BIOMECHANICAL EFFECTS ON LOWER-BODY EXTREMITIES DURING A MAXIMUM EFFORT KETTLEBELL SWING PROTOCOL

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DEDICATION

I dedicate this dissertation to my wife, Chelsea E. Levine and my son, Evan J. Levine. To Chelsea, without your support and love, this would not have been a reality. To Evan, nothing in life comes easy, but if you are willing to push through the tough times you can achieve anything.

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ABSTRACT

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BIOMECHANICAL EFFECTS ON LOWER-BODY EXTREMETIES DURING A MAXIMUM EFFORT KETTLBELL SWING PROTOCOL

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Kettlebell training provides multiple health benefits, including the generation of power. However, previous biomechanical research has been restricted to a few sets or a few repetitions performed in one effort. The primary purpose of this study was to examine the kinematics and kinetics of lower-body joints during a repeated, maximum effort kettlebell swing protocol. Sixteen resistance and kettlebell swing experienced males performed 10 rounds of a kettlebell swing routine (30 s of swings followed by 30 s of rest). Each participant utilized a kettlebell of approximately 20% of their respective body mass and were instructed to perform as many swings as possible each round. Kinematic (i.e., swing duration and angular velocities) and kinetic (i.e., normalized sagittal plane ground reaction force, resultant joint moment [RJM] and power) variables were extracted for the early portion and late portion of the round. Swing duration and normalized ground reaction forces (GRF) increased within a round, while hip joint power decreased. Changes in swing duration were minimal, but consistent due to an increase in overall fatigue. An increase in GRF was observed at the end of the round, which is a potential concern for injury. Hip joint power decreased primarily due to a slower angular velocity. For experienced (both kettlebell and overall resistance trained) individuals, this protocol may be beneficial towards power-training focused routines, as power was not different across rounds while also maintain large RJM values throughout the duration of the exercise.

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CHAPTER I

INTRODUCTION

The health benefits of a regular exercise regimen have been well documented (Faigenbaum & Myer, 2012; Hass et al., 2001; Kraemer, Adams et al., 2002). The potential health benefits include decreased fat mass, increased lean body mass, increased power for both activities of daily living and sports settings, reduction of muscle sarcopenia, and reduced psychological factors (e.g., anxiety; Kraemer, Adams et al., 2002; Kraemer, Ratamess et al., 2002). Proper exercise programming includes both aerobic and anaerobic components. One aspect of anaerobic exercise, resistance training, primarily focuses on utilizing an external piece of equipment to help facilitate physiological adaptations. Equipment traditionally includes barbells, dumbbells, and/or machines. Training intensity can be manipulated by increasing the resistance, increasing the repetition per set or the number of sets, repetition cadence, or decreasing the rest period between sets (Hass et al., 2001; Kraemer, Adams et al., 2002). Increasing the intensity of exercise allows for neuromuscular adaptations and the delay of fatigue (Ebbeling & Clarkson, 1989).

Muscle fatigue is typically associated with a decrease in force, velocity, and power of a given movement (Sargeant, 1994; Taylor et al., 2017). Muscular fatigue is thought to exist due to a downregulation process that acts to safeguard the body from damaging itself, or as an accumulation process of different metabolic processes (Dugan & Frontera, 2000; Sargeant, 1994). Caused by many factors, fatigue can be classified as central or peripheral. The combined effects of central and peripheral fatigue can elicit an increased rating of perceived exertion (RPE), decreased velocities (including those of individual segments and whole-body velocity), decreased ground reaction forces, decreased joint moments, increased joint antagonist moments, altered movement patterns, increased muscle electromyography (EMG) levels, and an increased risk of injury (Burnley et al., 2012; Hooper et al., 2014; Kellis, 1999; Knicker et al., 2011; Potvin et al., 1991).

The extent of adaptation is dependent on the fatigue protocol (Zadpoor & Nikooyan, 2012). When performed under atypical conditions, a specific movement may increase the chance of injury (e.g., landing or cutting; Padua et al., 2006; Thomas et al., 2010; Zadpoor & Nikooyan, 2012). Overall body changes due to repeated lifting of an external object and the subsequent effect on performance have also been characterized (Bonato et al., 2003; Hooper et al., 2014; Sparto et al., 1997). It is well established that the duration, the motion, and the equipment utilized will all affect the biomechanical outcomes observed (Burnley & Jones, 2018; Hunter et al., 2004; Sargeant, 1994). One type of exercise, the kettlebell swing (KBS), inherently requires proper mechanics to perform the movement safely and effectively (Lake & Lauder, 2012b). The effects of short-duration KBSs have been primarily investigated in the literature (Holmstrup et al., 2016; McGill & Marshall, 2012; Wesley, 2017). However, the biomechanical factors of the KBS during long-duration activities are mostly unknown.

In recent years, a resurgence in the utilization and incorporation of kettlebells in gyms has been observed. Kettlebells are described as a cannonball with a handle. Training with kettlebells can provide both anaerobic and aerobic benefits, particularly when performing many swings during an exercise bout (Budnar et al., 2014; Farrar et al., 2010). The KBS is a movement that utilizes rapid, cyclical hip muscular contractions to raise the kettlebell between the individuals' legs (Jay et al., 2011). This motion allows for large magnitudes of torque to be generated at the lower body joints, primarily targeting hip musculature (Bullock et al., 2017;

Levine et al., 2020). Additionally, this rapid application of torque is comparable to more traditionally power generating exercises (e.g., power cleans; Lake & Lauder, 2012a).

Exercise intensity is a variable that gets manipulated frequently in kettlebell training. One such way is called the ‘man maker’ drill, which is a 12-minute maximum effort KBS exercise. The goal is to complete as many swings as possible during the entire 12-minute period. This drill can elicit high levels of fatigue and can help maintain cardiovascular health (Jay et al., 2011). Indeed, exercise routines that consist of intermittent and repeated bouts of KBS can cause large amounts of cardiovascular stress (Budnar et al., 2014). Biomechanically, little is known regarding the effect of repeated KBS exercises on the body, particularly with the onset of fatigue.

Exercise with kettlebells can generate large amounts of power and is comparable to traditional power exercises (Lake & Lauder, 2012a). Power is calculated as the product of force and velocity and when fatigued, there is a decrease in either the speed of a movement, a decrease in force production, or a combination of both (Komi, 2000; Lake & Lauder, 2012b; Sargeant, 1994). When continuous movement is required, altered movement patterns appear when fatigued, which leads to an increased chance of injury (Bonato et al., 2003; Hooper et al., 2013; Sparto et al., 1997). As individuals improve and aspire for more challenging exercises, it is important to understand the underlying mechanics that may increase their chance for potential injury. Repeated KBS routines, both longer duration and intermittent exercise bouts, can be physiologically demanding (Farrar et al., 2010; Jay et al., 2011; Williams & Kraemer, 2015). As large torque values at lower-body joints exist during KBSs, it is important to examine how the body responds to this exercise, specifically for repeated, maximum effort kettlebell routines (Levine et al., 2020; Padua et al., 2006).

There is limited research with regard to KBSs, and differences in swing characteristics have not observed across multiple sets. A specific repetition count (e.g., 10) with a rest period afterwards, is the most common protocol described in the literature (Lake & Lauder, 2012b). The variables associated with the analysis of the KBS are then averaged across all repetitions performed, or derived from a specific number of swings performed (Lake & Lauder, 2012b; Levine et al., 2020). The amount of biomechanical analysis conducted with regard to KBS routines that include large amounts of repetitions is limited. This study aims to biomechanically characterize KBS performance across multiple rounds and within an exercise round.

Purpose of the Study

The primary purpose of this study is to examine the biomechanical effects of a repeated KBS bout on lower-body joint kinematics (swing duration and segmental angular velocities of the hip, knee, ankle) and kinetics (power, resultant joint moment (RJM), and ground reaction force) in recreationally active young adult males.

Research Questions/Hypotheses

1. As exercise duration increases within a trial and across trials, swing duration would increase.
2. As exercise duration increases within a trial and across trials, ground reaction force would decrease.
3. As exercise duration increases within a trial and across trials, angular velocity across lower body joints would decrease.
4. As exercise duration increases within a trial and across trials, resultant joint moments (RJM) would decrease across lower body joints.

5. As exercise duration increases within a trial and across trials, power would decrease across lower body joints.

Significance of Study

Exercise can elicit many health benefits, both physiologically and mentally (Connor & Herring, 2010; Hass et al., 2001; Winett & Carpinelli, 2001). Exercises with a kettlebell provide both aerobic and anaerobic adaptations, while also providing resistance training benefits (Farrar et al., 2010; Jay et al., 2011; Lake & Lauder, 2012a). Exercise incorporating the KBS can strengthen lower back musculature and shoulder musculature (Jay et al., 2011, Jay et al., 2013; McGill & Marshall, 2012). Research that has included a biomechanical analysis of KBSs has increased in recent years. However, there is still much that is unknown. In previous studies, analyses have only included a few swings performed at one time, followed by short periods of rest (Lake & Lauder, 2012a; Levine et al., 2020). For those who use kettlebell regularly, the programming utilized in these studies is not typical. For example, when initially starting kettlebell training, it is recommended to perform three sets of 20 repetitions (Tsatsouline, 2006). As an individual progresses, there is a variety of exercises based off of maximum effort bouts that can be performed. Therefore, the results of this study will contribute to the strength and conditioning knowledge regarding KBSs. This will provide value to strength and conditioning coaches who routinely examine exercise to maximize athletic potential.

Assumptions

1. The body was considered a linked system of body segments connected by frictionless pin joints.

2. The body segments were considered as rigid bodies, meaning they maintain their shape and mass distributions; so that the mass and the moments of inertia (MOI) about the segmental center of mass (COM) do not change

Delimitations

1. All participants performed KBS barefoot.
2. KBS height were maintained, by having an external apparatus to cue participants on the appropriate height (approximately eye-level).
3. Participants utilized a hip-hinge KBS technique.

Limitations

1. Participants' exercise history differed.
2. KBS rate differed, both within and across participants.

Definition of Terms

Global reference frame: a coordinate system defined by laboratory coordinates; marker coordinates are based off this frame.

Local reference frame: a coordinate system defined by markers placed on body segments, only relevant to that segment.

Kinematics: a branch of mechanics that examines positions, velocities and accelerations focusing on description of motion.

Kinetics: a branch of mechanics that examines forces acting on an object as the cause of motion.

Ground reaction force (GRF): a force acting from the ground to the body, equal to the amount of force applied to the ground but opposite to applied force direction.

Inverse dynamics: a calculation, measured indirectly, that estimates the net forces and torques acting on joints by using kinematics, inertial parameters, and ground reaction forces.

Torque: a rotary force that causes angular motion; classically calculated as force multiplied by moment arm.

Angular power: rate of energy flow through the muscle. It is the product of torque and angular velocity of the joint.

Resultant joint force: the sum of bone-on-bone forces and muscular contraction forces acting between the segments linked at a joint.

Resultant joint moment: the net torque acting between the segments linked at a joint by the muscles.

CHAPTER II

LITERATURE REVIEW

The literature review is broken into five sections. The first section is focused on resistance training and kettlebells, kettlebell mechanics, followed by classifications of fatigue, effects of fatigue on exercise performance, and summary.

Literature Search

The literature presented in this chapter was found using computerized databases, such as Google Scholar, PubMed, and Texas Woman's University Libraries, to capture all relevant articles that examined the biomechanical effects of repeated, maximum-effort KBSs. The literature search used the following terms and synonyms: "kettlebell swing," "kettlebell swing biomechanics," "kettlebell swing rate," "exercise performance," "exercise adaptations," "resistance training and health," "mental health and exercise," "exercise and fatigue," "mechanisms of exercise fatigue," "central fatigue factors," "peripheral fatigue and exercise," "Na/K pumps," "kettlebell mechanics," "kettlebell," "exercise adaptations," and "resistance training adaptations." The search was limited to articles written in English and full access to peer-reviewed journal articles. A total of 154 articles across the three data bases were examined. After examination of each article, articles not pertaining to the research questions were omitted (72 articles were retained).

Resistance Training and Kettlebells

Resistance training can be described as a predefined movement while using a combination of external equipment (e.g., dumbbells, barbells, and machines) or inertial characteristics (i.e., bodyweight) to increase the difficulty of movement. Many health benefits are provided by the inclusion of resistance training, including decreased fat mass, increased strength, decreased psychological factors (e.g., anxiety, depression, and stress), and increased bone mineral density (Connor & Herring, 2010; Hass et al., 2001; Winett & Carpinelli, 2001). Resistance training can be performed throughout the lifetime of an individual (Faigenbaum & Myer, 2012; Hass et al., 2001; Kraemer, Adams et al., 2002). With proper supervision from a qualified coach, potential injuries due to resistance training can be minimized, thus making it a relatively safe exercise modality compared to other forms (e.g., recreational participation in sports; Hass et al., 2001).

Depending on the modality of resistance training, the training effect can be enhanced. For example, if an individual decided to increase jumping performance, that individual would have to follow a resistance training program focused on high-speed force generating movements (Sapega & Drillings, 1983). Common modalities of resistance training include: hypertrophy, muscular endurance, power, and strength. Each modality is typically defined by a manipulation of various exercise elements, such as the number of repetitions performed within a set, the number of sets to be completed, and the percentage of a one-repetition maximum (1RM; Kraemer, Adams et al., 2002). As an individual becomes more experienced, the manipulation of other exercise variables (e.g., speed of movement, inclusion of a pause mid-repetition, supporting surface) can occur to provide addition demands on the body (Kraemer, Ratamess et al., 2002; Santana & Fukuda, 2011). The form of resistance training that simulates the motions that occur in daily life is known as functional training.

Functional training aims to not only simulate activities of daily living, but to enhance them. Examples include climbing stairs, walking with a briefcase, and movements on unstable surfaces (Ives & Shelley, 2003; Siff, 2002). The term is derived from the training principle of specificity, which states that adaptations will occur due to the specific loads, motions, and muscles utilized. Commonly, functional training is performed by manipulating the load placement on the body (e.g., weight in one hand vs both), exercise movement (e.g., walking with weight), and the type of equipment used. Various pieces of equipment are utilized in functional training, including tractor tires, weighted ropes, and exercise elastic bands (Santana & Fukuda, 2011). The kettlebell is also often used with functional training. Kettlebells are commonly referred to as a cannonball with a handle. With this design, exercise with a kettlebell can provide both anaerobic and aerobic benefits. Exercise with kettlebells can include both traditional movements (e.g., squats, deadlifts, strict one-arm presses) and more specific movements (e.g., KBS, figure eights, bent arm presses), all of which can elicit various metabolic stressors on the body (Budnar et al., 2014; Falatic et al., 2015; Farrar et al., 2010).

Kettlebells, also known as “girya,” have been utilized as a piece of resistance equipment in Eastern countries for centuries (Tsatsouline, 2006; Wesley, 2017). A resurgence in the popularity of kettlebells has occurred in Western countries, primarily due to their inclusion in crossfit gyms (Jay et al., 2013; Lake & Lauder, 2012a). Despite appearing to be a novel form of resistance, kettlebell-specific sports have been developed and are actively participated in by both men and women. The design of kettlebells allows for traditional lifts (e.g., shoulder press, snatch, clean and press) to be performed with one-arm. The first movement taught with kettlebells is typically the swing, a cyclical exercise that involves rapid hip muscular contractions (Jay et al., 2011).

The KBS can load the body in alternative ways compared to traditional exercise lifts (McGill & Marshall, 2012). When comparing resistance exercise protocols using kettlebells versus other equipment, similar amounts of torque are generated at the hips (Bullock et al., 2017). When considering individual joint torques, the hips and lower back have the largest torque values compared to the ankle and knee joints (Bullock et al., 2017; Levine et al., 2020). Additionally, KBSs generate an equal or increased rate at which force is applied when compared to traditional power exercises (i.e., power clean or snatch; Lake et al., 2014; Lake & Lauder, 2012b; Otto et al., 2012). McGill and Marshall (2012) found that the KBS elicits large muscle activation of trunk and lower limb musculature. These large forces may explain why the KBS elicits improvements in similar motions that involve triple extension (i.e., vertical jump), but has mixed results transferring to other skills (i.e., sprint performance; Holmstrup et al., 2016; Lake & Lauder, 2012a; Maulit et al., 2017; Otto et al., 2012).

When performing the KBS, specifically the hip-hinge technique, there are large motions occurring at the lower body joints, which help keep an individual safe (Back et al., 2016). For proper KBS performance, advanced kettlebell users will utilize more hip motion and restrict upper body motion when compared to novice users (Back et al., 2016). This reliance on lower-body motion requires large amounts of stabilization in the trunk musculature (Jay et al., 2013; McGill & Marshall, 2012) and activation of the hip musculature (Del Monte et al., 2020; Zebis et al., 2013). Even when compared to different variations of the KBS technique, the hip-hinge KBS elicits larger muscle activation in the hamstrings (Del Monte et al., 2020). This increase in hamstring activation may help alleviate stress placed on the anterior cruciate ligament (ACL) both during and after exercise (Del Monte et al., 2020; Opar & Serpell, 2014). The increase in activation will cause a pull on the posterior cruciate ligament (PCL), which will help resist the anterior translation of the tibia. The decrease in anterior translation should help reduce stress placed on the ACL.

Kettlebell Mechanics

Kinematics

The KBS is commonly performed as a hip-hinge technique, which means the motion is initiated by the hips in a similar fashion to a Romanian deadlift exercise. The kettlebell will pass through an individuals' legs with a forward flexed trunk. Afterwards, the individual will activate their hip musculature and the kettlebell will "swing" between their legs into an arc like motion, and the swing will end approximately eye-level with the individual. The KBS is a sagittal plane dominant motion, with the vertical component of an individual's COM position increase more than the horizontal component (Lake et al., 2014). The hip-hinge KBS repetition time is low, compared to other KBS styles (i.e., overhead KBS; Bullock et al., 2017). Despite an increase in kettlebell mass, the displacement of each swing remains relatively consistent (Lake & Lauder, 2012b). However, as kettlebell mass increased there was a decrease in both peak and average velocity during the KBS (Lake & Lauder, 2012b). An increase in time is spent slowing the kettlebell down rather than accelerating the kettlebell upwards (Lake et al., 2014). To perform a hip-hinge KBS technique proper hip motion is required, with max hip flexion reported to be around 60° as reported by Bullock et al. (2017) and 80° as reported by Zebis et al. (2019). Due to the primary motion occurring about the hip, knee joint and ankle joint relative motions are minimal (Bullock et al., 2017; Zebis et al., 2019). The largest joint rotational speed occurs in descending order from the hip joint, knee joint, and ankle joint (Bullock et al., 2017).

Kinetics

The KBS requires a large amount of GRF, primarily focused in the vertical and anterior-posteriorly directed forces (Bullock et al., 2017; Lake & Lauder, 2012b; Levine et al., 2020). The forces provide the ability to push against the ground to remain upright while the kettlebell is slowing down (Levine et al., 2020). While a secondary peak in GRF is generated in order to accelerate the kettlebell upwards to successfully complete the repetition (Lake & Lauder, 2012b; Levine et al., 2020). The large forces applied quickly onto the individual, meaning the impulse generated by the COM is large (Bullock et al., 2017; Lake et al., 2014; Lake & Lauder, 2012b). The KBS has been shown to have large impulse values in both vertical and horizontal directions (Bullock et al., 2017; Lake et al., 2014; Lake & Lauder, 2012b).

The hip-hinge KBS generates large amounts of torque in the lower-body joints (Bullock et al., 2017; Levine et al., 2020). Lower back torque is the largest due to the inclusion of the torque of both lower limbs and resists the torque generated by the upper-body (Levine et al., 2020). When compared to an back extension machine, the torque produced is lower but still sufficient enough to provide adaptations (Edinborough et al., 2016). The torque generated at the hip is quite large (Bullock et al., 2017; Levine et al., 2020). When comparing torque at the knee and ankle, the knee torque is smaller than the ankle torque (Bullock et al., 2017; Levine et al., 2020).

Power is calculated as the amount of mechanical work performed per unit of time, and has been highly related to both sports activities and activities of daily living. The KBS has shown to improve power of hip musculature (Bullock et al., 2017; Lake & Lauder, 2012b; Manocchia et al., 2013). While most of the power is generated by the hip joint, the ankle joint also contributes to the overall power of the KBS (Bullock et al., 2017). Meanwhile the knee joint power is minimalized (Bullock et al., 2017). The amount of hip power may explain why after completion of training program that routinely utilized KBS saw improvements in vertical jump height (Jay et al., 2013).

EMG

EMG is a tool used to measure muscle activation through myoelectrical signals. Two variations of EMG sensors exist where the sensors are placed either on the skin (i.e., surface EMG) or penetrating needles placed directly into a muscle belly (i.e., intramuscular needle EMG). Muscle groups tested during the KBS include: lower back, abdominal, gluteal, and hamstrings. In terms of back musculature, there is an increase in erector spinae (upper and lower portions) during the KBS, even when comparing handedness (i.e., one-handed KBS vs two-handed KBS; Andersen et al., 2015, Andersen et al., 2019; Lyons et al., 2016). While abdominal musculature sees the highest activation at the apex of the KBS (Lyons et al., 2016; McGill & Marshall, 2012). High levels of gluteal activation were noticed across various KBS styles (Van Gelder et al., 2015). While an overwhelming large amount of evidence suggests greater hamstring activation (specifically semitendinosus) during the KBS especially in the hip-hinge technique (Del Monte et al., 2020; Lyons et al., 2016; Zebis et al., 2013).

Fatigue

Fatigue can be defined in many ways. However, once fatigue occurs at the muscular level, a reduction in force, decreased velocity, or a decrease in power of a given movement often results (Sargeant, 1994; Taylor et al., 2017). Muscular fatigue is thought to exist due to a downregulation process that acts to safeguard the body from damaging itself, or as an accumulation process of different metabolic processes (Dugan & Frontera, 2000; Sargeant, 1994). Due to the complexity of the human body, fatigue can occur in various structures and mechanisms, and can be categorized as central or peripheral.

Central Factors

Central factors of fatigue are related to the balance and regulation of neurotransmitters and output signals from the brain (Padua et al., 2006; Taylor et al., 2017). Three primary neurotransmitters related to fatigue are serotonin, dopamine, and norepinephrine (Taylor et al., 2017). Serotonin levels may have a limited effect on fatigue; however, results are mixed (Parise et al., 2001; Roelands et al., 2009; Taylor et al., 2017). Dopamine and norepinephrine, in combination, may increase levels of fatigue in both thermoneutral and warmer temperatures (Taylor et al., 2017). When dopamine concentrations alone are elevated, an increase in power, and no change in perceived effort, is reported (Taylor et al., 2017). Neurotransmitters can play a key role in exercise performance, and are just one contribution to the fatigue process. Another central factor is neural drive. Neural drive refers to both the recruitment of motor neurons and how they interact with muscle fibers (Maffiuletti et al., 2016; Taylor et al., 2017). A motor unit is defined as a motor neuron and the muscle fibers they innervate (Enoka & Pearson, 2013). Each motor unit performs a particular function (i.e., fine vs gross motor) by how many muscles are controlled by a single motor neuron. This concept is the innervation ratio (Enoka & Pearson, 2013). When a motor unit fires, all the muscle fibers it innervates will then contract. This is more commonly referred to as the all-or-none principle (Enoka & Pearson, 2013). Additionally, muscle fibers are recruited in order from least to highly fatigable. This is described as the size principle due to the size of the neurons in each motor unit (Enoka & Pearson, 2013). When fatigued, there is a greater change in motor unit recruitment compared to a decrease in motor unit firing rate, but both occur (Hunter et al., 2004). This may be due to the decrease in motor unit sensitivity as fatigue increases (Burnley & Jones, 2018).

Peripheral Factors

Peripheral factors of fatigue are defined by the physiological processes that occur at, or distal to, the neuromuscular junction (Taylor et al., 2017). Fatigued states can alter whole-body movement patterns and can place additional forces on joints, which may lead to injury (Hooper et al., 2013; Hooper et al., 2014; Padua et al., 2006). For muscles, fatigue elicits a decrease in muscle contraction velocity, which can decrease the overall power generated (Burnley & Jones, 2018; Sanchez-Medina & Gonzalez-Badillo, 2011). EMG is used to measure the activation of muscle during contraction (Dionisio et al., 2008). Typically, amplitudes are lower during eccentric contractions when compared to concentric contractions (Sargeant, 1994). When fatigued, increased amplitudes are observed, and the continuous contraction of that muscle group may be limited (Cifrek et al., 2009; Taylor et al., 2017).

Metabolic by-products can also influence both local (i.e., muscles activated to perform a movement) and global (i.e., whole-body) fatigue states. With contraction, muscles require adenine triphosphate (ATP) to break the bond formed by myosin and actin after the power-stroke (Geeves & Holmes, 1999). A by-product of muscle contraction is adenine diphosphate (ADP) and an inorganic-phosphate ion (P_i; Geeves & Holmes, 1999). For exercise to continue, the phosphagen (ATP-PC) and anaerobic glycolysis cycles must supply ATP to the working muscle. This is particularly true for exercise that requires short bursts of activity (e.g., resistance exercise with a limited number of repetitions; Burnley & Jones, 2018). A by-product of glycolysis are hydrogen ions (H^+) and lactic acid formation (Surenkok et al., 2008). The combination of these by-products may decrease muscle contraction velocity, and therefore performance (Burnley & Jones, 2018; Maffiuletti et al., 2016). H^+ concentrations create an initially local acidic environment, which can have a greater effect of causing fatigue when compared to the lactic acid production alone (Burnley & Jones, 2018). Normal cellular functions rely upon sodium-potassium pumps, where sodium (Na^+) is pumped into a cell, while potassium (K^+) is pumped out of the cell (Clausen, 1996, 2003; Dutka & Lamb, 2007). As either exercise duration continues or intensity is unchanged, a concentration of K^+ accumulates, which can also lead to fatigue due to the inactivity of Na^+/K^+ pump (Burnley & Jones, 2018; Dugan & Frontera, 2000). A lack of abundant ATP will interfere with the enzymatic function of Na^+/K^+-ATPase, which may also lead to improper Na^+/K^+ pump function (Clausen, 1996, 2003; Dutka & Lamb, 2007). In addition, as both intensity and power requirements for exercise increase, so does the need for oxygen. Burnley and Jones (2018) noted that the respiratory-exchange-ratio (RER; i.e., the ratio of volume of carbon dioxide expired to the volume of oxygen inhaled) does not change as the power requirements of the exercise increase. However, the volume of oxygen consumed (VO_2) increases with power requirements, and thus fatigue in the neuromuscular system (Burnley & Jones, 2018).

Biomechanical Factors of Fatigue

Kinematics

As an individual becomes fatigued, compensatory movements are observed. As exercise intensity or duration increase and fatigue occurs, afferent sensory neurons become less sensitive, leading to a decrease in spatial awareness (Hooper et al., 2014). For example, when performing a squat, a decreased range-of-motion at the hip and knee in the sagittal plane occurs when muscles become fatigued. As a result, increased motion of the hip and knee joint occur in the frontal plane (Hooper et al., 2013). Compensatory changes in joint motions in any plane (e.g., decreased hip flexion during a lifting task) can potentially cause excessive forces on other joints (Hooper et al., 2013; Sparto et al., 1997). Additionally, as fatigue increases, range-of-motion will be more limited when completing a task (Sparto et al., 1997). A decrease in movement speed can lead to an increase in force production to maintain the power demands of the movement, which in turn can increase the rate of fatigue (Burnley & Jones, 2018; Jaric & Markovic, 2013).

Kinetics

Power is an important variable when calculated and commonly examined in relation to fatigue. Power is defined as the rate of mechanical work done or the output of mechanical energy (Sapega & Drillings, 1983). Power is calculated by multiplying the force applied to the object by the velocity of the force being applied. Depending on the task, power requirements may vary. If large amounts are needed, fatigue can increase rapidly (Burnley & Jones, 2018; Padua et al., 2006; Thomas et al., 2010). This could be caused by activities that demand an increase in muscle contraction velocity and muscle force, which require a large amount of type II fast-twitch muscle fibers with additional recruitment and firing rate of motor units (Burnley & Jones, 2018; Maffiuletti et al., 2016; Taylor et al., 2017). The onset of fatigue may occur rapidly in this environment, and cannot be sustained indefinitely. This may lead to a reduced power output, due to decreased force and velocity output, a decrease in force only, or a decrease in velocity only (Burnley & Jones, 2018; Sanchez-Medina & Gonzalez-Badillo, 2011). In an attempt to maintain power, an individual may rely on the utilization of the stretch-shortening cycle (SSC). This theory states that a muscle can generate more torque by performing an eccentric contraction followed by an immediate concentric contraction (Komi, 2000). When this occurs, the muscle is forcibly stretched (eccentric contraction), and energy becomes stored in the elastic tissues (i.e., negative work is done; Komi, 2000; Sargeant, 1994). When the stretched muscle concentrically contracts (i.e., performs positive work), the elastic energy stored gets released and helps generate more torque that can help to offset the effects of fatigue (Komi, 2000; Sargeant, 1994).

GRF, commonly measured using force plates, is equivalent in magnitude to the pushing force exerted by an individual on the ground (Zadpoor & Nikooyan, 2012). Due to the interaction with the ground via the feet, GRF is an important biomechanical variable that is commonly assessed. When an individual becomes fatigued, there is no general consensus on how GRF responds (Zadpoor & Nikooyan, 2012). This variability in GRF could place a larger demand on musculature, which may cause an injury to occur, especially during landing motions (Padua et al., 2006; Zadpoor & Nikooyan, 2012). Because it is an external force, the body has to produce internal forces to counteract the movement. This is accomplished via a kinetic quantity known as RJM. RJM is the total rotational force acting at a joint, which is estimated via a calculation method called inverse dynamics. This resultant moment is influenced by four different moments: the inertial moment (i.e., the body segments' resistance to angular motion), the gravitational moment (i.e., the torque due to gravity of body segments), the external moment (i.e., the torque due to the external force), and the free moment (i.e., the torque due to the interaction with the ground, purely in the vertical direction). At the onset of fatigue, RJM values can decrease in magnitude (Burnley et al., 2012; Kellis, 1999; Knicker et al., 2011). The rate and magnitude of decrease can be affected by the type of activity, environment, and the torque required to continue the activity (Burnley & Jones, 2018; Hunter et al., 2004; Knicker et al., 2011). The onset of fatigue can elicit observable changes in both kinematic and kinetic variables. This could potentially lead to altered movement patterns in any activity, including KBSs.

Summary

The health benefits of exercise are well documented (e.g., increased lean muscle mass, decreased fat mass, decreased anxiety; Connor & Herring, 2010; Winett & Carpinelli, 2001). To continue to build adaptations due to exercise, an individual must continuously challenge the body. This can be accomplished by several factors, including increasing resistance, decreasing rest periods, introducing more challenging variations, or the utilization of different equipment. Kettlebells are one piece of equipment that can be utilized while training. The KBS is a primary movement, in which more advanced kettlebell technique are based off of. For example, the kettlebell snatch requires the same hip movement that the KBS trains. The KBS has been shown to create large amounts of power. However, when performed for multiple repetitions, the KBS can accumulate fatigue. Fatigue can occur at both the central and peripheral levels. The cumulative effects of fatigue may alter the underlying biomechanical factors to successful KBS performance. Once an individual has become familiarized with kettlebells, there are a number of exercise protocols designed to test an individual's level of fitness. These tests are meant to stress both the muscular system and cardiovascular system simultaneously. For example, a repeated round-based KBS routine with limited breaks, or a 12-minute maximum swings performed routine. While these tests are performed regularly by advanced KBS performers, there is lack of biomechanical knowledge on how these tests affect the body. Therefore, understanding the mechanics of a particular test (repeated round-based swing routine) may provide insight to strength and conditioning coaches, personal trainers, and kettlebell users.

CHAPTER III

METHODS

The chapter consists of seven sections: participants, equipment utilized, trial capture process, data processing, variable calculations and statistical analyses.

Participants

Participants were recruited around Texas Woman's University and the Dallas-Fort Worth Metroplex area gyms (see Table 1). Recruitment was conducted via multiple methods including word-of-mouth, flyers, and social media platforms (i.e., Twitter, Instagram, and Facebook). All participants were screened to include those who: a) were free from any lower-body joint injuries for at least 6 months, b) were 18 to 44 years of age, c) were male, d) completed a Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) with no restrictions to participate, e) had been regularly performing resistance training over the past 3 years, f) had at least 3 months of experience using kettlebells during exercise, and g) must have been able to perform 15 KBSs/round. Individuals who had exercised consistently for 3 years were considered "advanced" by the American College of Sports Medicine (ACSM; Kraemer, Ratamess et al., 2002). Three months of KBS experience allows for efficient and correct form. This time frame (approximately 12 weeks) is sufficient for neural adaptations to occur (Carroll et al., 2011; Stone, 1993; Teo et al., 2016). Written informed consent were obtained from each participant prior to participation using a consent form approved by the Institutional Review Board at Texas Woman's University.

Table 1

Descriptive Measures for Study Participants (n = 16)

Measure	Mean ± *SD*
Age (years)	28.8 ± 4.3
Body Mass (kg)	89.9 ± 18.7
Height (cm)	177.8 ± 6.5
Resistance Training Experience (years)	11.6 ± 5.9
KB mass used (kg)	18.3 ± 3.7
Repetitions performed in Round 1 (# of swings)	19.8 ± 0.9
Repetitions performed in Round 5 (# of swings)	19.3 ± 0.9
Repetitions performed in Round 9 (# of swings)	19.1 ± 1.0
RPE end of Round 1	9.2 ± 1.5
RPE end of Round 5	14.1 ± 1.9
RPE end of Round 9	17.1 ± 2.2
Total repetitions performed (# of swings)	193 ± 8.1

Equipment

Ten infra-red cameras (Qualysis, Gothenburg, Sweden) and two force plates (Advanced Mechanical Technology, Inc., Watertown, MA, USA) were used to capture KBS data at 500 Hz and 1,000 Hz, respectively. Two free-standing squat racks (Unified Fitness Group, Inc., Houston, TX) were used to place a line in-front of the participants, at approximately eye-level, to ensure participants would not exceed a specific height during the KBS protocol.

Experimental Procedures

The initial visit was to determine if participants met the inclusion criteria. If inclusion criteria were met, the process of obtaining verbal and written consent was performed. Afterwards, participates were asked to demonstrate the hip-hinge KBS technique with a kettlebell that was approximately 20% of the participant's body mass. This helped participants become familiar with the swing height and kettlebell mass that was utilized throughout the study. After a brief familiarization period, participants performed three rounds of the testing protocol, in which KBS height and at least 15 swings/round were maintained. Upon successful completion of the three rounds, participants were able to proceed to the data collection visit.

The second visit was for data collection. Participants were instructed to return approximately 24 to 48 hours after the initial visit. Participants were asked to bring spandex clothing to avoid skin artifact motion. After changing clothes, participants performed a warm-up routine focused on hip musculature. If desired, the participant performed their own warm-up routine. Once completed, 59 reflective markers were placed on anatomical landmarks (see Table 2). Participants were instructed to stand motionless on two force plates, and a static trial was recorded. Six markers were removed as to avoid interference with the motion. Participants were asked to perform a KBS protocol designed to induce fatigue. This routine was performed at a 1:1 work-to-rest ratio for a total of 10 rounds (30 s max effort KBSs followed by 30 s of rest). Participants used a kettlebell mass of approximately 20% of their body mass (with a ± 2 kg allowance) due to discrete weight increments. The KBS rate was not controlled due to a potential influence on swing performance. The KBS rate can be affected by the influence of swing height. Therefore, participants were required to maintain proper swing height throughout data collection. Encouragement was provided to ensure kettlebell height was preserved. Failure to maintain swing height for three consecutive swings resulted in the termination of the study, as to avoid potential injuries and fatigue. Kinematic and kinetic data were recorded during the first, fifth, and ninth round. These rounds were chosen because a consistent difference in the number of rounds between observations (i.e., four rounds) was maintained, and a sufficient duration to observe possible changes in the KBS performance could be observed. For statistical testing, the data collected from the second KBS through the sixth swing, inclusive of both, were averaged together and classified as the "early" data set. The last five swings prior to the last KBS within a trial were averaged together, and were classified as the "late" data set. Data collected during first and last swing was discarded because unwanted events (picking up and putting down the kettlebell during the first and last swings, respectively) were present, which may have altered the KBS motion. The rate of perceived exertion, using the Borg scale, was recorded at the end of each round.

Table 2

59 Whole-Body Marker Placements

Body Segment	Primary Markers/ Secondary Markers	Marker Location/ Computed point
Head	4 Primary	Anterior, Vertex, Right and Left Lateral Marker.
	1 Secondary	Center head calculated as mid-point of the Right and Left head marker.
Upper Trunk	5 Primary	Suprasternal notch (SN), spinous process of 7th cervical vertebrae (C7), xiphoid process (XP), and the spinous process of the 8th and 12th thoracic vertebrae (T8 & T12).
	2 Secondary	Mid-Chest calculated as the mid-point from the SN and C7 markers. Mid-Abdomen calculated as the mid-point from the XP and T12 markers.
Arms (x2)	13 Primary (x2)	Anterior aspect of the glenoid-humeral joint (AShould), posterior aspect of the glenoid-humeral joint (PShould), acromion (Acrom), distal aspect of the triceps brachia (UA1), proximal lateral triceps

Body Segment	Primary Markers/ Secondary Markers	Marker Location/ Computed point
		brachia (UA2), lateral triceps head (UA3), medial epicondyle of the elbow (MElbow), lateral epicondyle of the elbow (LElbow), distal forearm (FA1 & FA2), radial and ulnar styloid process (MWrist & LWrist) and medial (2nd) metacarpal (proximal head; Hand). MElbow and LHand markers were removed during dynamic trials.
	3 Secondary (x2)	Shoulder joint is computed as the mid-point between the AShould and PShould markers. Elbow joint was computed as the mid-point of the MElbow and LElbow markers. Wrist joint is calculated as the mid-point of the MWrist and LWrist markers.
Pelvis	6 Primary	Left and right anterior superior iliac spine (ASIS), left and right posterior superior iliac spine (PSIS), left and right iliac crest (IC) and sacrum (SAC).
	6 Secondary	Mid-ASIS is calculated as the mid-point between the LASIS and RASIS markers. Mid-RPelvis is calculated as the mid-point between the RASIS and RPSIS markers. Mid-LPelvis is calculated as the mid-point of the LASIS and LPSIS markers. Mid-Pelvis is defined as the mid-point between the Mid-RPelvis and Mid-LPelvis. The hip joint is found by using the Tylkowski-Andriacchi hybrid method (Bell et al., 1990). The L4/5 joint is calculated through an indirect method (MacKinnon & Winter, 1993).
Legs	9 Primary (x2)	Greater trochanter (GT), lateral epicondyle of the knee (LKnee), medial epicondyle of the knee (MKnee), anterior tibial tuberosity proximal and distal (T1 and T2), medial malleoli (MAnkle), lateral malleoli (LAnkle), calcaneus (Heel), distal end of 2nd metatarsal (Toe). GT marker is removed during dynamic trials.
	2 Secondary (x2)	Knee joint center is calculated as the mid-point of the LKnee and MKnee markers. Ankle joint center is calculated as the mid-point of the MAnkle and LAnkle markers.

Note. P – posterior, A – Anterior, L – Lateral for legs and arms; left for pelvis and head, M – medial, and R - right.

Data Processing

Trial marker coordinates were processed and a c3d file of marker coordinates and force-plate data was created. The c3d file was imported into biomechanical software for further data analysis (Kwon3D XP, Visol, Seoul, South Korea). Marker coordinates were filtered using a 4th order zero-phase-lag-filter set at 6 Hz. Body segment parameters were estimated using data reported by de Leva (1996). Joint center calculations varied across the body (see Table 3) and rotation sequences were segment-dependent (see Table 3).

Five swing events were identified (see Figure 1): a) Start (hands' COM at the highest position), b) Downward Transition (downward acceleration-to-deceleration), c) Halfway (hands' COM at the lowest position), d) Upward Transition (upward acceleration-to-deceleration), and e) End (similar to start event). Four phases were defined based on events: a) Downward Acceleration (Start-DT), b) Downward Deceleration (DT-Halfway), c) Upward Acceleration (Halfway-UT), and d) Upward Deceleration (UT-End).

Table 3

Segmental Axes and Rotation Sequences

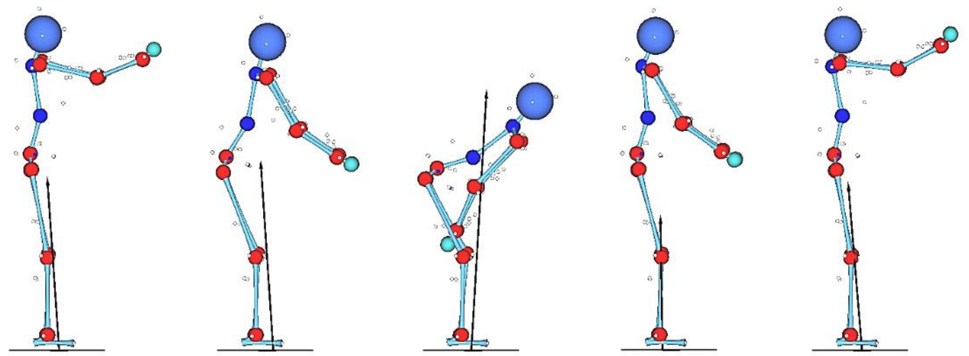
Body Segment	Linked Segments (Proximal-Distal)	Primary Axis	Secondary Axis (Temporary)	Anatomical Plane	Segmental Rotation Sequence
Pelvis	Pelvis-Abdomen; Pelvis-Thigh	+Z: Mid Hip to Mid Pelvis	+X: Joint left hip to joint right hip	Frontal	ZXY
Abdomen	Abdomen-Chest	+Z: Mid-Pelvis to Mid-Abdomen	-X: Mid right pelvis to Mid left pelvis	Frontal	XYZ
Chest	Chest-Upper Arm	+Z: Mid-Abdomen to Mid-Thorax	+Y: 7th cervical vertebrae to sternal notch	Sagittal	XYZ
Right Upper Arm	Right Upper Arm-Right Forearm	-Z: Shoulder JC to Elbow JC	+X: Shoulder JC to Upper Arm 1 marker	Frontal	XYZ
Right Forearm	Right Forearm-Right Hand	-Z: Elbow JC to Wrist JC	+X: Elbow JC to Lateral epicondyle of the elbow	Sagittal	XYZ
Right Hand	N/A	-Z: Wrist JC to Hand marker	+X: Lateral-Hand marker to Medial-Hand marker	Frontal	XYZ
Left Upper Arm	Left Upper Arm-Left Forearm	-Z: Shoulder JC to Elbow JC	-X: Shoulder JC to Upper Arm 1 marker	Frontal	XYZ
Left Forearm	Left Forearm-Left Hand	-Z: Elbow JC to Wrist JC	+X: Elbow JC to Medial epicondyle of the elbow	Frontal	XYZ

Body Segment	Linked Segments (Proximal-Distal)	Primary Axis	Secondary Axis (Temporary)	Anatomical Plane	Segmental Rotation Sequence
Left Hand	N/A	-Z: Wrist JC to Hand marker	-X: Lateral-Hand marker to Medial-Hand marker	Frontal	XYZ
Right Thigh	Right Thigh-Right Shank	-Z: Hip JC to Knee JC	+X: Hip JC to Lateral epicondyle of the knee	Frontal	XYZ
Right Shank	Right Shank-Right Foot	-Z: Knee JC to Ankle JC	+X: Knee JC to Lateral epicondyle of the knee	Frontal	XYZ
Right Foot	N/A	-Z: Ankle JC to Toe marker	-Y: Ankle JC to Heel marker	Sagittal	XYZ
Left Thigh	Left Thigh-Left Shank	-Z: Hip JC to Knee JC	-X: Hip JC to Lateral epicondyle of the knee	Frontal	XYZ
Left Shank	Left Shank-Left Foot	-Z: Knee JC to Ankle JC	-X: Knee JC to Lateral epicondyle of the knee	Frontal	XYZ
Left Foot	N/A	-Z: Ankle JC to Toe marker	-Y: Ankle JC to Heel marker	Sagittal	XYZ
Head	N/A	+Z: Head Center to Top-Head marker	+X: Left Head marker to Right Head marker	Frontal	XYZ

Note. JC (Joint Center) and N/A – not available.

Figure 1

Pictorial Depiction of Events During a KBS Exercise



Note. DT- downward transition and UT – upward transition.

Variable Calculations

The orientation (attitude) matrix of each segment relative to its linked proximal segment was decomposed into three consecutive rotation angles (e.g., XYZ rotational sequence):

$$\boldsymbol{T}_{xyz} = \boldsymbol{T}_z \cdot \boldsymbol{T}_y \cdot \boldsymbol{T}_x \ (1)$$

$$= \begin{bmatrix} \cos\theta_3 & \sin\theta_3 & 0 \\ -\sin\theta_3 & \cos\theta_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\theta_2 & 0 & -\sin\theta_2 \\ 0 & 1 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_1 & \sin\theta_1 \\ 0 & -\sin\theta_1 & \cos\theta_1 \end{bmatrix} \ (2)$$

$$= \begin{bmatrix} \cos\theta_2\cos\theta_3 & \sin\theta_1\sin\theta_2\cos\theta_3 + \cos\theta_1\sin\theta_3 & -\cos\theta_1\sin\theta_2\cos\theta_3 + \sin\theta_1\sin\theta_3 \\ -\cos\theta_2\sin\theta_3 & -\sin\theta_1\sin\theta_2\sin\theta_3 + \cos\theta_1\cos\theta_3 & \cos\theta_1\sin\theta_2\sin\theta_3 + \sin\theta_1\cos\theta_3 \\ \sin\theta_2 & -\sin\theta_1\cos\theta_2 & \cos\theta_1\cos\theta_2 \end{bmatrix} \ (3)$$

where θ_1, θ_2, and θ_3 are the rotation angles about each individual axis. As no joint reached the gimbal lock position ($\theta_2 = \pm 90°$), the orientation angles were computed from Equation 3.

The angular velocities for the segments for an XYZ rotation sequence were as follows:

$$\boldsymbol{\omega}_i = \begin{bmatrix} \cos\theta_3 & \sin\theta_3 & 0 \\ -\sin\theta_3 & \cos\theta_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\theta_2 & 0 & -\sin\theta_2 \\ 0 & 1 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix} \cdot \begin{bmatrix} \dot{\theta}_1 \\ 0 \\ 0 \end{bmatrix}$$

$$+\begin{bmatrix}\cos\theta_3 & \sin\theta_3 & 0\\ -\sin\theta_3 & \cos\theta_3 & 0\\ 0 & 0 & 1\end{bmatrix}\cdot\begin{bmatrix}0\\ \dot{\theta}_2\\ 0\end{bmatrix}+\begin{bmatrix}0\\ 0\\ \dot{\theta}_3\end{bmatrix}$$

$$=\begin{bmatrix}\cos\theta_2\cos\theta_3 & \sin\theta_3 & -\sin\theta_2\cos\theta_3\\ -\cos\theta_2\sin\theta_3 & \cos\theta_3 & \sin\theta_2\sin\theta_3\\ \sin\theta_2 & 0 & \cos\theta_2\end{bmatrix}\cdot\begin{bmatrix}\dot{\theta}_1\\ 0\\ 0\end{bmatrix}+\begin{bmatrix}\cos\theta_3 & \sin\theta_3 & 0\\ -\sin\theta_3 & \cos\theta_3 & 0\\ 0 & 0 & 1\end{bmatrix}\cdot\begin{bmatrix}0\\ \dot{\theta}_2\\ 0\end{bmatrix}+\begin{bmatrix}0\\ 0\\ \dot{\theta}_3\end{bmatrix}\quad(4)$$

where $\boldsymbol{\omega}_i$ denoted the angular velocity of a segment to its linked proximal segment, θ_1, θ_2, and θ_3 were the orientation angles of the segment (relative to a linked proximal segment), and $\dot{\theta}_1$, $\dot{\theta}_2$, and $\dot{\theta}_3$ were the time derivative of the orientation angles. The relative angular velocity was added by the angular velocity of the proximal segment to yield the angular velocity of the given segment.

To calculate the resultant joint force and moment, inverse dynamics were utilized:

$$\mathbf{F} = \sum_{i=1}^{n}\frac{d\mathbf{P_i}}{dt} - \sum_{i=1}^{n}\mathbf{W}_\mathrm{i} - \mathbf{F}_E \quad (5)$$

$$\mathbf{M} = \sum_{i=1}^{n}\left(\frac{d\mathbf{H}_i}{dt} + \boldsymbol{r_{ji}} \times \frac{d\mathbf{P}_\mathrm{i}}{dt}\right) - \sum_{i=1}^{n}\left(\mathbf{r}_{ji} \times \mathbf{W}_\mathrm{i}\right) - \left(\mathbf{r}_\mathrm{je} \times \mathbf{F}_\mathrm{e} + \mathbf{M}_\mathrm{e}\right) \quad (6)$$

where **F** was denoted as the resultant joint force (RJF) of a given joint, $\frac{\mathrm{d}\mathbf{P_i}}{\mathrm{dt}}$ was the time derivative of the linear momentum of each body segment, $\mathbf{W}_\mathrm{i}$ was the weight acting at the COM of each body segment, $\mathbf{F}_\mathrm{E}$ was the GRF, **M** was the RJM, $\frac{\mathrm{d}\mathbf{H}_\mathrm{i}}{\mathrm{dt}}$ was the time derivative of local angular momentum due to the rotation of the segment about its own COM, $\mathbf{r_{ji}}$ was the position vector drawn from a joint center to a segment's COM, $\mathbf{r_{ji}} \times \frac{\mathrm{d}\mathbf{P}_\mathrm{i}}{\mathrm{dt}}$ was the time-derivative of the remote angular momentum due to the revolution of a segment about the joint, $\mathbf{r}_\mathrm{ji} \times \mathbf{W}_\mathrm{i}$ was the torque produced by each segment's weight, $\mathbf{r}_\mathrm{je}$ was the position vector drawn from a joint center to the center of pressure, and $\mathbf{M}_\mathrm{e}$ was the free moment acting at the center of pressure. The components of RJM were calculated by using the joint-coordinate system formed by three consecutive rotation axes (JCS; Grood & Suntay, 1983).

Muscular power (work rate) was calculated by the dot product multiplication of the RJM of a joint and the difference in angular velocity of the proximal and distal segments:

$$P_{MW} = \mathbf{M}_i * (\boldsymbol{\omega}_d - \boldsymbol{\omega}_p) \ (7)$$

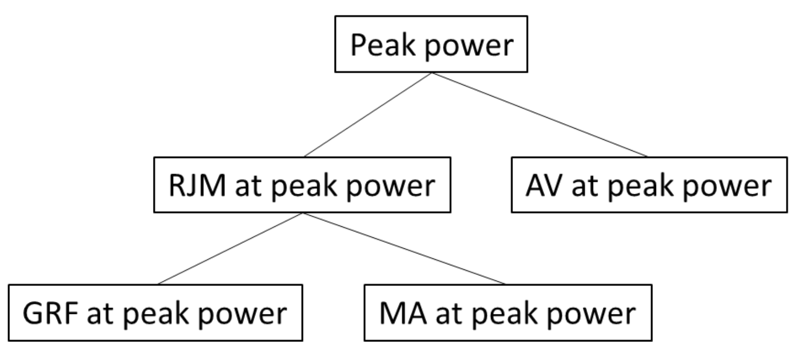
where P_{MW} represented the muscular power (work rate) about a joint, $\mathbf{M}_i$ was the RJM acting at the distal segment at the joint, $\boldsymbol{\omega}_p$ was the angular velocity of the proximal segment, and $\boldsymbol{\omega}_d$ was the angular velocity of the distal segment. The RJM and muscular work rate (power) data were normalized to the participant's body mass. GRFs were normalized to the participant's body weight. The generalized ensemble-average patterns were generated for the within and across rounds by combining the trials of all participants using Start and End as the 0% and 100% time points, respectively. For statistical testing, the following kinetic variables were extracted: a) normalized peak power, b) normalized sagittal plane RJMs, c) normalized RJMs at peak power, and d) normalized peak sagittal plane GRF. The following kinematic variables were also extracted: a) peak extension angular velocities (AV), b) peak extension velocities at their respective peak powers, and c) the average swing duration.

Statistical Analysis

An *a priori* statistical testing for power using G*Power (Faul et al., 2007) calculated that a total of 24 participants were suggested for recruitment. The independent variables used in this study were time within a round (early vs late) and time across rounds (1 vs 5 vs 9). The dependent variables include both kinematic variables (AV and average swing duration) and kinetic variables (GRF, RJM, and power). Statistical testing was performed with two main approaches: a global approach and a deterministic approach. A 2x3 repeated-measures analysis of variance (RM-ANOVA) was performed on swing duration. Another RM-ANOVA was utilized to examine peak sagittal plane GRF values. A 2x3 repeated-measures multivariate analysis of variance (RM-MANOVA) was used to examine peak normalized RJM values at each joint (hip, knee, and ankle). A second RM-MANOVA was used to examine peak AV values at each joint (hip, knee, and ankle). A third RM-MANOVA was used to examine peak power values across all joints (hip, knee, and ankle). The level of significance was set at 0.05. Bonferroni corrections were made for *post-hoc* analysis. In the deterministic approach, if a variable was found to be statistically significant, explanatory analysis was utilized to examine what may have caused the difference. This was performed only on variables that were computed from others (i.e., power is calculated as torque times angular velocity; see Figure 2). Variables that are not calculated from others are excluded from this deterministic approach (e.g., GRF). Explanatory analysis results utilized a level of significance set at 0.05, with Bonferroni corrections made for *post-hoc* analysis. If a variable violates the assumption of sphericity, a Greenhouse-Geisser correction was utilized. All statistical testing were performed using SPSS v.25 (International Business Machines, Armonk, NY, USA).

Figure 2

Logic Tree Example of Deterministic Statistical Analysis Approach



CHAPTER IV

RESULTS

No within-round*across-round interaction was observed for swing duration ($F_{(2,30)}$ = 2.903, p = 0.070, η_p^2 = 0.162). When adjusted, a significant within-round effect for swing duration was observed ($F_{(1,15)}$ = 25.720, p < 0.001, η_p^2 = 0.632). However, swing duration was not significant across rounds ($F_{(2,30)}$ = 2.820, p = 0.075, η_p^2 = 0.158). The swing duration was shorter in the earlier in the round compared to later within the round (p < 0.001; see Table 4).

Table 4

Average Swing Duration (mean ± S.D.; in s)

	Within Round Condition	Across Round Condition			
		Round 1	Round 5	Round 9	Combined
Swing duration	Early	1.49 ± 0.07	1.50 ± 0.07	1.51 ± 0.06	1.50 ± 0.02
	Late	1.51 ± 0.06	1.54 ± 0.07	1.55 ± 0.07	1.54 ± 0.01*
	Combined	1.50 ± 0.02	1.52 ± 0.02	1.53 ± 0.02	

Note. * significantly different from early within round (p < 0.001).

No significant within-round*across-round interaction was observed for normalized peak sagittal plane GRF ($F_{(2,30)}$ = 0.861, p = 0.433, η_p^2 = 0.054). A significant within-round effect was observed in the normalized peak sagittal plane GRF ($F_{(1,15)}$ = 4.692, p = 0.047, η_p^2 = 0.238). No across-round effect for GRF was observed ($F_{(2,30)}$ = 0.245, p = 0.784, η_p^2 = 0.016). Larger normalized sagittal plane GRF values were observed later in the round compared to earlier (see Table 5).

Table 5

Normalized Peak Sagittal Plane GRF (mean ± S.D.; in N/N)

	Within Round Condition	Across Round Condition			
		Round 1	Round 5	Round 9	Combined
GRF	Early	1.75 ± 0.11	1.77 ± 0.19	1.76 ± 0.19	1.76 ± 0.04
	Late	1.78 ± 0.13	1.78 ± 0.22	1.80 ± 0.21	1.79 ± 0.04*
	Combined	1.77 ± 0.03	1.78 ± 0.05	1.78 ± 0.05	

Note. * significantly different from early within round (p = 0.047). GRF – ground reaction force.

No within*across-round interaction for peak lower extremity joint angular velocities (Wilk's lambda [Λ] = 0.431, $F_{(6,10)}$ = 2.198, p = 0.130, η_p^2 = 0.569). The within-round effect was not significant (Wilk's lambda [Λ] = 0.569, $F_{(3,13)}$ = 3.284, p = 0.055, η_p^2 = 0.431). The across-round effect was also not significant (Wilk's lambda [Λ] = 0.765, $F_{(6,10)}$ = 0.511, p = 0.787, η_p^2 = 0.235; see Table 6).

Table 6

Peak Angular Velocity for the Lower Body Joints (mean ± S.D.; in deg/s)

Joint	Within Round Condition	Across Round Condition			
		Round 1	Round 5	Round 9	Combined
Hip	Early	-260.4 ± 36.4	-267.7 ± 45.0	-271.0 ± 51.2	-266.4 ± 10.5
	Late	-263.1 ± 40.6	-258.7 ± 46.1	-259.4 ± 51.2	-260.4 ± 10.9
	Combined	-261.7 ± 9.3	-263.2 ± 11.3	-265.2 ± 12.6	
Knee	Early	113.6 ± 39.9	126.7 ± 40.4	127.2 ± 47.0	122.5 ± 10.0

Joint	Within Round Condition	Across Round Condition			
		Round 1	Round 5	Round 9	Combined
	Late	123.2 ± 46.6	124.8 ± 47.8	134 ± 51.1	127.3 ± 11.1
	Combined	118.4 ± 10.5	125.8 ± 11.0	130.6 ± 12.1	
	Early	-35.7 ± 15.9	-41.6 ± 17.1	-41.8 ± 18.1	-39.7 ± 3.4
Ankle	Late	-40.8 ± 19.0	-40.0 ± 20.7	-44.4 ± 21.9	-41.7 ± 4.5
	Combined	-38.2 ± 4.3	-40.8 ± 4.6	-43.1 ± 4.9	

No within*across-round interaction for peak normalized RJM of the lower extremity joints was observed (Wilk's lambda [Λ] = 0.515, $F_{(6,10)}$ = 1.569, p = 0.252, η_p^2 = 0.485). No significant within-round effect (Wilk's lambda [Λ] = 0.645, $F_{(3,13)}$ = 2.390, p = 0.116, η_p^2 = 0.355) or across-round effect were observed for peak RJMs (Wilk's lambda [Λ] = 0.501, $F_{(6,10)}$ = 1.663, p = 0.227, η_p^2 = 0.499; see Table 7).

Table 7

Peak Normalized RJM for the Lower Body Joints (mean ± S.D.; in Nm/kg)

Joint	Within Round Condition	Across Round Condition			
		Round 1	Round 5	Round 9	Combined
	Early	-2.6 ± 0.3	-2.6 ± 0.4	-2.6 ± 0.4	-2.6 ± 0.1
Hip	Late	-2.6 ± 0.4	-2.7 ± 0.5	-2.6 ± 0.5	-2.6 ± 0.1
	Combined	-2.6 ± 0.1	-2.6 ± 0.1	-2.6 ± 0.1	
Knee	Early	-0.07 ± 0.5	-0.04 ± 0.44	-0.02 ± 0.5	-0.04 ± 0.1

Joint	Within Round Condition	Across Round Condition			
		Round 1	Round 5	Round 9	Combined
	Late	-0.11 ± 0.5	-0.02 ± 0.5	0.01 ± 0.5	-0.04 ± 0.1
	Combined	-0.09 ± 0.1	-0.03 ± 0.1	-0.002 ± 0.1	
Ankle	Early	-0.7 ± 0.2	-0.7 ± 0.1	-0.7 ± 0.1	-0.7 ± 0.03
	Late	-0.7 ± 0.2	-0.6 ± 0.2	-0.7 ± 0.2	-0.7 ± 0.04
	Combined	-0.7 ± 0.04	-0.7 ± 0.04	-0.7 ± 0.04	

No significant within*across-round interaction for peak normalized powers of the lower extremity joints (Wilk's lambda [Λ] = 0.541, $F_{(6,10)}$ = 1.412, p = 0.300, η_p^2 = 0.459). When the main effects were examined, peak normalized power of the lower extremity joints was significant (Wilk's lambda [Λ] = 0.517, $F_{(3,13)}$ = 4.045, p = 0.031, η_p^2 = 0.483). A significant within-round effect at the hip (p = 0.004), but not in the knee (p = 0.270) and ankle (p = 0.671), was observed. The early condition showed larger normalized hip joint power when compared to the late condition. No significant across-round effect was observed for peak normalized joint powers (Wilk's lambda [Λ] = 0.527, $F_{(6,10)}$ = 1.493, p = 0.274, η_p^2 = 0.473; see Table 8).

Table 8

Normalized Peak Mechanical Power Values (mean ± S.D.; in W/kg)

Joint	Within Round Condition	Across Round Condition			
		Round 1	Round 5	Round 9	Combined
Hip	Early	6.7 ± 1.4	6.5 ± 1.4	6.4 ± 1.6	6.6 ± 0.3
	Late	6.4 ± 1.5	6.2 ±1.4	6.0 ± 1.4	6.2 ± 0.3*
	Combined	6.5 ± 0.4	6.4 ± 0.3	6.2 ± 0.4	
Knee	Early	0.4 ± 0.3	0.4 ± 0.3	0.5 ± 0.3	0.4 ± 0.1
	Late	0.4 ± 0.3	0.4 ± 0.3	0.5 ± 0.4	0.4 ± 0.1
	Combined	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	
Ankle	Early	0.3 ± 0.2	0.3 ± 0.2	0.3 ± 0.2	0.3 ± 0.04
	Late	0.3 ± 0.2	0.3 ± 0.2	0.3 ± 0.2	0.3 ± 0.04
	Combined	0.3 ± 0.04	0.3 ± 0.05	0.3 ± 0.04	

Note. * significantly different from early within round (p = 0.004).

The explanatory analysis was conducted for the hip joint power only, and the knee and ankle joints were excluded due to lack of statistical significance in the global perspective of power. No within*across-round interaction (Wilk's lambda [Λ] = 0.651, $F_{(4,12)}$ = 1.611, p = 0.235, η_p^2 = 0.349) was observed. A significant within-round effect was observed (Wilk's lambda [Λ] = 0.514, $F_{(2,14)}$ = 6.616, p = 0.009, η_p^2 = 0.486), and a significant within-round effect in the AV at peak power of the hip joint (p = 0.004), but not for RJM at peak power at the hip joint (p = 0.159), was observed. The AV at peak power was larger in the early condition than the late condition. No across-round effect was observed (Wilk's lambda [Λ] = 0.823, $F_{(4,12)}$ = 0.647, *p* = 0.648, η_p^2 = 0.177; see Table 9).

Table 9

Explanatory Analysis of Right Hip Joint Peak Power (mean ± S.D.)

Variable	Within Round Condition	Across Round Condition			
		Round 1	Round 5	Round 9	Combined
RJM at Peak Power (Nm/kg)	Early	-1.81 ± 0.24	-1.77 ± 0.24	-1.75 ± 0.29	-1.78 ± 0.06
	Late	-1.75 ± 0.27	-1.77 ± 0.26	-1.73 ± 0.26	-1.75 ± 0.06
	Combined	-1.79 ± 0.06	-1.77 ± 0.06	-1.74 ± 0.07	
AV at Peak Power (deg/s)	Early	-229.0 ± 30.1	-233.5 ± 41.1	-232.5 ± 40.6	-231.7 ± 8.9
	Late	-229.8 ± 38.1	-221.9 ± 38.7	-219.7 ± 38.9	-223.8 ± 9.2*
	Combined	-229.4 ± 8.3	-227.7 ± 9.8	-226.1 ± 9.8	

Note. * indicates a statistical difference from early within round (*p* = 0.004).

CHAPTER V

DISCUSSION

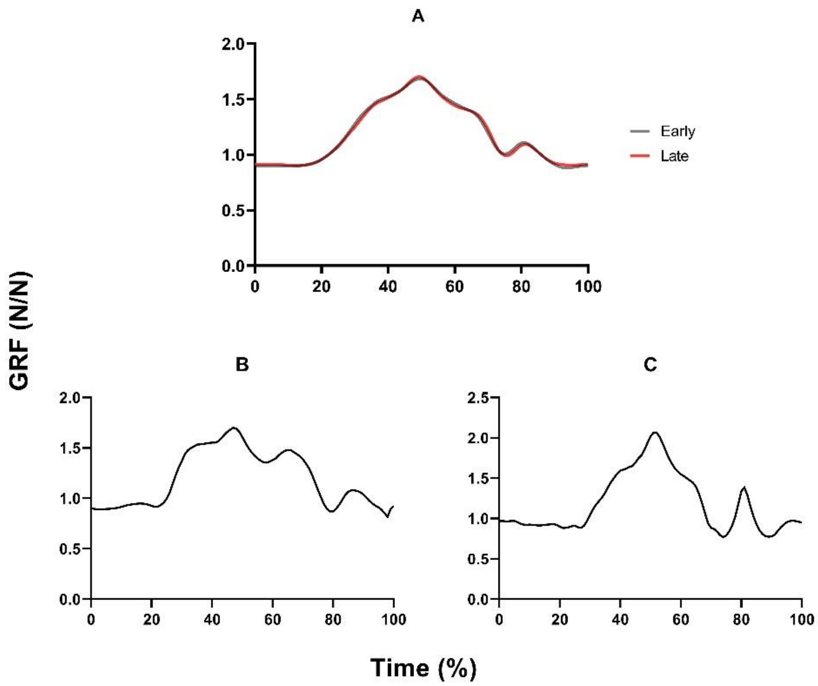
The primary purpose of this study was to examine the biomechanical effects of a repeated KBS bout on lower-body joint kinematics (swing duration and segmental AVs of the hip, knee, ankle) and kinetics (power, RJM and GRF) in recreationally active young adult males utilizing a dual analysis strategy. Global measures were first examined, and a deterministic approach implemented to examine the individual components that made up the global variable when applicable. A total of 17 were recruited and finished the experimental protocol, but one was removed due to equipment error. A total of 16 participants were utilized in the in the results section. Following data collection, processing and statistical testing, an *a posteriori* analysis was performed. Using the values obtained in the results section, a sample size of 10 was calculated. The sample size calculations differ due to the conservative estimate on effect size utilized in the *a priori* sample size calculation. The *a priori* calculation utilized a medium effect size value, while the data from statistical calculations had a large effect size.

There was an increase in swing duration within a trial, but no difference was observed across rounds (see Table 4). Swing duration was calculated as the difference in time from the End event and the Start event. While a statistical difference was present, and was approximately four tenths of a second. This difference may be partially explained by the fact that no metronome was used to control KBS cadence. The KBS duration in the present study was slower when compared to swing duration calculated elsewhere (Bullock et al., 2017). This might be explained due to a difference in methodology. Bullock et al. (2017) had participants perform only a set amount of KBSs (i.e., 10 repetitions) followed by a self-selected rest period to minimize participant’s fatigue. In the current study, participants were required to perform at least 15 repetitions per round. Rest periods were limited and may have impacted the ability to maintain a small swing duration (i.e., faster swing speed; see Table 5) due to an increase in overall fatigue (i.e., increased RPE scores; see Table 2). Additional factors that may affect KBS duration include incorporating a metronome and kettlebell mass. Typically, a KBS routine will not include a metronome, and a focus on swing height is used as the criteria for performance (e.g., kettlebell height must maintain shoulder height; Bullock et al., 2017; Levine et al., 2020). A heavier kettlebell may increase the speed of the downward portion of the KBS (see Figure 1; Start-Halfway) due to the body's inherent kinematically linked-chain system, and the additional mass accelerating the downward motion versus the use of a lighter mass. The kettlebell mass in this study was relative to each participant (i.e., 20% of body mass), whereas others have utilized an absolute mass that was closer to 30% of the sample's mean body mass (Bullock et al., 2017). This may explain the shorter swing duration observed in previous research compared to the current study. Further research is required to examine if KBS cadence, swing height, or kettlebell mass effects KBS duration.

Normalized sagittal plane GRF values were higher in the late portion of the round compared to the early portion. GRF reflects the magnitude and direction of a push on a force plate. A consistent pattern emerged in the later rounds, as participants appeared to push harder, which may have been evidence of fatigue. A common definition of a fatigued state is indicated by a decrease in force as fatigue progresses (Sargeant, 1994; Taylor et al., 2017). While in a fatigued state, the magnitude of GRFs may be increased, decreased, or relatively constant, depending on the type of movement (Zadpoor & Nikooyan, 2012). When an increase in the magnitude of GRF is observed, the individual should be cautious for other signs of fatigue, as it can be an indicator for increased chance of injury (Zadpoor & Nikooyan, 2012). During the late portion, participants exhibited a higher magnitude of push against the ground to maintain the swing height requirement. The magnitude of GRFs in this study were comparable to previous research when a relative load was implemented (Levine et al., 2020), and lower when using an absolute load (Bullock et al., 2017; Lake & Lauder, 2012b). Compared to previous research, the ensemble average sagittal plane GRF in this study differed (see Figure 3A; Lake & Lauder, 2012b; Levine et al., 2020). Upon further analysis, two distinct GRF profiles emerged. One approach the subjects utilized was a "spread" approach (*n* = 6; see Figure 3B) while the other approach was a "spike" approach (*n* = 10; see Figure 3C). The spread approach would have two to three GRF peaks in a single swing, and max GRF would occur early on in the swing. This was due to participants actively slowing down the kettlebell. A max peak would occur slightly after the Halfway event (see Figure 1) to propel the kettlebell upwards. Most of the subjects utilized the spike approach, in which the maximum GRF would peak approximately at the Halfway event. The GRF profiles of skilled kettlebell users should be further examined to determine if one approach is superior to another.

Figure 3

Ensemble Average Pattern for Normalized Sagittal Plane GRF



Note. Time is percentage of one swing cycle (ST-END). A - all participants' patterns combine for the Early and Late condition, B - an example of the 'spread' GRF pattern, C - and example of the 'spike' GRF pattern. Note: the examples provided are from two different participants, but are taken from the same swing and same condition (e.g., round 5, late, 3rd swing).

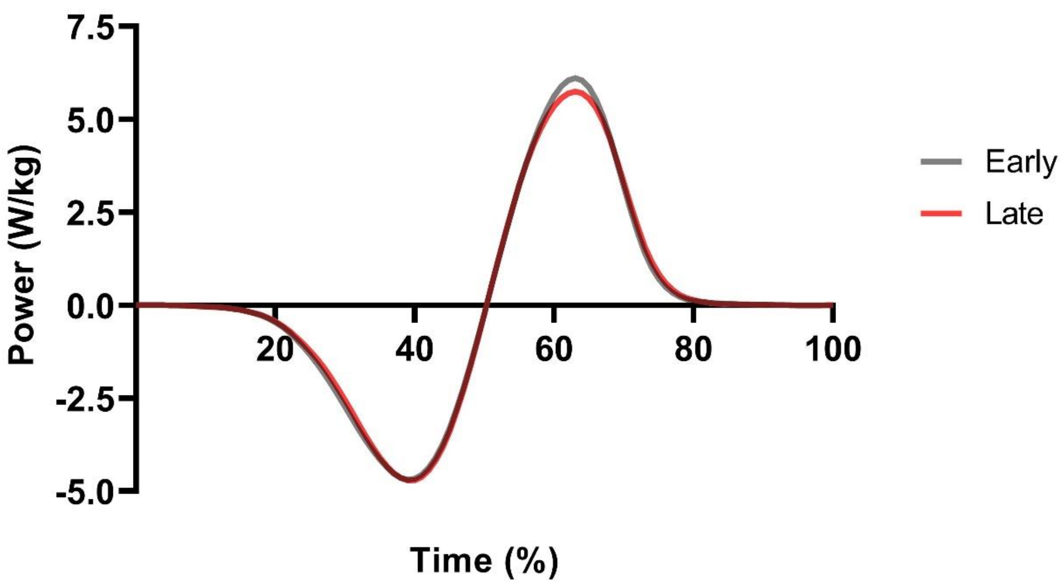
Normalized sagittal plane hip power was higher in the early portion of the round compared to the late portion of the round. The ensemble average patterns for mechanical hip joint power (Equation 7) show a large, negative trend (eccentric contraction) followed by a large, positive power generation (concentric contraction; see Figure 4). With an eccentric contraction followed by a concentric contraction, the power pattern exhibits the stretch shortening cycle

(SSC; Komi, 2000; Sargeant, 1994). It is well known that incorporating the SSC may help decrease the onset of muscular fatigue (Komi, 2000; Sargeant, 1994).

The hip-hinge style KBS is characterized as a rapid, ballistic movement (Levine et al., 2020; McGill & Marshall, 2012; Van Gelder et al., 2015). This swing style may allow for the muscles to rapidly contract and relax, which may remove muscle metabolites faster (Keilman et al., 2017). The removal of these by-products may reduce the onset of fatigue and maintain mechanical power output, which may help to extend exercise performance (Bullock et al., 2017; Komi, 2000; Lake & Lauder, 2012b, 2012a; Maulit et al., 2017).

Figure 4

Ensemble Average Patterns for Sagittal Plane Normalized Mechanical Hip Power



Note. W- Watts, kg- kilograms.

The research hypothesis of decreased power across rounds was not supported. This may be due to the conditioning, the KBS experience level of the participants recruited for this study, the study design (i.e., the total number of rounds), or the amount of resistance used. For highly experienced, recreationally active adult males, this protocol can provide a way to consistently elicit large mechanical power out of the hip musculature. A relative kettlebell load (i.e., 20% of body mass) was used in this study, which differs from previous studies in which a fixed load, regardless of participant size, was typically used (Bullock et al., 2017; Lake & Lauder, 2012b; McGill & Marshall, 2012). The current protocol may not be exhaustive enough to elicit stronger fatigue responses in this particular population (i.e., 'advanced' recreationally trained men with KBS experience). This can be modified by manipulating the duration (e.g., 12 rounds), resistance (e.g., 25% of body mass), timing (e.g., 30 s of swing followed by 15 s of rest), or a combination of these.

Exploratory analysis revealed a decrease in AV at the instant of peak mechanical power of the hip joint (see Table 9). This only occurred within a round, as AV values were higher in the early portion of the round compared to the late portion of the round. The magnitude of the AV values observed in this study are less than those in previous work (Bullock et al., 2017). This may be due to the differences in the load utilized (absolute versus relative). The decrease in AV at the instant of peak mechanical power is consistent with various definitions of fatigue (i.e., a decrease in the speed of a movement; Komi, 2000; Sanchez-Medina & Gonzalez-Badillo, 2011; Sargeant, 1994). As there was no observed difference in the RJM at peak mechanical power at the hip joint, the contributing factor to decreased mechanical power is due to the decrease in AV (Equation 7).

Although the research hypotheses were not well supported, there is benefits to the current research design. RJM was not found statistically significant in both the global approach (see Table 7) and in the deterministic approach (see Table 9), but participants were able to generate large amounts of torque, primarily at the hip, with the least amount acting at the knee (see Table 7). This remains consistent with previous literature examining sagittal plane RJM values at lower-body joints during a KBS (Bullock et al., 2017; Levine et al., 2020). Additionally, participants were able to output higher RJM values at the hip at the beginning of the protocol and maintain higher hip RJM values throughout the protocol; when compared to more acute experimental protocols with extended breaks (Bullock et al., 2017; Levine et al., 2020). Even with a decrease in power within a round, increased GRF and swing duration, some of the changes are small. Given the changes occur only within a round and not across rounds, this population of participants may benefit from the protocol. Participants on average performed almost 200 KBS (see Table 1) in a matter of 10 minutes, with minimal drop off in power at the hips, and without decreasing RJM at the hips. Therefore, strength and conditioning coaches interested in trying to maintain large amounts of RJM and power-maintenance throughout an exercise duration may want to consider this protocol.

Limitations to the study include no use of a metronome, participant inclusion, and the load utilized. The lack of a metronome might have affected KBS timing. Future research should be completed to examine if swing height or swing cadence differ on hip-hinge KBS performance. This current study was restricted to males who had at least 3 years of resistance training experience and who had at least 24 sessions of KBS experience (i.e., at least 3 sets of 20 or more swings/set). An increase in RPE was observed in the KBS protocol with these participants, which should have negatively impacted affected exercise performance, as was observed previous literature (Budnar et al., 2014; Knicker et al., 2011). A decrease in performance was not observed in this study, as swing count remained relatively consistent (see Table 1). This could indicate a stronger fatiguing protocol may be required for this specific population, and may not be the same for less experienced individuals or females. The load for this study utilized was approximately 20% of body mass and may not have been sufficient to obtain a true fatigue response (e.g., a decrease in torque production) in this population. Future research should be conducted to examine if a load of more than 20% of body mass would elicit a fatigue response while also examining upper-body mechanics during a KBS. Upper-body motion kinematics and kinetics related to the KBS should be examined. While the KBS is a full-body exercise, the emphasis is placed on the lower-body movement and the upper-body is supposed to be semi-rigid (e.g., a rigid trunk but shoulders are allowed to move). Due to the linked body segments, there is enough description on lower-body biomechanics that warrants upper-body investigation to obtain the full picture of the KBS. Additionally, this study should be replicated with highly experienced resistance trained females to examine potential fatigue effects during a repeated maximum effort protocol. Females were initially excluded from this study due to a potential increase in injury risk when they are fatigued (Kernozek et al., 2008). Due to limited biomechanical research on this particular KBS protocol, only highly experienced (both resistance and KBS) recreationally active males were utilized in the current study.

CHAPTER VI

CONCLUSION

The primary purpose of this study was to examine the biomechanical effects of the lower-body joints during a repeated maximum effort KBS protocol utilizing the hip-hinge KBS technique in recreationally active males.

- Swing duration increased (i.e., each swing took longer).
- Normalized sagittal plane GRF increased within a round. Caution should be taken as an increase in GRF and fatigue both may be a concern for an increase chance of injury.
- Normalized sagittal plane hip power was different early in the round compared to late in the round. No differences were observed across rounds.
- Angular velocity at the instant of peak mechanical power was lower later in the round when compared to earlier in the round.
- Since the RJM at the instant of peak mechanical power was not significant, the primary factor effecting mechanical power was a decrease in angular velocity later in the round.
- Strength and conditioning coaches and experienced (resistance trained and KBS trained) males looking to target hip musculature may benefit from this protocol as it allows for minimal drop off in KBS performance and outputs large torque and power generation over an extended period.

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APPENDIX A

INFORMED CONSENT

TEXAS WOMAN'S UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Title: **Biomechanical effects of repeated maximum effort kettlebell swings on lowerbody joints**

Principal Investigator: Nicholas Levine……..……………………………...940-898-2618

Research Advisor: Young-Hoo Kwon, Ph.D.………………………………940-898-2598

Explanation and Purpose of the Research

The kettlebell is a piece of equipment that has shown to have various positive cardiovascular outcomes based on longer duration kettlebell swing exercise protocols. Additionally, even shorter more intense duration protocols have been examined with again, positive cardiovascular adaptations. Biomechanically speaking, research into the kettlebell swing exercise has increased. But these studies have examined the kettlebell swing into a small window, usually one swing is examined. Additionally, the participants would perform about 10 swings and are allowed rest. This however, is not a common training routine when performing the kettlebell swing. It is important to understand the underlying mechanics that may increase their chance for potential injury. Therefore, the purpose of this study is to evaluate forces acting on lower body joints during a repeated maximum effort kettlebell swing protocol. You have been asked to participate in this study because you identified yourself as a potential participant that meets the inclusion criteria for this study.

Key Information

You are asked to participate in a repeated maximum effort kettlebell swing protocol. This is to examine the effects of the lower-body joint forces during this style of exercise. You will be asked to perform 10 rounds of a 1:1 work-to-rest ratio. This means, in a 30s time limit you will be asked to perform as many hip-hinge kettlebell swings that you can, with a kettlebell the weighs approximately 20% of your body mass. Upon the 30s of work, you will place the kettlebell on the ground and rest for 30s. After the 30s rest period, another round will begin. A total time commitment on up to two hours will be spread over two meetings. One hour maximum for the first meeting (screening, consent, and familiarization) and one hour maximum for data collection (warm-up, marker placement, exercise protocol, and cool down). Major risk for this study includes: injury, fatigue, and COVID-19. This study will be conducted in the Motion Analysis Laboratory (PH 124) on the Texas Woman's University Denton campus. There are no monetary benefits for participating in this study, but if requested study results can be sent to you.

Description of Procedures

You will be asked to read, fill out and sign this informed consent prior to the initiation of the study in the PH 123, Biomechanics Laboratory in Texas Woman's University. The principal investigator will record your age, height and weight. You will then enter the Motion Analysis Laboratory (PH 124) and be requested to change into specific clothing required for biomechanical research – close fitting, dark spandex material. Spandex shorts will be available to you if you do not have your own (recommended). A separate preparation room will be provided for you to change clothes. Fully shaving your chest hair is not required, but if hair impedes marker placement, then a local shave will be performed. Prior to you showing up, a trimmer will be cleaned with an alcohol pad. Your hair will be trimmed and cleaned with an alcohol pad prior to marker placement. Additionally, please refrain from using lotion prior to data collection.

As a safety precaution, the principal investigator will take you through a brief warm-up focused primarily on hip musculature. The warm-up will include two sets of ten body weight squats, and dynamic hip stretches. If you still want to, you may perform a warmup based on your own comfort level, such as stretching, before the data collection to assure that the core body temperature is raised and the muscles are prepared. Warming up your connective tissues reduces the possibility of injury and risk of premature fatigue.

All experimental procedures will be conducted in in the Motion Analysis Laboratory (PH 124). A real-time motion capture system will be used to capture the motions of kettlebell swings through the use of reflective markers placed on your body (see page 3). Data will be collected by force-plates (an instrument used to measure the forces generated by a body on standing or moving) during the kettlebell swing.

Reflective markers (10 mm diameter) will be placed on specific parts of your body so that each part is properly defined on the camera system to track the motion being recorded. A total of 60 reflective markers will be placed on anatomical markers (See diagram below).

When the motion capture system is ready for data collection, you will be asked to perform a static trial (standing in a T-pose with arms spread out laterally) to locate your joint centers. After the capture of the static trial is over, you will be asked to swing the kettlebell to approximately eye level, an external apparatus will be placed in front of you. The apparatus is two free standing squat racks are connected via string. This will be used to maintain kettlebell swing height throughout the data collection process. The work-torest ratio is defined as a 1-to-1 ratio. Meaning you will perform as many kettlebell swings in a 30s duration and then immediately get 30s of rest, this is considered one round. After the 30s of work, you will place the kettlebell down on the ground, in front of you. A total of ten rounds will be performed. The kettlebell mass used for the resistance will be 20% of your body mass (± 2% due to the variations in kettlebell weights).

At least 150 kettlebell swings will be performed, throughout the entire data collection (at least 15 swings/round). You will begin the trial with the weight in front, pick up the weight in the correct form, swing the weight until the 30s-time limit is up. You will then place the kettlebell on the ground and rest for 30s. Each trial will be initiated by the word “Go” in order to control the capture of motion. You will be able to rest between each round (a maximum of 30s) to limit fatigue and potential injury. If the fatigue becomes too much, you may request to stop at any time during the data collection process. Upon completion of all 10 rounds, you will perform a cool-down (walking around for 3-5 minutes at your own pace). Once the cool down is complete, the markers will be removed from your skin and you will go into the preparation room to place your regular clothes back on.

Time Commitment

1st Meeting: up to an hour maximum (Consent, kettlebell swing familiarization and screening)

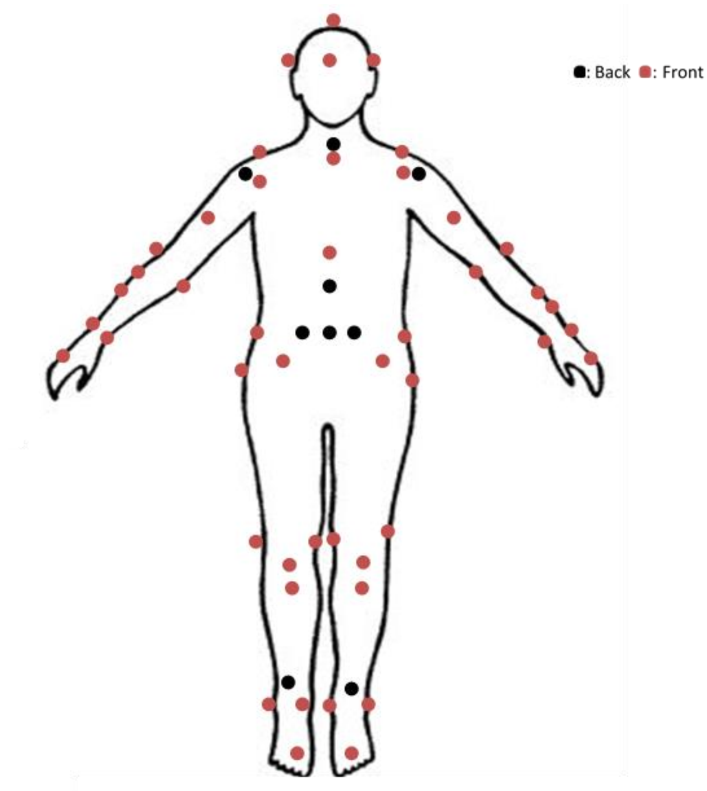
2nd Meeting (data collection): up to an hour maximum.

Data preparation: up to 30 minutes (includes warm-up and marker placement)

Data collection: approximately 10 minutes

Post data collection: up to 20 minutes (includes cool-down and marker removal)

Total: 1.5-2.0



Potential Risks

Coercion: Participation in this study is voluntary and you may withdraw at any time at your discretion. Your decision to participate or to not participate will not affect any current or future relationships with TWU or the School of Health Promotion and Kinesiology.

Loss of Anonymity: You will be assigned a personal identification number. It is possible that more than one researcher will be present at the same time. Participation in this study is voluntary, and you may withdrawal at any time at your discretion.

Loss of Confidentiality: All data will be coded and names of those in the study will not be used. Only the principal investigator, co-principal investigators, and faculty advisor will have access to your name and your associated ID number and these will be kept in a locked file in the Advisor's office on the Denton campus. To ensure your personal privacy, only your ID numbers will be used in the analysis.

Only primary research staff will have access to collected data, which will be labeled with your ID numbers to ensure participant confidentiality. All electronic data will be stored on computers located in the Motion Analysis Laboratory and the Biomechanics Laboratory Office (PH 123 & 124). These computers are all password protected. Confidentiality will be protected to the extent that is allowed by law. There is a potential risk of loss of confidentiality in all email, downloading, and internet transactions. Data will be destroyed within 3 years after study completion.

Muscle soreness: Muscle soreness will be minimized by having you warm-up and stretch at the beginning of the exercise and data collection session. If soreness persists, then you will be advised to seek medical attention. However, TWU does not provide medical services or financial assistance for injuries that might happen because of participation in the current research study. You may withdraw from the study.

Injury to a muscle or joint: Performing a kettlebell swing is a highly explosive activity and injury can occur. Potential of injury will be minimized by allowing a proper warm-up of your body. If you should feel uncomfortable with any of trials, you are free to discontinue your involvement in this research study. Every precaution will be taken by the researchers to prevent any injury or problem that could happen during the research study. If an injury should occur, all proper and necessary medical and/or first aid procedures will be followed as dictated by the type or extent of the injury.

Embarrassment: Data collection sessions could be attended by mixed genders, due to coinvestigators. No other participant or lab member other than those whose name is included in the research protocol will be present during data collection sessions. The researchers will try to prevent any embarrassment issues that may occur prior to incident. You will be advised to let the researchers know at once if there is a problem or if you are uncomfortable. Each practitioner will be instructed to assist you to meet your needs.

Fatigue: You may experience fatigue while performing the kettlebell swing. You will be allowed to rest in between trials if you feel tired (up to a maximum of 30s). Every effort will be made to ensure your safety during the time of data collection. If you express a desire to stop at any time, you will be allowed to do so without any penalty.

Shortness of breath, lightheadedness, nausea: During high intensity exercise, you may feel symptoms that include shortness of breath, lightheadedness, and/or nausea. If these symptoms appear, you must tell the primary researcher and data collection process will cease immediately. If needed, first aid will be available.

Cardiac or cerebrovascular event during high-intensity exercise: The overall risk of a cardiac or cerebrovascular event has been estimated at 6 in 10,000 during high-intensity, maximal exercise tests among healthy individuals and individuals with a known cardiovascular disease (Gibbons et al., 1980). Additional risks that may occur include heart rhythm abnormalities and blood pressure fluctuations. In order to minimize these risks, ratings of perceived exertion (RPE) will be taken after each round. If the participant is scoring a 19 or 20 for two consecutive sets with a three or more decrease in kettlebell swing repetitions, then the data collection process will end. All technicians present during testing and training are certified in CPR and AED techniques.

Skin irritation due to skin preparation: Prior to the data collection, you will be asked whether you have any skin allergies. This step is necessary to ensure good skin-reflective marker adherence during each trials. Erroneous results can occur if this step is not taken. Care will be taken in skin preparation to minimize this risk. Disposable alcohol prep pads will be used to clean the skin before and after the application of markers. You will be asked if you have any skin sensitivity and if you are sensitive to such treatments, you will not be recruited.

Coronavirus (COVID-19) Exposure: The potential risk of COVID-19 will be minimized based on the current CDC plan, state and local guidelines. These are as follows:

a) Prior to coming to research lab, the individuals conducting the evaluations and the participants will self-screen for any of the following new or worsening signs or symptoms of COVID-19: cough, shortness of breath or difficulty breathing, chills, repeated shaking with chills, muscle pain, headache, sore throat, loss of taste or smell, diarrhea, or feeling feverish.
b) Upon arrival to Pioneer Hall participants will be screened and body temperature will be measured via non-contact thermometer.
c) A non-contact thermometer will be used to monitor all evaluators and participants' temperature upon entry into the building. Individuals with temperature greater than or equal to 100 degrees Fahrenheit will be requested to refrain from testing that day and isolate for 14 days before returning to campus.
d) Participants and investigators will be discouraged from gathering in any common areas in all spaces. A 6 feet distance will always be kept between individuals at all possible times.
e) All TWU evaluators will use adequate personal protective equipment (PPE) including gloves, facemasks, and lab coats while conducting test procedures.
f) All equipment/ testing devices will be sanitized using disinfectant sprays and wipes after every individual test.
g) Evaluators will attempt to maintain social distancing while monitoring the kettlebell swing protocol.
h) A facemask that covers the mouth and nose must be worn at all times, except when performing the kettlebell swing protocol.

__TWU Disclaimer Statement__

The researchers will try to prevent any problem that could happen because of this research. You should let the researchers know at once if there is a problem and they will help you. However, TWU does not provide medical services or financial assistance for injuries that might happen because you are taking part in this research.

To reduce contact as much as possible, it is requested that you review and sign this form prior to arrival at TWU if you agree to participate. A researcher will make contact with the you to address any possible concerns you may have prior to signing.

Participation and Benefits

Participation in this study is voluntary and you are free to withdraw at any time without penalty. There is no monetary compensation for this study. If you would like to know the results of this study you can provide your mailing address, or email address, and they will be sent directly to you following completion.

Questions Regarding the Study

You will be given a copy of this signed and dated consent form to keep. If you have any questions about the research study you should ask the researchers. Their phone numbers are located at the top of this form for you convenience. If you have questions about your rights as a participant in this research or the way this study has been conducted, you may contact the Texas Woman's University Office of Research and Sponsored Programs at 940898-3378 or via e-mail at IRB@twu.edu.

All of your personal identifiable information will be de-identified and will not be used for future research.

____ _______________

Signature of Participant Date

*If you would like to know the results of this study tell us where you want them to be sent:

Email: ___________________________ or
Address:

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