THE EFFECTS OF VERTICAL JUMP FATIGUE AND SPRINT FATIGUE ON TOTAL-BODY BIOMECHANICS

By

Eric M. Mosier

Ph.D., 2018

M.S.E., University of Kansas, 2015

B.G.S., University of Kansas, 2012

Submitted to the graduate degree program in Health Sport and Exercise Science and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Exercise Physiology.

Chairperson Dr. Andrew C. Fry

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The Dissertation Defense Committee for Eric M. Mosier certifies

that this is the approved version of the following:

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ABSTRACT

The Effects of Vertical Jump Fatigue and Sprint Fatigue on Total-Body Biomechanics

Eric M. Mosier

The University of Kansas, 2018

Supervising Professor: Andrew C. Fry, Ph.D.

INTRODUCTION: Motion capture systems (MCS) can be used to assess an individual's upper-and lower-body motions, both explosive and functional in nature. Advancements in technology and screening protocols are capable of detecting acute biomechanical alterations of the lower-extremities following fatiguing tasks. **PURPOSE:** This study compared the kinetic and kinematic variables measured by a 3-dimesional video MCS to identify alterations in lower-extremity performance following VJ and sprint fatiguing tasks. **METHODS:** Eleven healthy, recreationally active women ($\bar{X}$±SD; age=20.8±1.1 yrs., hgt.=172.2±7.4 cm, wgt.=68.0±7.2 kg) and eleven men (age=23.0±2.6 yrs., hgt.=180.3±4.8 cm, wgt.=80.4±7.3 kg) volunteered for this investigation, and were screened using the Performance Motion Analysis (PMA) protocol, consisting of 19 motions. These include shoulder ranges of motions (i.e., shoulder abduction and adduction, horizonal abduction and adduction, internal and external rotation, flexion and extension). Also assessed were trunk rotation, bilateral overhead squat, unilateral squats, forward lunges, single leg balance, bilateral counter-movement vertical jump (CMVJ), unilateral CMVJs, concentric-only VJ, multiple unilateral CMVJs, and depth VJ. A three-dimensional markerless MCS (DARI Motion, Scientific Analytics, Lincoln, NE) was used to analyze the kinetic and kinematic data, from which 192 variables were calculated and reported in PMA Scores (i.e. Composite Score, Power Score, Functional Strength Score, Dysfunction Score, Vulnerability Score, and Exercise Readiness Score). Each subject completed one familiarization session, three experimental sessions consisting of three randomized acute fatiguing protocols (i.e. Control Session, Modified jump test, 25-sec Sprint Test). PMA Test, accumulated lactate and heart rate (HR) was collected pre-and post-fatigue tests. Statistical analyses were conducted for the performance measures using the scores [Composite Score, Power Score, Functional Strength Score, Dysfunction Score, Exercise Readiness Score (ERS), and Vulnerability Score] x conditions (VJ, Sprint, CON) x time (pre-test, post-test) x within sex (females, males) repeated measures MANOVA**. RESULTS:** The MANOVA indicated a three-way interaction (score x condition x time). Follow-up analyses indicated significant differences between pre-and post-tests for the ($\overline{X}$ ± SD for pre-test; post-tests) Composite Score (1556.43±307.8; 1368.00±264.62), Power Score (813.34±242.39; 687.32±164.83), and ERS (18.16±4.75; 16.02±3.54) during the VJ experimental sessions. Significant increases in accumulated lactate and HR were indicated for the post-test during the modified VJ and 25-sec sprint tests. **CONCLUSION:** The current investigation demonstrated the viability of a MCS test to evaluate changes in performance due to acute fatigue. The investigation determined the MCS was capable of detecting acute lower-body biomechanical changes. The PMA Scores suggested decrements in performance are first observed in the decreases in power production during high velocity movements (i.e. VJs). **PRACTICAL APPLICATION:** Documentation and tracking of changes in performances will give future insights on how fatigue can be rated and evaluated. Advancements in technology and screening protocols may be capable of predicting increased risk of season ending injuries. This may provide the strength and conditioning professional

helpful longitudinal information as an athlete/patient/client progresses through a training program and season.

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CHAPTERS

I. CHAPTER I - REVIEW OF LITERATURE

A. ORIGINS / BACKGROUND

The vertical jump (VJ) is a well-recognized essential component of successful athletic performance. More specifically, strength and conditioning specialists, coaches, and health professionals commonly administer the VJ test to determine an athlete's or client's jumping ability and/or to determine lower-body power (16, 50, 141, 201, 215). It was originally developed by Dudley Sargent in 1921 as "the physical test of man (201)." VJ height (VJH) was assessed as the difference between standing reach and jump height. VJH may be a good predictor of changes in lower-body power in weightlifting, football, and track and field events (20, 95, 146, 202). In addition, the VJ has been shown to correlate with speed, agility, and lower body power performances in soccer players (141). Furthermore, strength and conditioning professionals use a variety of devices to compare pre- and post-tests of VJH to determine the effectiveness of a prescribed training program (40, 220).

B. USAGE OF VERTICAL JUMP TESTING

Numerous methods and testing equipment have been used to measure VJH. Traditionally, the most commonly used testing methods is the Sargent's test (9, 41, 84, 156, 224), also known as the jump and reach test (9, 41, 84, 156, 217, 224). This method is simple and effective with the reported reliability of ($r = 0.93$) (9, 75, 156). Subjects would either have a tape or chalk on their fingers, and in a counter-movement vertical jump (CMVJ) with an arm swing, the subjects would slap their fingers or tape against the wall or board. The VJH height is obtained by subtracting the standing reach by the highest VJ reach of the individual (9, 14, 84, 156, 217). Other devices measure VJH using basic kinematic equation to calculate jump height by flight time (41, 83-85, 140). Comparison of flight times for a VJ mat was not consistent with flight times from a force plate, however, correlations between them were very strong (r = 0.995) (224). Vertical jump mat has been shown to be effective at measuring VJ reach height for many individuals when compared with a Vertec (83, 84, 125, 224), despite the fact the timed VJ mat device reported 100 milliseconds longer flight times than those measured by a force plate (224).

Video analysis can also determine the vertical displacement of the center of mass (COM) from the standing position to the apex of the jump (15, 34, 83-85, 110, 156). Some studies suggest this method could be considered the criterion reference, or "gold standard" method, for VJH measurement (15, 83-85). Many studies have examined the kinematic characteristics of the human body during a VJ. Improvements in motion capture systems (MCS) have led to analytical tools that allow detailed analyses of the CMVJ, and to determine the vertical displacement of the center of mass (COM) (72, 73, 97, 136). A MCS allows derivation of the individual joint torques and the net ground reaction forces produced. Additionally, a MCS quantifies movement of body segments and joints which influence the forces generated. This method requires expensive motion analysis equipment and the placement of reflective markers on the subject's body that are recorded during the jumping movement and then analyzed by computer software. However, this method is cost prohibitive for many sport or gym settings (3, 15, 41, 85).

As previously discussed there are variety of different approaches used for measuring VJH, with force platforms being considered as the gold standard (85, 192). Force platforms can measure VJH both time in the air and take-off velocity methods (122, 164). While take-off velocity is considered the most accurate method for measuring VJH, time in the air method have been proven to be highly valid and reliable. Most instrumental calculation of VJH by measuring flight time (85, 164). Force platforms, accelerometers, contact platforms, infrared platforms, and high-speed cameras (42, 85, 192). An inexpensive approach is using a low-cost high-speed camera, license-free computer software, and download applications to evaluate VJH (17, 18). Recently, companies are releasing smartphones with high-speed cameras. One such company is Apple Inc. (USA), which released a smartphone with a high-speed camera capable of recording 120 Hz (17). Balsalobre-Fernandez and colleagues examined the validity and reliability of the smartphone application for measuring VJH (17). The investigation concluded that the application and force platform displayed almost perfect agreement for the CMVJ (17). Software and application development can provide alternatives for CJVH analysis more specifically of VJH.

C. VERTICAL JUMP THEORIES

The counter-movement vertical jump (CMVJ) is a complex multi-joint action where muscles of both the lower and upper extremities collectively summate forces to produce a movement. In the standard vertical jump test, as well as in many sports events, the upper limb (i.e., arms) swing vigorously upward during takeoff to enhance the VJH and performance at takeoff (45, 72, 73, 97, 98, 136, 137, 186, 204). Several theories have been proposed for the positive effect of the arm swing (AS) swing on enhanced CMVJ performances. One of the earliest was the ‘transmission of force’ theory which suggested the arms are accelerated upward, exerting a downward force through the body and increasing the ground reaction force (GRF), thus positively influencing the vertical velocity of the center of mass (COM) (186). A second theory, the ‘joint torque augmentation’ theory, suggested the reaction force exerted onto the trunk is due to the upward acceleration of the arm swing causing the lower limb joints (hips, knees, and ankles) to slow their rate of extension, thus enabling them to collectively produce greater muscle forces (73). A third theory, the ‘pull’ theory, proposed that towards the end of the concentric phase as the arms begin to decelerate, the high vertical velocity of the upper limbs relative to the trunk enables the upper limbs to ‘pull’ on the trunk, transferring energy from the arms to the rest of the body (98).

D. TRAINING COMPARISION

An examination on VJ performance was performed based on training styles, such as powerlifting, Olympic lifting, and sprinting, on strength and power characteristics in the squat movement (147). Olympic lifters and sprinters require explosive strength or maximal power. Powerlifters are known to focus on maximal force production during heavy load and slow velocity lifts. Sprinters, however, would primary focus on specific events, characterized by low resistance, explosive, and high-velocity movements. Olympic lifts incorporate exercises similar to sprinters and powerlifters, but include both heavy loads and explosive types of lifts. Over one year of training, Olympic lifters demonstrated a significant improvement in both rate of force development and maximal force production (94). This type of training is very effective for increasing muscle strength and power (95). The training style used by sprinters results in smaller strength gains, but greater rates of force development due to the explosiveness (147). CMVJ peak forces and peak velocity were significantly higher in the Olympic lifting group and the sprinters group. Thus, peak power was significantly higher in the Olympic lifters when compared to the powerlifters. Furthermore, VJH was significantly higher VJH in the Olympic lifters and the sprinters. As a result, the Olympic lifters outperformed the sprinter group, by jumping higher, producing higher force, and generating the highest power outputs.

E. PERFORMANCE COMPARISON

When Olympic lifters are compared to a plyometric training group, the Olympic lifting training group consistently resulted in the greatest VJ performance. Through an eight week training program the plyometric group produced higher improvements in maximum strength but failed to increase performance in the squat jump test (214). However, strong correlation were reported between maximum strength and power performance (214). The differences observed between the Olympic lifting group and the plyometric group could be due to the development of a greater rate of force development with external resistance applied to the center of mass.

F. RELATIONSHIP TO LOWER BODY POWER

The program design or training status of the athlete can influence the VJ performance. An athlete’s development of strength and power can be very crucial in sport specific performances. One recent study analyzed the relationship between lower body muscular power and linear sprint speed in soccer players based upon vertical jump and full squat power outputs (141). The authors proposed a new method to analyze them to improve soccer specific acceleration. Thus, it is argued that squats and jumps are two exercises that can improve lower body strength, power, and speed. Training programs of full squats, CMVJ and sprinting exercises indicate significant increases in CMVJ loading and mean and peak squat power. Significant correlation were reported between the sprint times and peak power in the 20 kg, loaded CMJ, and between the loaded CMJs and split times from the 10 to 30 meter sprint (141). The average power with the full squat with a load of 70 kg showed a significant positive correlation with sprint times (141). These results suggest that power produced either with vertical jump or full squat exercises could explain much of the sprint performances in those soccer players.

G. PREDICTOR OF LIFTING PERFORMANCE

Heavy-resistance training uses high loads and slower velocities of concentric muscle actions that may lead to improvement in maximal strength, that is the high force and low velocity portion of the force velocity curve (220). Power training incorporates lighter resistances and high velocities of muscle action, which this may result in increases in force output at higher velocities and increased rate of force development (220). The United States Olympic Committee and USA-Weightlifting correlated estimates of average power and peak power, derived from the vertical jump, with performance in weightlifting movements among national-level men and women, and junior squads (39). Estimated VJ was correlated with lifting ability among 64 USA National-level weightlifters. As one would expect, the National-level men had higher absolute power outputs and VJH. Furthermore, correlations indicated maximum strength from 1 RM squat and peak power derived from vertical jumps are strongly related to weightlifting performance (39). A strong correlation was also reported between peak power during vertical jump and weightlifting performance. Since lifting typically begins from a static position, a static vertical jump may correlate with lifting performance (40).

H. WEIGHLIFTING INJURY RATES

As weightlifting is becoming increasingly popular, safety is a growing concern (96, 209). The lifts in the sport of weightlifting emphasize explosive muscular power (128, 209) and essential property of many sports (127). As a result, weightlifting related exercises are often a training tool used to enhance performance for numerous of other sports (127, 193). Injuries always concern athletics, and weightlifting is no exception. Injuries mechanics, prevalence, and rates provide critical information for the coach, athlete, and athletic trainer. Such information may help provide a safe environment for athletes (37, 113, 209, 211). Three anatomical areas though to be at high risk of injury for weightlifting are also common injury sites in many sports (60, 88, 143) the knee, low back, and the shoulder. Data on powerlifting and body building indicate that most injuries occur in the shoulder region, followed by the low back, and the knee (86). Injuries in weightlifting have been reported to include not only soft tissue muscle injuries, but also conditions such as spondylolysis and meniscal injuries (1, 128, 193). In weightlifting, previous literature has indicated that most injuries occur at the knee, followed by the shoulder and back (21, 113, 128, 209). Kulund et al. has indicated the highest percentage occurs during the clean and jerk lift in weightlifting (128). Knee injuries are a high concern not only for weightlifting but for all sports (37). Knee tendinitis especially patellar tendinitis is a problem for many athletes (60).

Calhoon and Fry indicated the most commonly injured sites to include the back, knee, and shoulder, and most of the injuries can be described either as acute or chronic rather than recurring or due to complications and consisted primarily of trains tendinitis and sprains among elite weightlifters over a 6-year period (37). Most of the injuries were relatively minor resulting in missed training time recommendations of less than 1 day (37). The injuries typical of elite weightlifters are primarily overuse injuries, not traumatic injuries comprising joint integrity. Overall the injury rates for weightlifters are similar to rates for many other sports (7, 21, 37, 113, 128). Lower back, knees, and shoulders constitute the most commonly injured anatomical areas in the sport of weightlifting (37).

I. VERTICAL JUMP PHASES

I-1. COUNTER-MOVEMENT VERTICAL JUMP ECCENTRIC PHASE

An eccentric muscle action occurs when the muscle cannot develop sufficient force and is overcome by an external load, resulting in a lengthening of the muscle (69). An eccentric phase is commonly found during the deceleration of joint motion, or the downward phase of the CMVJ. The thin filaments are pulled further away from the center of the sarcomere, stretching the muscle (120). The preparation phase, or eccentric phase, of a vertical jump is defined as the period when the body is being lowered to a desirable position for an upward acceleration (174). During the preparatory phase, "the ankles dorsiflex, the knees, and hips flex, and the shoulders hyperextend (148)."

I-2. COUNTER-MOVEMENT VERTICAL JUMP CONCENTRIC PHASE

A concentric muscle action occurs when a muscle overcomes a load and shortens, resulting in an upward phase during the vertical jump (69). The thin filaments are pulled toward the center of the sarcomere (120). The concentric phase, or propulsion phase, is defined by the period when the body is in an upward acceleration motion acting against gravity (24). During the concentric phase, "ankles plantar flex, the knees, and hips extend, and the shoulders flex (148)." Whether the contraction of the muscle is concentric or eccentric, "force is generated dependent on the number and type of motor units activated, the frequency of stimulation of each motor unit, the size of the muscle, the muscle fiber and sarcomere length, and muscle's speed of contraction" (120). The ability to develop force depends on the speed of the muscle contraction during the eccentric and concentric phases. However, if the downward motion is not included in the vertical jump, the jump is considered a squat jump, therefore only the concentric phase is performed.

I-3. COMBINATION OF ECCENTRIC & CONCENTRIC PHASES FOR THE COUNTERMOVEMENT VERTICAL JUMP

When the duration of the eccentric, concentric, and amortization phases combined are minimized, it can result in the greatest improvement in performance (213). It has been suggested that the neuromuscular adaptation of “increased inhibition of antagonist muscles after training causes an increased activation of synergistic muscles, an inhibition of neural protection mechanisms, and/or increased in motor neuron excitability can all contribute to the increased work (213).” For example, the energy that is stored in a rubber band when it is stretched (eccentric phase), is released once it is released (concentric phase). Therefore, a greater amount of work can be used if there is a right amount of time duration between the two phases that allows the synergistic muscles to activate and to deactivate the antagonist muscles. Training programs that combine both phases involve the union between strength and speed, commonly referred as the stretch shortening cycle (SSC) (213). Many studies have analyzed training certain phases or training the combination of phases to cause the maximum performance in the vertical jump. Training these phases allows for a rapid switch from the eccentric phase to the concentric phase during a vertical jump. Furthermore, this type of training allows for a decrease in the duration of the amortization phase resulting in the jumper reaching the propulsion phase quicker, and in turn increasing power production and vertical displacement of the center of mass. Increasing force and power during the SSC are necessary to increase the vertical jump performance. If the period between the two phases is delayed, the potential energy (PE) stored during the eccentric phase will be lost and dissipated as heat. The stretch reflex will not be able to increase muscle activity during the concentric phase (69).

J. INDIVIDUAL STRATEGIES FOR THE VERTICAL JUMP

Previous research has identified discrete biomechanical variables as discriminators of “good” or “bad” jumpers, indicating a skill component which can be collected from kinematic and kinetic data (8, 217). A feature of the skill component of the VJ has been identified as the sequencing of joint and segment actions (98, 216). Bobbert and colleagues originally found the proximal-to-distal strategy generated net joint movement-time curves where the hips reached maximum torque early in the jump, followed by the extensions of the knees and ankles (28, 45, 216). Allowing for large hip, knee and ankle extensor net joint movements resulted in maximizing vertical accelerations of the pelvis (45). The sequencing consists of two principles; (a) optimal timing of segment motions to maximize vertical velocity of the body’s COM, and (b) an energy efficient transfer of force from proximal to distal segments (28, 45, 216). However, there is disagreement as to whether this strategy, or simultaneous joint extensions, is ideal for vertical jump performance (111).

Comparison of VJ with arm swing and without indicated a longer relative time between the initiation of the hip extension and knee extensions resulting in higher vertical jumps with the usage of the upper limbs (45). The highest jumps displayed a longer relative time delay between joint extension of the hips and knees compared to lower jumps (45). It was hypothesized that the proximal-to-distal strategy allows maximal force of the hamstring muscles to occur before maximal force of the quadriceps, minimizing the antagonism between the muscle groups (45). The simultaneous strategy resulted in maximum force of both muscle groups concurrently, resulting in decreased knee extension torque (45). Sequential extension increased the GRF towards the end of the lower extremity extension, but reduces force earlier in the movement (6).

Van Igen Schenau and colleagues (1989) suggested that the sequential extension movement pattern would improve jumping performance if rates of extension were limited by muscle properties (i.e., fiber types) (216). Furthermore, it may be beneficial if the joint extension is driven by the elastic recoil of tendons and the stretch-shortening cycle (6, 27, 29). Regardless, both jumping patterns are observed among individuals with diverse training statuses and backgrounds (217). Chiu and colleagues (2014) stated that in untrained individuals, the muscles contributing to the sequential strategy may have insufficient levels of fitness, such as strength and flexibility (45). The proximal-to-distal and simultaneous strategies display the influences of the net joint movements during a CMVJ, thus suggesting that coordination must also be considered when evaluating vertical jump performance.

K. KINETIC JUMP PERFORMANCE VARIABLES

Direct measurement of kinetic and kinematic variables can provide an insight pertaining to (a) neuromuscular strategies used to achieve maximal jump performance, reflecting the movement efficiency of the athlete, (b) neuromuscular status of an athlete in response to training and competition, intimating the presence of adaptation (48, 49, 107, 145, 149, 210); and (c) lower-body explosive qualities of an athlete (56, 203, 233), thus highlighting areas of deficiency for a more efficient training program (149). Therefore, assessment of VJ kinetic and kinematic variables is a useful tool in the routine monitoring of athletes. The degree of precision associated with VJ performance and associated kinetic and kinematic variables has shown an implication for the interpretation of true lower-body explosive capacity and changes in VJ performance. Furthermore, several studies have shown that the shape of the force-time curve is dependent on expertise (51, 52, 54, 130). Coaches and practitioners must be aware of typical variations and or reliability associated with VJ performance (68). The reliability of the individual performance may encompass biological (i.e. within subjects) and nonsystematic measurement error (i.e. equipment, tester) (68, 130). The variability and measurement of the performer is critical for the interpretation of the VJ data.

Cormack et al. (2008) calculated the intraday and interday reliability of CMVJ variables in elite Australian Rules Football players, reporting coefficient of variations (CV values) of 1.1-1.7% (intraday), and 1.0-5.7% (interday) (48). Sheppard et al. (2008) assessed unloaded (body mass) and loaded (body mass + 25%) CMVJs in elite and developmental athletes, and observed CVs of 3.5% (peak force) to 36.3% [concentric and peak rate of force development (RFD)] in unloaded jumps, and 3.0% (mean power) to 47.4% (concentric peak RFD) in loaded jumps (203). Further RFD seems to play a role in activities involving plyometr ic muscular contractions such as sprinting or jumping (93, 119, 130, 138, 152, 226).

Laffaye and colleagues (2014) have shown football and baseball players exhibit VJ "signature" or profiles scores ranging from (r = -1.5 to 2.8), with higher values of eccentric RFD than volleyball and basketball players (Figure 1) (130). Football and baseball players tend to display explosive profiles, with high values of eccentric RFD, average concentric force, and VJH (130). Although RFD and impulse provide valuable insight pertaining to the jumping strategy, researchers report higher variability for these variables compared to peak power and jump height (47, 129, 144, 152, 163, 210). Moir et al. (2005) report CVs for peak and average eccentric RFD ranging from 17 to 21% in physically active men and women (165). The reliability statistics for eccentric RFD, more specifically, average eccentric RFD is limited.

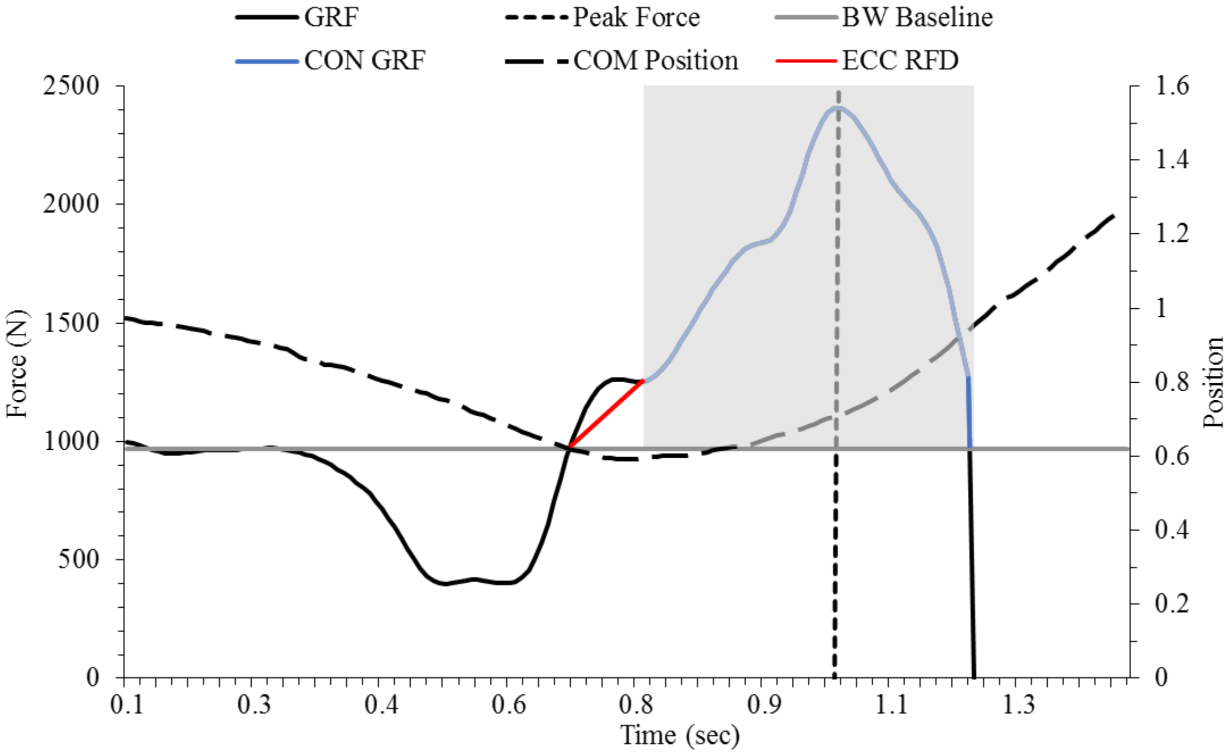


Figure 1. Ground reaction force (GRF) for a subject during the counter-movment vertical jump (dark solid line), the center of mass (COM Position) (dark dashed line), and GRF peak force before takeoff (dark short dash line). Body weight (BW) baseline (dark solid line), eccentric rate of force development (ECC RFD) (red solid line), concentric (CON) GRF (blue solid line), and the CON positive impulse (shaded area) in the area under GRF above BW baseline.

The intention of the performance test is to assess the specific qualities of an athlete or to monitor the changes in performance in response to the intervention or training (108). Moir et al, examined the influence of a familiarization session on squat jumps performance of physically active individuals (165). No systematic changes in the means was reported for the kinetic and kinematic variables with the exception of CMVJs concentric peak RFD (165, 176). Similarity the learning effect was not observed in the performance of 30 consecutive loading jump squats in male soldiers (5).

The evaluation of repetitive trials revealed trivial or small non-systematic changes in the mean for average eccentric RFD, concentric mean force, concentric impulse, and VJH. Nibali et al. (2013) suggests no evidence of systematic error in any of the 3 variables, nor for the combined pool encompassing all levels of athletes (175). It was reported that the familiarization trials before VJ assessment are not necessary in athletes, irrespective of the competitive level or sport, suggesting adequate proficiency of the athlete with VJ performance (5, 163, 165, 176). Average eccentric RFD has been reported to be highly correlated with VJH of elite athletes (118, 129), and potentially could be sued as a key variable when it is examined in the relation to average concentric force (129, 176).

Nibali and colleagues (2015) stated that the average eccentric RFD can be a sensitive measure in training adaptations despite the variability, owning the to the magnitude eccentric RFD changes (176). Cormie et al. (2010) reports significant improvements in eccentric RFD in stronger power, weak power, and weaker strength groups. A significant improvement was reported; however, the magnitude of change was not present (53). Average concentric force and concentric impulse were reported to be the most reliable variables, however, were less effective in detecting small changes in performance (176). Average eccentric RFD has been reported to be unreliable and is incapable of detecting small changes (176). The assessment of VJ kinetics and kinematic variables are a useful tool in the routinely monitoring of athletes.

L. MOTION CAPTURE SYSTEMS

Many studies analyze the development of the vertical jump and use discrete measures to analyze the performances such as mean or peak values. This can disregard the important measurements needed to analyze motion and forces. The evaluation of variations in force, velocity, and displacement-time curves can provide one of the best ways to assess the changes in the kinematic and kinetic properties thus resulting in improved jump performance. Force platforms have been used to measure the kinetic data to measure the reaction forces. Kinetics is the understanding of the forces that cause the changes in motion. Kinematics examine the description of the body in motion based upon motion capture system (MCS). These systems are used to capture in digital form the three-dimensional (3D) movements of the whole body. A muscle can contribute to the energy of a segment in two ways. The muscle can change the segments of velocity, and there by its kinetic energy (KE) (67). The muscle can induce an upward movement of the segment, increasing the PE (67). A typical system is comprised of six or more video cameras, marker system, and specialized software to organize the date to produce a digital representation of the movement (148). Typically, full-body marker sets consist of more than 50 markers. Recently the advancements in technology have allowed the development of markerless MCS. Dynamic Athletes Research Institute’s (DARI Motion) 3-D motion capture markerless system has been in the fore front of advancements in analysis of performance.

L-1. MARKERLESS MOTION CAPTURE SYSTEM

Dynamic Athletics Research Institute (Overland Park, Kansas) MCS is comprised of a 3D markerless MCS which access and analyze kinetic and kinematic data (57, 80, 100, 166-168, 187, 218, 222). The OpenStage and BioStage systems designed by Organic Motion (New York, New York) and DARI Motion (Overland Park, KS) provide accurate tracking and MCS data without markers or special suits. Eighteen vision cameras positioned at different orientations sampling at 120 Hz or 120 frames per second. From these different 2D coordinates and orientations a 3D spatial coordinates are generated by establishing a linear relationship between the 2D cameras coordinates of each body landmark and represent these in a 3D space (194). The direct linear transformation method is used to calculate the 3D coordinates from a series of control points (2). The visual hull technology model records and subtracts the visional signal minus the background which converts to pixels and thus the visual and pixel signals generate a pixilated person. The algorithm searches for 5 appendages during the consistent "scarecrow pose" figure, which estimates the lengths, COM, joints, height, and etc. Either DXA scans or anthropometric estimates (227, 228) used to calculate and analyze 3D kinetic and kinematic data from vector masses. The 3D MCS kinematics and kinetics are accurately measured simultaneously without a force platform to provide performance data. The DARI markerless system has been validated and has the ability to collect kinetic and kinematic data and relay the information to the specific athlete (79, 187). The 3D motion capture system can be used to improve performance to a degree that allows the viewer to know exactly where the athlete is from an objective standpoint.

L-2. COMPARISON OF MARKERLESS MOTION CAPTURE SYSTEM AND FORCE PLATE

Study conducted by the Biomechanics Laboratory at the University of Kansas, compared the GRF derived from a force plate and MCS during body weight squats. Subjects wore form fitting full body suite on which 43 markers were placed (i.e., ankles, knees, hips, etc.) to from rigid bodies to track joint positions (100). Subjects were instructed to squat with a controlled velocity to parallel depth and back to the starting position. The results of the study indicated that the GRF can be successfully calculated with the MCS. Fourteen different cameras result in calculation of position, velocity, and force acting on each part of the body over 100 Hz, or 100 times per second (100). The full body motion capture system records and tracks a stick figure moving in real time.

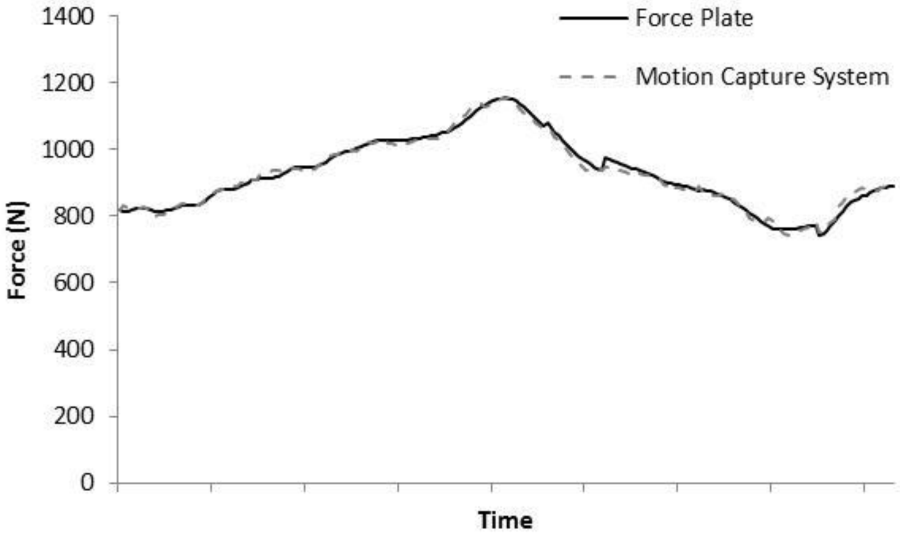


Figure 2. The composite mean force values (N) for the ground reaction forces calculated from the force plate and motion captures system (100).

A similar study was conducted in 1996 by Department of Sport, Leisure, and Exercise Science from the University of Connecticut, which analyzed the relationship of the kinetic and kinematic data between squatting vertical jump and the Olympic hang snatched. The kinematic data was analyzed through a Peak 3D system and the kinetic data was analyzed through a force plate system. The multi-joint Olympic lift is very similar to the quick and explosive mechanics of a squat vertical jump. Thus a significant relationship between all kinetic comparisons, maximal power, time to maximal power, relative power, maximal force, and time to maximal force, during the propulsive phase (38). Angular displacement of the left hip, knee, and ankle joints, were statistically dissimilar between both exercises during the propulsion phase. This could have been due to the backward movement of the COM in order for the barbell to pass the subject’s face during the second pull (38). The researchers did notice that the force-time curves displayed different scales per subject, meaning that each curve is unique to the individual. The relationship between the kinetic and kinematic data provides an advanced analysis during any type of athlete’s performance.

M. VERTICAL JUMPS WITH AND WITHOUT ARM SWING

M-1. ARMS SWING VRSUS NO-ARM SWING

Comparison of the squat jump with and without arms, the push-off or propulsion phase was quicker during the squat jump without arms, or 1.49 to 1.54 times quicker (25). Shoulder work was calculated to be estimated of 6.6% of the total work during the vertical jump (25). The greater VJH during the squat jump with arm swing corresponds to a greater effective energy during the propulsion phase. Forty-two percent difference between then squat jump with and without arm swing relative to 58% difference in CMJ (25). Athletes achieve 20% higher in height, 44% VJH difference, and 56% by the COM height at take-off (25). The squat jump VJH increased with arm swing resembling an increase of 0.86J/kg of total work (25). In addition the subjects jumped 23% higher with arm swing, which can be explained by a greater vertical position of COM at take-off (25). Slower contractile element slows velocity in the early and later stages of the propulsive phase thus affecting the squat jump with arm swing resulting in generating greater contractile element force. Furthermore, greater force production was generated during the arm swing and slower contractile element shortening velocity. Not only had the hip extensor muscles produced more work with the arm swing, but also the erector spine, and gluteus maximus muscles (25). It is anticipated that the mechanisms underlying the increase are different for each muscle in the lower extremities. The shortening velocity provides an explanation in the force production and the force-velocity relationship. The vertical velocity of the COM at take-off was recorded to be 12.7% larger in the arm swing compared to the no-arm swing jumps, resulting in 8.2 centimeter in the vertical displacement between take-off and apex of the jump (73).

M-2. CONTRIBUTION OF UPPER LIMBS USING MARKERLESS MOTION CAPTURE SYSTEM

The DARI markerless motion capture system was used to access the contribution of the upper extremities during CMVJ while using arm swing (AS) or no-arm swing (NAS). The usage of the upper extremities increased the VJH by an average of three inches (171). Dual-energy X-ray absorptiometry scans determined that the upper limbs were 12.0% of the total body mass. Movement of the upper limbs during the AS CMVJ produced 32.2% of the total GRF and 11.3% during the NAS CMVJ (171). The enhancement performance when jumping using an AS resulted in a 13.6% increase in VJH (171). The contribution of the upper limbs during the AS CMVJ averaged 31.5% of the peak GRF, which occurred immediately before takeoff (171). The upper extremities can influence the vertical jump performances and the accompanying kinetics. It was purposed that when analyzing jump GRFS, one must be aware of how much the upper limbs contribute to these forces. In addition, proper AS mechanics must be emphasized when instructing correct jump technique.

N. JOINT TORQUES

Stimulation of joint torques listed in the order of joint extension: knee, hip, and ankle for the NAS, however, during AS the CMVJ begins: hip, shoulder, knee, and ankle. Incorporating the upper limbs cause an early hip activation in order to effectively swing the arms upward. Knee joint torque is decreased in the arm swing due to the decreased duration of torque generation. Arm motion can increase the jump performance and vertical velocity contributes to nearly 2/3 of the increased height (44). In addition, arm swing influences an onset of early hip torque and lengthens the duration on the ground. A jump with arm swing slows the hip extension allowing for more force production. The slowing of hip extension allows longer muscle activation to escalate therefore allows for greater force production and more work generation (67). Larger the torque value at the hip and knee result in larger mean downward vertical forces applied at the joints. The no-arm swing jumps produce greater hip and knee extension torques during the propulsive phase. Once the arms pass the vertical, the shoulder load torque acting on the trunk become negative, thus affecting the slowing of the angular velocity of the hip and a reduction in the power output. Arm swing jumps have a reduction in the muscle shorting velocities for the hip extensors, thus allowing for greater force productions (67). "Jump height can be increased by arm swing specifically by slowing leg extension permitted muscles to work on favorable region of the force-velocity curve, thereby allowing them to produce higher forces and to generate greater work (joint torque augmentation mechanism), and energy contributions from the arm swing (pull mechanisms) (67)".

O. GENDER DIFFERENCES

O-1. ANTERIOR CRUCIATE LIGAMENT INJURY DURING JUMPS

Anterior cruciate ligament (ACL) injuries are among the most common knee injuries observed in athletes (4, 11, 66, 158). The ACL is considered an important ligament that limits anterior movement and rotation of the tibia during activity (62, 177). Seventy percent of all ACL tears happen in a noncontact mechanism when an athlete rapidly deaccelerates and pivots with a large amount of torsion while the foot is planted (35, 92, 180, 191, 199, 205). Noncontact ACL injuries are common in sports such as soccer, basketball, field hockey, and volleyball (4, 11, 66, 158). These sports required a high amount of energy and fatiguing muscular performance. When fatigue occurs, reaction times to external stimuli are delayed and injuries are more likely to occur (43). Fatigue is an extrinsic factor affecting the musculoskeletal and neurological systems (22, 43). The system of fatigue seems to create an environment that increases the risk of noncontact ACL injuries by altering the lower extremity landing strategies. Fatigue has been reported to result in decreased motor control performance (117, 230), increased knee joint laxity (199, 207, 230) decreased balance skill (117), and decreased proprioception (105, 134, 135, 160, 199). Muscle fibers have a decreased capacity to absorb energy when fatigued, and altered neuromuscular function with fatigue which has been shown to increase anterior tibial transition (200, 206). These effects indicate a decreased capacity for controlling body movement after fatigue and may indicate fatigue as a contributor to noncontact ACL injuries (22, 105, 178, 195).

ACL tear is a debilitating sports injury with an estimated 80,000 ACL occurrences in the United States annually (91, 161, 185). The literature unanimously suggests that females are substantially more susceptible than males in suffering acute noncontact injury of the ACL (10, 61, 89, 185). American Orthopaedic Society for Sports Medicine in 1999 issued a consensus statement suggesting that biomechanical and neuromuscular factors appear to be the most important factors associated with ACL injury and higher incidents in injury with female athletes (90, 185). Although ACL tears can occur during bilateral and unilateral landings (30), unilateral landings are considered more dangerous due to the decreased base of support and the increased demand required by absorption of the impact of landing. Boden et al. have suggested that ACL tears occur more commonly during unilateral than bilateral landings (30).

O-2. THEORIES OF GENDER BIOMECHANICAL DIFFERENCES

Although the ACL gender bias is likely multifactorial, three main theories have been proposed to explain the higher incidence of female ACL injury: the ligament dominance theory (101), the quadriceps dominance theory (101), and the straight knee landing theory (114). The ligament dominance theory suggests that the lower extremity muscles do not adequately absorb the impact of landing, resulting in knee valgus which causes increased loading of the ACL (76, 185). The quadriceps dominance theory suggests that females tend to rely on their quadriceps more than their hamstrings creating excessive anterior translation of the tibia (76, 104, 115, 185). The straight knee landing theory suggests that females exhibit less knee flexion at the time of impact that may lead to ACL injury either by hyperextension or by anterior tibial translation (59, 114, 185).

O-3. GENDER BIOMECHANICAL DIFFERENCES

Several epidemiological studies support the notion that fatigue is a predisposing factor responsible for increased number of injuries (33, 81, 82, 99, 121, 185). According to Rozzi and colleagues, males and females athletes were fatigued to 25% of original torque with the use of a isokinetic dynamometer, the researchers found decreased knee proprioception and increased onset of contraction time for hamstrings and gastrocnemius as subjects preformed a landing task (199). Chappell et al. suggested that a fatigue protocol of vertical jumps and sprints caused subjects to land with increased proximal tibia peak anterior shear force and decreased kneed flexion at the time that peak anterior sheer force occur (43, 185). Muscle fatigue has been shown to alter the lower extremity biomechanics of healthy individuals (178, 188). Madigan and Pidcoe, accessed the effects of lower extremity muscle fatigue on drop-landing biomechanics and documented an increase in performance at the hip to compensate for the weakness created in the thigh muscles (142).

These biomechanical changes are believed to decrease shock absorption and knee stabilization during landing. Following quadriceps targeted fatiguing protocol, Augustsson et al. determined reduction in negative power at the knee and hip during single-leg hop landings (12). During drop landings, the lower extremity acts to absorb impact and to deceleration the COM primarily in the vertical direction (181). It appears that the hip extensors are mostly responsible for controlling the vertical position of the COM and preventing collapse of the knee flexion when comprised by fatigue of the thigh muscles (59, 155). During cross-cutting tasks, quadriceps fatigue resulted in increased ankle dorsiflexion movements, and displaced peak knee flexion angles (43, 178). Hamstring fatigue resulted in decreased peak impact knee flexion moment, increased internal tibial rotation, and decreased peak ankle dorsiflexion (43, 178). Madigan and Pidcoe observed that the motor patterns shift proximally and the performance at the hip increases to compensate for the loss in order to show the downward momentum (142). However high demand is placed on the knees and hips to maintain stability during a single-leg hop landing. After creating weakness in the quadriceps and other muscles surrounding the knee, a compensatory adaptation in landing strategy can be observed at the ankle. Peak extension moment and power to the knee decrease, however, the total amount of knee flexion increases following fatigue (181).

Moreover, females landed with an external knee valgus moment that was increased in the post-fatigue condition while males exhibited an external vargus moment. Females also exhibited a greater external knee flexion moment that the authors suggested may be due to increased quadriceps contraction, decreased hamstring contraction or a combination of both conditions (43, 185). Fatigue of the hamstrings have resulted in decreased peak impact knee flexion moments, and increased internal tibial rotation at peak knee flexion and decreased peak ankle dorsiflexion (22). However, quadricep fatigue results increased peak ankle dorsiflexion moments, decreased peak knee extension moments, delayed peak knee flexion and delayed peak knee extension moments, delayed knee flexion and delayed subtalar peak inversion moments (178). More recently, others found that fatigue results in increased initial and peak knee abduction and internal rotation motions and peak knee internal rotation, adduction, and abduction moments with the latter being more pronounced in females (151).

Furthermore, increased knee valgus may produce excessive stress on the inert structures and lead to traumatic injury, consistent with the ligament dominance theory (76, 102, 185). Females exhibited greater peak knee valgus than males in variety of athletic activities (74, 109, 124). Females athletes subsequently suffered ACL injury were found to have increased peak knee valgus compared to female athletes who did not injury ACL. Pappas et al. stated that females land with increased peak knee valgus and VGRF suggested that the stress on the inert structures can become excessive and lead to traumatic injury (185). Fatigue elicit a similar response in males and females, resulting in significantly increased peak VGRF, peak foot abduction, and peak rectus femoris normalized EMG activity (185). Fatigue has been defined as 'any reduction in the force generating capacity of the total neuromuscular system regardless of the force required in any given situation' (23). Recreational athletes preforming unilateral landings, compared to bilateral landings, exhibit increases in knee valgus and normalized EMG activity, and decreased knee flexion at initial contact and decreased peak knee flexion(184). Localized quadriceps and hamstring fatigue also have been found to induce significant changes in female lower-limb control during crossover cutting tasks (178). Clark et al. analyzed the fatigability differences between men and women by accessing muscle activity of the thigh musculature during a knee extension (46). Women appeared to have longer time-to-task failure during a normal submaximal knee extension (46). Suggesting different fatigue induced muscle activation patterns between sexes, especially in the rectus femoris (46). Generalized neuromuscular fatigue has been suggested to increased ACL injury risk during stop jump tasks, primarily via promotion of potentially hazardous anterior tibial shear loading, particularly in females (43). Females have executed jump landing movements with more initial-contact ankle plantar flexion, peak stance-phase ankle supination, peak knee abduction, and peak knee internal rotation compared with men (151). In addition, women also executed jump landing movements with larger peak stance-phase external knee adduction, knee abduction, and knee internal rotation movements and smaller peak external ankle-dorsiflexion moments compared with men (151). Fatigue causes large increases in initial-contact and peak stance-phase knee abduction and knee internal rotation motions and in peak external knee-adduction, abduction, and internal rotation moment (151). Lastly, fatigue-induced increases in external knee-abduction moments occur noticeably earlier and are more pronounced in females than in males, suggestion a potential link with the increased risk of noncontact ACL injuries observed in women (151).

P. BIOMECHANICS OF JUMP LANDINGS

Microfractures, medial tibial stress syndrome, spinal injuries and other degenerative changes in joint and articular cartilage in humans also have been suggested to be significantly increased by the body's ability to attenuate the associated shock from continual impacts (55, 139, 153). These have been associated to propagate in humans whose lower extremities are subjected to continual sub-maximal loading. The shock experienced by the body due jump landings must be attenuated by several structures and mechanisms in the body in joint kinematics and muscular activity (55, 131, 179). Several studies have reported significant decreases in shock attenuation with fatigue during running (64, 157, 219). These studies have concluded that there is a relationship between fatigue and increased heel strike-induced shock waves. It is thought that the fatigue muscles will be less able to protect the body effectively from impact forces and predispose the body to impact-related injuries (55). This loss in protection may be due to a variety of changes that occur with fatigue, including both central and peripheral mechanisms (55). The greater peak anterior shear force on the proximal tibia due to fatigue is associated with decreased knee flexion ankle and increased valgus moment (43). The hip generally has the greatest joint moment and power during two-legged landings, the knee has the greatest joint excursion and preforms the greatest amount of work (59, 65). The landing strategy changes as fatigue progresses in a way that maintained the same level of shock attenuation (55). During single leg-landings, shock parameters did not change, however, altered body positions and use of the hip and ankle may shift the locations of peak stresses (55). The energy absorption in the lower extremity indicates from the ankle to the hip, but knee dynamics remained the same despite the fatiguing exercise focusing on the muscle group (55). This may indicate that an overriding goal of the neuromuscular system is to maintain the functionality of the knee joint in order to maintain shock attenuation (55).

Q. BIOMECHANICS OF SINGLE LEG JUMPS

Biomechanical analysis of the landing portion of the single-leg hop may provide insightful information about the lower extremity function in dynamic situations. Single-legged jump landings have resulted in an increase valgus movement (angle from frontal plane) at the knee joint, decreased knee flexion, and increase in rectus femoris muscle activity compared to bilateral landings (35, 184) Increased valgus movement (increased frontal knee angle) and knee extension are believed to contribute to increased stress on the ACL which may predispose an individual to sustaining an ACL specific injury (35, 103, 229). The human body absorbs the GRFs during movements, and if the musculature surrounding the joints are not properly developed, maintained, or fatigued, it may lead to ligament susceptibility (35, 173). After fatigue, individuals land with more knee flexion and ankle plantar flexion, display greater VGRF, and require longer times to stabilize the body after landing (35). Bejaminse et al. determined that both males and females used a stiff landing strategy following fatigue by landing with less maximal knee valgus and less knee flexion at initial contact of the single-leg stop-jump, without changing the hip joint angles (22). The decrease in knee flexion at the initial contact may be an attempt to increase knee stability while relying on the static structures of the knee more than the dynamic structures following fatigue (22).

Time to stabilization (TTS) is a common measure when researching postural stability and the function of the ankle and knee (35, 36, 198, 225). Time to stabilization is defined as the amount of time it takes for an individual to return to baseline, or static state, calculated from the GRF. TTS is measured across the 3 axes, medial to lateral, anterior to postural, and vertical. These are reported as individual measures (35).

R. BIOMECHANICS OF DEPTH (DROP) JUMP

A few of exercise for the lower body that have been previously discussed have suggested that plyometric training could take place under fatigued conditions to maximize task-specific adaptations. However, there may be an increased impact loads and accelerations when the body impacts the ground in a fatigued state, as evidence in running (64, 162, 221), increased the risk of injury (139, 142, 162, 221). Furthermore, when a foot contacts the ground during landings, a GRF causes a transient acceleration (shock wave), which travels up the musculoskeletal system from the foot to the head (63, 132, 162). When excessive shock wave is applied from movements, impact accelerations can cause a number of musculoskeletal overuse injuries. Such injuries include stress fractures, (159, 232), articular cartilage and joint degeneration (71, 190, 212), and osteoarthritis (190, 223, 231). Moran et al. indicated the relationship between high-impact accelerations and various injuries (stress fractures, articular cartilage and joint degeneration, and osteoarthritis), indicated that there an increased risk of injury in performing plyometric drop jumps (30 and 50 cm) when fatigued through running (170). It is advice to preform drop jumps at 30 cm when fatigued and higher drop jumps (50 cm) when non-fatigued (170).

S. BIOMECHANICS DURING FATIGUE PROTOCOLS

Quammen et al. compared two fatigue protocols [slow linear oxidative fatigue protocol (SLO-FP), and functional agility short-term fatigue protocol (FAST-FP)] to determine biomechanical differences (189). Following fatiguing tasks, individuals appeared to be more erect or extended position. Landing with the knee in a more extended position is thought to increase an anterior shear force on the proximal end of the tibia via an increased patellar tendon-tibia shaft angle (112). Blackburn and Padua have shown that landing with more erect posture results in increased GRF and subsequent quadriceps activation (26). These participants might have increased the strain placed on the ACL and increased loading. Decreased joint angles (i.e. knee flexion) is thought to produce a mechanical disadvantage for the hamstring muscles by decreasing their angles of pull and reducing the amount of posterior force that can be applied on the tibia (183, 189). The decreased posterior force allows for an increased anterior translation, which could increase the load placed on the ACL (183, 189). Quammen found that the FAST-FP induced changes in frontal-plane hip and knee biomechanics when compared to the SLO-FP. Hip abduction at peak knee flexion was greater during FAST-FP than during SLO-FP. FAST-FP may induce greater amount of fatigue to the hip musculature resulting in greater hip abduction (189). Furthermore FAST-FP produced increased in hip abduction, internal knee adduction moment, and knee internal rotation, which results in increased valgus loading on the knee joint (35). Fatigue-induced has been shown to decrease in hip and knee flexion, resulting in more extended landing posture. Further increasing anterior tibial translation and increasing strain.

T. BIOMECHANICS COORDINATION FOLLOWING FATIGUE

Fostier and Nougier described different segment coordination patterns in response to fatiguing upper limb multi-segment movements during throwing (77). Participants appeared to increase the rigidity of the system and the proximal-distal segment motion order. Activation amplitude of the knee extensor and flexor muscle increased at the end of fatiguing exercises, the pattern of the electromyographic traces remained similar to the observed before fatigue (196). Bonnard et al. reported that multi-segment movements under fatigue showed that hopping could be maintained for long periods of time by using two difference strategies (earlier preactivation and trade-offs between muscles across different joint levels) (31). Stiffness regulation under fatigue conditions may have an effect on the motion of segments and different coordination patterns may emerge (87, 195). Under fatigue, the inability of the neuromuscular system to sustain the required power output around the joint, the segmental coordination of the vertical jump many be rearrange (70, 195). It is disputed if a of the segmental movement and/or muscle activation pattern would occur when muscle strength decreases due to fatigue. Following a vertical jump fatiguing protocol a decline in vertical jump height was observed, however, no modifications were observed in the proximal-distal sequence (195). Vertical jump performance is affected by fatigue of the knee extensor muscle, but not by fatigue of knee flexors (196). Despite the decrease in VJH, the subjects appeared to use a robust pattern which ensured consistent responses to generate maximal performance. The same strategy was followed before and after a fatigue protocol.

U. LANDING ERROR SCORING SYSTEM

The Landing Error Scoring System (LESS) is a clinical assessment tool that was developed to provide a standardized instrument to identify subjects displaying jump-landing biomechanics that potentially place them at risk for noncontact ACL injury (182). The LESS may be used as a clinical assessment tool to use during large-scale screening to identify those at risk for noncontact ACL injury and other lower extremity injury (182). It is comprised of two standard video cameras for identifying potentially high-risk movement patterns (“errors”) during a jump-landing maneuver (182). Furthermore, to determine and detecting an individual for the high risk for an ACL injury by the presence of multiple high-risk movement patterns. Individuals with poor (high) LESS scores demonstrate different lower extremity kinematics and kinetics across multiple biomechanical factors and in multiple planes of motion. The individuals with poor jump-landing technique demonstrated less knee and hip flexion motion, more knee valgus and hip internal rotation, greater knee joint loading (anterior tibial shear force, knee extension motion, and knee valgus), and greater vertical GRF (182).

V. REPEATED ANAEROBIC JUMP TEST

Repeated jumps protocols are becoming more prevalent for assessing athlete’s anaerobic power and capacity. The *Bosco test* is a repeated-jump protocol in which an athlete performance continuous vertical jumps for a specific duration (typically 60 sec) (32, 154). The jump test was reported to be suitable to evaluate the power output of leg extensor muscle during natural motion (32). The test evaluates an athlete’s anaerobic power utilizing SSC actions of the lower extremity. Bosco test has shown to be strongly related to performance on the Wingate test, the most commonly used measure of anaerobic power capacity (32, 123, 154). However, the

Wingate test is limited to concentric muscle actions, any may not reflect anaerobic processes utilizing the SSC (106, 154). The SSC activities under fatigue conditions tend to reduce muscle activation preceding contact and during the concentric phase of the movement, (13, 87, 126). Angular displacements and velocities are reduced (87, 196), and force production deceases (208). Reduction in muscular preactivation magnitude may indicate that fatigue in jumping task impairs stiffness and other lower extremity, which in turn impairs the transfer of elastic energy for eccentric phase to the concentric phase movement (154). According to Mclean et al. the flight time was affect early in the jump series (20 sec) than was ground contact time, which was significantly increased until 50 sec (154). As contact time increases it was assumed that the coupling between the eccentric and concentric phases of the amortization phase is increased, which reduces the efficiency of potentiation in performance the task (87, 154). The repeated jump tests results in decrements in muscle activation, force production, and jumping technique (154). Furthermore reductions in muscle activation and fight time appeared early in the jumping protocol, whereas decrements in the force production appeared towards the end of the jump task (154). When participants appeared to minimize the lower extremity involvement and began to favor increasing contribution from truck motion (154). McNeal reported that repeated jump protocols assessing fatigue during SSC activities should last a minimum of 20 sec; however, 40 sec was necessary to observe significant changes to all measured parameters (154).

W. ANAEROBIC SPRINT RUNNING TEST

There are wide variety of anaerobic tests that incorporate different modes of exercise or movement patterns, which also varying in duration. Currently, the Wingate anaerobic test on a cycle ergometer is the most used and most reported anaerobic performance test (19, 116, 150).

The non-motorized treadmill (NMT) offers a suitable tool for the assessment of all-out sprint running performance in a controlled setting (133). The NMT offers measurement performance such as time to peak running speed, distance covered, mean and peak power, mean and peak velocity, and peak and peak force. A number of sports incorporate running, the NMT is more of a sport specific anaerobic test. McLain et al. indicated that the 25 sec tethered maximal sprint using an NMT represents an acceptable and reliable assessment of anaerobic power and capacity (150). Zemkova and Hamar found that analysis of power during short-term bouts of cycling and tethered running showed that sprinters performed significantly better and higher power on the treadmill than cycle ergometer (234). Anerobic performance testing using a 25 sec with a load of 18% on an NMT has been reported to be a suitable method (150). The protocol has been shown to provide the ability to exert peak anaerobic power and anaerobic capacity, mainly for athletes whom train and preform weight-bearing activities that include running/sprinting.

X. CONCLUSION

Many studies have been conducted to comprehend the mechanical movements of the human body during a vertical jump. The biomechanical motion research has observed that a vertical jump is a complex ballistic multi-joint actions, where the musculature around the lower extremity joints collectively operate to produce patterned movements (197). The analysis of muscular function during a vertical jump is complicated due to the interactions of the position of the body, angle of take-off, muscle involved, eccentric and concentric contractions of antagonist muscle patterns, and the use of arm movements. The MCS which records the kinetic and kinematic data provides the leading analysis tool that allows individual analysis of athlete’s vertical jump signature in retrospect to the force-time curve. Furthermore, the relationship of the kinetic and kinematic data provides the best representation of the forces generated by the body; thus, allowing the researcher to quantify results. Segments and joints can further alter the forces generated, particularly the upper limbs, which can influence the overall force-time curve.

Several studies support the notion that fatigue is a predisposing factor that is responsible for the increased number of injuries Musculoskeletal injuries are common in sports which require a high amount of energy and fatiguing muscular performance. The system of fatigue increases the risk of noncontact injuries by altering the lower extremity landing strategies. Biomechanical changes are believed to decrease shock absorption and knee stabilization during landing. Furthermore, the shock experiences by the human body absorbs the GRFs during the movements, and if the musculature surrounding the joints are not properly developed, maintained, or fatigued, it may lead to ligament susceptibility. Understanding of the body segments in motion during a vertical jump and following fatiguing tasks allows for improvement in performance.

II. CHAPTER II – INTRODUCTION

Improvements in motion capture systems (MCS) have led to analytical tools that allow detailed analyses of the counter-movement vertical jumps (CMVJ), and to determine the vertical displacement of the center of mass (COM) (72, 73, 97, 136). MCS has been used to assess an individual's upper-and lower-body motions, both explosive and functional in nature. A MCS allows derivation of the individual joint torques and the net ground reaction force (GRFs) produced. Additionally, a markerless MCS quantifies the kinetic and kinematic movement of body segments and joints which influence the forces generated, and the enhancement of performance during a CMVJ with an arm swing (79, 171, 187). Advancements in MCS and screening protocols is capable of identified American football athletes at high-risk for non-contact season-ending injuries (172).

Vertical jumps (VJ) are commonly performed in many sports skills and athletic events resulting in the incorporation of jump variations or sport specific motions into the training of athletes. The VJ is well-recognized essential component of successful athletic performance. The VJ relies upon the ability of involved muscles to actively synchronize to raise the COM of the body. The VJ test was originally designed by Dr. D.A. Sargent in 1921 to test the physical health status of an individual by examining the relationship of bodily movements and vital functions (201). The CMVJ has been extensively used as a measurement of lower-body power to label the increased performance among athletes. Typically, in the athletic performance settings, coaches and teachers use a variety of devices to measure lower-body power and VJH, however, evaluation of biomechanical of lower-muscular fatigue during CMVJ testing has not been evaluated.

There are wide variety of anaerobic tests that incorporate different modes of exercise or movement patterns, which also varying in duration. Repeated jumps and sprinting protocols are becoming more prevalent for assessing athlete's anaerobic power and capacity. The *Bosco test* is a repeated-jump protocol in which an athlete performance continuous vertical jumps for a specific duration (typically 60 sec) (32, 154). The jump test was reported to be suitable to evaluate the power output of leg extensor muscle during natural motion (32). Currently, the Wingate anaerobic test on a cycle ergometer is the most used and most reported anaerobic performance test (19, 116, 150). However, a number of sports incorporate running. McLain et al. indicated the non-motorized treadmill (NMT) (typically 25 sec with resistance of 18% body weight) offers a suitable tool for the assessment of all-out sprint running performance to provide the ability to exert peak anaerobic power and anaerobic capacity, mainly for athletes whom train and preform weight-bearing activities that include running/sprinting in a controlled setting (150).

Anterior cruciate ligament (ACL) injuries are among the most common knee injuries observed in athletes (4, 11, 66, 158). The ACL is considered an important ligament that limits anterior movement and rotation of the tibia during activity (62, 177). Seventy percent of all ACL tears happen in a non-contact mechanism when an athlete rapidly deaccelerates and pivots with a large amount of torsion while the foot is planted (35, 92, 180, 191, 199, 205). Non-contact ACL injuries are common in sports such as soccer, basketball, field hockey, and volleyball (4, 11, 66, 158). These sports required a high amount of energy and fatiguing muscular performance. When fatigue occurs, reaction times to external stimuli are delayed and injuries are more likely to occur (43). Fatigue is an extrinsic factor affecting the musculoskeletal and neurological systems (22, 43). The system of fatigue seems to create an environment that increases the risk of non-contact

ACL injuries by altering the lower extremity landing strategies. Fatigue has been reported to result in decreased motor control performance (117, 230), increased knee joint laxity (199, 207, 230) decreased balance skill (117), and decreased proprioception (105, 134, 135, 160, 199). Muscle fibers have a decreased capacity to absorb energy when fatigued, and altered neuromuscular function with fatigue which has been shown to increase anterior tibial transition (200, 206). These effects indicate a decreased capacity for controlling body movement after fatigue and may indicate fatigue as a contributor to noncontact ACL injuries (22, 105, 178, 195). Chappell et al. suggested that a fatigue protocol of vertical jumps and sprints caused subjects to land with increased proximal tibia peak anterior shear force and decreased kneed flexion at the time that peak anterior sheer force occur (43, 185). Muscle fatigue has been shown to alter the lower extremity biomechanics of healthy individuals (178, 188). Madigan and Pidcoe, accessed the effects of lower extremity muscle fatigue on drop-landing biomechanics and documented an increase in performance at the hip to compensate for the weakness created in the thigh muscles (142). Further evaluation and understanding the biomechanical changes in performance will give future insight into how fatigue can be rated and prevent fatigue related injuries.

A. Problem Statement

The notion that fatigue is a predisposing factor responsible for the increased number of musculoskeletal injuries is common in sports. The system of fatigue increases the risk of non-contact injuries by altering the lower extremity takeoff and landing strategies. Biomechanical changes are believed to decrease shock absorption and knee stabilization during landing. Furthermore, the shock experiences by human body absorbs the GRFs during movements, and if the musculature surrounding the joints are not properly developed, maintained, or fatigued, it may lead to ligament susceptibility. Furthermore, evaluation of acute biomechanical fatigue rates may determine when an athlete is able to return to sport following rehabilitation.

B. Purposes

The purposal of the present study is to determine the acute biomechanical alterations on total-body following VJ fatiguing and sprint fatiguing tasks. Understanding acute total-body biomechanical fatigue may further provide information for understanding when an athlete begins altering mechanics to sustain performance.

III. CHAPTER III - METHODS

A. Experimental Approach to the Problem

To determine the acute biomechanical performance alterations of the lower extremities following acute fatiguing protocols. Specifically, a markerless three-dimensional (3-D) video motion capture system (MCS) and force place will be used to compare the kinetic and kinematic changes in performance following a variety of fatiguing protocols. An experimental with-in subjects design will be used to compare performance decrements.

B. Subjects

Eleven healthy, recreationally active women ($\bar{X}$±SD; age=20.8±1.1 yrs., hgt.=172.2±7.4 cm, wgt=68.0±7.2 kg) and eleven men (age=23.0±2.6 yrs., hgt.=180.3±4.8 cm, wgt.=80.4±7.3 kg) volunteered for this investigation (Table 1).

Table 1. Descriptives Characteristics

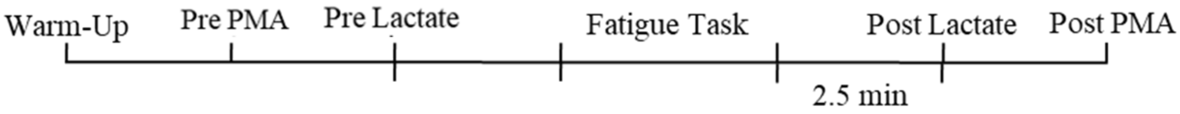
Mean ± SD	Subjects (#)	Age (yrs)	Height (cm)	Weight (kg)
Females	11	20.8 ± 1.1	172.2 ± 7.4	68.0 ± 7.2
Males	11	23.0 ± 2.6	180.3 ± 4.8	80.4 ± 7.3

All subjects were physically active a minimum of one hour for three days a week for at least the preceding three months. None of the participants reported a history of current or prior neuromuscular diseases or musculoskeletal injuries specific to the ankle, knee, or hip joints. Subjects demonstrated functional range of motion in hip, knee, ankle, and shoulder joints without limiting mechanical motion and performance during a VJ and running. This study was approved by the University's institutional review board for human subjects' research. Each subject read and signed an informed consent form and completed a health history questionnaire prior to participating.

C. Procedures

Each subject visited the laboratory for four visits, one familiarization session, one control session, and two experimental sessions. The familiarization consisted of subjects signing informed consents, vertical jump and sprint screening, a warm-up protocol, practice of light fatiguing protocols, and completion of the performance movement analysis (PMA). During the experimental session, subjects completed a 10-min standardized warm-up protocol followed by performing the pre-test PMA, starting with the jump motions, followed by the squat motions, and then the remaining motions. The subjects preformed one of the three randomized acute fatiguing protocols (i.e. control session, modified jump test, 25-second sprint test) followed by the post-test PMA (Figure 1). Each subject completed 1 session per week at the same time of day. The laboratory temperature (75-82°F) and humidity (38-42%) remained in a consistent range.

Figure 1.



D. Performance Motion Analysis

The Performance Motion Analysis (PMA) is a collection of nineteen different motions to assess an individual's upper extremity and lower extremity. The motions include shoulder ranges of motion (ROM) (i.e. shoulder abduction and adduction, shoulder horizonal abduction, shoulder internal and external rotation, shoulder flexion and extension), trunk rotation, bilateral overhead squat, right and left unilateral squat, right and left leg lunge, right and left balance test, bilateral CMVJ, right and left unilateral CMVJ, concentric VJ, 5 right leg and 5 left leg VJs, and depth jump. All nineteen motions are incorporated into the PMA report.

The motions believed to be most affected by the acute fatigue were tested first. During the experimental sessions the PMA began with the jump motions followed by the squat motions. The order of the PMA during the experimental sessions is the following: bilateral CMVJ, right and left unilateral CMVJ, concentric VJ, 5 right leg and 5 left leg VJs, and depth jump, bilateral overhead squat, right and left unilateral squat, right and left leg lunge, right and left 20-sec balance test, shoulder abduction and adduction, shoulder horizonal abduction, shoulder internal and external rotation, shoulder flexion and extension, trunk rotation.

E. Performance Motion Analysis Scores

The 192 variables collected from the kinetic and kinematic variables during the 19 motions of the PMA were used to calculated six different analysis scores focusing on certain movement variables. These scores consist of the Composite Score, Power, Score, Strength, Score, Dysfunction Score, Exercise Readiness Score, and Vulnerability Score (Figure 2). The

Composite Score is a cumulative score based on the overall performance, (Power Score + Functional Strength Score – Dysfunction Score). The Power Score consists of data from jump heights and is an aggregate of all the jump performances. The Functional Strength Score is the accumulation of squat depths and is an aggregate of all the squat performances. The Dysfunction Score consists of asymmetries (upper limb, lower limb, and trunk), knee valgus, lower limb kinetic chaining, and balance performances. The Exercise Readiness Score (ERS) is a scale that the depicts the level of training and readiness. The score consists of three factors: rebalance, development, and optimize. The rebalance (level 1) is to remove compensations and find symmetry between right and left upper and lower extremities consisting of unilateral forces, joint flexions and joint torques. Which the individual is depicted in the structuring phase and to focus on basic mechanics. The development (level 2) is that the individual is on the right path and needs to continue to the development, which the displays kinetic and kinematic symmetry and the individual is in developmental performance phase. The optimize (level 3) is that the individual needs to maintain, which the individual is displaying mechanics of peak performance. The Vulnerability Score is the aggregate of the overall performances, stresses (consisting of unilateral high forces, joint flexions and joint torques), and compensation patterns (overuse of dominant side or limited usage due to history of an injury). This score is presented as a percentage of 0-100%.

Mosier et al. has previously indicated from a k-means cluster analysis that vulnerability score >60, MCS composite score <1800, functional strength and power score difference of ≥350 points, and joint torque differences greater than 30%, has indicated American collegiate football athletes as a high risk for non-contact season-ending injuries (172). Of the 5 athletes indicated as a high risk for injury, three suffered a non-contact season-ending injury to the lower-extremities. Although two individuals were reported as false positives, there were no false negatives (i.e., suffered a season-ending non-contact injury but not identified by the MCS testing).

Figure 2. Functional/Performance Motion Analysis

Score Definitions

Composite Score

Combination of power score, strength score, and dysfunction score. (power + strength - dysfunction)

Power Score

Accumulation of jump heights, and aggregate of all of jump performance metrics.

Functional Strength Score

Accumulation of squat depths, and aggregate of all squat performance metrics.

Dysfunction Score

Asymmetry, valgus, kinetic chaining, balance performances.

Exercise Readiness Score

Scale of three levels consisting of rebalance, development, and optimize.

Rebalance: (level 1) is to remove compensations and find symmetry between right and left upper and lower extremities consisting of unilateral forces, joint flexions and joint torques. Which the individual is in the structuring phase and focus on basic mechanics.

Develop: (level 2) is the individual is on the right path and needs to continue to the development, which the individual displays kinetic and kinematic symmetry and is in developmental performance phase.

Optimize: (level 3) is the individual needs to maintain, which the individual is displaying peak performance mechanics.

Vulnerability Score

Aggregate of the overall performances, stresses (consisting of unilateral high forces, joint flexions and joint torques), and compensation patterns (overuse of dominant side or limited usage due to history of an injury).
Scale of 0-100%.
if score >60% has been shown as high risk for injury.

Motions

Shoulder abduction and Adduction
Shoulder Horizontal Abduction
Shoulder Internal and External Rotation
Shoulder Flexion and Extension
Trunk Rotation
Bilateral (Overhead) Squats
Right Unilateral Squat
Left Unilateral Squat
Right Leg Lunge
Left Leg Lunge
Right Leg (20 sec) Balance Test
Left Leg (20 sec) Balance Test
Bilateral CMVJ
Right Unilateral Vertical Jump
Legft Unilateral Vertical Jump
Concentric Vertical Jump
5 Right Leg Vertical Jumps
5 Left Leg Vertical Jumps
Depth Jump

F. Acute Fatigue Protocols

F-1. Warm-up Protocol. Each subject was instructed through a 10-min dynamic warm-up at the beginning of each experimental session. The warm-up consisted in the order of 10 quadricep pull to romanian deadlift reach, 10 tin soldiers, 10 figure 4, 10 walking lunges with a T-spine, 5 inchworms, forward skip with forward arm circles, backward skip with backward arm circles, forward skip with hip internal rotation, backward skip with hip external rotation, A-skip, A-skip to squat, and 10 body weight squats.

F-2. Control Session. Each subject was instructed to sit for 15 min. The PMA was completed before the rest period in order of the jump motions, followed by squat motions, and remaining PMA motions. The PMA was completed following the blood samples which was collected for lactate determination pre- and 2.5 min post-control period. In addition, heart rate was collected throughout the entire session.

F-3. Modified Jump Test. Each subject was instructed to bend the knee to about 90 degrees and jump explosively, and repeat immediately on landing for one set (15 sec jumping, 15 sec rest, 15 sec jumping, 15 sec rest). Each subject completed 5 sets. The PMA was completed before the jump test. The PMA was again completed following the blood samples which was collected for lactate determination pre- and 2.5 min post-jump test. In addition, heart rate was collected throughout the entire session. This fatigue test was used based on accumulated lactate responses during pilot investigations the modified jump test was determined to be more fatiguing than the Bosco 60 sec jump test.

F-4. 25-Second Sprint Test. Each subject was attached to the resistive harness of a non-motorized treadmill (NMT) (Woodway Force 3.0 treadmill, Waukesha, WI), which was set to a resistance equal to 18% of the subject's body weight. Subjects carried out a 25-sec maximal sprint on the Woodway treadmill (150). The PMA was completed before the sprint test in the order of jump motions, followed by squat motions, and remaining motions. The PMA was again completed following the blood samples which were collected for lactate determination pre- and 2.5 min post-sprint test. In addition, heart rate was collected throughout the entire session.

G. Blood Samples

Each subject gave three minimal blood samples (approximately one drop) at each testing session (baseline, pre, and post) by way of a lancet finger stick. Fingertip samples were collected into a lactate testing strip for analysis via a Lactate Plus handheld blood lactate analyzer. Samples were collected immediately prior to the PMA, before the randomized experimental test, and 2.5-min post jump or sprint tests.

H. Performance Tests

H-1. Motion Capture Device. During each PMA motion the kinetic and kinematic variables were collected, and analyzed using the DARI (DARI Motion, Scientific Analytics, Lincoln NE) 3D markerless MCS system (169). Anthropometric estimates (58) were used to estimate the segmental COMs. In addition, full body GRFs and extremity joint kinematics were assessed. This 3D MCS has been shown to validly measure full body and segmental kinetics and kinematics without a force plate or video, thus providing accurate performance measures (79, 187). In addition, this system has been used to determine the contribution of the upper extremities during a CMVJ (171).

H-2. Force Plate Device. During each squat and jump motions the kinetic variables was collected and analyzed using a uni-axial force plate (Rice Lake Weighing Systems, Rice Lake, WI) through a data acquisition system (Biopac MP 150 System, Goleta, CA) sampling at 1000 Hz was used to monitor the ground reaction force (GRF). In addition, the modified jump test was collected and analyzed to determine flight time and positive impulse with a sampling rate at 1000 Hz.

H-3. Non-motorized Treadmill. During the 25-sec sprint test the kinetic variables was collected on the non-motorized treadmill (NMT) (Woodway Force 3.0 treadmill, Waukesha, WI), which was set to a resistance equal to 18% of the subject's body weight.

I. Statistical Analyses

Statistical analyses were conducted for the performance measures using the scores (Composite Score, Power Score, Functional Strength Score, Dysfunction Score, Exercise Readiness Score, and Vulnerability Score) x conditions (VJ, Sprint, CON) x time (pre-test, post-test) x between sex (females, males) repeated measures MANOVA. A Pearson correlation matrix was used to compare the relationship between each of the PMA Scores during the familiarization session. Two-way ANOVAs were used to examine the differences in HR [condition (VJ, Sprint, CON) x time (pre-test, post-test)]. In addition, 2-way ANOVAs were used to examine the differences in accumulated lactate [condition (VJ, Sprint, CON) x time (pre-test, 2.5 min post-test)]. Paired samples *t*-tests were used to examine the differences in flight times and positive impulses of the second jump of set 1 and last jump of set 10 during the modified jump test. These VJs were selected to include the VJ rebound and the next CMVJ. *Post hoc* comparisons were conducted when needed using the Bonferroni correction. The level of significant was set to $P \leq 0.05$ for the statistical tests. Statistical analyses were performed using SPSS 24 (IBM Corporation, Amonk, New York USA) and Microsoft Excel 2016 (Microsoft Corporation, Redmond WA, USA).

IV. CHAPTER IV - RESULTS

Table 2 lists the $\bar{X}$ ± SD and pre- and post-test significance levels for the PMA Scores for each pre-test and post-test during each condition. The Pearson correlations matrix (table 3) indicated moderate to strong correlations between the PMA Scores, indicating that the PMA Scores should be analyzed via a MANOVA (score x condition x time x sex). The MANOVA indicated a three-way interaction (score x condition x time). Follow-up analyses indicated significant differences between pre-and post-tests for the Composite Score, Power Score, and ERS during the VJ experimental sessions.

Table 4 lists the HR during the pre- and post-tests, and accumulated lactate during the pre- and 2.5 min post-tests. Two-way ANOVAs indicated a significant interaction (condition x HR). Follow-up analysis indicated the post-test HR was significantly greater than the pre-tests. Furthermore, the VJ and Sprint conditions were significantly greater compared to the CON during the post-tests. In addition, 2-way ANOVA indicated a significant interaction (condition x time for lactate) (table 4). Follow-up analysis indicated the post-test lactate were significantly greater compared to the pre-tests, and the VJ and Sprint conditions were significantly greater than the CON.

Table 5 lists the number of jumps, flight time, and positive impulse $\bar{X}$ ± SD of set 1 and set 10 during the modified jump test. The paired samples *t*-tests indicated the flight time and positive impulse during the last vertical jump during set 10 were significantly less than the second jump of set 1 (table 5).

Table 6 lists the force, velocity and power during the 25-sec non-motorized sprint tests. Females and males exhibited a reduction in power (Females, -47.36 ± 12.15) (Males, -66.24 ± 11.04) and velocity (-24.32 ± 6.77) (-33.86 ± 10.80). Table 7 lists the fatigue rates for each PMA score per condition. The fatigue scores indicated the greatest reduction in the Composite Score, Power Score, and ERS, during the VJ session.

Table 2. Reported MCS Composite, power, functional strength, dysfunction, vulnerability, and exercise readiness scores during the familarization (FAM), and pre and post test during the vertical jump (VJ), sprint, and control (CON) experimental sessions.

Condition	Sex	MCS Composite Score	Power Score	Functional Strength Score	Dysfunction Score	Vulnerability Score	Exercise Readiness Score
FAM	F	1363.0 ± 200.8	663.6 ± 114.3	840.6 ± 94.3	141.5 ± 72.4	44.3 ± 14.7	15.7 ± 2.7
	M	1859.3 ± 152.3	1009.5 ± 141.3	974.1 ± 94.9	124.2 ± 36.5	40.1 ± 9.6	21.7 ± 2.0
Pre VJ	F	1387.2 ± 184.6	665.6 ± 86.0	830.6 ± 97.4	108.8 ± 48.8	40.9 ± 10.1	16.0 ± 2.3
	M	1839.2 ± 159.4†	1015.3 ± 132.0†	949.7 ± 83.1	126.0 ± 32.3	37.0 ± 8.0	21.7 ± 2.3
Post VJ	F	1217.9 ± 166.9*	585.5 ± 45.1*	779.2 ± 113.0*	146..7 ± 60.8	46.7 ± 11.0*	13.8 ± 1.6*†
	M	1518.1 ± 264.1*	789.2 ± 173.6*	883.6 ± 101.8*	163.7 ± 73.5	42.6 ± 13.4	18.2 ± 3.6*
Pre Sprint	F	1414.8 ± 212.1	691.1 ± 95.4	840.5 ± 101.5	116.7 ± 37.1	39.9 ± 7.1	16.4 ± 2.2
	M	1804.0 ± 143.0	999.0 ± 126.1	928.3 ± 107.4	123.2 ± 56.6	37.6 ± 9.1	21.0 ± 2.3
Post Sprint	F	1365.9 ± 170.1	633.8 ± 82.2	838.6 ± 85.4	164.5 ± 203.2	41.6 ± 7.3	15.4 ± 1.9
	M	1662.8 ± 221.9*	889.9 ± 155.2	907.4 ± 114.8	131.6 ± 48.0	37.8 ± 10.9	20.2 ± 2.8
PRE CON	F	1387.3 ± 210.1	655.3 ± 106.3	834.6 ± 85.4	102.6 ± 44.5	40.6 ± 9.0	15.7 ± 2.6
	M	1799.7 ± 145.6	965.1 ± 138.2	948.7 ± 100.4	114.2 ± 51.9	37.4 ± 10.2	21.3 ± 2.2
Post CON	F	1354.7 ± 210.1	643.5 ± 121.1	823.9 ± 100.4	112.5 ± 46.7	41.1 ± 8.7	15.3 ± 2.9
	M	1676.4 ± 276.9	918.0 ± 160.2	806.1 ± 307.5	126.5 ± 51.3	39.0 ± 14.3	20.1 ± 3.5

Mean ± SD for reported scores for females (F) and males (M). * indicates significant differences between pre to post. MANOVA significant differences between score x condition x time (p=0.14). † indicates further the MANOVA significant differences (*p* <0.05).

Table 3. Pearson correlation matrix among the reported performance scores during the familiarization session

	MCS Composite Score	Power Score	Functional Srength Score	Dysfunction Score	Vulnerability Score	Exercise Readiness Score
MCS Composite Score	----	0.90*	0.78*	-0.41	-0.26	0.92*
Power Score	----	----	0.47*	-0.12	-0.18	0.89*
Functional Strength Score	----	----	----	-0.39	-0.42	0.64*
Dysfunction Score	----	----	----	----	0.64*	-0.33
Vulnerability Score	----	----	----	----	----	-0.47*
Exercise Readiness Score	----	----	----	----	----	----

n=22; *correlation indicates significance p <0.05

Table 4. Heart rate and accumulated lactate changes during multiple time points throughout the vertical jump (VJ), sprint, and control (CON) sessions

		Heart Rate (bpm)		Accumulated Lactate (mmol/L)	
Condition	Sex	Pre	Post	Pre	2.5 min Post
VJ	F	80.9 ± 15.5	183.9 ± 12.8*†	2.6 ± 1.7	11.2 ± 2.4*†
	M	69.9 ± 10.5	171.2 ± 23.9*†	2.1 ± 1.2	13.6 ± 1.8*†
Sprint	F	79.3 ± 18.9	168.5 ± 30.8*†	2.5 ± 1.6	10.7 ± 2.0*†
	M	75.1 ± 10.0	176.6 ± 8.8*†	3.3 ± 3.0	14.8 ± 3.0*†
CON	F	75.4 ± 18.9	74.7 ± 6.4	1.7 ± 0.5	3.1 ± 2.9
	M	81.6 ± 17.0	86.7 ± 11.9	3.2 ± 2.5	2.3 ± 2.2

Heart rate and change in accumulated lactate for females (F) and males (M). * indicates significant differences between pre to post, † indicates significant differences from the control ($p<0.05$).

Table 5. Vertical jump performances $\bar{X} \pm SD$ for females (F) and males (M) during the modifed vertical jump test during the first and last set

	Set 1			Set 10				
		Jump 2 of Set 1			Last Jump of Set 10		Change in Flight Time (%)	Change in Positive Impulse (%)
Sex	# of Jumps	Flight Time (sec)	Positive Impulse (N·sec)	# of Jumps	Flight Time (sec)	Positive Impulse (N·sec)		
F	13.0 ± 1.0	0.4 ± 0.1	250.0 ± 48.5	13.0 ± 1.0	0.3 ± 0.0*	161.5 ± 52.8*	-33.7 ± 12.7	-33.8 ± 20.4
M	14.0 ± 1.0	0.5 ± 0.0	381.4 ± 46.5	13.0 ± 1.0	0.3 ± 0.1*	204.1 ± 80.5*	-41.8 ± 9.7	-46.2 ± 20.6

Females (F), Males (M). * indicates significant differences between set 1 and set 10, ($p<0.05$), Change in flight time and positive impulse during the selected vertical jump

Table 6. Sprint performance $\bar{X}$ ± SD of females (F) and males (M) during the 25 sec non-motorized resisted sprint test

Sex	Distance (m)	Mean Sum Force (N)	Mean Power (W)	Peak Power (W)	Change in Power (%)	Mean Velocity (m/s)	Peak Velocity (m/s)	Change in Velocity (%)
F	70.2 ± 7.5	155.4 ± 15.9	400.4 ± 76.2	1577.1 ± 316.4	-47.4 ± 12.2	2.8 ± 0.3	3.5 ± 0.5	-24.3 ± 6.8
M	94.7 ± 8.0	190.2 ± 17.1	716.3 ± 114.7	2825.2 ± 439.9	-66.2 ± 11.0	3.8 ± 0.3	5.1 ± 0.6	-33.9 ± 10.8

Mean sum force is the sum of horizontal and vertical forces; mean power and mean velocity is the average across the 25 sec sprint; peak power and peak velocity is the maximum value across the 25 sec sprint; change in power and change in velocity is the difference between the maximum peak to the last peak represented as a percent

Table 7. Reported the fatigue rates X ± SD for the MCS composite, power, functional strength, dysfunction, vulnerability, and exercise readiness scores during the vertical jump (VJ), sprint, and control (CON) experimental session

Condition	Sex	MCS Composite Score	Power Score	Strength Score	Dysfunction Score	Vulnerability Score	Exercise Readiness Score
VJ	F	-11.9 ± 8.1	-11.40± 9.2	-6.2 ± 8.3	57.9 ± 96.7	17.2 ± 23.4	-12.6 ± 8.9
	M	-17.7 ± 10.1	-22.7 ± 11.1	-7.0 ± 5.6	46.0 ± 94.4	21.4 ± 47.4	-16.2 ± 11.8
Sprint	F	-3.0 ± 5.2	-8.0 ± 7.2	-0.1 ± 6.8	48.7 ± 170.4	5.3 ± 18.3	-6.0 ± 6.3
	M	-7.7 ± 10.9	-10.6 ± 13.5	-1.9 ± 9.6	20.7 ± 52.0	2.7 ± 23.9	-3.6 ± 12.6
Control	F	- 2.3 ± 10.0	-1.0 ± 17.7	-1.3 ± 5.5	26.6 ± 80.5	4.0 ± 23.4	-2.1 ± 13.5
	M	-7.1 ± 11.3	-5.2 ± 3.9	-15.1 ± 31.6	25.4 ± 62.7	3.6 ± 15.5	-6.1 ± 10.0

Fatigue rate is the difference between the pre score and post score as a percent of mean change across subjects

V. CHAPTER V - DISCUSSION

The notion that fatigue is a predisposing factor responsible for the increased number of musculoskeletal injuries is common in sports. The currently investigation determined the MCS was capable of detecting acute lower-body biomechanical changes due to acute fatigue. The PMA Scores indicate the alterations of performance following the modified jump test. The decrease in the Power Score can explain and account for the reduction in the Composite Score since the Power Score is one of the three other scores that accounts for the Composite Score and is based on the calculation of the Power Score which is an aggregate of VJ measurements. The decrease in the score can be explained by a reduction in power and velocity due to fatigue onset following the modified jump test. Although significant changes were not observed for the Functional Strength Scores, this can be explained by the measurements of the score which is an aggregate of all squat performances. Although there was an onset of muscle fatigue, the squat motion mechanics were not affected by the fatiguing tasks. The differences in the Power and Functional Strength Scores further indicates that high power and velocity movements are the first to falter and are most susceptible to fatigue. Typically, the strength is maintained unless the fatigue stimulus is extended for a longer duration (78). The significant decrease in the ERS following the modified jump test indicates a change in one of the three categories (rebalance, develop, optimize) used in determining ERS. It is speculated the decrease in ERS is resulted in a decrease in the optimize score due to the acute decrease in the velocity and power performance. There were no changes for either the Vulnerability Score and the Dysfunction Score suggesting that these are more stable scores. Furthermore, the acute VJ fatigue did not significantly affect the asymmetry, kinetic chaining, compensation, and balance performances. Differences were observed between males and females performance scores, however, both sexes responded in a similar manner during each fatiguing test.

The PMA fatigue rates indicate the greatest differences in the PMA Score from pre-to post-test for each condition (Table 7). The fatigue protocols showed significant physiological changes to confirm that fatigue occurred, further highlighting significant drops in all performance scores. The greatest decrease in performance was indicated by the Composite Score, Power Score, and ERS. Furthermore, the greatest decrease in PMA Scores were observed during the modified jump test. No changes were observed by the Dysfunction Score and Vulnerability Score, further indicating these are stable scores. Similar fatigue rates in PMA Scores were indicated for both males and females, indicating biomechanical changes due to fatigue for both sexes.

The significant increases for HR pre- to post-test and accumulated lactate from pre- to 2.5 min post-test indicates that the modified jump test and resisted sprint tests involved glycolytic fatigue. In addition, both acute fatiguing tests were significantly different from the CON session. Similar pre- to post-tests were observed for both fatiguing sessions. Previous research has indicated blood lactate reaching 15.4 mmol·L following a Wingate test and 8.1 mmol·L following the Bosco 60 sec jump test (32). Both of these measurements were collected 5 mins post fatigue exercise. In comparison the modified jump test was more fatiguing than what was previously reported for the Bosco 60 sec jump test. McLain et al. reported accumulated lactate of 15.8 mmol·L 5 min post following the 25 sec resistance sprint (150). The current investigation measured accumulated lactate levels 2.5 min post fatigue test to prevent excessive recovery from affecting biomechanical assessment during the post-PMA test. Furthermore, accumulated lactate indicated that these fatigue tests still indicated significant fatigue responses. Suggested that these performances were maximal efforts.

There were similar decreases in performance comparing the flight times and the positive impulse during the modified jump test. Both the flight time and the positive impulse of the 2nd VJ of set 1 to the last VJ indicated a significant decrease in performance. Equal numbers of VJs per set were performed by both males and females. Previous literature has reported both a longer flight time or great positive impulse have indicated a higher VJH (164). Therefore, individuals spent more time on the ground than time spent in the air. There were similar decreases in performance following the 25-sec non-motorized resisted sprint test. Previous literature has reported similar decreases in velocity and power during the 25-sec sprint test (150). A greater fatigue rate/index (% change) among males was indicated for the modified jump test (i.e. flight times, positive impulses) and for the 25-sec resisted sprint test (power, velocity).

A. Conclusion

MCS have been used to assess individuals’ upper- and lower-body motions both explosive and functional in nature. The current investigation demonstrated the viability of the MCS test to evaluate changes in performance due to the acute fatigue. Differences in PMA Scores and performances following acute fatigue protocols indicate biomechanical alterations on the lower-extremities following modified jump test. Similar fatigue indexes and physiological responses were reported for the modified jump test and the 25-sec non-motorized sprint test. The PMA Scores indicated decrements in performance are first observed in the decreases in power production during high velocity movements (i.e. VJs). Further research is needed with difference populations, other fatiguing methods, and impact on performance.

B. Practical Application

Documentation and tracking of changes in performances will give future insights on how fatigue can be rated and understand the PMA and modified jump test could be applied in situations related to determine if an individual is ready for exercise. Advancements in technology and screening protocols may be capable of predicting increased risk of season ending injuries. This may provide the strength and conditioning professional helpful longitudinal information as an athlete/patient/client progresses through a training program and season.

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VII. APPENDIX A

Informed Consent

The Effects of Vertical Jump Fatigue and Sprint Fatigue on Lower-Body Biomechanics

INTRODUCTION

The Department of Health, Sport, and Exercise Sciences, at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. This study will be conducted in the Jayhawk Athletic Performance Laboratory (Robinson Center 207). Sports performance monitoring equipment and video recording will be used to analyze lower-body biomechanics. The following information is provided to help you make an informed decision on whether or not to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services to you, or the University of Kansas.

PURPOSE OF THE STUDY

The purposal of the present study is to determine the acute biomechanical alterations on the lower-body following VJ fatiguing and sprint fatiguing tasks. Specifically, a markerless motion capture system will be used to determine biomechanical differences following fatiguing tasks. It is hypothesized that the performance motion analysis protocol can be used to determine biomechanical alterations immediately following fatiguing tasks.

PROCEDURES

A time-line of the testing procedures and an overview of the testing sequence are below. You will be asked to visit the Jayhawk Athletic Performance Laboratory (Robinson Center, Rm 207) for **4 sessions**, in a randomized order. These sessions include one familiarization session, one control session, and two experimental sessions. The first visit will be a familiarization session and will last approximately 30 minutes, and the control and experimental sessions will last about 30 minutes. You will complete session 2-4 in a randomized order.

Session 1: (Familiarization visit, 30 minutes): You will be informed of the details of the study. You will be asked to complete the consent form, health exercise status questionnaire, and audio/video authorization form. Anthropometric data will be collected (age, height, weight, etc.) You will be familiarized with the markerless motion capture system, audio/video recording procedure, testing protocol, and the vertical jump and sprint technique. You will then practice the performance motion analysis, the vertical jump fatigue task, and the sprint task.

Session 2: (Control visit, 30 minutes): You will complete a 10-minute standardized warm-up. You will be asked to perform the performance motion analysis before and after a rest period of 15 minutes. Small blood samples will be collected from a finger prick for lactate determination 2.5 min pre- and post-rest period. In addition, heart rate will be collected throughout the entire session.

Session 3: (Experimental visit, 30 minutes): You will complete a 10-minute standardized warm-up. You will be asked to perform the performance motion analysis before and after a vertical jump fatigue task. You will be instructed to place your hands on your hips, bend the knee to about 90 degrees and jump explosively, and repeat immediately on landing for a total of 5 sets. Each set consists of 15 seconds of jumping followed by 15 seconds of rest and repeat for a duration of a min. Small blood samples will be collected from a finger prick for lactate determination 2.5 min pre- and post-rest period. In addition, heart rate will be collected throughout the entire session.

Session 4: (Experimental visit, 30 minutes): You will complete a 10-minute standardized warm-up. You will be asked to perform the performance motion analysis before and after a sprint task on a non-motorized treadmill against a resistance of 18% of your body weight. Small blood samples will be collected from a finger prick for lactate determination 2.5 min pre- and post-rest period. In addition, heart rate will be collected throughout the entire session.

Motion capture system – Dynamic Athletics Research Institute (DARI) 3D motion capture marker less system will be used to access and analyze kinetic and kinematic data. Eight separate cameras film and record the human body segmental movements to calculated position, velocity, and force acting on each part of the body 50 times per second (50 Hz). Participants will step into the center of the 8 cameras and assume a standardized pose; standing upright and raising the arms until abducted and perpendicular to the torso, and 90 degrees flexion at the elbows. The system quickly converts the pose into a stick figure. The full body motion capture system tracks and records the human body as a stick figure moving in real time. Human body kinematics and kinetics are accurately measured simultaneously without a force platform to provide performance data.

Performance Motion Analysis - The Performance Motion Analysis (PMA) is a collection of nineteen different motions to assess individual upper extremities and lower extremities mechanics that is tailored to the individual. The motions include flexibility measures, body weight strength and jumping movements. In all, nineteen motions are incorporated into the PMA report.

Blood Samples - Each subject will give two small blood samples (approximately one drop) at each testing session by way of a lancet finger stick. Samples will be collected into a lactate testing strip for analysis via a Lactate Plus handheld blood lactate analyzer. Sampling will take place immediately prior to the PMA, as well as 2.5-min post jump or sprint tests.

Force Plate – The jumps during the jump fatiguing task will be performed on a force plate. Ground reaction forces will be collected, and analyzed using a uni-axial force plate (Rice Lake Weighing Systems, Rice Lake, WI) through a data acquisition system (Biopac MP 150 System, Goleta, CA) sampling at 1000 Hz from which velocities and powers will be derived.

Non-motorized Treadmill – During the 25-second sprint task performance variables will be collected on a non-motorized treadmill (NMT) [Woodway Force, Woodway Force 3.0 treadmill (Waukesha, WI)], You will sprint against a resistance equal to 18% of the subject's body weight.

RISKS

As with all types of physical activity, the vertical jump and sprint protocols in this study carry a low risk of injury or harm to the musculoskeletal system. A medical history record will also be required prior to participation, which will include personal and private information. You may experience muscle soreness during the 48-72 hours following your testing sessions. There is also the possibility of injury to your shoulder, hips, knees, ankles, and skeletal muscles when performing the activities in this study. You may also experience some bruising or discomfort at the site of the blood sampling. You will be given a 24-hour contact number for study personnel to convey any type of unusual discomfort or injury.

BENEFITS

You will be given a chance to learn about Dynamic Athletic Research Institute (DARI) 3-D motion capture system. You will be able to observe your body's biomechanics following fatiguing tasks, and receive Performance Motion Analysis results based on your performance. In addition, you will receive a chance to learn about your body's lactate production following different fatiguing exercise tasks.

PAYMENT TO PARTICIPATIONS

There will be no compensation for participation in this study.

PARTICIPANT CONFIDENTIALITY

Confidentiality will be maintained by coding all information with your identification numbers. The master list will be kept in a locked file cabinet in the Jayhawk Athletic Performance laboratory. By signing this form and audio/video authorization forms you give permission for the use and disclosure of your information for the disclosure of this study. Only qualified research personnel at the Jayhawk Athletic Performance Laboratory and University of Kansas Institutional Review Board (IRB) will have access to the database containing study information. Your identifiable information will be shared unless (a) it is required by law or university policy, or (b) you give written permission. All study data entered into statistical analyses and publications reports will refer to group mean data. No individual or group other than the research team will be given information, unless specifically requested by the IRB. Jayhawk Athletic Performance Laboratory employees will only be granted access to the audio/video recordings and performance data collected. All electronic data will be kept on password protected computers. All data will be stored for a minimum of three years or until papers and abstracts can no longer be published off the data, and then these recordings will then be destroyed. Only abstracts and papers without identifying information will be transmitted through email with the study participation and research personnel that are involved with the project.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form, you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

DISCLAIMER STATEMENT

In the event of injury, the Kansas Tort Claims Act provides for compensation if it can be demonstrated that the injury was caused by the negligent or wrongful act or omission of the state employee acting within the scope of his/her employment.

INFORMATION TO BE COLLECTED

To perform in this study, researchers will collect information about you. This information will be obtained from the medical history form. Your name and personal information will not be associated in any way with the information collected about you or with the research findings from this study. The researchers will use a numbering system in which you will be randomly assigned to any number between in which you will be randomly assigned to any number between 01 through 20 as your study identification. All screen forms will only contain the subject number that is assigned to you. The audio/video recording is required to participate in the study. All the data collected will be stored on a password protected computer in a locked office of the Jayhawk Athletic Performance Laboratory (Robinson Center 207).

REFUSAL TO SIGN CONSENT AND AUTHORIZATION

You are not required to sign this Consent and Audio/Video Authorization forms and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign the informed consent and audio/video authorization form, you cannot participate in this study. You have the option to cancel your authorization and/or stop the recording at any time.

DISQUALIFICATION

You will be excluded from the study if you report any on the following information on the health history questionnaire. If you report any cardiovascular disease or metabolic, renal, hepatic disorders, and/or any history of severe ankle, knee, and/or hip injury, and other pathological conditions that could impair your jumping, or running.

CANCELLING THIS CONSENT AND AUTHORIZATION

You may withdraw your consent to participate in this study at any time. You also have the right to cancel your permission to use and disclose further information collected about you, in writing, at any time, by sending your written request to: Andrew C. Fry, 1301 Sunnyside Avenue 146C, Robinson Center, Lawrence, KS 66045.

If you cancel permission to use your information, the researchers will stop collecting additional information about you. However, the research team may use the disclosure information that was gathered before they receive your cancellation, as described above.

QUESTIONS ABOUT PARTICIPATION

Questions about procedures should be directed to the researcher(s) listed at the end of this consent form.

PARTICIPANT CERTIFICATION:

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I have regarding the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or (785) 864-7385, write the Human Research Protection Program (HRPP), University of Kansas, 2385 Irving Hill Road, Lawrence Kansas 66045-7568, or email irb@ku.edu.

I agree to take in this study as a research participant. By my signature I affirm that I am at least 18 years old and I have received a copy of this Consent and Authorization form.

_______________________________________ _____________________

Print Participant's Name Date

____

Participant's Signature

_______________________________________ _____________________

Print Person Name Obtaining Consent Date

____

Signature of Person Obtaining Consent

Research Contact Information

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VII. APPENDIX B

Authorization for Release of Photography and/or Video

AUTHORIZATION FOR RELEASE OF PHOTOGRAPH AND/OR VIDEO

I,________________________________(name of individual), by signing this release, authorize the University of Kansas, the Department of Health, Sport and Exercise Science, and their staff to use photographs, and video images, or other likenesses of myself, for the following purposes:

1. Use in University and Department of Health, Sport and Exercise Science education and training activities and materials (including print and on line or electronic instructional materials); and

2. Use in print or electronic form in University or Department of Health, Sport and Exercise Science publications, presentations, brochures, newsletters/bulletins, and websites for educational, public relations or promotional purposes which may result in the rising of funds for Department of Health, Sport and Exercise Science.

I understand that the images and written testimonials described above may be included in, copied and distributed by means of various print or electronic media. I understand that my name will not be included with the images or testimonials.

I understand that the study involves audio and/or visual recordings. I am not required to sign Authorization form and I may refuse to do so without affecting my right to any services I am receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, these recordings are required to participate so if I refuse to sign the Authorization form, I cannot participate in the study. I have the option to cancel my authorization or stop the recordings at any time.

I understand that this Authorization can be revoked at any time to the extent that the use or disclosure has not already occurred prior to my request for revocation. In order to revoke the authorization, I must notify Department of Health, Sport and Exercise Science in writing at the following address:

Department of Health, Sport and Exercise Science
University of Kansas
Lawrence, KS 66045
(785) 864-4656
acfry@ku.edu

If I cancel this Authorization after publication of the materials outlined above, I understand that my cancellation may not be able to be honored. If I revoke this Authorization, the University and Department of Health, Sport and Exercise Science shall not engage in any new uses or disclosures of the images or testimonials.

All of the data collected from this project will be stored on a password protected computer in a locked office of the Jayhawk Athletic Performance Laboratory. Jayhawk Athletic Performance Laboratory employees only will be granted access to the data collected. The recordings will be stored on a password protected computer from a minimum of three years or until papers can no longer be published off the data, and then these recordings will then be destroyed.

The University and Department of Health, Sport and Exercise Science will not condition treatment, payment, enrollment or eligibility for services or benefits on the execution of this Authorization. I understand that the images and recordings may be subject to disclosure by the person or entity receiving such information and thus will no longer be protected by federal privacy regulations.

This Authorization is given without promise of compensation. The photos and video images specified above become the property of the University of Kansas and I release to the University any right, title and/or interest of any kind that I may have in the information or images produced.

I have read this document and understand its contents.

______________________________________	____________________
Type/Print Participant's Name	Date

____
Participant's Signature

The Authorization must be signed, dated, and a copy, provided to the individual completing the form.

IX. APPENDIX C

Medical History Form

PRE-EXERCISE TESTING HEALTH & EXERCISE STATUS QUESTIONNAIRE

THE UNIVERSITY OF KANSAS

Name____ Date______________

Home Address____

Phone Number _______________________ Email ________________________

Birthday (mm/dd/yy)____/_____/______

Person to contact in case of emergency____

Emergency Contact Phone ______________________

Personal Physician ____________________________Physician's Phone________________

Gender_________ Age_______(yrs) Height______(ft)______(in) Weight______(lbs)

Does the above weight indicate: a gain_____ a loss_____ no change_____ in the past year?

If a change, how many pounds?___________(lbs)

A. JOINT-MUSCLE STATUS (⚐Check areas where you currently have problems)

Joint Areas

( ) Wrists
( ) Elbows
( ) Shoulders
( ) Upper Spine & Neck
( ) Lower Spine
( ) Hips
( ) Knees
( ) Ankles
( ) Feet
( ) Other________________________

Muscle Areas

( ) Arms
( ) Shoulders
( ) Chest
( ) Upper Back & Neck
( ) Abdominal Regions
( ) Lower Back
( ) Buttocks
( ) Thighs
( ) Lower Leg
( ) Feet
( ) Other______________________

B. HEALTH STATUS (⚐Check if you currently have any of the following conditions)

( ) High Blood Pressure
( ) Heart Disease or Dysfunction
( ) Peripheral Circulatory Disorder
( ) Lung Disease or Dysfunction
( ) Arthritis or Gout
( ) Edema
( ) Epilepsy
( ) Multiple Sclerosis
( ) High Blood Cholesterol or Triglyceride Levels
( ) Allergic reactions to rubbing alcohol

( ) Acute Infection
( ) Diabetes or Blood Sugar Level Abnormality
( ) Anemia
( ) Hernias
( ) Thyroid Dysfunction
( ) Pancreas Dysfunction
( ) Liver Dysfunction
( ) Kidney Dysfunction
( ) Phenylketonuria (PKU)
( ) Loss of Consciousness

* *NOTE: If any of these conditions are checked, then a physician's health clearance will required.*

C. PHYSICAL EXAMINATION HISTORY

Approximate date of your last physical examination________________________________

Physical problems noted at that time____

Has a physician ever made any recommendations relative to limiting your level of physical exertion? _________YES __________NO

If YES, what limitations were recommended?_____________________________________

____

D. CURRENT MEDICATION USAGE (List the drug name, the condition being managed, and the length of time used)

MEDICATION	CONDITION	LENGTH OF USAGE
______________________	_______________________________	_________________
______________________	_______________________________	_________________

E. PHYSICAL PERCEPTIONS (Indicate any unusual sensations or perceptions. ⚐Check if you have recently experienced any of the following during or soon after *physical activity* (PA); or during *sedentary periods* (SED))

PA	SED	
( )	( )	Chest Pain
( )	( )	Heart Palpitations
( )	( )	Unusually Rapid Breathing
( )	( )	Overheating
( )	( )	Muscle Cramping
( )	( )	Muscle Pain
( )	( )	Joint Pain
( )	( )	Other________________________

PA	SED	
( )	( )	Nausea
( )	( )	Light Headedness
( )	( )	Loss of Consciousness
( )	( )	Loss of Balance
( )	( )	Loss of Coordination
( )	( )	Extreme Weakness
( )	( )	Numbness
( )	( )	Mental Confusion

F. FAMILY HISTORY (⚐Check if any of your blood relatives . . . parents, brothers, sisters, aunts, uncles, and/or grandparents . . . have or had any of the following)

( ) Heart Disease
( ) Heart Attacks or Strokes (prior to age 50)
( ) Elevated Blood Cholesterol or Triglyceride Levels
( ) High Blood Pressure
( ) Diabetes
( ) Sudden Death (other than accidental)

G. EXERCISE STATUS

Do you regularly engage in aerobic forms of exercise (i.e., jogging, cycling, walking, etc.)? YES NO

How long have you engaged in this form of exercise?________years_______months

How many hours per week do you spend for this type of exercise?_________hours

What is your fastest 5 km time? _______________

What is your fasted 10 km time? ______________

What is your fasted mile time? ________________

What is your fasted times at other distances not listed? _____________________________________

Do you regularly lift weights? **YES** **NO**

How long have you engaged in this form of exercise?________years_______months

How many hours per week do you spend for this type of exercise?_________hours

What is your back squat 1 repetition maximum (RM)? ______________

What is your deadlift 1 RM? _____________

What is your power clean 1 RM? _____________

What are your other 1 RMs that are not listed? ____

Do you regularly play recreational sports (i.e., basketball, racquetball, volleyball, etc.)? **YES** **NO**

How long have you engaged in this form of exercise?________years_______months

How many hours per week do you spend for this type of exercise?_________hours