentric Mean Force (*d* = 0.75), Concentric Peak Force (*d* = 0.60), Eccentric Mean Force (*d* = 0.71), Force @ Peak Power (*d* = 0.52), and Takeoff Peak Force (*d* = 0.59). Large effects were revealed Pre-to-24hPost- for

Concentric Impulse (*d* = 1.05), Concentric Mean Force (*d* = 1.04), Concentric Peak Force (*d* = 1.00), Eccentric Mean Force (*d* = 1.09), Force @ Zero Velocity (*d* = 0.80), and Takeoff Peak Force (*d* = 0.97), with medium effects in Eccentric Peak Force (*d* = 0.78) and Force @ Peak Power (*d* = 0.76). Medium effects were shown Post-to-24hPost- for Concentric Impulse (*d* = 0.55), Concentric Mean Force (*d* = 0.54), Eccentric Mean Force (*d* = 0.58), Eccentric Peak Force (*d* = 0.61), and Force @ Zero Velocity (*d* = 0.59), while small effects were observed in Concentric Peak Force (*d* = 0.48), Force @ Peak Power (*d* = 0.41), and Takeoff Peak Force (*d* = 0. 49).

There were no significant Time*Condition interactions for any of the Raw Score variables. A small effect was shown between Conditions Pre- for Concentric Impulse (*d* = 0.27), while all other Raw Scores revealed trivial effects. Small effects were shown between Conditions Post- for Eccentric Braking RFD (*d* = 0.23), Eccentric Deceleration RFD (*d* = 0.20), and Force @ Zero Velocity (*d* = 0.20), while all other Raw Score variables remained trivial (*d* < 0.20). Only trivial effects were shown between Conditions for all Raw Score variables 24hPost- (*d* < 0.20).

Sex*Time Interactions

There were no significant Sex*Time interactions for any Asymmetry Score variables. Females demonstrated small effects Pre-to-Post- for Concentric Impulse (*d* = 0.28), Concentric Mean Force (*d* = 0.28), Concentric Peak Force (*d* = 0.34), Eccentric Mean Force (*d* = 0.28), Eccentric Peak Force (*d* = 0.24), Force @ Zero Velocity (*d* = 0.27), Force @ Peak Power (*d* = 0.33), and Takeoff Peak Force (*d* = 0.28), a small effect Pre-to-24hPost- for Eccentric Deceleration RFD (*d* = 0.32), and small effects Post-to-24hPost- for Concentric Impulse (*d* = 0.33), Concentric Mean Force (*d* = 0.33), Concentric Peak Force (*d* = 0.24), Eccentric Mean Force (*d* = 0.34), Force @ Peak Power (*d* = 0.39), and Takeoff Peak Force (*d* = 0.25), while all other values for these time points were interpreted as trivial (*d* < 0.20). Males showed trivial effects for all Asymmetry Score variables for all time points (*d* < 0.20).

There were no significant Sex*Time interactions for the Change Score variables. Males demonstrated large effects for Concentric Impulse (*d* = 0.98), Concentric Mean Force (*d* = 1.02), Eccentric Mean Force (*d* = 1.18), Force @ Peak Power (*d* = 0.86), and Takeoff Peak Force (*d* = 0.80), while medium effects were shown in Concentric Peak Force (*d* = 0.79), Eccentric Peak Force (*d* = 0.55), and Force @ Zero Velocity (*d* = 0.51), small effects were shown in Eccentric Braking RFD (*d* = 0.26) and Eccentric Deceleration RFD (*d* = 0.23) Pre-to-Post-, large effects for Concentric Impulse (*d* = 1.31), Concentric Mean Force (*d* = 1.36), Concentric Peak Force (*d* = 1.30), Eccentric Mean Force (*d* = 1.63), Eccentric Peak Force (*d* = 1.01), Force @ Zero Velocity (*d* = 1.03), Force @ Peak Power (*d* = 1.13), and Takeoff Peak Force Pre-to-24hPost-, and large effect in Concentric Impulse (*d* = 0.81), Concentric Mean Force (*d* = 0.83), Concentric Peak Force (*d* = 0.85), and Force @ Zero Velocity (*d* = 0.85), medium effect in Eccentric Mean Force (*d* = 0.77), Eccentric Peak Force (*d* = 0.78), Force @ Peak Power (*d* = 0.66), and Takeoff Peak Force (*d* = 0.71), and small effect in Eccentric Braking RFD (*d* = 0.24), and Eccentric Deceleration RFD (*d* = 0.40) Post-to-24hPost-. Females showed medium effect in Eccentric Braking RFD (*d* = 0.54), small effects in Eccentric Deceleration RFD (*d* = 0.43), Eccentric Peak Force (*d* = 0.48), and Force @ Zero Velocity (*d* = 0.42) Pre-to-Post-, while large effect was shown in Concentric Impulse (*d* = 0.90), Concentric Mean Force (*d* = 0.93), Concentric Peak Force (*d* = 1.05), Eccentric Mean Force (*d* = 1.08), Force @ Peak Power (*d* = 0.97), and Takeoff Peak Force (*d* = 0.99), medium effect in Eccentric Peak Force (*d* = 0.67) and Force @ Zero Velocity (*d* = 0.70), and small effect in Eccentric Deceleration RFD (*d* = 0.49) Pre-to-24hPost-, as well as large effect Post-to24hPost- in Concentric Impulse (*d* = 1.58), Concentric Mean Force (*d* = 1.61), Concentric Peak Force (*d* = 1.34), Eccentric

Braking RFD (*d* = 1.25), Eccentric Deceleration RFD (*d* = 1.11), Eccentric Mean Force (*d* = 1.39), Eccentric Peak Force (*d* = 1.52), Force @ Zero Velocity (*d* = 1.43), Force @ Peak Power (*d* = 1.57), and Takeoff Peak Force (*d* = 1.32). Important to note is the difference in effect particularly Post-to-24hPost for both Sexes within most of the variables between other Time points.

Sex Effects

There was a significant Sex main effect for Duration (Men = 86.5(0.1) min; Women = 68.7(0.1) min, $p < 0.001$), though PL (Men = 434.4(26.2) au; Women = 403.5(34.3) au, $p = 0.485$) did not reach statistical significance.

There were no significant Sex main effects among any of the Asymmetry Score variables. Eccentric Mean Force demonstrated medium effect (*d* = 0.78) between sexes, Eccentric Braking RFD (*d* = 0.29), Eccentric Peak Force (*d* = 0.34), and Force @ Zero Velocity (*d* = 0.33) revealed small effect, while all others remain trivial (*d* < 0.20).

There were no significant Sex effects for any of the Change Score variables. However, Concentric Impulse (*d* = 1.13) and Concentric Mean Force (*d* = 1.12) demonstrated large effects of Change Score on Sex, while Eccentric Deceleration RFD (*d* = 0.56), Eccentric Mean Force (*d* = 0.55), and Eccentric Peak Force (*d* = 0.67) showed medium effect, Concentric Peak Force (*d* = 0.32), Eccentric Braking RFD (*d* = 0.40), Force at Zero Velocity (*d* = 0.33), and Force at Peak Power (*d* = 0.39) showed small effect, and Takeoff Peak Force (*d* = 0.59), indicating small to large changes in Change Scores within Sex.

Time Effects

There were no significant Time main effects for any of the Asymmetry Score variables. Subjects showed trivial effects (*d* < 0.20) for all Asymmetry Score variables Pre-to Post-. Eccentric

Deceleration RFD showed small effect (*d* = 0.20) Pre-to-24hPost-, and Force @ Peak Power showed small effect (*d* = 0.20) Post-to24hPost-, while all others showed trivial effect (*d* < 0.20).

There were no significant Time effects for any of the Change Score variables. When comparing Change Scores Pre- to Post- Concentric Impulse (d = 0.46), Concentric Mean Force (*d* = 0.49), Concentric Peak Force (*d* = 0.49), Eccentric Mean Force (*d* = 0.41), Eccentric Peak Force (*d* = 0.20), Force at Peak Power (*d* = 0.43), and Takeoff Peak Force (*d* = 0.41) demonstrated small effects, while Eccentric Braking RFD (*d* = 0.04), Eccentric Deceleration RFD (*d* = 0.19), and Force at Zero Velocity (*d* = 0.19) showed trivial effects. When comparing Change Scores across Time Point 2 (**Δ_2 = 24hPost-Pre**) Concentric Impulse (*d* = 0.69), Concentric Mean Force (*d* = 0.72), Concentric Peak Force (*d* = 0.64), Eccentric Mean Force (*d* = 0.63), Eccentric Peak Force (*d* = 0.55), Force at Zero Velocity (*d* = 0.55), Force at Peak Power (*d* = 0.58), and Takeoff Peak Force (*d* = 0.61) demonstrated medium effects, while Eccentric Braking RFD (*d* = 0.16) and Eccentric Deceleration RFD (*d* = 0.02) showed trivial effects. When comparing Change Scores across Time Point 3 (**Δ_3 = 24hPost-Post**), Concentric Mean Force (*d* = 0.50), Eccentric Peak Force (*d* = 0.54), and Force at Zero Velocity (*d* = 0.54) demonstrated medium effects, while Concentric Impulse (*d* = 0.48), Concentric Peak Force (*d* = 0.42), Eccentric Mean Force (*d* = 0.34), Force at Peak Power (*d* = 0.34), and Takeoff Peak Force (*d* = 0.36) showed small effects, and Eccentric Braking RFD (*d* = 0.15) and Eccentric Deceleration RFD (*d* = 0.19) showed trivial effects.

There were significant Time main effects for Eccentric Mean Force (p = 0.011; η_p^2 = 0.259), Eccentric Peak Force (p = 0.03; η_p^2 = 0.208), and Force at Peak Power (p = 0.002; η_p^2 = 0.333), though all others did not reach statistical significance. There were significant differences in Eccentric Mean Force Pre-Post (3.2(1.1)N; p = 0.040), and Post-24hPost (-4.2(1.4)N; p = 0.027), and Force at Peak Power Pre-Post (-21.5(7.7)N; p = 0.044), Post-24hPost (23.4(6.3)N; p = 0.007).

There were no significant differences between time points for Eccentric Peak Force (p = 0.057-0.590). Only trivial effects were observed Pre-to-Post- for all other Raw Score variables (*d* < 0.20). A small effect was observed Pre-to-24hPost- for Concentric Impulse (*d* = 0.27), while all others remained trivial for this time point (*d* < 0.20). A small effect was seen Post-to-24hPost- for Eccentric Peak Force (*d* = 0.23) and Force @ Zero Velocity (*d* = 0.20), while all other variables remained trivial (*d* < 0.20).

Condition Effects

There were no significant main effects between Conditions. All of the Asymmetry Score variables showed trivial effect between Conditions (*d* < 0.20).

There were no significant Condition main effects for any of the Change Score variables. Small effects were observed between Conditions for Concentric Impulse (*d* = 0.36), Concentric Mean Force (*d* = 0.32), Eccentric Peak Force (*d* = 0.20), and Eccentric Deceleration RFD (*d* = 0.33), while all other effects were interpreted as trivial (*d* < 0.20).

There were no significant Condition main effects for any of the Raw Score variables. A small effect was observed between Conditions for the Raw Score variables in Concentric Impulse (*d* = 0.24), while all other variables remained trivial (*d* < 0.20).

Limb*Condition*Time Interactions

There was a significant Limb*Time*Condition interaction for Eccentric Mean Force (Pre-to Post-High eTL exposure in the nondominant limb: 11.4 ± 4.2N; p = 0.049), though Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Braking RFD, Eccentric Deceleration RFD, Eccentric Peak Force, Force at Zero Velocity, Force at Peak Power, and Takeoff Peak Force did not reach statistical significance.

*Limb*Condition Interactions*

There was a significant Limb*Condition interaction for Eccentric Mean Force ($p = 0.035$; $\eta_p^2 = 0.263$), however, all others did not reach statistical significance. There were significant differences between Conditions for the Dominant Limb in Eccentric Mean Force (-7.4(2.7N); $p = 0.016$). A small effect was shown between Conditions for the Nondominant limb for Concentric Impulse ($d = 0.27$), while all other Raw Score variables remain trivial ($d < 0.20$). Additionally, a small effect was observed between Conditions for the Dominant limb for Concentric Impulse ($d = 0.20$), while all other Raw Score variables showed trivial effect.

*Limb*Time Interactions*

There were no significant Limb*Time interactions for Raw Score variables. Trivial effects were demonstrated for Dominant and Nondominant Limbs Pre-to-Post- for all Raw Score variables ($d < 0.20$). Small effects were observed for the Nondominant Limb Pre-to-24hPost- for Concentric Impulse ($d = 0.27$), and the Dominant Limb Pre-to-24hPost- for Concentric Impulse ($d = 0.26$), while all other variables remained trivial ($d < 0.20$). Small effects were observed for the Nondominant Limb Post-to-24hPost- for Eccentric Peak Force ($d = 0.23$) and Force @ Zero Velocity ($d = 0.20$), while the Dominant Limb showed small effects for Eccentric Peak Force ($d = 0.20$) Post-to-24hPost-, and all other variables remained trivial ($d < 0.20$).

Limb Effects

There were no significant Limb main effects for any of the Raw Score variables. Only trivial effects were observed between Limb Dominance for all Raw Score variables ($d < 0.20$).

Discussion

The primary purpose of this investigation was to evaluate acute lower extremity interlimb asymmetries following varied levels of basketball-specific training loads. The Low eTL Condition appeared to have minimal effects on asymmetry change, which was consistent with the hypotheses, whereas High eTL appeared to have larger, though insignificant, effects on asymmetry for most variables Pre- to Post- and 24hPost-practice. As hypothesized, females appeared to exhibit larger effects of asymmetry change for most of the analyses, consistent with previous work (Fort-Vanmeerhaeghe et al., 2016), though the findings were not statistically significant. Additionally, some of these interactions observed may have been limited due to the small sample size of this analysis (Male: n = 12; Female: n = 4), therefore these findings may not be generalizable outside of the given population. Future investigations with greater statistical power should confirm or refute the present observarions.

External Training Load

Previous literature has evaluated the physiological and mechanical training load demands of basketball competition (Scanlan et al., 2011; Svilar et al., 2018; Ransdell et al., 2018; Freitas et al., 2020). Svilar et al. (2018) found differences in eTL between positions, as centers showed greater quantities of accelerations than forwards and guards. Additionally, the forward position showed larger quantities of decelerations compared to the other positions. These accelerometer-based findings are contributors to the PL algorithm, as used in the present study. Time-motion analysis showed that elite backcourt and frontcourt basketball players performed a larger total duration of jogging and running than of sub-elite players during competition, however the durations of high acceleratory movements were much shorter for elite players, indicating that the intensities of the accelerations were much greater in elite players, concomitant with increased metabolic demand (Scanlan et al., 2011).

There were significant Sex*Condition interactions for Duration, as the male subjects appeared to participate in significantly longer practice durations than the females, however, there was no indication that any Sex differences existed in PL. The High eTL Condition appeared to be shorter in Duration, though the PL of the High Condition session was larger, indicating that the density of the High eTL session was larger. Heishman et al. (2018) found significant differences in CMJ height and power with similar mean PL values (between 309.7 ± 109.3 and 312.0 ± 96.5). Bromley et al. (2019) did not reported external training loads, therefore it is assumed that all of the participants performed SLCMJs to evaluate asymmetry in response to the 90 minute soccer match.

The accelerometer-based findings of the present study must be examined with the known limitations of accelerometers in mind. Accelerometry fails to detect the high metabolic demands of player to player contact, as the data is assessed as only low velocity outputs (Freitas et al., 2020).

Bilateral Asymmetry Index-1 - Asymmetry Scores

There were no significant Condition*Time interactions for any of the Asymmetry Score variables. However, each of the variables appeared to shift between condition from trivial to small effects as the workload increased.

There were no observed significant Sex*Time interactions for any of the Asymmetry Score variables, however, there appeared to be slightly larger effects for females, particularly Pre- to Post- and Post- to 24hPost-practice. Females exhibited small effects for Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Mean Force, Eccentric Peak Force, Force @ Zero Velocity, Force @ Peak Power, and Takeoff Peak Force Pre- to Post-practice, as well as small effect Pre- to 24hPost- for Eccentric Deceleration RFD, and small effects Post- to 24hPost- for Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Mean Force, Force @ Peak Power, and Takeoff Peak Force, while all other values for these time points were interpreted as trivial. Males showed trivial to no effects for all Asymmetry Score variables for all time points.

There were no observed Condition*Sex interactions for all of the Asymmetry Score variables, though females appeared to exhibit slightly larger effects than the males. Females showed small effects between Conditions for Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Mean Force, Eccentric Peak Force, Force @ Zero Velocity, Force @ Peak Power, and Takeoff Peak Force between conditions, whereas males exhibited only trivial effects between conditions. No significant Time main effects were observed among the Asymmetry Score variables. Only a small effect was shown for Eccentric Deceleration RFD Pre- to 24hPost-practice, and Force @ Peak Power Post- to 24hPost-practice. There were no significant Sex main effects for any of the Asymmetry Score variables, though Eccentric Mean Force revealed a medium-large effect between sexes, and Eccentric Braking RFD, Eccentric Peak Force, and Force @ Zero Velocity showed small effects between sexes. There were no significant main effects between Conditions, and all of the Asymmetry Score variables revealed only trivial effects between Conditions.

Change Score Results

There were no significant Condition*Sex interactions for any Change Score variables. A large effect was noted for Females for Concentric Peak Force, as well as medium effect for Eccentric Deceleration RFD, and small effects for Concentric Impulse, Concentric Mean Force, Eccentric Braking RFD, Force @ Peak Power, and Takeoff Peak Force between Conditions. Males demonstrated medium effects between Conditions for Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Deceleration RFD, Force @ Zero Velocity and Force @ Peak Power, while Eccentric Braking RFD, Eccentric Mean Force, Eccentric Peak Force, and Takeoff Peak Force produced small effects.

Eccentric Mean Force displayed a significant Condition*Time interaction for the Change Score variables, signifying a significant reduction in symmetry between limb for Eccentric Mean Force. Trivial effects existed for all three time points during the Low eTL Condition, with Concentric Mean Force and Force @ Peak Power at the Pre- to 24hPost- point, while Concentric Mean Force, Eccentric Peak Force, and Force @ Zero Velocity exhibited small effect Post- to 24hPost-practice.

The High eTL session showed medium effect in Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Mean Force, Force @ Peak Power, and Takeoff Peak Force Pre- to Post-practice. Large effects were produced Pre-to-24hPost- for Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Mean Force, Force @ Zero Velocity, and Takeoff Peak Force, with medium effects in Eccentric Peak Force and Force @ Peak Power. Medium effects were shown Post-to-24hPost- for Concentric Impulse, Concentric Mean Force, Eccentric Mean Force, Eccentric Peak Force, and Force @ Zero Velocity, while small-medium effects were observed in Concentric Peak Force, Force @ Peak Power, and Takeoff Peak Force.

Limb Dominance Raw Scores

There was a significant Limb*Condition interaction for Eccentric Mean Force. Significant differences between Conditions for the Dominant Limb in Eccentric Mean Force were observed. A small effect was shown between Conditions for the Nondominant limb for Concentric Impulse, while all other Raw Score variables remain trivial. Additionally, a small effect was observed between Conditions for the Dominant limb for Concentric Impulse, while all other Raw Score variables showed trivial effect. Eccentric Mean Force showed a significant difference for the Dominant Limb between Conditions. There were significant Time main effects for Eccentric Mean Force, Eccentric Peak Force, and Force at Peak Power. There were significant differences in Eccentric Mean Force Pre-Post, and Post-24hPost, and Force at Peak Power Pre-Post, Post-24hPost.

Synopsis

In this investigation, bilateral interlimb asymmetry was calculated and examined via three different methods: Bilateral Asymmetry Index – 1 (BAI-1) equation, Change Score method (T_x-T_y), and Raw Score comparisons between the Dominant and Nondominant limbs. Due to the scope differences of the equations, comparisons of asymmetry outcomes between equations are not advised, as some equations tend to artificially inflate outcome measures (Exell et al., 2012). However, it is important to identify trends and interactions in the results in order to better understand the magnitude of intervention that load prescription plays on athlete monitoring modalities, such as interlimb imbalance quantification. Change Scores and Limb Dominance Raw Scores appeared highly sensitive as compared to the BAI-1 Asymmetry Scores. Likely gross performance measures would have been suppressed at the Post- and 24hPost- time points, consistent to previous works (Bromley et al., 2019; Bishop et al., 2019). Previous research has shown high within-subject reliability (Heishman et al., 2019; Bishop et al., 2018). The findings may have been limited to the magnitude of PL exposure as well, as this selected Offseason period has traditionally been shown to be less physiologically demanding than that of Preseason and In-Season periods. There were no significant differences in PL/min between Conditions, which could also be a potential limitation.

The overall consensus of the surrounding literature indicates lack of clarity on the influence of interlimb asymmetry on sports or physical performance. In addition, the field of literature on functional asymmetry along an acute timeline following a fatiguing protocol is scarce, as the only known works on the subject are the present study, as well as a work by Bromley et al. (2019) and a thesis by Hodges (2010). However, load prescription appears to have an effect on CMJ performance (Gathercole et al., 2015; Heishman et al., 2018; Cormack et al., 2008), as well as asymmetry on performance (Bishop et al., 2017, 2018, 2019; Bailey et al., 2013) with few results confounding (Maloney et al., 2017). Therefore, it may seem logical that there is an association between concepts, as shown in Bromley's work (2019). The load prescription of the present study may not have been synonymous with Bromley et al. (2019), as the external load demand and intensity may have surpassed that of the offseason basketball training. Additionally, similar results may have been collected with likewise testing methods, as Bromley et al. performed the SL CMJ compared to the bilateral CMJ of the present study. However, previous researchers believe that the testing modality of the bilateral CMJ may be more representative of asymmetry during sport than the SL CMJ (Heishman et al., 2019; Benjanuvatra et al., 2013).

Some of the results of bilateral limb asymmetry in the literature seem confounding. Training methodologies to help reduce asymmetry have shown positive effects with bilateral interventions (Bazyler et al., 2014), as well as unilateral interventions (Gonzalo-Skok et al., 2017). However, it is important to note that a common finding in the literature was the association between strength and symmetry (Bazyler et al., 2014; Impellizzeri et al., 2007; Brown et al., 2017). When groups were median split (and placed into quartiles or percentiles), the weaker groups (categorized typically by force produced) appear to have significantly larger asymmetry. Additionally, several 6-9 week strength and balance-based training interventions appear to have profound effects on reduction of asymmetry (Impellizzeri et al., 2007; Sannicandro et al., 2014; Bazyler et al., 2014; Gonzalo-Skok et al., 2017; Brown et al., 2017). Therefore, a prominent starting point to reducing asymmetry through training would be, merely put, to increase strength.

Limitations

There were several limitations in the present study. This study took place during the offseason training phase of a basketball team, and furthermore the results may not be generalizable to other training phases, or other team sports. The load or intensity of the basketball training load may not have been vast enough to appropriate the dose-response seen in previous literature. Outside activity was not controlled, though it was documented to the best of the authors' ability. Finally, nutrition habits were not monitored.

Chapter V: Conclusions

The prominence of unilateral soft tissue injury in sport is on the rise, and asymmetry is a heavily examined risk factor. In conjunction with injury risk, optimizing performance is of the secondarily utmost performance in team or individual sport. Athletes particpating in limb dominant sports are predisposed to developing imbalances over time, whether it be lean tissue differences or lateralized motor coordination, and the physiological demand of competition and training enhances the effects over time. The need for investigation of proper measurement techniques, coercive findings, and enhanced understanding of the effects of bilateral asymmetry on athletic performance is paramount in the literature. Findings in the literature on the effects of asymmetry on sports performance are, at times, contraindicating. Specifically for jumping-based testing, the effects seem less clear, but the body of literature is particularly lacking in the effects of neuromuscular fatigue via prescription of load on asymmetry trends. To the author's knowledge, only three current works investigated these associations including the present study (Bromley et al., 2019; Hodges, 2010). Future research is warranted with similar study designs longitudinally, in order to monitor asymmetry responses to sport-specific training over time.

Primary Research Question

Were there significant differences in lower-limb asymmetries during the countermovement jump pre-, immediately post-, or 24-hours following exposures of high and low load sport-specific basketball training?

There were no significant differences in asymmetry between Conditions across time. However, there were significant differences in Concentric Impulse, Concentric Mean Force, and Eccentric Peak Force asymmetry between High and Low Conditions.

Primary Hypothesis

It was hypothesized that the trend in asymmetry will increase with high training load immediately post-training, similar to the findings of Bromley et al. (2018).

We will reject the Primary Hypothesis, that training loads would appear to influence interlimb asymmetry, we did not observe Condition*Time differences in asymmetry scores.

Secondary Research Question

Were there significant sex differences in lower-limb asymmetries during the countermovement jump pre-, immediately post-, or 24-hours following exposures of high and low load sport-specific basketball training?

There were no significant Sex differences within any of the asymmetry variables between sexes across time or condition. However, we did see small effects within males and females in Asymmetry Score, with Concentric Impulse, Concentric Mean Force, Concentric Peak Force, Eccentric Peak Force, Force at Zero Velocity, Force at Peak Power, and Takeoff Peak Force Pre to Post- and Post to 24hPost- for females, while males exhibited trivial effects.

Secondary Hypothesis

It is hypothesized that lower-limb asymmetries will be significantly larger in women than in men, as seen previously by Fort-Vanmeerhaeghe et al. (2016).

We reject the Secondary Hypothesis, that bilateral asymmetry would be significantly larger in females than in males.

Practical Significance

Based upon the findings of the present study, practitioners may be able to better understand the effects of Offseason basketball practices of varied training loads on acute changes in jump characteristics between limbs. Monitoring changes in asymmetry may be valuable for biomechanists or medical staff to identify dose-response relationships to these stimuli. Additional interventions, such as resistance training to reduce imbalance or weakness, orthopedic additions to footwear, or visual aids to alter kinesthetic awareness, may provide enough of a competitive advantage to succeed at the collegiate and professional levels. The aforementioned interventions, along with an exponential amount of others, may give coaching staffs and athletes peace of mind, due to the inherent risk of injury reduction throughout the training process, as these are the people most affected by time loss from injury.

The present findings appear to show no change in acute asymmetry following offseason training basketball specific loads. Additionally, the present information may provide Strength & Conditioning professionals, as well as Athletic Medicine staff, the ability to apply a more drastic perturbation in training load, in order to increase preparedness though musculotendinous degradation and regeneration, to build a more robust foundation for force application, for the upcoming season. Perhaps, if there had been a decrease in shear jump performance, there would have been a subsequent change in bilateral jump performance imbalance leading to the decrease in performance.

Abundant in the literature is the use of hand-picked countermovement jump variables during the concentric or propulsive phases of the jump. However, very few appear to identify the eccentric phase mechanics prior to propulsion, along with landing mechanics asymmetries specifically of the countermovement jump. We saw larger variability in our data with other variables than most works across High and Low conditions, which may limit these variables' application as a parameter used to quantify neuromuscular asymmetry. In the present study, the most sensitive of the selected variables appeared to be Eccentric Mean Force. These findings may be deemed valuable and logical, as fatigue is known to influence stretch-shortening cycle output, and the small to moderate changes in Eccentric Mean Force asymmetry may contribute to that notion.

Future Research Directions

Future research should attempt to replicate the present study with an increase in sample size, in hopes of studying the bimodal recovery patterns of acute muscle fatigue on asymmetry performance. Additionally, future investigation should aim to identify longitudinal changes in individual performance asymmetries, in order to asymmetry-profile athletes based upon training loads throughout the season. In comparison with other literature, future research should investigate these differences respective to sport position, as loads have been shown to vary between positions. Another potentially robust investigation would be to compare the asymmetry changes of different training phases (preseason, competitive season, postseason, offseason) in order to identify what specific training loads may have a larger influence on the development of asymmetry. Finally, future investigation should attempt to clarify the responses found in interlimb asymmetry to training loads via multiple subsequent measurement techniques (SL CMJ, CMJ, isokinetics) in order to elucidate the difference between measurement techniques.

References

Agel, J., Palmieri-Smith, R. M., Dick, R., Wojtys, E. M., & Marshall, S. W. (2008). Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. Journal of Athletic Training, 42(2), 295–302. https://doi.org/10.1016/S0276-1092(08)79204-6

Allen, D. G., Lamb, G. D., & Westerblad, H. (2008). Skeletal muscle fatigue: Cellular mechanisms. Physiological Reviews, 88(1), 287–332. https://doi.org/10.1152/physrev.00015.2007

Allen, D. G., Lamb, G. D., & Westerblad, H. (2008). Skeletal muscle fatigue: Cellular mechanisms. Physiological Reviews, 88(1), 287–332. https://doi.org/10.1152/physrev.00015.2007

Amann, M. (2011). Central and peripheral fatigue: Interaction during cycling exercise in humans. Medicine and Science in Sports and Exercise, 43(11), 2039–2045. https://doi.org/10.1249/MSS.0b013e31821f59ab

Amann, M. (2012). Significance of Group III and IV muscle afferents for the endurance exercising human. Clinical and Experimental Pharmacology & Physiology, 39(9), 831–835. https://doi.org/10.1111/j.1440-1681.2012.05681.x

Aoki, M. S., Ronda, L. T., Marcelino, P. R., Drago, G., Carling, C., Bradley, P. S., & Moreira, A. (2017). Monitoring Training Loads in Professional Basketball Players Engaged in a Periodized Training Program. Journal of Strength and Conditioning Research, 31(2), 348–358. https://doi.org/10.1519/JSC.0000000000001507

Arevalo, J. A., Lynn, S. K., Bagley, J. R., Brown, L. E., Costa, P. B., & Galpin, A. J. (2018). Lower-Limb Dominance, Performance, and Fiber Type in Resistance-trained Men. Medicine and Science in Sports and Exercise, 50(5), 1054–1060. https://doi.org/10.1249/MSS.0000000000001533

Auerbach, B. M., & Ruff, C. B. (2006). Limb bone bilateral asymmetry: Variability and commonality among modern humans. Journal of Human Evolution, 50(2), 203–218. https://doi.org/10.1016/j.jhevol.2005.09.004

Augustsson, J., Thomeé, R., Lindén, C., Folkesson, M., Tranberg, R., & Karlsson, J. (2006). Single-leg hop testing following fatiguing exercise: reliability and biomechanical analysis. Scandinavian Journal of Medicine & Science in Sports, 16(2), 111–120. https://doi.org/10.1111/j.1600-0838.2005.00446.x

Bailey, C. A., Sato, K., Burnett, A., & Stone, M. H. (2015). Carry-Over of Force Production Symmetry in Athletes of Differing Strength Levels. Journal of Strength and Conditioning Research, 29(11), 3188–3196. https://doi.org/10.1519/JSC.0000000000000983

Bailey, C. A., Sato, K., Burnett, A., & Stone, M. H. (2015). Carry-Over of Force Production Symmetry in Athletes of Differing Strength Levels. Journal of Strength and Conditioning Research, 29(11), 3188–3196. https://doi.org/10.1519/JSC.0000000000000983

Bailey, C. A., Sato, K., Burnett, A., & Stone, M. H. (2015). Kinetic asymmetry and center of mass displacement during jumps. Isbs, (JANUARY). https://doi.org/10.13140/RG.2.1.4062.0645

Balsalobre-Fernández, C., Bishop, C., Beltrán-Garrido, J. V., Cecilia-Gallego, P., Cuenca-Amigó, A., Romero-Rodríguez, D., & Madruga-Parera, M. (2019). The validity and reliability of a novel app for the measurement of change of direction performance. Journal of Sports Sciences, (July). https://doi.org/10.1080/02640414.2019.1640029

Barnett Anthony. (2006). Using recovery modalities between training sessions in elite athletes. Does it help? Sports Medicine, 36(9), 781–796.

Barnett, F., & Gilleard, W. (2005). The use of lumbar spinal stabilization techniques during the performance of abdominal strengthening exercise variations. The Journal of Sports Medicine and Physical Fitness, 45(1), 38–43. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16208289

Barnett, M. L., Ross, D., Schmidt, R. A., & Todd, B. (1973). Motor skills learning and the specificity of training principle. Research Quarterly of the American Association for Health, Physical Education and Recreation, 44(4), 440–447. https://doi.org/10.1080/10671188.1973.10615224

Barrett, S., Midgley, A., & Lovell, R. (2014). PlayerLoadTM: reliability, convergent validity, and influence of unit position during treadmill running. International Journal of Sports Physiology & Performance, 9(6).

Bassett, D. R., & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. Medicine and Science in Sports and Exercise, 32(1), 70–84. https://doi.org/10.1097/00005768-200001000-00012

Bates, N. A., Ford, K. R., Myer, G. D., & Hewett, T. E. (2013). Impact differences in ground reaction force and center of mass between the first and second landing phases of a drop vertical jump and their implications for injury risk assessment. Journal of Biomechanics, 46(7), 1237–1241. https://doi.org/10.1016/j.jbiomech.2013.02.024

Baumgartner, T. A., & Chung, H. (2001). Confidence Limits for Intraclass Reliability Coefficients. Measurement in Physical Education and Exercise Science, 5(3), 179–188. https://doi.org/10.1207/S15327841MPEE0503_4

Bell, D. R., Sanfilippo, J. L., Binkley, N., & Heiderscheit, B. C. (2014). Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. Journal of Strength and Conditioning Research, 28(4), 884–891. https://doi.org/10.1519/JSC.0000000000000367

Bell, D. R., Sanfilippo, J. L., Binkley, N., & Heiderscheit, B. C. (2014). Lean Mass Asymmetry Influences Force and Power Asymmetry During Jumping in Collegiate Athletes. Journal of Strength and Conditioning Research, 28(4), 884–891. https://doi.org/10.1519/JSC.0000000000000367

Benjanuvatra, N., Lay, B. S., Alderson, J. A., & Blanksby, B. A. (2013). Comparison of ground reaction force asymmetry in one- and two-legged countermovement jumps. Journal of Strength and Conditioning Research, 27(10), 2700–2707. https://doi.org/10.1519/JSC.0b013e318280d28e

Bigland-Ritchie, B., & Woods, J. J. (1984). Changes in muscle contractile properties and neural control during human muscular fatigue. Muscle & Nerve, 7(9), 691–699. https://doi.org/10.1002/mus.880070902

Bishop, C. (n.d.). Magnitude or Direction? Seasonal Variation of Inter-limb Asymmetry in Elite Academy Soccer Players, 1–22. Retrieved from http://eprints.mdx.ac.uk/29034/

Bishop, C., Blagrove, R., Turner, A., & Cscs. (2018). Pronounced inter-limb asymmetry in an international female 400m athlete : a 14-week case study using periodised strength training, (51), 7–12.

Bishop, C., Brashill, C., Abbott, W., Read, P., Lake, J., & Turner, A. (2019). Jumping Asymmetries Are Associated With Speed, Change of Direction Speed, and Jump Performance in Elite Academy Soccer Players. Journal of Strength and Conditioning Research, 00(December), 1042–1049. https://doi.org/10.1519/JSC.0000000000003058

Bishop, C., Lake, J., Loturco, I., Papadopoulos, K., Turner, A., & Read, P. (2018). Interlimb Asymmetries. Journal of Strength and Conditioning Research, 00(00), 1. https://doi.org/10.1519/JSC.0000000000002729

Bishop, C., McAuley, W., Read, P., Gonzalo-Skok, O., Lake, J., & Turner, A. (2019). Acute Effect of Repeated Sprints on Interlimb Asymmetries During Unilateral Jumping. Journal of Strength and Conditioning Research, (10), 1. https://doi.org/10.1519/jsc.0000000000003109

Bishop, C., Pereira, L. A., Reis, V. P., Read, P., Turner, A. N., & Loturco, I. (2019). Comparing the magnitude and direction of asymmetry during the squat, countermovement and drop jump tests in elite youth female soccer players. Journal of Sports Sciences, 1–8. https://doi.org/10.1080/02640414.2019.1649525

Bishop, C., Read, P., Brazier, J., Jarvis, P., Chavda, S., Bromley, T., & Turner, A. (2019). Effects of Interlimb Asymmetries on Acceleration and Change of Direction Speed. Journal of Strength and Conditioning Research, 1. https://doi.org/10.1519/jsc.0000000000003135

Bishop, C., Read, P., Bromley, T., Brazier, J., Jarvis, P., Chavda, S., & Turner, A. (2020). The Association Between Interlimb Asymmetry and Athletic Performance Tasks. Journal of Strength and Conditioning Research, 1. https://doi.org/10.1519/JSC.0000000000003526

Bishop, C., Read, P., Chavda, S., & Turner, A. (2016). Asymmetries of the Lower Limb: The Calculation Conundrum in Strength Training and Conditioning. Strength and Conditioning Journal, 38(6), 27–32. https://doi.org/10.1519/SSC.0000000000000264

Bishop, C., Read, P., Chavda, S., Jarvis, P., & Turner, A. (2019). Using Unilateral Strength, Power and Reactive Strength Tests to Detect the Magnitude and Direction of Asymmetry: A Test-Retest Design. Sports, 7(3), 58. https://doi.org/10.3390/sports7030058

Bishop, C., Read, P., Lake, J., Chavda, S., & Turner, A. (2018). Interlimb asymmetries: Understanding how to calculate differences from bilateral and unilateral tests. Strength and Conditioning Journal, 40(4), 1–6. https://doi.org/10.1519/SSC.0000000000000371

Bishop, C., Read, P., McCubbine, J., & Turner, A. (2018). Vertical and Horizontal Asymmetries are Related to Slower Sprinting and Jump Performance in Elite Youth Female Soccer Players. Journal of Strength and Conditioning Research, 1. https://doi.org/10.1519/JSC.0000000000002544

Bishop, C., Read, P., Stern, D., & Turner, A. N. (n.d.). Effects of Soccer Match-play on Unilateral Jumping and Inter-limb Asymmetry : A Repeated Measures Design, 1–26.

Bishop, C., Turner, A., & Read, P. (2018). Effects of inter-limb asymmetries on physical and sports performance: a systematic review. Journal of Sports Sciences, 36(10), 1135–1144. https://doi.org/10.1080/02640414.2017.1361894

Bishop, C., Turner, A., & Read, P. (2018). Training methods and considerations for practitioners to reduce interlimb asymmetries. Strength and Conditioning Journal, 40(2), 40–46. https://doi.org/10.1519/SSC.0000000000000354

Bishop, C., Turner, A., Jarvis, P., Chavda, S., & Read, P. (2017). Considerations for Selecting Field-Based Strength and Power Fitness Tests to Measure Asymmetries. Journal of Strength and Conditioning Research, 31(9), 2635–2644. https://doi.org/10.1519/JSC.0000000000002023

Bjerkefors, A., Ekblom, M. M., Josefsson, K., & Thorstensson, A. (2010). Deep and superficial abdominal muscle activation during trunk stabilization exercises with and without instruction to hollow. Manual Therapy, 15(5), 502–507. https://doi.org/10.1016/j.math.2010.05.006

Boerio, D., Jubeau, M., Zory, R., & Maffiuletti, N. A. (2005). Central and peripheral fatigue after electrostimulation-induced resistance exercise. Medicine and Science in Sports and Exercise, 37(6), 973–978. https://doi.org/10.1249/01.mss.0000166579.81052.9c

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. Int J Sports Physiol Perform, 6(3), 311–321.

Bromley, T., Turner, A., Read, P., Lake, J., Maloney, S., Chavda, S., & Bishop, C. (2018). Effects of a Competitive Soccer Match on Jump Performance and Interlimb Asymmetries in Elite Academy Soccer Players. Journal of Strength and Conditioning Research, 00(February), 1. https://doi.org/10.1519/JSC.0000000000002951

Brophy-Williams, N., Driller, M. W., Kitic, C. M., Fell, J. W., & Halson, S. L. (2017). Effect of Compression Socks Worn Between Repeated Maximal Running Bouts. International Journal of Sports Physiology and Performance, 12(5), 621–627. https://doi.org/10.1123/ijspp.2016-0162

Byrne, P. J., Moody, J. A., Cooper, S.-M., Kinsella, S., & Byrne, P. J. (2017). The reliability of countermovement jump performance and the reactive strength index in identifying drop-jump drop height in hurling players. Isamed Journals Open Access Journal of Exercise and Sports Medicine, 1(1), 1–10. Retrieved from http://hdl.handle.net/10369/8751%0Ahttps://repository.cardiffmet.ac.uk/bitstream/handle/10369/8751/The Reliability of Countermovement Jump Performance and the Reactive.pdf?sequence=1

Cairns, S. P. (2013). Holistic approaches to understanding mechanisms of fatigue in high-intensity sport. Fatigue: Biomedicine, Health & Behavior, 1(3), 148–167. https://doi.org/10.1080/21641846.2013.765086

Cairns, S. P., Knicker, A. J., Thompson, M. W., & Sjøgaard, G. (2005). Evaluation of models used to study neuromuscular fatigue. Exercise and Sport Sciences Reviews, 33(1), 9–16.

Campbell, C. J., Carson, J. D., Diaconescu, E. D., Celebrini, R., Rizzardo, M. R., Godbout, V., … Cote, M. (2014). Canadian Academy of Sport and Exercise Medicine Position Statement. Clinical Journal of Sport Medicine, 24(3), 263–267. https://doi.org/10.1097/JSM.0000000000000068

Carabello, R. J., Reid, K. F., Clark, D. J., Phillips, E. M., & Fielding, R. A. (2010). Lower extremity strength and power asymmetry assessment in healthy and mobility-limited populations: Reliability and association with physical functioning. Aging Clinical and Experimental Research, 22(4), 324–329. https://doi.org/10.3275/6676

Carpes, F. P., Mota, C. B., & Faria, I. E. (2010). On the bilateral asymmetry during running and cycling - A review considering leg preference. Physical Therapy in Sport, 11(4), 136–142. https://doi.org/10.1016/j.ptsp.2010.06.005

Carter, H., Grice, Y., Dekerle, J., Brickley, G., Hammond, A. J. P., & Pringle, J. S. M. (2005). Effect of prior exercise above and below critical power on exercise to exhaustion. Medicine and Science in Sports and Exercise, 37(5), 775–781. https://doi.org/10.1249/01.MSS.0000162631.07404.7C

Castanharo, R., Da Luz, B. S., Bitar, A. C., D’Elia, C. O., Castropil, W., & Duarte, M. (2011). Males still have limb asymmetries in multijoint movement tasks more than 2 years following anterior cruciate ligament reconstruction. Journal of Orthopaedic Science, 16(5), 531–535. https://doi.org/10.1007/s00776-011-0118-3

Chalker, W. J., Shield, A. J., Opar, D. A., Rathbone, E. N., & Keogh, J. W. L. (2018). Effect of acute augmented feedback on between limb asymmetries and eccentric knee flexor strength during the Nordic hamstring exercise. PeerJ, 2018(6), 1–14. https://doi.org/10.7717/peerj.4972

Clark, N. C. (2001). Functional performance testing following knee ligament injury. Physical Therapy in Sport, 2(2), 91–105. https://doi.org/10.1054/ptsp.2001.0035

Cleasby, G. W., Fung, W. E., & Shekter, W. B. (1967). Astrocytoma of the retina. Report of two cases. American Journal of Ophthalmology, 64(3 PART 2), 633–637. https://doi.org/10.1016/0002-9394(67)90569-7

Conte, D., Tessitore, A., Smiley, K., Thomas, C., & Favero, T. G. (2016). Performance profile of NCAA Division I men’s basketball games and training sessions. Biology of Sport, 33(2), 189–194. https://doi.org/10.5604/20831862.1200512

Coratella, G., Beato, M., & Schena, F. (2018). Correlation between quadriceps and hamstrings inter-limb strength asymmetry with change of direction and sprint in U21 elite soccer-players. Human Movement Science, 59(April 2017), 81–87. https://doi.org/10.1016/j.humov.2018.03.016

Cordova, M. L., & Armstrong, C. W. (1996). Reliability of ground reaction forces during a vertical jump: implications for functional strength assessment. Journal of Athletic Training, 31(4), 342–345. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16558421

Cormack, S. J., Mooney, M. G., Morgan, W., & McGuigan, M. R. (2013). Influence of neuromuscular fatigue on accelerometer load in elite Australian football players. International Journal of Sports Physiology and Performance, 8(4), 373–378. https://doi.org/10.1123/ijspp.8.4.373

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Cormie, P. (2008). Neuromuscular and endocrine responses of elite players during an Australian rules football season. International Journal of Sports Physiology and Performance, 3(4), 439–453. https://doi.org/10.1123/ijspp.3.4.439

Cormack, S. J., Newton, R. U., McGulgan, M. R., & Doyle, T. L. A. (2008). Reliability of measures obtained during single and repeated countermovement jumps. International Journal of Sports Physiology and Performance, 3(2), 131–144. https://doi.org/10.1123/ijspp.3.2.131

Cormie, P., McBride, J. M., & McCaulley, G. O. (2009). Power-time, force-time, and velocity-time curve analysis of the countermovement jump: impact of training. Journal of Strength and Conditioning Research, 23(1), 177–186. https://doi.org/10.1519/JSC.0b013e3181889324

Cronin, J., & Sleivert, G. (2005). Challenges in understanding the influence of maximal power training on improving athletic performance. Sports Medicine, 35(3), 213–234. https://doi.org/10.2165/00007256-200535030-00003

Cunanan, A. J., DeWeese, B. H., Wagle, J. P., Carroll, K. M., Sausaman, R., Hornsby, W. G., … Stone, M. H. (2018). The General Adaptation Syndrome: A Foundation for the Concept of Periodization. Sports Medicine, 48(4), 787–797. https://doi.org/10.1007/s40279-017-0855-3

Dai, B., Butler, R. J., Garrett, W. E., & Queen, R. M. (2014). Using ground reaction force to predict knee kinetic asymmetry following anterior cruciate ligament reconstruction. Scandinavian Journal of Medicine and Science in Sports, 24(6), 974–981. https://doi.org/10.1111/sms.12118

Dai, B., Layer, J., Vertz, C., Hinshaw, T., Cook, R., Li, Y., & Sha, Z. (2019). Baseline Assessments of Strength and Balance Performance and Bilateral Asymmetries in Collegiate Athletes. Journal of Strength and Conditioning Research, 33(11), 3015–3029. https://doi.org/10.1519/JSC.0000000000002687

Davies, G. J., McCarty, E., Provencher, M., & Manske, R. C. (2017). ACL Return to Sport Guidelines and Criteria. Current Reviews in Musculoskeletal Medicine, 10(3), 307–314. https://doi.org/10.1007/s12178-017-9420-9

Deitch, J. R., Starkey, C., Walters, S. L., & Moseley, J. B. (2006). Injury risk in professional basketball players: A comparison of Women's National Basketball Association and National Basketball Association athletes. American Journal of Sports Medicine, 34(7), 1077–1083. https://doi.org/10.1177/0363546505285383

DeWeese, B. H., Hornsby, G., Stone, M., & Stone, M. H. (2015). The training process: Planning for strength-power training in track and field. Part 1: Theoretical aspects. Journal of Sport and Health Science, 4(4), 308–317. https://doi.org/10.1016/j.jshs.2015.07.003

Dorrel, B., Long, T., Shaffer, S., & Myer, G. D. (2018). The functional movement screen as a predictor of injury in national collegiate athletic association division II athletes. Journal of Athletic Training, 53(1), 29–34. https://doi.org/10.4085/1062-6050-528-15

Dos'Santos, T., Bishop, C., Thomas, C., Comfort, P., & Jones, P. A. (2019). The effect of limb dominance on change of direction biomechanics: A systematic review of its importance for injury risk. Physical Therapy in Sport, 37, 179–189. https://doi.org/10.1016/j.ptsp.2019.04.005

Dos'Santos, T., Thomas, C., Comfort, P., & Jones, P. A. (2019). The Effect of Training Interventions on Change of Direction Biomechanics Associated with Increased Anterior Cruciate Ligament Loading: A Scoping Review. Sports Medicine, 49(12), 1837–1859. https://doi.org/10.1007/s40279-019-01171-0

Dos'Santos, T., Thomas, C., Jones, P. A., & Comfort, P. (2019). Assessing Asymmetries in Change of Direction Speed Performance: Application of Change of Direction Deficit. Journal of Strength and Conditioning Research, 33(11), 2953–2961. https://doi.org/10.1519/JSC.0000000000002438

Dousset, E., Avela, J., Ishikawa, M., Kallio, J., Kuitunen, S., Kyröláinen, H., … Komi, P. V. (2007). Bimodal recovery pattern in human skeletal muscle induced by exhaustive stretch-shortening cycle exercise. Medicine and Science in Sports and Exercise, 39(3), 453–460. https://doi.org/10.1249/mss.0b013e31802dd74e

Dunlop, G., Ardern, C. L., Andersen, T. E., Lewin, C., Dupont, G., Ashworth, B., … McCall, A. (2019). Return-to-Play Practices Following Hamstring Injury: A Worldwide Survey of 131 Premier League Football Teams. Sports Medicine, (2). https://doi.org/10.1007/s40279-019-01199-2

Edwards, R. H., Hill, D. K., Jones, D. A., & Merton, P. A. (1977). Fatigue of long duration in human skeletal muscle after exercise. The Journal of Physiology, 272(3), 769–778. https://doi.org/10.1113/jphysiol.1977.sp012072

Edwards, T., Spiteri, T., Piggott, B., Bonhotal, J., Haff, G. G., & Joyce, C. (2018). Retraction: Reliability and Sensitivity of Neuromuscular and Perceptual Fatigue Measures in Collegiate Men's Basketball (Journal of strength and conditioning research (2018) 32 12 (e57)). Journal of Strength and Conditioning Research, (February). https://doi.org/10.1519/JSC.0000000000002517

Edwards, T., Spiteri, T., Piggott, B., Bonhotal, J., Haff, G. G., & Joyce, C. (2018). Monitoring and Managing Fatigue in Basketball. Sports, 6(1), 19. https://doi.org/10.3390/sports6010019

Ekstrand, J., Hägglund, M., & Waldén, M. (2011). Epidemiology of muscle injuries in professional football (soccer). The American Journal of Sports Medicine, 39(6), 1226–1232. https://doi.org/10.1177/0363546510395879

El-Ashker, S., Allardyce, J. M., & Carson, B. P. (2019). Sex-related differences in joint-angle-specific hamstring-to-quadriceps function following fatigue. European Journal of Sport Science, 19(8), 1053–1061. https://doi.org/10.1080/17461391.2019.1574904

Enoka, R. M. (1995). Mechanisms of muscle fatigue: Central factors and task dependency. Journal of Electromyography and Kinesiology, 5(3), 141–149. https://doi.org/10.1016/1050-6411(95)00010-W

Enoka, R. M., & Duchateau, J. (2008). Muscle fatigue: What, why and how it influences muscle function. Journal of Physiology, 586(1), 11–23. https://doi.org/10.1113/jphysiol.2007.139477

Enoka, R. M., & Duchateau, J. (2016). Translating Fatigue to Human Performance HHS Public Access. Med Sci Sports Exerc, 48(11), 2228–2238. https://doi.org/10.1249/MSS.0000000000000929

Exell, T. A., Irwin, G., Gittoes, M. J. R., & Kerwin, D. G. (2012). Implications of intra-limb variability on asymmetry analyses. Journal of Sports Sciences, 30(4), 403–409. https://doi.org/10.1080/02640414.2011.647047

Ferioli, D., Bosio, A., Bilsborough, J. C., Torre, A. La, Tornaghi, M., & Rampinini, E. (2018). The preparation period in basketball: Training load and neuromuscular adaptations. International Journal of Sports Physiology and Performance, 13(8), 991–999. https://doi.org/10.1123/ijspp.2017-0434

Fort-Vanmeerhaeghe, A., Gual, G., Romero-Rodriguez, D., & Unnitha, V. (2016). Lower Limb Neuromuscular Asymmetry in Volleyball and Basketball Players. Journal of Human Kinetics, 50(1), 135–143. https://doi.org/10.1515/hukin-2015-0150

Fort-Vanmeerhaeghe, A., Montalvo, A. M., Sitjà-Rabert, M., Kiefer, A. W., & Myer, G. D. (2015). Neuromuscular asymmetries in the lower limbs of elite female youth basketball players and the application of the skillful limb model of comparison. Physical Therapy in Sport, 16(4), 317–323. https://doi.org/10.1016/j.ptsp.2015.01.003

Fousekis, K., Tsepis, E., & Vagenas, G. (2010). Lower limb strength in professional soccer players: Profile, asymmetry, and training age. Journal of Sports Science and Medicine, 9(3), 364–373.

Fowles, J. R. (2006). Technical issues in quantifying low-frequency fatigue in athletes. International Journal of Sports Physiology and Performance, 1(2), 169–171. https://doi.org/10.1123/ijspp.1.2.169

Fox, J. L., Stanton, R., & Scanlan, A. T. (2018). A Comparison of Training and Competition Demands in Semiprofessional Male Basketball Players. Research Quarterly for Exercise and Sport, 89(1), 103–111. https://doi.org/10.1080/02701367.2017.1410693

Gandevia, S. C. (2001). Spinal and supraspinal factors in human muscle fatigue. Physiological Reviews, 81(4), 1725–1789. https://doi.org/10.1152/physrev.2001.81.4.1725

Gardinier, Emily; Manal, Kurt; Buchanan Thomas; Snyder-Mackler, L. (2013). Gait and Neuromuscular Asymmetries after Acute ACL Rupture. Medicine & Science in Sports & Exercise, 44(8), 1490–1496. https://doi.org/10.1249/MSS.0b013e31824d2783.Gait

Gathercole, R. J., Sporer, B. C., Stellingwerff, T., & Sleivert, G. G. (2015). Comparison of the Capacity of Different Jump and Sprint Field Tests to Detect Neuromuscular Fatigue. Journal of Strength and Conditioning Research, 29(9), 2522–2531. https://doi.org/10.1519/JSC.0000000000000912

Gathercole, R., Sporer, B., & Stellingwerff, T. (2015). Countermovement Jump Performance with Increased Training Loads in Elite Female Rugby Athletes. International Journal of Sports Medicine, 36(09), 722–728. https://doi.org/10.1055/s-0035-1547262

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. International Journal of Sports Physiology and Performance, 10(1), 84–92. https://doi.org/10.1123/ijspp.2013-0413

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. International Journal of Sports Physiology and Performance, 10(1), 84–92. https://doi.org/10.1123/ijspp.2013-0413

Girard, O., Brocherie, F., Morin, J. B., & Millet, G. P. (2017). Lower limb mechanical asymmetry during repeated treadmill sprints. Human Movement Science, 52, 203–214. https://doi.org/10.1016/j.humov.2017.02.008

Girard, O., Brocherie, F., Morin, J. B., & Millet, G. P. (2017). Lower limb mechanical asymmetry during repeated treadmill sprints. Human Movement Science, 52, 203–214. https://doi.org/10.1016/j.humov.2017.02.008

Gokeler, A., Welling, W., Zaffagnini, S., Seil, R., & Padua, D. (2017). Development of a test battery to enhance safe return to sports after anterior cruciate ligament reconstruction. Knee Surgery, Sports Traumatology, Arthroscopy, 25(1), 192–199. https://doi.org/10.1007/s00167-016-4246-3

Gonzalo-Skok, O., Moreno-Azze, A., Arjol-Serrano, J. L., Tous-Fajardo, J., & Bishop, C. (2019). A Comparison of 3 Different Unilateral Strength Training Strategies to Enhance Jumping Performance and Decrease Interlimb Asymmetries in Soccer Players. International Journal of Sports Physiology and Performance, 14(9), 1256–1264. https://doi.org/10.1123/ijspp.2018-0920

Granata, K. P., & Gottipati, P. (2008). Fatigue influences the dynamic stability of the torso. Ergonomics, 51(8), 1258–1271. https://doi.org/10.1080/00140130802030722

Gray, J., Aginsky, K. D., Derman, W., Vaughan, C. L., & Hodges, P. W. (2016). Symmetry, not asymmetry, of abdominal muscle morphology is associated with low back pain in cricket fast bowlers. Journal of Science and Medicine in Sport, 19(3), 222–226. https://doi.org/10.1016/j.jsams.2015.04.009

Gregory, J. E., Morgan, D. L., & Proske, U. (2004). Response of muscle spindles following a series of contractions. Experimental Brain Research, 157(2), 234–240. https://doi.org/10.1007/s00221-004-1838-9

Grenier, S. G., & McGill, S. M. (2007). Quantification of Lumbar Stability by Using 2 Different Abdominal Activation Strategies. Archives of Physical Medicine and Rehabilitation, 88(1), 54–62. https://doi.org/10.1016/j.apmr.2006.10.014

Gueugnon, M., Torre, K., Mottet, D., & Bonnetblanc, F. (2014). Asymmetries of bilateral isometric force matching with movement intention and unilateral fatigue. Experimental Brain Research, 232(6), 1699–1706. https://doi.org/10.1007/s00221-014-3862-8

Hackett, D. A., Selvanayagam, V. S., Halaki, M., & Cobley, S. P. (2019). Associations between Perceptual Fatigue and Accuracy of Estimated Repetitions to Failure during Resistance Exercises. Journal of Functional Morphology and Kinesiology, 4(3), 56. https://doi.org/10.3390/jfmk4030056

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. Sports Medicine (Auckland, N.Z.), 44 Suppl 2, S139-47. https://doi.org/10.1007/s40279-014-0253-z

Hara, M., Shibayama, A., Takeshita, D., Hay, D. C., & Fukashiro, S. (2008). A comparison of the mechanical effect of arm swing and countermovement on the lower extremities in vertical jumping. Human Movement Science, 27(4), 636–648. https://doi.org/10.1016/j.humov.2008.04.001

Hargreaves, M. (2008). Fatigue mechanisms determining exercise performance: Integrative physiology is systems biology. Journal of Applied Physiology, 104(5), 1541–1542. https://doi.org/10.1152/japplphysiol.00088.2008

Hart, L. M., Cohen, D. D., Patterson, S. D., Springham, M., Reynolds, J., & Read, P. (2019). Previous injury is associated with heightened countermovement jump force-time asymmetries in professional soccer players. Translational Sports Medicine, 2(5), 256–262. https://doi.org/10.1002/tsm2.92

Hart, N. H., Nimphius, S., Weber, J., Spiteri, T., Rantalainen, T., Dobbin, M., & Newton, R. U. (2016). Musculoskeletal Asymmetry in Football Athletes: A Product of Limb Function over Time. Medicine and Science in Sports and Exercise (Vol. 48). https://doi.org/10.1249/MSS.0000000000000897

Heishman, A. D., Curtis, M. A., Saliba, E. N., Hornett, R. J., Malin, S. K., & Weltman, A. L. (2017). Comparing Performance During Morning vs. Afternoon Training Sessions in Intercollegiate Basketball Players. Journal of Strength and Conditioning Research, 31(6), 1557–1562. https://doi.org/10.1519/JSC.0000000000001882

Heishman, A. D., Curtis, M. A., Saliba, E., Hornett, R. J., Malin, S. K., & Weltman, A. L. (2018). Noninvasive Assessment of Internal and External Player Load: Implications for Optimizing Athletic Performance. Journal of Strength and Conditioning Research, 32(5), 1280–1287. https://doi.org/10.1519/JSC.0000000000002413

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., & Bemben, M. G. (2018). Longitudinal Hydration Assessment in Collegiate Basketball Players Over Various

Training Phases. Journal of Strength and Conditioning Research, (September), 1. https://doi.org/10.1519/jsc.0000000000002845

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., Frantz, B. A., & Bemben, M. G. (2018). Countermovement Jump Reliability Performed With and Without an Arm Swing in NCAA Division 1 Intercollegiate Basketball Players. Journal of Strength and Conditioning Research, (August), 1. https://doi.org/10.1519/JSC.0000000000002812

Heishman, A., Brown, B., Daub, B., Miller, R., Freitas, E., & Bemben, M. (2019). The Influence of Countermovement Jump Protocol on Reactive Strength Index Modified and Flight Time: Contraction Time in Collegiate Basketball Players. Sports, 7(2), 37. https://doi.org/10.3390/sports7020037

Heishman, A., Daub, B., Miller, R., Brown, B., Freitas, E., & Bemben, M. (2019). Countermovement Jump Inter-Limb Asymmetries in Collegiate Basketball Players. Sports, 7(5), 103. https://doi.org/10.3390/sports7050103

Hewit, J. K., Cronin, J. B., & Hume, P. A. (2012). Asymmetry in multi-directional jumping tasks. Physical Therapy in Sport, 13(4), 238–242. https://doi.org/10.1016/j.ptsp.2011.12.003

Hickey, K. C., Quatman, C. E., Myer, G. D., Ford, K. R., Brosky, J. A., & Hewett, T. E. (2009). Methodological report: dynamic field tests used in an NFL combine setting to identify lower-extremity functional asymmetries. Journal of Strength and Conditioning Research, 23(9), 2500–2506. https://doi.org/10.1519/JSC.0b013e3181b1f77b

Hodges, S. J., Patrick, R. J., & Reiser, R. F. (2011). Effects of fatigue on bilateral ground reaction force asymmetries during the squat exercise. Journal of Strength and Conditioning Research, 25(11), 3107–3117. https://doi.org/10.1519/JSC.0b013e318212de7b

Hoffman, J. R., Ratamess, N. A., Klatt, M., Faigenbaum, A. D., & Kang, J. (2007). Do bilateral power deficits influence direction-specific movement patterns? Research in Sports Medicine, 15(2), 125–132. https://doi.org/10.1080/15438620701405313

Hopper, D. M., Goh, S. C., Wentworth, L. A., Chan, D. Y. K., Chau, J. H. W., Wootton, G. J., … Boyle, J. J. W. (2002). Test-retest reliability of knee rating scales and functional hop tests one year following anterior cruciate ligament reconstruction. Physical Therapy in Sport, 3(1), 10–18. https://doi.org/10.1054/ptsp.2001.0094

Hori, N., Newton, R. U., Kawamori, N., McGuigan, M. R., Kraemer, W. J., & Nosaka, K. (2009). Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. Journal of Strength and Conditioning Research, 23(3), 874–882. https://doi.org/10.1519/JSC.0b013e3181a00ca2

Impellizzeri, F. M., Rampinini, E., Maffiuletti, N., & Marcora, S. M. (2007). A vertical jump force test for assessing bilateral strength asymmetry in athletes. Medicine and Science in Sports and Exercise, 39(11), 2044–2050. https://doi.org/10.1249/mss.0b013e31814fb55c

Ireland, M. L. (1999). Anterior cruciate ligament injury in female athletes: epidemiology. Journal of Athletic Training, 34(2), 150–154. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16558558%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC1322904

Iwanska, D., Tabor, P., Polak, E., Karczewska, M., Madej, A., Mastalerz, A., & Urbanik, C. (2016). Symmetry during the take-off phase of countermovement jump in fencers. Revista de Artes Marciales Asiáticas, 11(2s), 26. https://doi.org/10.18002/rama.v11i2s.4155

Jones, A. M., Vanhatalo, A., Burnley, M., Morton, R. H., & Poole, D. C. (2010). Critical power: Implications for determination of ⊙ O2max and exercise tolerance. Medicine and Science in Sports and Exercise, 42(10), 1876–1890. https://doi.org/10.1249/MSS.0b013e3181d9cf7f

Jones, D. A. (1996). High- and low-frequency fatigue revisited. Acta Physiologica Scandinavica, 156(3), 265–270. https://doi.org/10.1046/j.1365-201X.1996.192000.x

Jordan, M. J., Aagaard, P., & Herzog, W. (2015). Lower limb asymmetry in mechanical muscle function: A comparison between ski racers with and without ACL reconstruction. Scandinavian Journal of Medicine and Science in Sports, 25(3), e301–e309. https://doi.org/10.1111/sms.12314

Kavanaugh, A. A., Mizuguchi, S., Sands, W. A., Ramsey, M. W., & Stone, M. H. (2018). Long-Term Changes in Jump Performance and Maximum Strength in a Cohort of National Collegiate Athletic Association Division I Women's Volleyball Athletes. Journal of Strength and Conditioning Research, 32(1), 66–75. https://doi.org/10.1519/JSC.0000000000002214

Keeton, R. B., & Binder-macleod, S. A. (2006). Low-Frequency Fatigue, 86(8), 1146–1150.

Kent-Braun, J. A., Ng, A. V., Doyle, J. W., & Towse, T. F. (2002). Human skeletal muscle responses vary with age and gender during fatigue due to incremental isometric exercise. Journal of Applied Physiology, 93(5), 1813–1823. https://doi.org/10.1152/japplphysiol.00091.2002

Klavora, P. (2000). Vertical-jump Tests : A Critical Review, 22(5).

Knapik, J. J., Bauman, C. L., Jones, B. H., Harris, J. M., & Vaughan, L. (1991). Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. The American Journal of Sports Medicine, 19(1), 76–81. https://doi.org/10.1177/036354659101900113

Kobayashi, Y., Kubo, J., Matsubayashi, T., Matsuo, A., Kobayashi, K., & Ishii, N. (2013). Relationship between bilateral differences in single-leg jumps and asymmetry in isokinetic knee strength. Journal of Applied Biomechanics, 29(1), 61–67. https://doi.org/10.1123/jab.29.1.61

Koh, H. W., Cho, S. H., & Kim, C. Y. (2014). Comparison of the effects of hollowing and bracing exercises on cross-sectional areas of abdominal muscles in middle-aged women. Journal of Physical Therapy Science, 26(2), 295–299. https://doi.org/10.1589/jpts.26.295

Komi, P. V. (2000). Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. Journal of Biomechanics, 33(10), 1197–1206. https://doi.org/10.1016/S0021-9290(00)00064-6

Kraemer, Wi. J. K. (n.d.). Strength Training : Development and Evaluation of Methodology.

Kuenze, C. M., Hertel, J., Weltman, A., Diduch, D., Saliba, S. A., & Hart, J. M. (2015). Persistent neuromuscular and corticomotor quadriceps asymmetry after anterior cruciate ligament reconstruction. Journal of Athletic Training, 50(3), 303–312. https://doi.org/10.4085/1062-6050-49.5.06

Kujala, U. M., Friberg, O., Aalto, T., Kvist, M., & Osterman, K. (1987). Lower limb asymmetry and patellofemoral joint incongruence in the etiology of knee exertion injuries in athletes. International Journal of Sports Medicine, 8(3), 214–220. https://doi.org/10.1055/s-2008-1025658

Kuki, S., Konishi, Y., Okudaira, M., Yoshida, T., Exell, T., & Tanigawa, S. (2019). Asymmetry of force generation and neuromuscular activity during multi-joint isometric exercise. The

Journal of Physical Fitness and Sports Medicine, 8(1), 37–44. https://doi.org/10.7600/jpfsm.8.37

Kyritsis, P., Bahr, R., Landreau, P., Miladi, R., & Witvrouw, E. (2016). Likelihood of ACL graft rupture: Not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. British Journal of Sports Medicine, 50(15), 946–951. https://doi.org/10.1136/bjsports-2015-095908

Laffaye, G., Bardy, B., & Taiar, R. (2006). Upper-limb motion and drop jump: Effect of expertise. Journal of Sports Medicine and Physical Fitness, 46(2), 238–247.

Laffaye, G., Wagner, P. P., & Tombleson, T. I. L. (2014). Countermovement jump height: gender and sport-specific differences in the force-time variables. Journal of Strength and Conditioning Research, 28(4), 1096–1105. https://doi.org/10.1519/JSC.0b013e3182a1db03

Lake, J. P., Mundy, P. D., Comfort, P., & Suchomel, T. J. (2018). Do the peak and mean force methods of assessing vertical jump force asymmetry agree? Sports Biomechanics, 1–8. https://doi.org/10.1080/14763141.2018.1465116

Lake, J., & McMahon, J. (2018). Within-Subject Consistency of Unimodal and Bimodal Force Application during the Countermovement Jump. Sports, 6(4), 143. https://doi.org/10.3390/sports6040143

LaStayo, P. C., Woolf, J. M., Lewek, M. D., Snyder-Mackler, L., Reich, T., & Lindstedt, S. L. (2003). Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. The Journal of Orthopaedic and Sports Physical Therapy, 33(10), 557–571. https://doi.org/10.2519/jospt.2003.33.10.557

Lattier, G., Millet, C. Y., Martin, A., & Martin, V. (2004). Fatigue and recovery after high-intensity exercise part I: Neuromuscular fatigue. International Journal of Sports Medicine, 25(6), 450–456. https://doi.org/10.1055/s-2004-820939

Lawson, B. R., Stephens, T. M., DeVoe, D. E., & Reiser, R. F. (2006). Lower-extremity bilateral differences during step-close and no-step countermovement jumps with concern for gender. Journal of Strength and Conditioning Research, 20(3), 608–619. https://doi.org/10.1519/R-18265.1

Lees, A., Vanrenterghem, J., & Clercq, D. De. (2004). Understanding how an arm swing enhances performance in the vertical jump. Journal of Biomechanics, 37(12), 1929–1940. https://doi.org/10.1016/j.jbiomech.2004.02.021

Leister, I., Kulnik, S. T., Kindermann, H., Ortmaier, R., Barthofer, J., Vasvary, I., … Mattiassich, G. (2019). Functional performance testing and return to sport criteria in patients after anterior cruciate ligament injury 12–18 months after index surgery: A cross-sectional observational study. Physical Therapy in Sport, 37, 1–9. https://doi.org/10.1016/j.ptsp.2019.01.010

Lonergan, B., Senington, B., Patterson, S. D., & Price, P. (2018). The effect of fatigue on phase specific countermovement jump asymmetries in ACL-R and non-injured rugby union players. Translational Sports Medicine, 1(6), 238–249. https://doi.org/10.1002/tsm2.48

Loturco, I., Pereira, L. A., Kobal, R., Abad, C. C. C., Rosseti, M., Carpes, F. P., & Bishop, C. (2019). Do asymmetry scores influence speed and power performance in elite female soccer players? Biology of Sport, 36(3), 209–216. https://doi.org/10.5114/biolsport.2019.85454

Lynch, A. D., Logerstedt, D. S., Grindem, H., Eitzen, I., Hicks, G. E., Axe, M. J., … Snyder-MacKler, L. (2015). Consensus criteria for defining "successful outcome" after ACL injury and reconstruction: A Delaware-Oslo ACL cohort investigation. British Journal of Sports Medicine, 49(5), 335–342. https://doi.org/10.1136/bjsports-2013-092299

Macintosh, B. R., & Rassier, D. E. (2002). What Is Fatigue? Canadian Journal of Applied Physiology, 27(1), 42–55. https://doi.org/10.1139/h02-003

Madruga-Parera, M., Bishop, C., Fort-Vanmeerhaeghe, A., Beltran-Valls, M. R., Skok, O. G., & Romero-Rodríguez, D. (2019). Interlimb Asymmetries in Youth Tennis Players. Journal of Strength and Conditioning Research, (12), 1. https://doi.org/10.1519/jsc.0000000000003152

Madruga-Parera, M., Bishop, C., Read, P., Lake, J., Brazier, J., & Romero-Rodriguez, D. (n.d.). Jumping-based Asymmetries are Negatively Associated with Jump , Change of Direction , and Repeated Sprint Performance , but not Linear Speed , in Adolescent Handball Athletes, 1.

Madruga-Parera, M., Romero-Rodríguez, D., Bishop, C., Beltran-Valls, M. R., Latinjak, A. T., Beato, M., & Fort-Vanmeerhaeghe, A. (2019). Effects of Maturation on Lower Limb

Neuromuscular Asymmetries in Elite Youth Tennis Players. Sports, 7(5), 106. https://doi.org/10.3390/sports7050106

Maestroni, L., Read, P., Bishop, C., & Turner, A. (2019). Strength and Power Training in Rehabilitation: Underpinning Principles and Practical Strategies to Return Athletes to High Performance. Sports Medicine, (0123456789). https://doi.org/10.1007/s40279-019-01195-6

Maloney, S. J. (2019). The Relationship Between Asymmetry and Athletic Performance: A Critical Review. Journal of Strength and Conditioning Research, 33(9), 2579–2593. https://doi.org/10.1519/JSC.0000000000002608

Maloney, S. J., Fletcher, I. M., & Richards, J. (2016). A comparison of methods to determine bilateral asymmetries in vertical leg stiffness. Journal of Sports Sciences, 34(9), 829–835. https://doi.org/10.1080/02640414.2015.1075055

Maloney, S. J., Richards, J., Nixon, D. G. D., Harvey, L. J., & Fletcher, I. M. (2017). Do stiffness and asymmetries predict change of direction performance? Journal of Sports Sciences, 35(6), 547–556. https://doi.org/10.1080/02640414.2016.1179775

Maloney, S. J., Richards, J., Nixon, D. G. D., Harvey, L. J., & Fletcher, I. M. (2017). Vertical stiffness asymmetries during drop jumping are related to ankle stiffness asymmetries. Scandinavian Journal of Medicine and Science in Sports, 27(6), 661–669. https://doi.org/10.1111/sms.12682

Maly, T., Sugimoto, D., Izovska, J., Zahalka, F., & Mala, L. (2018). Effect of Muscular Strength, Asymmetries and Fatigue on Kicking Performance in Soccer Players. International Journal of Sports Medicine, 39(4), 297–303. https://doi.org/10.1055/s-0043-123648

Mangine, G. T., Hoffman, J. R., Gonzalez, A. M., Jajtner, A. R., Scanlon, T., Rogowski, J. P., … Stout, J. R. (2014). Bilateral differences in muscle architecture and increased rate of injury in National Basketball Association players. Journal of Athletic Training, 49(6), 794–799. https://doi.org/10.4085/1062-6050-49.3.60

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. Journal of Strength and Conditioning Research, 18(3), 551–555. https://doi.org/10.1519/1533-4287(2004)18<551:RAFVOS>2.0.CO;2

Martin, V., Millet, G. Y., Martin, A., Deley, G., & Lattier, G. (2004). Assessment of low-frequency fatigue with two methods of electrical stimulation. Journal of Applied Physiology, 97(5), 1923–1929. https://doi.org/10.1152/japplphysiol.00376.2004

Matinlauri, A., Alcaraz, P. E., Freitas, T. T., Mendiguchia, J., Abedin-Maghanaki, A., Castillo, A., … Cohen, D. D. (2019). A comparison of the isometric force fatigue-recovery profile in two posterior chain lower limb tests following simulated soccer competition. PLoS ONE, 14(5), 1–16. https://doi.org/10.1371/journal.pone.0206561

Maulder, P., & Cronin, J. (2005). Horizontal and vertical jump assessment: Reliability, symmetry, discriminative and predictive ability. Physical Therapy in Sport, 6(2), 74–82. https://doi.org/10.1016/j.ptsp.2005.01.001

McCubbine, J., Turner, A., Dos Santos, T., & Bishop, C. (2018). Reliability and measurement of inter-limb asymmetries in four unilateral jump tests in elite youth female soccer players. Professional Strength & Conditioning , (49), 7–12.

McElveen, M. T., Riemann, B. L., & Davies, G. J. (2010). Bilateral comparison of propulsion mechanics during single-leg vertical jumping. Journal of Strength and Conditioning Research, 24(2), 375–381. https://doi.org/10.1519/JSC.0b013e3181c06e0b

McLean, B. D., Coutts, A. J., Kelly, V., McGuigan, M. R., & Cormack, S. J. (2010). Neuromuscular, Endocrine, and Perceptual Fatigue Responses During Different Length Between-Match Microcycles in Professional Rugby League Players. International Journal of Sports Physiology and Performance, 5(3), 367–383. https://doi.org/10.1123/ijspp.5.3.367

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). The role of rate of force development on vertical jump performance. Journal of Strength and Conditioning Research, 25(2), 379–385. https://doi.org/10.1519/JSC.0b013e3181be305c

McMahon, J. J., Murphy, S., Rej, S. J. E., & Comfort, P. (2017). Countermovement-Jump-Phase Characteristics of Senior and Academy Rugby League Players. International Journal of Sports Physiology and Performance, 12(6), 803–811. https://doi.org/10.1123/ijspp.2016-0467

McMahon, J. J., Suchomel, T. J., Lake, J. P., & Comfort, P. (2018). Understanding the key phases of the countermovement jump force-time curve. Strength and Conditioning Journal, 40(4), 96–106. https://doi.org/10.1519/SSC.0000000000000375

McMahon, J., Lake, J., & Comfort, P. (2018). Reliability of and Relationship between Flight Time to Contraction Time Ratio and Reactive Strength Index Modified. Sports, 6(3), 81. https://doi.org/10.3390/sports6030081

Menzel, H.-J., Chagas, M. H., Szmuchrowski, L. A., Araujo, S. R. S., de Andrade, A. G. P., & de Jesus-Moraleida, F. R. (2013). Analysis of lower limb asymmetries by isokinetic and vertical jump tests in soccer players. Journal of Strength and Conditioning Research, 27(5), 1370–1377. https://doi.org/10.1519/JSC.0b013e318265a3c8

Meylan, C., McMaster, T., Cronin, J., Mohammad, N. I., Rogers, C., & Deklerk, M. (2009). Single-leg lateral, horizontal, and vertical jump assessment: reliability, interrelationships, and ability to predict sprint and change-of-direction performance. Journal of Strength and Conditioning Research, 23(4), 1140–1147. https://doi.org/10.1519/JSC.0b013e318190f9c2

Miles, J. J., King, E., Falvey, É. C., & Daniels, K. A. J. (2019). Patellar and hamstring autografts are associated with different jump task loading asymmetries after ACL reconstruction. Scandinavian Journal of Medicine and Science in Sports, 29(8), 1212–1222. https://doi.org/10.1111/sms.13441

Miyachi, M. (2013). Effects of resistance training on arterial stiffness : a meta-analysis, 393–396. https://doi.org/10.1136/bjsports-2012-090488

Mokha, M., Sprague, P. A., & Gatens, D. R. (2016). Predicting musculoskeletal injury in national collegiate athletic association division II athletes from asymmetries and individual-Test versus composite functional movement screen scores. Journal of Athletic Training, 51(4), 276–282. https://doi.org/10.4085/1062-6050-51.2.07

Moresi, M., Bradshaw, E. J., Thomas, K., Greene, D., & Braybon, W. (2013). Intra-Limb Variability and Inter-Limb Asymmetry in Gymnastics Jump Tests. ISBS - Conference Proceedings Archive, 1(1). Retrieved from https://ojs.ub.uni-konstanz.de/cpa/article/view/5592%5Cnhttps://ojs.ub.uni-konstanz.de/cpa/article/download/5592/5086

Morin, J. B., Samozino, P., Edouard, P., & Tomazin, K. (2011). Effect of fatigue on force production and force application technique during repeated sprints. Journal of Biomechanics, 44(15), 2719–2723. https://doi.org/10.1016/j.jbiomech.2011.07.020

Morin, J. B., Slawinski, J., Dorel, S., de villareal, E. S., Couturier, A., Samozino, P., … Rabita, G. (2015). Acceleration capability in elite sprinters and ground impulse: Push more, brake less? Journal of Biomechanics, 48(12), 3149–3154. https://doi.org/10.1016/j.jbiomech.2015.07.009

Moya-Angeler, J., Vaquero, J., & Forriol, F. (2017). Evaluation of lower limb kinetics during gait, sprint and hop tests before and after anterior cruciate ligament reconstruction. Journal of Orthopaedics and Traumatology, 18(2), 177–184. https://doi.org/10.1007/s10195-017-0456-9

Myer, G. D., Ford, K. R., & Hewett, T. E. (2004). Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. Journal of Athletic Training, 39(4), 352–364.

Neupert, E. C., Cotterill, S. T., & Jobson, S. A. (2019). Training-Monitoring Engagement: An Evidence-Based Approach in Elite Sport. International Journal of Sports Physiology and Performance, 14(1), 99–104. https://doi.org/10.1123/ijspp.2018-0098

Newton, R. U., Gerber, A., Nimphius, S., Shim, J. K., Doan, B. K., Robertson, M., … Kraemer, W. J. (2006). Determination of functional strength imbalance of the lower extremities. Journal of Strength and Conditioning Research, 20(4), 971–977. https://doi.org/10.1519/R-5050501x.1

Opar, D. A., Williams, M. D., & Shield, A. J. (2012). Hamstring strain injuries: Factors that Lead to injury and re-Injury. Sports Medicine, 42(3), 209–226. https://doi.org/10.2165/11594800-000000000-00000

Opar, D. A., Williams, M. D., Timmins, R. G., Hickey, J., Duhig, S. J., & Shield, A. J. (2015). Eccentric Hamstring Strength and Hamstring Injury Risk in Australian Footballers. Medicine & Science in Sports & Exercise, 47(4), 857–865. https://doi.org/10.1249/MSS.0000000000000465

Pappas, E., & Carpes, F. P. (2012). Lower extremity kinematic asymmetry in male and female athletes performing jump-landing tasks. Journal of Science and Medicine in Sport, 15(1), 87–92. https://doi.org/10.1016/j.jsams.2011.07.008

Parrish, L. W., Valliant, M. W., Knight, K., & Bass, M. A. (2018). Impact of Hydration on Physiological Parameters in Collegiate Football Athletes, 2(1), 14–19.

Paterno, M. V., Ford, K. R., Myer, G. D., Heyl, R., & Hewett, T. E. (2007). Limb asymmetries in landing and jumping 2 years following anterior cruciate ligament reconstruction. Clinical Journal of Sport Medicine, 17(4), 258–262. https://doi.org/10.1097/JSM.0b013e31804c77ea

Patterson, C., Raschner, C., & Platzer, H.-P. (2009). Power variables and bilateral force differences during unloaded and loaded squat jumps in high performance alpine ski racers. Journal of Strength and Conditioning Research, 23(3), 779–787. https://doi.org/10.1519/JSC.0b013e3181a2d7b3

Patterson, C., Raschner, C., & Platzer, H.-P. (2009). Power variables and bilateral force differences during unloaded and loaded squat jumps in high performance alpine ski racers. Journal of Strength and Conditioning Research, 23(3), 779–787. https://doi.org/10.1519/JSC.0b013e3181a2d7b3

Pechar, G. S., McArdle, W. D., Katch, F. I., Magel, J. R., & DeLuca, J. (1974). Specificity of cardiorespiratory adaptation to bicycle and treadmill training. Journal of Applied Physiology, 36(6), 753–756. https://doi.org/10.1152/jappl.1974.36.6.753

Perttunen, J. R., Anttila, E., Södergård, J., Merikanto, J., & Komi, P. V. (2004). Gait asymmetry in patients with limb length discrepancy. Scandinavian Journal of Medicine and Science in Sports, 14(1), 49–56. https://doi.org/10.1111/j.1600-0838.2003.00307.x

Peterson, K. D., & Quiggle, G. T. (2017). Tensiomyographical responses to accelerometer loads in female collegiate basketball players. Journal of Sports Sciences, 35(23), 2334–2341. https://doi.org/10.1080/02640414.2016.1266378

Pinto, B. L., & McGill, S. M. (2019). Voluntary Muscle Relaxation Can Mitigate Fatigue and Improve Countermovement Jump Performance. Journal of Strength and Conditioning Research, 1. https://doi.org/10.1519/jsc.0000000000003326

Pitkänen, H. T., Nykänen, T., Knuutinen, J., Lahti, K., Keinänen, O., Alen, M., … Mero, A. A. (2003). Free amino acid pool and muscle protein balance after resistance exercise. Medicine and Science in Sports and Exercise, 35(5), 784–792. https://doi.org/10.1249/01.MSS.0000064934.51751.F9

Place, N., & Millet, G. Y. (2019). Quantification of Neuromuscular Fatigue: What Do We Do Wrong and Why? Sports Medicine, (0123456789). https://doi.org/10.1007/s40279-019-01203-9

Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star excursion balance test as a predictor of lower extremity injury in high school basketball players. Journal of Orthopaedic and Sports Physical Therapy, 36(12), 911–919. https://doi.org/10.2519/jospt.2006.2244

Ransdell, L. B., Murray, T., Gao, Y., Jones, P., & Bycura, D. (2019). A 4-Year Profile of Game Demands in Elite Women's Division I College Basketball. Journal of Strength and Conditioning Research, (February), 1. https://doi.org/10.1519/jsc.0000000000003425

Read, P. J., Oliver, J. L., De Ste Croix, M. B. A., Myer, G. D., & Lloyd, R. S. (2019). A Review of Field-Based Assessments of Neuromuscular Control and Their Utility in Male Youth Soccer Players. Journal of Strength and Conditioning Research, 33(1), 283–299. https://doi.org/10.1519/JSC.0000000000002069

Read, P. J., Oliver, J. L., Myer, G. D., De Ste Croix, M. B. A., & Lloyd, R. S. (2018). The Effects of Maturation on Measures of Asymmetry During Neuromuscular Control Tests in Elite Male Youth Soccer Players. Pediatric Exercise Science, 30(1), 168–175. https://doi.org/10.1123/pes.2017-0081

Reilly, T., Drust, B., & Clarke, N. (2008). Muscle fatigue during football match-play - Reilly Sports Med 2008.pdf. Sports Medicine, 38(5), 357–367.

Rohman, E., Steubs, J. T., & Tompkins, M. (2015). Changes in Involved and Uninvolved Limb Function During Rehabilitation After Anterior Cruciate Ligament Reconstruction: Implications for Limb Symmetry Index Measures. American Journal of Sports Medicine, 43(6), 1391–1398. https://doi.org/10.1177/0363546515576127

Ross, E. Z., Middleton, N., Shave, R., George, K., & Nowicky, A. (2007). Corticomotor excitability contributes to neuromuscular fatigue following marathon running in man. Experimental Physiology, 92(2), 417–426. https://doi.org/10.1113/expphysiol.2006.035972

Rowell, A. E., Aughey, R. J., Hopkins, W. G., Stewart, A. M., & Cormack, S. J. (2017). Identification of Sensitive Measures of Recovery After External Load From Football Match Play. International Journal of Sports Physiology and Performance, 12(7), 969–976.

Sainburg, R. L., Schaefer, S. Y., & Yadav, V. (2016). Lateralized motor control processes determine asymmetry of interlimb transfer. Neuroscience, 334(August), 26–38. https://doi.org/10.1016/j.neuroscience.2016.07.043

Samozino, P., Morin, J. B., Hintzy, F., & Belli, A. (2010). Jumping ability: A theoretical integrative approach. Journal of Theoretical Biology, 264(1), 11–18. https://doi.org/10.1016/j.jtbi.2010.01.021

Scanlan, A., Dascombe, B., & Reaburn, P. (2011). A comparison of the activity demands of elite and sub-elite Australian men's basketball competition. Journal of Sports Sciences, 29(11), 1153–1160. https://doi.org/10.1080/02640414.2011.582509

Schiltz, M., Lehance, C., Maquet, D., Bury, T., Crielaard, J. M., & Croisier, J. L. (2009). Explosive strength imbalances in professional basketball players. Journal of Athletic Training, 44(1), 39–47. https://doi.org/10.4085/1062-6050-44.1.39

Shei, R. J., & Mickleborough, T. D. (2013). Relative contributions of central and peripheral factors in human muscle fatigue during exercise: A brief review. Journal of Exercise Physiology Online, 16(6), 1–17.

Sheppard, J. M., Cormack, S., Taylor, K.-L., McGuigan, M. R., & Newton, R. U. (2008). Assessing the force-velocity characteristics of the leg extensors in well-trained athletes: the incremental load power profile. Journal of Strength and Conditioning Research, 22(4), 1320–1326. https://doi.org/10.1519/JSC.0b013e31816d671b

Simon, A. M., & Ferris, D. P. (2008). Lower limb force production and bilateral force asymmetries are based on sense of effort. Experimental Brain Research, 187(1), 129–138. https://doi.org/10.1007/s00221-008-1288-x

Slinde, F., Suber, C., Suber, L., Edwén, C. E., & Svantesson, U. (2008). Test-retest reliability of three different countermovement jumping tests. Journal of Strength and Conditioning Research, 22(2), 640–644. https://doi.org/10.1519/JSC.0b013e3181660475

Spiteri, T., Binetti, M., Scanlan, A. T., Dalbo, V. J., Dolci, F., & Specos, C. (2019). Physical Determinants of Division 1 Collegiate Basketball, Women's National Basketball League, and Women's National Basketball Association Athletes. Journal of Strength and Conditioning Research, 33(1), 159–166. https://doi.org/10.1519/JSC.0000000000001905

Spiteri, T., Nimphius, S., Wolski, A., & Bird, S. (2013). Monitoring Neuromuscular Fatigue in Female Basketball Players Across Training and Game Performance, 21(Figure 2), 73–74.

Stephens, T. M., Lawson, B. R., DeVoe, D. E., & Reiser, R. F. (2007). Gender and bilateral differences in single-leg countermovement jump performance with comparison to a double-leg jump. Journal of Applied Biomechanics, 23(3), 190–202. https://doi.org/10.1123/jab.23.3.190

Strojnik, V., & Komi, P. V. (2000). Fatigue after submaximal intensive stretch-shortening cycle exercise. Medicine and Science in Sports and Exercise, 32(7), 1314–1319. https://doi.org/10.1097/00005768-200007000-00020

Suchomel, T. J., Sato, K., DeWeese, B. H., Ebben, W. P., & Stone, M. H. (2016). Relationships between potentiation effects after ballistic half-squats and bilateral symmetry. International Journal of Sports Physiology and Performance, 11(4), 448–454. https://doi.org/10.1123/ijspp.2015-0321

Suchomel, T. J., Sole, C. J., & Stone, M. H. (2016). Comparison of Methods That Assess Lower-body Stretch-Shortening Cycle Utilization. Journal of Strength and Conditioning Research, 30(2), 547–554. https://doi.org/10.1519/JSC.0000000000001100

Suchomel, T., & Stone, M. (2017). The Relationships between Hip and Knee Extensor Cross-Sectional Area, Strength, Power, and Potentiation Characteristics. Sports, 5(3), 66. https://doi.org/10.3390/sports5030066

Svilar, L., Castellano, J., & Jukic, I. (2018). Load monitoring system in top-level basketball team: Relationship between external and internal training load. Kinesiology, 50(1), 25–33. https://doi.org/10.26582/k.50.1.4

Thomas, T. D. C., Comfort, P., & Jones, P. A. (2018). Comparison of Change of Direction Speed Performance and Asymmetries between Team-Sport Athletes: Application of Change of Direction Deficit. Sports, 6(4), 174. https://doi.org/10.3390/sports6040174

Timoteo, T. F., Debien, P. B., Miloski, B., Werneck, F. Z., Gabbett, T., & Bara Filho, M. G. (2018). Influence of Workload and Recovery on Injuries in Elite Male Volleyball Players. Journal of Strength and Conditioning Research, (August), 1. https://doi.org/10.1519/jsc.0000000000002754

Van Iterson, E. H., Fitzgerald, J. S., Dietz, C. C., Snyder, E. M., & Peterson, B. J. (2017). Reliability of Triaxial Accelerometry for Measuring Load in Men's Collegiate Ice Hockey. Journal of Strength and Conditioning Research, 31(5), 1305–1312. https://doi.org/10.1519/JSC.0000000000001611

Vanrenterghem, J., Nedergaard, N. J., Robinson, M. A., & Drust, B. (2017). Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. Sports Medicine, 47(11), 2135–2142. https://doi.org/10.1007/s40279-017-0714-2

Vaverka, F., Jandačka, D., Zahradník, D., Uchytil, J., Farana, R., Supej, M., & Vodičar, J. (2016). Effect of an Arm Swing on Countermovement Vertical Jump Performance in Elite Volleyball Players: FINAL. Journal of Human Kinetics, 53(1), 41–50. https://doi.org/10.1515/hukin-2016-0009

Verschueren, J., Tassignon, B., De Pauw, K., Proost, M., Teugels, A., Van Cutsem, J., … Meeusen, R. (2019). Does Acute Fatigue Negatively Affect Intrinsic Risk Factors of the Lower Extremity Injury Risk Profile? A Systematic and Critical Review. Sports Medicine, (0123456789). https://doi.org/10.1007/s40279-019-01235-1

Vøllestad, N. K. (1997). Measurement of human muscle fatigue. Journal of Neuroscience Methods, 74(2), 219–227. https://doi.org/10.1016/S0165-0270(97)02251-6

Wackerhage, H., Schoenfeld, B. J., Hamilton, D. L., Lehti, M., & Hulmi, J. J. (2019). Stimuli and sensors that initiate skeletal muscle hypertrophy following resistance exercise. Journal of Applied Physiology, 126(1), 30–43. https://doi.org/10.1152/japplphysiol.00685.2018

Walsh, M. S., Böhm, H., Butterfield, M. M., & Santhosam, J. (2007). Gender BIAS in the effects of arms and countermovement on jumping performance. Journal of Strength and Conditioning Research, 21(2), 362–366. https://doi.org/10.1519/R-19825.1

Walsh, M. S., Ford, K. R., Bangen, K. J., Myer, G. D., & Hewett, T. E. (2006). The validation of a portable force plate for measuring force-time data during jumping and landing tasks. Journal of Strength and Conditioning Research, 20(4), 730–734. https://doi.org/10.1519/R-18225.1

Ward, P. A., Ramsden, S., Coutts, A. J., Hulton, A. T., & Drust, B. (2018). Positional Differences in Running and Nonrunning Activities During Elite American Football Training. Journal of Strength and Conditioning Research, 32(7), 2072–2084. https://doi.org/10.1519/JSC.0000000000002294

Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. Journal of Strength and Conditioning Research, 19(1), 231–240. https://doi.org/10.1519/15184.1

Williams, J. H., Batts, T. W., & Lees, S. (2013). Reduced Muscle Glycogen Differentially Affects Exercise Performance and Muscle Fatigue. ISRN Physiology, 2013, 1–8. https://doi.org/10.1155/2013/371235

Wilson, G. J., Lyttle, A. D., Ostrowski, K. J., & Murphy, A. J. (1995). Assessing Dynamic Performance: A Comparison of Rate of Force Development Tests. The Journal of Strength and Conditioning Research, 9(3), 176. https://doi.org/10.1519/1533-4287(1995)009<0176:ADPACO>2.3.CO;2

Yanci, J., & Camara, J. (2016). Bilateral and unilateral vertical ground reaction forces and leg asymmetries in soccer players. Biology of Sport, 33(2), 179–183. https://doi.org/10.5604/20831862.1198638

Young, W. B., Pryor, J. F., & Wilson, G. J. (1995). Effects of Instructions on Charicteristics of Countermovement and Drop Jump Performance. Journal of Strength and Conditioning Research, 9(4), 232–236. https://doi.org/10.1519/1533-4287(1995)009<0232

Young, W., Cormack, S., & Crichton, M. (2011). Which jump variables should be used to assess explosive leg muscle function? International Journal of Sports Physiology and Performance, 6(1), 51–57. https://doi.org/10.1123/ijspp.6.1.51

Zifchock, R. A., Davis, I., Higginson, J., & Royer, T. (2008). The symmetry angle: A novel, robust method of quantifying asymmetry. Gait and Posture, 27(4), 622–627. https://doi.org/10.1016/j.gaitpost.2007.08.006

Ziv, G., & Lidor, R. (2010). Vertical jump in female and male basketball players-A review of observational and experimental studies. Journal of Science and Medicine in Sport, 13(3), 332–339. https://doi.org/10.1016/j.jsams.2009.02.009

Appendices

Appendix A – Study Documents

701-A-1

CONSENT FORM
University of Oklahoma – Norman Campus

Acute Neuromuscular and Endocrine Responses following High and Low External Training Loads in Collegiate Basketball Players

Principal Investigator: Michael Bemben, PhD.
University of Oklahoma
405-325-2717

This is a research study. Research studies involve only individuals who choose to participate. Please take your time to make your decision. Discuss this with your family and friends.

Would you like to be involved in research at the University of Oklahoma?

I am Michael Bemben, PhD, from the Department of Health and Exercise Science and I invite you to participate in my research project entitled Acute Neuromuscular and Endocrine Responses following High and Low External Training Loads in Collegiate Basketball Players. This research is being conducted at The Lloyd Noble Center and Griffin Family Performance Center. You were selected as a possible participant because of your engagement in the varsity basketball program at the University of Oklahoma. You must be at least 18 years of age to participate in this study.

What is the purpose of this research? The purpose of this research is to examine time course of fatigue and recovery following different training loads during basketball practice.

How many participants will be in this research? About 40 collegiate basketball players, including 20 male collegiate basketball players and 20 female collegiate basketball players, between the ages of 18 and 26 will take part in this research.

What will I be asked to do? If you agree to participate in this research, you will partake in a total of 12 visits, divided into 2 parts, with *Part 1* consisting of 9 visits and *Part 2* consisting of 3 visits. Part 1 and Part 2 can be completed in any order as long as the order of subsequent visits in each part remains the same.

In ***Part 1***; Visit 1 will consist of a study protocol and testing familiarization, consent, privacy forms, and questionnaires including: Sport Health Status Questionnaire, Physical Activity Readiness Questionnaire (PAR-Q), and Menstrual History Questionnaire (women only) (approximately 60 minutes).

Part 1; Visit 2 will take place on a day of regularly scheduled team basketball practice and will include the following activities (approximately 150 minutes):

- *Pre-practice assessments:* Prior to the start of practice, you will provide a salivary sample, a urine sample for hydration assessment, and fill out a recovery questionnaire. Following a standardized warm-up, you will then perform 3 countermovement jumps on dual-cell force platform to assess neuromuscular performance.

- *During Practice:* You will participate in your regularly scheduled basketball practice of either high or low external load intensity, where you will be wearing your external training load monitor and heart rate monitor, throughout the duration of practice as you normally

OKLAHOMA
WOMEN'S BASKETBALL

3
FINAL FOURS

9
SWEET 16 APPEARANCES

19
CONSECUTIVE NCAA TOURNAMENT APPEARANCES

8
ASSOCIATED PRESS ALL-AMERICANS

1
ASSOCIATED PRESS PLAYER OF THE YEAR

10
BIG 12 CHAMPIONSHIPS

6
BIG 12 PLAYER OF THE YEAR

7
BIG 12 FRESHMAN OF THE YEAR

Institutional Support Letter

To the University of Oklahoma Institutional Review Board:

I am familiar and fully supportive of Dr. Mike Bemben's research project entitled "*Acute Neuromuscular and Endocrine Responses following High and Low External Training Loads in Collegiate Basketball Players*." I understand the involvement of Dr. Bemben and his research team's to be recruiting potential participants from our team, as well as using the Griffin Family Performance Center and Lloyd Noble Center Basketball Facilities to execute the testing protocol.

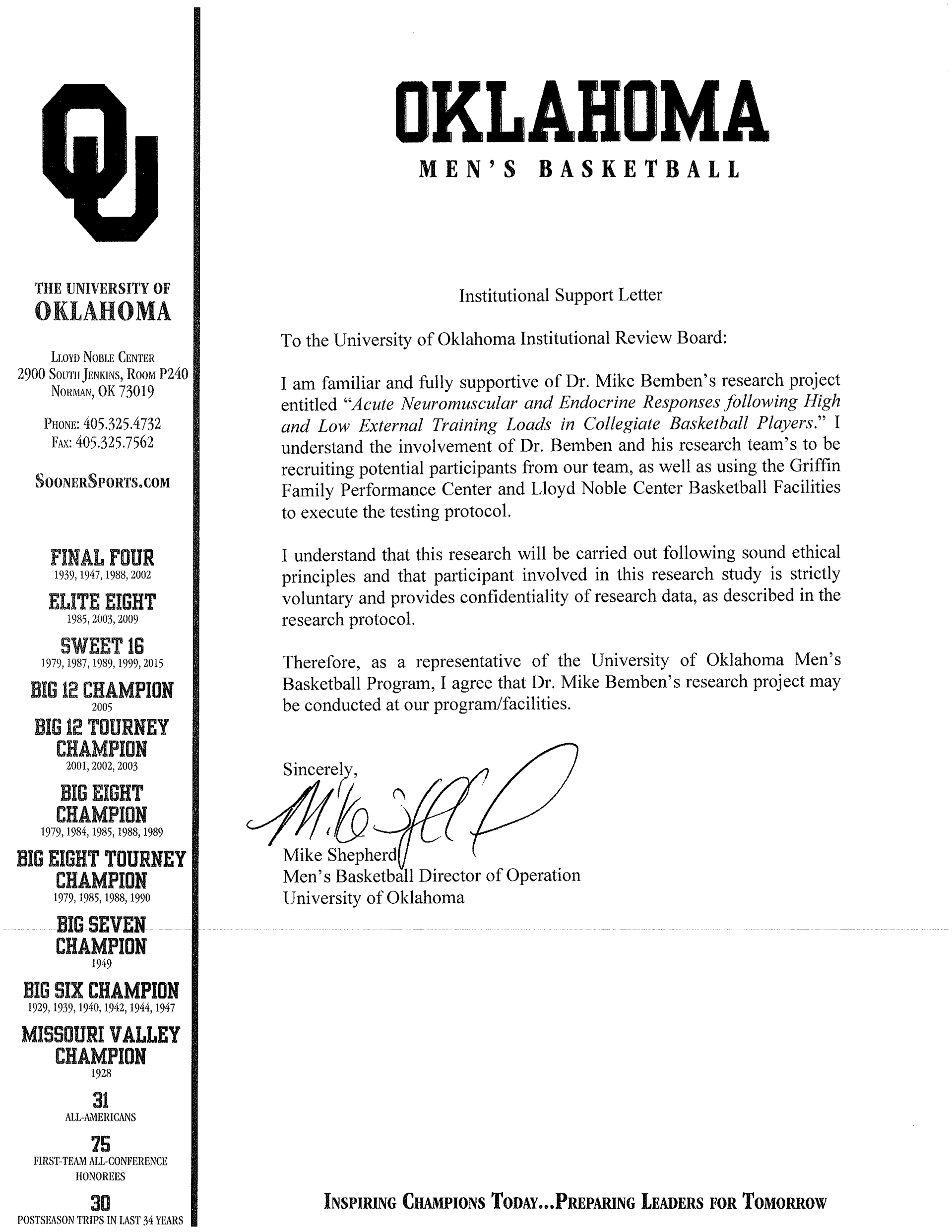
I understand that this research will be carried out following sound ethical principles and that participant involved in this research study is strictly voluntary and provides confidentiality of research data, as described in the research protocol.

Therefore, as a representative of the University of Oklahoma Women's Basketball Program, I agree that Dr. Mike Bemben's research project may be conducted at our program/facilities.

Sincerely,

Sherri Coale
Head Women's Basketball Coach
University of Oklahoma

THE UNIVERSITY OF OKLAHOMA | LLOYD NOBLE CENTER
2900 S. JENKINS | NORMAN, OK 73019
SOONERSPORTS.COM | @OU_WBBALL



OKLAHOMA

MEN'S BASKETBALL

THE UNIVERSITY OF
OKLAHOMA

Lloyd Noble Center
2900 South Jenkins, Room P240
Norman, OK 73019

Phone: 405.325.4732
Fax: 405.325.7562

SoonerSports.com

FINAL FOUR
1939, 1947, 1988, 2002

ELITE EIGHT
1985, 2003, 2009

SWEET 16
1979, 1987, 1989, 1999, 2015

BIG 12 CHAMPION
2005

BIG 12 TOURNEY CHAMPION
2001, 2002, 2003

BIG EIGHT CHAMPION
1979, 1984, 1985, 1988, 1989

BIG EIGHT TOURNEY CHAMPION
1979, 1985, 1988, 1990

BIG SEVEN CHAMPION
1949

BIG SIX CHAMPION
1929, 1939, 1940, 1942, 1944, 1947

MISSOURI VALLEY CHAMPION
1928

31
ALL-AMERICANS

75
FIRST-TEAM ALL-CONFERENCE HONOREES

30
POSTSEASON TRIPS IN LAST 34 YEARS

Institutional Support Letter

To the University of Oklahoma Institutional Review Board:

I am familiar and fully supportive of Dr. Mike Bemben's research project entitled "*Acute Neuromuscular and Endocrine Responses following High and Low External Training Loads in Collegiate Basketball Players*." I understand the involvement of Dr. Bemben and his research team's to be recruiting potential participants from our team, as well as using the Griffin Family Performance Center and Lloyd Noble Center Basketball Facilities to execute the testing protocol.

I understand that this research will be carried out following sound ethical principles and that participant involved in this research study is strictly voluntary and provides confidentiality of research data, as described in the research protocol.

Therefore, as a representative of the University of Oklahoma Men's Basketball Program, I agree that Dr. Mike Bemben's research project may be conducted at our program/facilities.

Sincerely,

Mike Shepherd
Men's Basketball Director of Operation
University of Oklahoma

INSPIRING CHAMPIONS TODAY...PREPARING LEADERS FOR TOMORROW

IRB APPROVED
IRB NUMBER: 10752
IRB APPROVAL DATE: 05/20/2019

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ____________________

SIGNATURE OF PARENT ____ WITNESS ____________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Supported by: Health Canada Santé Canada

continued on other side...

Appendix B – Questionnaires

Neuromuscular Research Laboratory
OU Department of Health and Exercise Science
Sport Specific Health Status Questionnaire

Instructions Complete each question accurately. All information provided is confidential.

PART 1. INFORMATION ABOUT INDIVIDUAL

1. ____
Date

2. ____
Legal name Preferred Name

3. ____
Mailing address

4. ____
Home Phone Cell Phone

5. Sex (circle one): Female Male

6. Year of birth: ___________________________ Age __________

7. What is your dominant foot? (What foot would you kick a soccer ball with?)

Right Foot Left Foot

PART 2. MEDICAL HISTORY

7. Date of last medical physical exam: ____________________
Year

8. Date of last physical fitness test: ____________________
Year

9. Circle operations you have had:

Back Heart Kidney Eyes Joint Neck

Ears Hernia Lung Other____________________________

NONE

10. Circle all medicine taken in last 6 months:

Asthma (list type) ____________________
High-blood-pressure medication (list type) __________________
Blood thinner
Corticosteroids
Depression
Diabetic pill
Digitalis
Diuretic
Epilepsy medication
Estrogen
Heart-rhythm medication
Insulin
Nitroglycerin
Thyroid
Other ______________________
NONE

Subject ID: _______________ Date: ____________________

Neuromuscular Research Laboratory
Department of Health and Exercise Science
University of Oklahoma

MENSTRUAL HISTORY QUESTIONNAIRE

We are asking you to give us as complete a menstrual history as possible. All information is strictly confidential.

Are you pregnant? (circle your response)
YES- Do not complete the rest of this form
NO- Continue to section A.

SECTION A: CURRENT MENSTRUAL STATUS

1. Approximately how many menstrual periods have you had during the past 12 months?
(please circle what months you have had a period. This means from this time last year to the present month)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

2. What is the usual length of your menstrual cycle (first day of your period to the next onset of your period)?

_____________days. Today is day ____________ of your present menstrual cycle.

3. What was the date of the onset of your last period?

4. When do you expect you next period?

5. What is the average length (number of days) of your menstrual flow? ________________ days

How many of these days do you consider "heavy"? __________________days

6. Do you experience cramps during menstruation (dysmenorrheal)? If yes, how many days does this last?

7. Do you experience symptoms of premenstrual syndrome (i.e., weight gain, increased eating, depression, headaches, anxiety, breast tenderness)? If yes, please list the symptoms.

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Participant ID: _______________ Date ____________

Recovery Questionnaire

Study Part: *Part 1 or Part 2*

Time Point: *Pre- 24-Hours Post 48-Hours Post 72- Hours Post*

1. How many hours of sleep did you get last night? __________ hours
2. How many hours did you participate in basketball or training outside of mandatory team activity (Playing, shooting, conditioning, etc.)? ___________ hours
3. In reference to Question 2: How strenuous was that exercise (1-10) ____________

	5	**4**	**3**	**2**	**1**	**Record Score**
Sleep Quality	Very restful	Good	Difficulty Falling Asleep	Restless Sleep	Insomnia	
Fatigue	Very Fresh	Fresh	Normal	More tired than normal	Always tired	
General Muscle Soreness	Feeling great	Feeling good	Norman	Increase in soreness/tightness	Very sore	
Stress Levels	Very Relaxed	Relaxed	Normal	Feeling Stressed	Highly Stressed	
Mood	Very positive mood	Generally good mood	Less interested in others&/or activities than usual	Snappiness at teammates, family, and co-workers	Highly annoyed/irritable/down	

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