Validation of a Joint-Analysis Software, the Microsoft Kinect as a Real-Time Strength Training and Evaluation Tool

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This thesis titled 
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Abstract
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Validation of a Joint-Analysis Software, the Microsoft Kinect as a Real-Time Strength Training and Evaluation Tool
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Introduction: Athletic performance and injury prevention are important for athletes and coaches. Different types of movement analyses have been created to aid in injury prevention and performance. The reliability of the Microsoft Kinect for movement analysis has not been widely tested. If reliable and accurate it could decrease the cost and time necessary for movement analysis. Purpose: The purpose of this study was to determine if the Microsoft Kinect is an accurate measure of knee displacement during the parallel squat when compared to the Dartfish Team Pro Software 6.0. Methods: This research used the Dartfish Team Pro Software 6.0 to validate the Microsoft Kinect as a tool to measure knee displacement. Subjects performed a parallel squat with a 7-ft long dowel rod. This exercise was used to compare value between systems. Participants were healthy members of the Athens Ohio community ages 18-30. Statistical Analysis: The intraclass correlation coefficient and paired-samples t-test were used to compare Dartfish Team Pro Software 6.0 and Microsoft Kinect. Intrarater reliability of each system was also assessed. Results: There were 29 participants in the study. The interclass correlation coefficient for Dartfish Team Pro Software 6.0 and Microsoft Kinect showed that the Microsoft Kinect had a high-reliability ICC = 0.96. Intrarater reliability for Kinect and Dartfish were .98 and .99, respectively. The mean difference between systems for
measured knee displacement was 1.06 cm. The mean for the Microsoft Kinect was 49.11 ± 1.9 and 50.16 ± 96 for the Dartfish ($p > 0.05$). **Discussion:** The Microsoft Kinect is reliable against the Dartfish Team Pro Software 6.0 as a tool to measure knee displacement using the parallel squat. It appears for healthy young adults, the Microsoft Kinect is reliable for movement analysis.
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Chapter 1: Introduction

Anterior cruciate ligament (ACL) injuries from athletics are extremely common and costly. For example, annually more than 250,000 ACL injuries are estimated in the United States (Albright, 2013; Steiner, 2009). The total medical expenses, including ACL reconstruction and rehabilitation, are approximately $17,000 per injury. As a nation, over 2 billion dollars per year are spent on ACL injury rehabilitation (Childs, 2002; Gottlob, Baker, Pellissier, & Colvin, 1999).

Cost and incidence are not the only concerns for ACL injury/reconstruction. The quality of life of the individuals who sustain an ACL injury is of major concern. In previous research, 31% of these individuals had moderate to severe disability in walking alone, 44% had moderate to severe disability during activities of daily living, and 75% could not return to their sport at the same level of performance as before the injury (Noyes, Mooar, Matthews, & Butler, 1983).

Investigating the risk factors associated with noncontact ACL injuries is an important area of study to aid in the prevention of injury. A noncontact ACL injury occurs without direct contact to the knee resulting from a sudden deceleration cutting or landing force (Boden, Dean, Feagin, & Garrett, 2000). Some of the risk factors are as follows: lower extremity alignment, femoral intercondylar notch size, posterior tibial plateau slope, intrinsic ACL material properties patella tendon-tibia shaft angle, hormonal variation, and neuromuscular control and biomechanics (Chappell, Yu, Kirkendall, & Garrett, 2002; Dai, Herman, Liu, Garrett, & Yu, 2012; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). Most of the above risk
factors are not modifiable due to being biological or anatomical. When decreasing the risk of injury only modifiable risk factors are of interest.

Of the above risk factors, biomechanics and neuromuscular control have the greatest ability to be impacted by interventions. The differences between male and female movement patterns have been studied to great ends in order to define risk factors for noncontact ACL injury. Female athletes sustain more ACL injuries within sports compared to males. According to NCAA injury surveillance report, females have four times as many ACL injuries in soccer and three times in basketball than males (Dai et al., 2012). Neuromuscular risk factors for ACL injury include: lower gluteus maximus activation (Hewett, Zazulak, Myer, & Ford, 2005); greater quadriceps to hamstring activation (Chappell et al., 2002; Malinzak et al., 2001; Sigward & Powers, 2006); and smaller medial to lateral activation ratio for the quadriceps and hamstring muscles (Myer, Ford, & Hewett, 2005; Palmieri-Smith, Thomas, & Wojtys, 2008; Rozzi, Lephart, & Fu, 1999). Studies have suggested that small knee flexion angles, increased knee valgus angle and increased quadriceps activation and decreased hamstring activation tend to increase the strain on the ACL (Bendjaballah, Shirazi-Adl, & Zukor, 1997; Buff, Jones, & Hungerford, 1988; Smidt, 1973; van Eijden, de Boer, & Weijs, 1985).

Approximately 70% of ACL injuries occur with no contact injury (Boden et al., 2000; Krosshaug et al., 2007b). Due to the high incidence of noncontact injuries, strengthening the muscles of lower extremities is very important for injury prevention. The squat exercise can expose some of the functional deficits that could lead to risk for
ACL injury as mentioned above. The squat exercise can also be used as an intervention for these deficits (Myer et al., 2014).

Increasing lower body strength will aid in the performance of many athletes by improving vertical jump height and sprint speed (Seitz, Reyes, Tran, Saez de Villarreal, & Haff, 2014). The back squat is regarded as the most effective way to enhance athletic performance because of the muscle groups strengthened during this exercise are the prime movers for running, jumping, and lifting (Escamilla, 2001). Multiple studies have used the back squat as the measure of lower body strength. Sietz et al. (2014) used the back squat to demonstrate the correlation between lower body strength and 20 meter sprint time. The study showed a strong correlation between increases in squat strength and decreased sprint times (r = -0.77, p = 0.001). Baker and Nance (1999) performed a similar study to find the relationship between back squat strength and running speed of professional rugby players. When normalized to body mass a three repetition maximum, back squat was well correlated with 40 meter sprint time (r = -0.66, p < 0.05) (Baker & Nance, 1999).

The back squat may serve as a training tool for injury prevention, as well as a tool for screening athletes for potential risk prior to participation in the activity (Myer et al., 2014). The back squat can be used to assess neuromuscular control, strength, stability, and mobility throughout the body’s joint segments or kinetic chain. The Back Squat Assessment (BSA) tool was created to evaluate injury risk and identify suboptimal physical performance (Myer et al., 2014). BSA analyzes the upper body, the lower body, and the movement mechanics of the squat. It has been shown that a body weight squat
that can be performed at or below 90 degrees of flexion indicates good movement quality (Cook, 2003). With these analyses, neuromuscular strength and mobility problems are exposed through visible errors in technique. These errors consist of excessive trunk flexion, the knee moving into valgus, ankle pronation and the heel rising off the ground (Kritz, Cronin, & Hume, 2009; Myer et al., 2014). The BSA was created to minimize the cost and time of analysis software to safely and effectively prepare an individual for the activity of any kind. However, improvements in movement analysis software may have made it possible to combine tests assessing proper technique, quality of movement, and joint measurements.

Biomechanical analysis is necessary for sports performance, injury prevention, and rehabilitation. The dynamic joint kinematics such as greater knee abduction (valgus), and hip internal rotation angle involved in jumping and landing movements, can also be used to evaluate risk factors for ACL injuries (Ford, Myer, & Hewett, 2003; Malinzak et al., 2001; McLean, Lipfert, & van den Bogert, 2004; McLean, Walker, & van den Bogert, 2005). Knee valgus and varus are two biomechanical errors that can increase the risk of injury if they occur in dynamic movement. Knee valgus is defined by medial knee displacement and varus is defined as lateral knee displacement. These weaknesses in the kinetic chain can be exposed during the squat exercise. Furthermore, Myer, Brent, Ford and Hewett (2011) states that knee valgus and knee varus can be corrected by immediate feedback. As mentioned earlier, the BSA has been used to expose biomechanical errors with the squat exercise that may contribute to increased risk of injury in athletic tasks. The squat can expose a weakness in the gluteal muscles that will cause femoral internal
rotation and abduction that result in increased valgus. Coaches use verbal cues and progression to help correct technique in real time during strength training. However, video analysis can be used in combination with this to quantify errors in technique (Myer et al., 2014).

It is important that biomechanics of human movement are viewed and evaluated by motion analysis. Motion analysis allows a clinician or coach to view a movement multiple times in order to correctly define functional deficits. Therefore, three-dimensional (3D) joint analysis is most common methods to investigate clinical and sport biomechanics. The 3D camera system can measure spatiotemporal factors such as trajectories of movement, movement duration and movement velocity (Jaspers et al., 2011). However, these multiple high-speed camera systems are costly and are often hard to obtain in the clinical or sports performance setting (Pfister, West, Bronner, & Noah, 2014).

Due to the complexity and cost of the 3D motion analysis systems, different types of two-dimensional (2D) software have been developed. McLean, Walker, Ford, et al., (2005) evaluated a 2D analysis method using a standard video camera and a customized software as a screening tool for ACL injury. Males and females were used in the study, and it was concluded that the 2D camera method could be used to screen for knee valgus, specifically frontal plane movements. The validity of 2D software has been tested against the 3D software during mechanical lifting. In comparing the 2D and 3D analyses, a 2D joint analysis and 3D peak angle measures correlated well for the side jump ($r^2 = 0.64$) and side step ($r^2 = 0.58$). Researchers also claim that 2D analysis may be a useful tool
when reducing valgus in dynamic movement is of concern (McLean, Walker, Ford, et al., 2005).

Eltoukhy, Asfour, Thompson, and Latta (2012) investigated the Dartfish Team Pro Suite 5.5, which uses digital video as input, for its ability to generate values for the location of markers in 2D. The video footage is imported to the software where it can be edited. The footage is analyzed by having a known distance within the camera frame such as a ruler or yard stick to select areas of interest to find distances or angles. Reflective markers were placed on the anatomical locations, to determine if the Dartfish could accurately find the markers verifying the location against the Vicon system. The data was collected on the markers during the simple squat motion. Forty markers were observed and there were not significantly different in 38/40 of the anatomical locations (Eltoukhy et al., 2012).

The Microsoft Kinect system uses motion analysis of the major joints in the body to provide real-time feedback and cost less than high-speed multiple camera system analysis. Not only does the Microsoft Kinect provide real-time feedback, but it does not require reflective markers, which is a time consuming part of 3D and 2D movement analysis preparation. In a previous study, the Microsoft Kinect was used to identify anatomical landmarks in comparison to a 3D motion analysis software. The anatomical landmarks were found by evaluating postural control which confirmed the Microsoft Kinect ability to identify the joints in space with its infrared technology (Clark et al., 2012). The Microsoft Kinect and 3D motion analysis software were highly correlated with a concurrent validity value of $R = 0.90$. Based on these correlations, the Microsoft
Kinect can accurately identify anatomical landmarks such as the hip, knee, and ankle when compared to a multiple camera 3D systems (Clark et al., 2012). The Microsoft Kinect may have benefits beyond that of postural control and in this study, its validity of hip, knee, and ankle displacement will be validated against the Dartfish, a 2D motion analysis software.

**Purpose of the Study**

The purpose of this study was to determine if the Microsoft Kinect accurately quantifies knee displacement during the back squat compared to the Dartfish analysis system. Lack of neuromuscular control and poor biomechanics are risk factors for ACL injury that can be identified through movement analysis (McLean, Walker, Ford, et al., 2005). The Microsoft Kinect software has already demonstrated its ability to validly record anatomical landmarks in the form of postural control (Clark et al., 2012). When correlated with 3D, 2D motion analysis has proved to be valid (Norris & Olson, 2011). Therefore, it is of importance and logic to use a 2D motion analysis, the Dartfish analysis system, to validate the Microsoft Kinect as a tool to evaluate hip, knee, and ankle displacement during the back squat exercise.

**Significance of Study**

There are more than 250,000 ACL injuries in the United States every year (Moses, Orchard, & Orchard, 2012). ACL injuries are not only common, but also very costly. ACL surgery is calculated to be an annual cost of 1.5 billion dollars per year. The majority (75%) of the ACL injuries sustained are a result of noncontact activities. Due to the high incidence of noncontact ACL injuries, the risk factors associated with these are
an important area of study. The modifiable risk factors that have been identified are those associated with biomechanical errors and poor neuromuscular control (Dai et al., 2012; Uhorchak et al., 2003). For this study, the method of validating a tool that can assess biomechanics and also help to improve neuromuscular control by improving back squat technique in a simple, low cost manner is of great significance.

The back squat is the best exercise for strengthening the lower body and can also help to identify, target and enhance fundamental movement patterns. There are many errors associated with performing the back squat that could hinder performance (Myer et al., 2014). These errors may need further analysis beyond the coaches’ eye and that is where motion analysis becomes valuable.

Movement analysis is important for the prevention of injury, as well as enhancing performance in movement (Norris & Olson, 2011). Video analysis enhances the ability to evaluate the degree of risk or possible improvements in the movement to provide an ergogenic effect in performance (Krosshaug et al., 2007a). The 3D video analysis systems consist of multiple, high-speed cameras and postanalysis systems. These are costly and analysis is time consuming. However, they have been proven to be accurate in assessing joint angles and displacement of joint during movement. Recent developments have shown that 2D video movement analyses have comparable abilities to find joint angles and displacement during movement. The 2D camera system requires reflective marker use as does the 3D and user must film and upload video to software for further editing (Norris & Olson, 2011). Therefore, it is essential to further the research to simplify movement analysis even more by providing real-time accurate feedback about
the location of anatomical landmarks. The Microsoft Kinect has been shown to be an accurate measure of anatomical landmarks and postural control when compared to 3D motion analysis (Clark et al., 2012). To take this one step further, this study will use the 2D motion Dartfish analysis software to validate the Microsoft Kinect ability to accurately detect joint displacement during the unloaded back squat exercise.
Chapter 2: Review of Literature

This literature review consists of three major parts: motion analysis, ACL injury, and the back squat.

Motion Analysis

During a movement such as lifting, running or jumping, it is easy to quantify the amount of weight lifted, speed or height of the jump respectively. The mechanics of each of these movements is important for optimizing these variables. Often times it is left up to the eyes of a coach or simple recording to analyze the movement because there are no useful for measuring dynamic movement (Krosshaug et al., 2007a). Increasing research and improvements in technology have allowed for the development of different movement analysis software.

The gold standard of this software is high-speed 3D motion analysis. In a systematic review of 3D gait analysis, McGinley, Baker, Wolfe, and Morris (2009) selected 23 articles to determine the validity of the system. The researchers sought out to determine if the system was useful in the clinical setting for determining pathology. Subjects were mainly healthy males and females although one study included stroke patients. Ages of patients varied. The reliability was determined by the difference in the result between repeated trials of gait. Errors were less than 4 degrees and 2 degrees for the sagittal and coronal plane respectively, however, hip rotation ranged from 16 degrees to 34 degrees. The transverse plane seems to be more difficult to achieve low levels of error. Acceptable error for clinical significance of joint angles is between 2 and 5 degrees. As a whole the majority of the studies in the review showed all variables
measured (pelvic tilt, pelvic obliquity, pelvic rotation, hip flexion, hip abduction, hip rotation, knee valgus, knee varus, knee rotation, ankle dorsi flexion and foot progression) to be less than 5 degrees of error (McGinley et al., 2009).

Tzong-Ming and Dar-Zen (2014) used the Vicon 3D camera in a biomechanical study for upper limb exoskeleton for resistance training. There were 8 high-speed infrared charged coupled displays that were used. Spherical double-sided markers were placed on anatomical landmarks of interest. The analysis was performed on the subject’s shoulders and elbows. Through the 3D motion analysis, these researchers were able to calculate torques involved in strength training exercises involving the upper extremities (Tzong-Ming & Dar-Zen, 2014).

Motion analyses using 3D have been compared to an accelerometer as another verification of its status as the gold standard analyzing movement. Chung and Ng (2012) determined the reliability and concurrent variability of an accelerometer and three-dimensional motion analysis. Researchers stated that the 3D camera systems are a complex tool that is often difficult to set up in a clinical setting. An accelerometer is a simple tool that can detect movement and force. Twelve subjects participated in the study and the timing of knee extension or onset time of lower limb movement was recorded using both the accelerometer and the Vicon 3D motion analysis system simultaneously. The accelerometer showed high reliability with 3D motion analysis (Chung & Ng, 2012). Mechanical lifting such as in a factor type setting where a load is lifted from different heights has been analyzed by 3D motion analysis (McLean, Walker, Ford, et al., 2005). Norris and Olson (2011) states again that 3D motion analysis has proven very useful for
primary discoveries but for future endeavors into movement analysis expensive and timely use of the high speed 3D camera system may be unnecessary due to the availability and cost-effective method of two dimensional (2D) analysis if deemed reliable. 2D analysis requires a normal video camera and kinematic evaluation software. For 2D motion analysis, video feedback is recorded from the desired movement. This footage is then imported into software in which the movement can be analyzed via joint angles and displacements. Many researchers have looked at the comparison between 2D and 3D motion analysis. They compared values between side step, side jump and drop landing (Hollman et al., 2009; McLean, Walker, Ford, et al., 2005; Miller & Callister, 2009). There were high correlations between frontal plane knee angles. Sagittal plane kinematics have also been evaluated using 2D analysis. Single leg squat measures were looked at via goniometry and compared to the 2D video analysis. The ankle and knee showed a less than 4-degree error between measures and less than 11 degrees for hip and thigh (Gribble et al., 2005). Specifically, the 2D Dartfish motion analysis software can track angles through its function angle tracking tool. Norris and Olson (2011) evaluated the concurrent validity and reliability of the Dartfish for measuring sagittal plane angles of the hip and knee. The validation was against a two-arm 12-inch 360-degree goniometer.

The Microsoft Kinect has been used as a tool to further simplify the movement analysis process. It has been validated against the three dimensional high-speed camera systems during postural control and gait analysis (Clark et al., 2012; Pfister et al., 2014). Twenty healthy subjects median age 27 years old participated in the posture study.
Markers were placed on the head, arms, wrists, hands, trunk, pelvis, legs, and feet. Three postural control tests were performed and analyzed by the 3D system and the Microsoft Kinect. The three tests were a lateral reach, forward reach, and single-leg balance test. The systems methods are comparable for test/retest reliability. Clark et al. (2012) stated “Microsoft Kinect showed excellent concurrent validity with the 3D camera method” (Clark et al., 2012).

**Anterior Cruciate Ligament Injury**

Before introducing the mechanisms of injury risk factors and epidemiology of ACL injury it is important to understand the structure of the knee and the associated ligaments. The knee joint has 2 degrees of freedom; six of the movements are rotational and three are translational. Ligaments connect bone to bone and are made of dense connective tissue. The ACL and PCL provide stability and primarily assist the knee with flexion-extension movements and sliding movements. These ligaments can withstand forces up to 500 lb. (Walgenbach, 1996). The muscles responsible for stabilizing the knee are the quadriceps, hamstrings and the gastrocnemius (Childs, 2002; Walgenbach, 1996).

ACL injuries are the most common injury of the knee in team sports (Moses et al., 2012). In the United States, there are approximately 250,000 ACL injuries each year. These injuries are common and also very expensive with rehabilitation and surgery amounting to an average of $20,000 per injury (Brophy, Wright, & Matava, 2009). ACL injuries are often a result of athletically related incidents. Among various sports ACL incidence rates of injuries per 1000 exposures were as follows: .17 in college basketball, .18 in lacrosse .21 in soccer, .22 in rugby, .25 in wrestling, .33 in handball, and .33 in
general population alpine skiing (Prodromos, Han, Rogowski, Joyce, & Shi, 2007).

ACL injuries are extremely common and costly, fortunately, three quarters of ACL injuries are a result of noncontact (Boden et al., 2000). These noncontact ACL injuries are often preventable with intervention where contact ACL injuries are unavoidable without cessation of activity. The majority of ACL injuries being noncontact have allowed researchers to categorize risk factors that aid in the prevention of these injuries. Uhorchak et al. (2003) did a four year prospective study of incoming cadets at West Point to observe potential risk factors of ACL injury. There were a total of 859 cadets that were observed in the study 739 men and 120 women. Over the 4-yr study, there were 29 ACL injuries. Only five of these resulted from contact. The researchers found that joint laxity, increased BMI and anatomical characteristics of the knee were significantly correlated with the ACL injuries (Uhorchak et al., 2003). These researchers did not find any significance in the strength of the quadriceps and hamstring as a risk factor in ACL injury. However, as in many other studies, strength was measured isokinetically. Measuring as such which is not specific to the sport. Which is a limitation of these studies. For example, Uhorchak et al. (2003) states that even though there was no statistical significance for eccentric quadriceps to hamstring strength, the men that had eccentric quadriceps strength ratios one standard deviation above the mean did have a relative risk two times that of men in the normal range (Uhorchak et al., 2003).

Biomechanical issues are also a risk factor for ACL injury, specifically lower body kinetics and kinematics (Dai et al., 2012). Hewett, Myer, and Ford (2001) suggested that females may be more likely to have an ACL injury to lower strength in sagittal plane
movements. Due to the decreased muscle, there is limited hip and knee flexion during dynamic task increasing the risk of ACL injury. When hip and knee flexion are limited this causes an increased valgus force where the knee travels toward the center of the body under a load (Hewett et al., 2005). Pollard, Sigward, and Powers (2010) suggested that lack of use/strength of the hip flexors and over reliance on the quadriceps cause the low flexion angle of the hip and knee. That results in increased risk for ACL injury due to the increase in knee valgus angle (Pollard et al., 2010).

Most of the understanding of the modifiable risk factors for ACL injuries has been discovered through the studies comparing male to female traits. In a review by Dai et al. (2012) smaller knee and hip flexion angles, greater knee valgus, greater hip internal rotation angle, greater knee internal rotation moment were modifiable risk factors for ACL injury that are more prominent among women.

Neuromuscular control or the lack thereof is a risk factor for ACL injury. Improving neuromuscular control consists strengthening the quadriceps and hamstrings by plyometric and weightlifting. It has been hypothesized that this may reduce the risk of ACL injury. Caraffa, Cerulli, Projetti, Aisa, and Rizzo (1996) showed that implementing proprioceptive training can reduce the risk of ACL injury in in soccer players. The soccer players used wobble boards to participate in balance training and after three seasons the control group had 70 ACL injuries and the experimental group had only 10, which was significantly less statistically (Caraffa et al., 1996). Neuromuscular control follows a similar trend with biomechanical risk factors were differences among men and women expose specific movement errors that could increase the risk for injury. For example,
Hewett et al. (2005) did an electromyographic review of muscle activation during a single leg landing exercise. These researchers found that women had greater adductor moments, which pull the knee toward the midline increasing knee valgus when compared to males in the study. Gluteal activation was lower in the females attributing even greater to increased knee valgus due to the lack of the ability to externally rotate the hip.

ACL injury is a great financial and physical burden on an individual’s life. Due to the great burden of this injury, researchers have developed and studied risk factors of ACL injury and discovered interventions to prevent new and reoccurring ACL injury. The specific type of ACL injury that will be focused on in this study is noncontact ACL injury. Three quarters of the ACL injuries sustained in the United States are noncontact and are contact injuries are unpredictable when it comes to prevention.

**Back Squat**

The squatting movement is necessary for activities of daily living such as sitting down and picking things up. Squatting is required for almost all athletic activity. For this reason, squatting has been implemented as a necessary exercise within training programs in order to increase performance as well as prevent injury (McLaughlin, Lardner, & Dillman, 1978). In the clinical setting health care providers prescribe the squat exercise to increase ligament, tendon, and bone strength as well as develop strength speed and power in the muscles of the lower back, hip and knee (Palmitier, An, Scott, & Chao, 1991). Not only a measure of strength, the back squat can help to develop becoming a more efficient movement and mechanical strategies for various activities (Lubans, Morgan, Cliff, Barnett, & Okely, 2010; Myer et al., 2014). The back squat as a training method for the
elderly, can improve activities of daily living can be improved such as sitting, standing and lifting tasks (Myer et al., 2011; Myer, Ford, Palumbo, & Hewett, 2005).

The basic squat movement is considered to be extremely important to training because it is a single compound maneuver that is very susceptible to biomechanical deficits. Deficits within the squat exercise are important to identify to prevent injury. Chronic deficits in the squat movement pattern can be indicators of insufficient motor unit recruitment or muscle weakness, strength and joint asymmetry and joint immobility combined with muscle tightness (Schoenfeld, 2010). Injuries sustained during the back squat exercise are uncommon when proper technique is being used. Injuries can occur however, when proper technique is not used and/or exercise prescription is incorrect. The type of injuries likely to occur due to these squatting deficits are muscle and ligament sprains, ruptured intervertebral disks, spondylolysis, and spondylolisthesis.
Chapter 3: Methods

Participants

Participants were 15 males, 15 females, ages 18-30 (see Appendix A) recruited from areas around Athens County, Ohio.

Inclusion/Exclusion Criteria

Participants were apparently healthy without physical impairment. A health history questionnaire (see Appendix B) was completed to ensure subjects were ready for physical activity. Any answers on questionnaire indicating they would be at physical risk during a bodyweight back squat excluded them from the study. Subjects had no current orthopedic, musculoskeletal or comorbid conditions that limited physical activity. Participants ranged between 18-29.9 kg/m$^2$ on the BMI or body mass index scale. Any subject with a BMI $\geq 30$ kg/m$^2$ were excluded from the study.

Instrumentation

Instruments used were the Dartfish© Team Pro Software 6.0 (Dartfish USA Inc; Alpharetta, Georgia) and Microsoft® Kinect™ for Windows® Software Development Kit (SDK) for tools of movement analysis. The Microsoft Kinect is a video recording device with many attributes a standard camera is lacking. The proper term for the device is the Kinect sensor and within the sensor case there is an RGB camera or red green and blue camera (“Archived: What is an RGB Camera?”, 1997). This camera is a 1280 x 960 resolution this is necessary for accurate color image capturing. Within the Kinect sensor case, there is also an infrared emitted and infrared depth transmitter. Reflective beams between the sensor and object allow the depth information to be collected. A gravitational
accelerometer also lies within the sensor case, this allows the user to determine the orientation of the Kinect ("Kinect for Windows Specifications," 2013). A JVC digital video recorded the footage for Dartfish analysis. A 7-ft long one-half inch thick dowel rod was used for the representation of the barbell during the back squat movement. Black spandex clothing was worn during movement and/or tight fitting apparel. Silver colored circular reflective markers were placed on the patella.

Protocol

The protocol consisted of three parts: preparation, pretest, and back squat testing procedures.

Preparation Procedures

Upon arrival at the Biomechanics Laboratory, the participant was given written and verbal information about the study and testing procedures. Participants were given time to ask questions regarding the study prior to participation. If eligible, interested participants signed the informed consent document (see Appendix C) approved by the institutional review board.

Next, the participant completed the health history questionnaire. The answers were reviewed with the participant by the principal investigator to ensure that the participant met the health- and sport related inclusionary criteria and not the exclusionary criteria. Anthropometric measures were measured according to ACSM’s guidelines for body mass index and the distance between right and left acromion was considered as shoulder width (Riebe, 2016). A shoulder width stance was used for the back squat. Reflective markers in camera frame were viewed on the patella as the subject squatted to
a position where the thighs were parallel to the floor. A meter stick was placed on the
ground in front of the individual’s feet to maintain stance width also the meter stick is
necessary for determining the distance within the frame for Dartfish analysis.

A video camera was placed directly in front of the subject in line with the patella
above the ground, and 10 ft in front of the subject. Microsoft Kinect was placed at the
same distance and just above the camera for the trials. A dowel rod was used to simulate
a barbell and was placed on the upper trapezius muscles while in the shoulder width squat
stance. This is appropriate back squat according to the NSCA essentials of strength and
conditioning (Earle, 2008). Researchers helped to center the simulated barbell on the
upper back. Subjects picked up dowel rod placed it on their back and while in frame
began the squat movement on researchers command. During the downward movement
phase, subjects kept elbows tucked and the chest up and out. While maintaining the same
torso position the subject would continue to flex at knees and hips. The proper squat
depth was the point in which a subject’s thighs became parallel with the floor. In the up
phase, the subject stood up by extending the hips and knees simultaneously while
maintaining a flat back until in an erect position. Subjects were instructed to squat with
their feet flat and not translate their weight to their toes during the squat movement. The
participant was instructed on how to perform the squat technique, practice trials were
performed until the subject felt comfortable with the movement. The subject performed a
maximum of five recorded trials. Once values were obtained from each system, they were
compared.
Statistical Analysis

Intraclass Correlation Coefficient (ICC\(_{1,k}\)) was used as measures to determine the agreement and the strength of the relation for the knee displacement from the two different biomechanical data analysis systems: Dartfish and Kinects. Also, the intrarater reliability was used to compare results of each Dartfish and Kinect with ICC\(_{1,k}\). Finally, a paired \(t\)-test was performed to compare the means across the 5 trials between the Dartfish and Kinect. All values are reported as mean ± standard deviation and significance was set at \(p < 0.05\) (SPSS v.22).
Chapter 4: Results

The characteristic for the 29 participants are shown below (see Table 1). One of the subjects was excluded, because during data collection the subject’s video footage was corrupted. All participants performed five back squats in front of both Microsoft Kinect sensor and a video camera.

The values of the knee displacements and difference of the two analysis tools are presented in Table 2. There was no significant difference between the mean values for knee displacement obtained from the Kinect and Dartfish \((t(29) = -1.618, p > 0.05)\). We also found a strong linear relationship between the analysis tools for knee displacement during the back squat as ICC\(_{1,k}\) = 0.96 (see Table 3). Furthermore, Dartfish and Kinect showed a high degree of reliability (see Table 4) for the knee displacement corresponding to the back squats (ICC\(_{1,k}\) = 0.98 and 0.99, respectively).

Table 1

<table>
<thead>
<tr>
<th>Participant Characteristics (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
</tr>
</tbody>
</table>
Table 2

Microsoft Kinect and Dartfish Values for Knee Displacement and the Difference for Knee Displacement between Systems

<table>
<thead>
<tr>
<th>Subject#</th>
<th>Kinect (cm)</th>
<th>Dartfish (cm)</th>
<th>Difference (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>46.97 ± 1.25</td>
<td>46.23 ± 0.76</td>
<td>0.74</td>
</tr>
<tr>
<td>2</td>
<td>61.30 ± 1.65</td>
<td>59.27 ± 0.12</td>
<td>2.03</td>
</tr>
<tr>
<td>3</td>
<td>44.27 ± 5.05</td>
<td>48.10 ± 1.02</td>
<td>-3.83</td>
</tr>
<tr>
<td>4</td>
<td>61.00 ± 1.87</td>
<td>58.12 ± 1.35</td>
<td>2.88</td>
</tr>
<tr>
<td>5</td>
<td>41.20 ± 0.90</td>
<td>40.37 ± 0.31</td>
<td>0.83</td>
</tr>
<tr>
<td>6</td>
<td>65.20 ± 1.77</td>
<td>65.17 ± 1.19</td>
<td>0.03</td>
</tr>
<tr>
<td>7</td>
<td>42.87 ± 0.42</td>
<td>40.97 ± 0.40</td>
<td>1.90</td>
</tr>
<tr>
<td>8</td>
<td>50.10 ± 0.20</td>
<td>51.47 ± 0.55</td>
<td>-1.37</td>
</tr>
<tr>
<td>9</td>
<td>35.40 ± 1.23</td>
<td>38.17 ± 1.23</td>
<td>-2.77</td>
</tr>
<tr>
<td>10</td>
<td>35.87 ± 0.70</td>
<td>36.50 ± 0.70</td>
<td>-0.63</td>
</tr>
<tr>
<td>11</td>
<td>36.03 ± 0.35</td>
<td>36.60 ± 1.25</td>
<td>-0.57</td>
</tr>
<tr>
<td>12</td>
<td>53.6 ± 0.70</td>
<td>50.57 ± 1.14</td>
<td>3.03</td>
</tr>
<tr>
<td>13</td>
<td>58.27 ± 1.22</td>
<td>59.47 ± 0.45</td>
<td>-1.20</td>
</tr>
<tr>
<td>14</td>
<td>35.9 ± 0.53</td>
<td>34.63 ± 0.72</td>
<td>1.27</td>
</tr>
<tr>
<td>15</td>
<td>41.63 ± 0.95</td>
<td>42.23 ± 0.49</td>
<td>-0.60</td>
</tr>
<tr>
<td>16</td>
<td>55.13 ± 4.22</td>
<td>61.70 ± 0.95</td>
<td>-6.57</td>
</tr>
<tr>
<td>17</td>
<td>65.87 ± 2.41</td>
<td>63.70 ± 0.40</td>
<td>2.17</td>
</tr>
<tr>
<td>18</td>
<td>49.53 ± 4.46</td>
<td>55.18 ± 1.60</td>
<td>-5.65</td>
</tr>
</tbody>
</table>
Table 2, continued

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>39.70 ± 0.53</td>
<td>41.90 ± 1.91</td>
<td>-2.20</td>
</tr>
<tr>
<td>20</td>
<td>54.13 ± 3.29</td>
<td>57.40 ± 0.26</td>
<td>-3.27</td>
</tr>
<tr>
<td>21</td>
<td>45.03 ± 5.66</td>
<td>47.27 ± 2.30</td>
<td>-2.24</td>
</tr>
<tr>
<td>22</td>
<td>63.33 ± 1.42</td>
<td>65.53 ± 2.21</td>
<td>-2.20</td>
</tr>
<tr>
<td>23</td>
<td>65.80 ± 1.71</td>
<td>59.00 ± 0.78</td>
<td>6.80</td>
</tr>
<tr>
<td>24</td>
<td>49.03 ± 0.90</td>
<td>56.03 ± 1.25</td>
<td>-7.00</td>
</tr>
<tr>
<td>25</td>
<td>32.07 ± 0.35</td>
<td>35.47 ± 0.93</td>
<td>-3.40</td>
</tr>
<tr>
<td>26</td>
<td>46.10 ± 4.62</td>
<td>46.50 ± 0.53</td>
<td>-0.40</td>
</tr>
<tr>
<td>27</td>
<td>53.43 ± 3.06</td>
<td>52.27 ± 0.70</td>
<td>1.16</td>
</tr>
<tr>
<td>28</td>
<td>44.83 ± 3.94</td>
<td>42.93 ± 0.40</td>
<td>1.90</td>
</tr>
<tr>
<td>29</td>
<td>50.50 ± 1.41</td>
<td>62.13 ± 2.24</td>
<td>-11.63</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>49.11 ± 1.96</td>
<td>50.39 ± 0.99</td>
</tr>
</tbody>
</table>

*Note.* A positive difference score indicates that the value of the Kinect was greater than the value of the Dartfish.
Table 3

*Intraclass Correlation for Measures of Knee Displacement Using Dartfish© Team Pro Software 6.0 and Microsoft Kinect©*

<table>
<thead>
<tr>
<th>Knee Displacement</th>
<th>ICC1,k (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.96 (0.92-0.98)</td>
</tr>
</tbody>
</table>

Note. ICC1,k: Type 1,k intraclass correlation coefficient CI: 95% confidence interval Upper 95% reported in brackets.

Table 4

*Test-Retest Reliability for Measures of Knee Displacement Using Dartfish Team Pro Software 6.0 vs. Microsoft Kinect*

<table>
<thead>
<tr>
<th>Knee Displacement</th>
<th>Kinect</th>
<th>Dartfish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC1,k (95%CI)</td>
<td>ICC1,k (95%CI)</td>
</tr>
<tr>
<td>Knee Displacement</td>
<td>0.98 (0.96-0.98)</td>
<td>0.99 (0.99-1.0)</td>
</tr>
</tbody>
</table>

Note. ICC1,k: Type 1,k intraclass correlation coefficient CI: 95% confidence interval Upper 95% reported in brackets.
Chapter 5: Discussion

The aim of this study was to evaluate the ability of the Microsoft Kinect to obtain accurate measures of knee displacement during the back squat. Using the Dartfish software as the tool to measure reliability, we hypothesized that when using intraclass correlation coefficients, we could demonstrate that knee displacement could be measured using the Microsoft Kinect.

We found that the Microsoft Kinect values for knee distance at the bottom of the parallel back squat correlated well with the values obtained by the Dartfish analysis. The intra-class correlation value was 0.96 for the two systems (see Table 4). Comparison between the Dartfish and Kinect showed good evidence that the Microsoft Kinect is useful for movement analysis where immediate feedback is necessary. Another important finding was the Microsoft Kinect showed accuracy without the use of reflective markers, eliminating a timely step in a standard motion analysis.

The Dartfish Team Pro Software 6.0 that was used to compare Microsoft Kinect had accurate intrarater reliability, meaning during analysis of raw video footage where knee displacement was measured at the bottom of the squat the distances obtained by the researcher were consistent among trials. This also held true for the Kinect where the system could repeatedly obtain the same measure for knee displacement among individuals. These values are important to mention during a discussion of the reliability of Microsoft Kinect as a tool to measure knee displacement. Often, during training sessions in the weight room or on the playing field where the Kinect could be used to correct errors in technique, the activity will be repeated many times in practice. If
intrarater reliability was low the Microsoft Kinect would not be a great option for activities that involve so much repetition.

The reliability of the Microsoft Kinect to detect knee displacement is conducive to the recent research involving the Microsoft Kinect software. Dolatabadi, Taati, and Mihailidis (2016) measured the validity of the Microsoft Kinect to measure spatiotemporal gait patterns. They found similar results for gait indicating the Kinect software has the ability to accurately measure these gait patterns. Our research showed an ICC of $r = 0.96$ which shows a higher correlation than the previous study (report their ICC here in parentheses). (Dolatabadi et al., 2016). And statistically, greater than 0.75 for ICC is considered as an excellent correlation (Lin, 1989).

Other similar research using the second version of the Microsoft Kinect to identify joint center location showed a large range of accuracy when compared to a global coordinate system (Xu & McGorry, 2015).

These researchers found that there was not much improvement from the first version of the Microsoft Kinect. Xu and McGorry (2015) stated that previous research demonstrates good measurement agreement regardless of the version of Kinect for body segments lengths, joint angle and, more importantly, the displacement of certain joints while testing specific body postures. The claims of these researchers support our findings where the agreement of the joint displacements from the two different software was highly correlated. These findings may elude to the fact that the specificity of the software used is important. For example, in our study, we used the back squat to determine knee displacement. During this specific activity, the measures for each participant in the study
were highly repeatable, with a difference between measures ranging from .03 to 11.63 cm. These general tasks may be well suited for using the Microsoft Kinect for motion analysis. However, large, complex movements where many joints and rotational movements are involved may not be accurately analyzed by the current version of the Microsoft Kinect.

The Kinect is limited by its inability to detect 3D joint motions. When the knee joint rotates in the frame, it becomes difficult to track. As of now, the movements are limited to the frontal plane with Kinect being aligned on the sagittal axis. There are many athletic events that the Kinect would be useful for analyzing. Dynamic movements, other than the back squat, include the vertical jump, which is a common measure of power, the 40 yard dash, which measures speed and acceleration, and the drop landing, where errors in muscle activation and biomechanics of lower extremities are often exposed. The Kinect would be useful in practice for basketball players and volleyball players where knee displacement often results in injury during the drop landing.

Limitations

The limitations of our study are as follows: Subjects in our study were healthy, normal weight individuals, meaning all subjects had a healthy BMI. Overweight individuals may be more difficult to obtain accurate measures on because the tracking markers on the participants can easily fluctuate through the squat performance. Subjects were all over 18 with mature statues, so the use of this software on youth, who have shorter limbs and less neuromuscular coordination, is unknown. This Microsoft Kinect
software was only tested with a slow squat movement; other dynamic high speed movements may not have the same accurate measures.

**Conclusions**

The purpose of the present study was to examine the capacity of the Microsoft Kinect as a reliable tool to measure knee displacement in healthy weight populations. For small, single-plane specific movements, the Microsoft Kinect obtains valid, reliable measures of knee displacement compared to using Dartfish Team Pro Software. The Microsoft Kinect is a low-cost, quick way to find knee displacement without the use of reflective markers. Future research in the Kinect software are needed to further validate this method for analyzing multi plane, quick movements.
References


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https://dx.doi.org/10.3109/03091902.2014.909540

Pollard, C. D., Sigward, S. M., & Powers, C. M. (2010). Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and


https://dx.doi.org/10.1097/JSA.0b013e3181c0ccf8


https://dx.doi.org/:10.1682/JRRD.2012.12.0227


Appendix A: Recruitment Flyer

Are you a healthy male or female?
If so, and you can perform a body weight squat.
We need you!
Here’s your chance to:

- Participate in research to help us validate a joint analysis software using the Microsoft Kinect.

Additional requirements: You must

- Be between the ages of 18-35
- Currently be free of injury.
- Have no physical or mental ailments
- Have a BMI between 18-29.9 kg/m²

What is involved: Approximately 30 min. of time in Biomechanics Laboratory (Grover E 116). You will perform five squatting movements which will be recorded by a Microsoft Kinect and Standard digital video camera.
Appendix B: Health Status and Physical Activity Questionnaire

The purpose of this questionnaire is to help us assess your past medical history and current health status to ensure your safety and that you have no current or past conditions that would affect your performance today. Second, we are gathering information about your prior and current participation in selected sports and other physical activities.

Please ask the researcher if you have any questions or need assistance. Your participation is greatly appreciated!

Age: _____ yr Gender: (Place an X in appropriate blank)    ____ Female     ____ Male

MEDICAL HISTORY AND CURRENT HEALTH STATUS

Medical History

- X out the “Y” (yes) or “N” (no).
- If more room is needed to answer a question, continue answer on back of page.)

1. Have you ever had any injuries to your ankle(s)?       Y/N

   If yes, list each injury, when it occurred and whether medical attention was required.

________________________________________________________________________

2. Have you ever had any injuries to your knee(s)?            Y/N

   If yes, list each injury, when it occurred and whether medical attention was required.

________________________________________________________________________
3. Have you ever had any injuries to your hip(s)? Y/N
   If yes, list each injury and when it occurred. ________________________________
   ______________________________________________________________________

4. Have you ever had any injuries to your head? Y/N
   If yes, list each injury and when it occurred. ________________________________
   ______________________________________________________________________

5. Have you ever had any broken bones? Y/N
   If yes, list each broken bone and when it occurred. __________________________
   ______________________________________________________________________

6. Have you ever had any back or spine injuries? Y/N
   If yes, list each injury and when it occurred. ________________________________
   ______________________________________________________________________

7. Have you ever had any major surgeries? Y/N
   If yes, list each surgery and when it occurred. ______________________________
   ______________________________________________________________________

8. Have you experienced chronic, severe or recurring inner ear problems (e.g., recurrent infections)? Y/N
   If yes, list each problem and when it occurred. ______________________________
   ______________________________________________________________________

10. Have you experienced chronic or severe dizziness, problems with balance, and/or excessive clumsiness within the last year? Y/N
    If yes, please explain. __________________________________________________
    ______________________________________________________________________
11. Do you have any medical-related problems or conditions? Y/N

If yes, list each condition. ____________________________________________
_________________________________________________________________

Current Health Status

1. If you have any of the following symptoms, place a check in the blank provided.

___tired ___ dizzy ___ trouble with balance ___ muscle soreness ___ unusual clumsiness

2. Are you currently experiencing any physical discomfort or pain? Y/N

If yes, please explain. ________________________________________________
_________________________________________________________________

3. Are you currently ill? Y/N

If yes, please explain. ________________________________________________

4. How much sleep did you get the night before last? ___ hr  last night? _________

hr

5. Are you currently taking any prescription or over-the-counter medications? Y/N

If yes to above, if you have possibly experienced side effects:

a. List the medicine(s): _____________________________________________

b. List your side effects (including but not limited to: pain, discomfort, dizziness, trouble with balance, coordination difficulties, vision or hearing-related problems, muscle aches, trouble understanding directions, inability to concentrate):
_________________________________________________________________
**PHYSICAL ACTIVITY:**

Please fill out the following chart with your current level of physical activity (i.e., how often you workout each week) and the type of physical activity you engage in.

<table>
<thead>
<tr>
<th>Activity</th>
<th>0-1 hours/week</th>
<th>1-2 hours/week</th>
<th>2-3 hours/week</th>
<th>4+ hours/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>soccer/basketball/volleyball if you are not on a competitive team at present?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>aerobic-related (running, swimming, cycling, spinning etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yoga/Pilates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weight lifting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor (e.g., hiking, kayaking, rockclimbing, orienteering, geocaching)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Martial arts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gymnastics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>court sports (e.g., tennis, squash, racquetball)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C: Ohio University Consent Form

Title of Research: **Validation of a joint analysis software the Microsoft Kinect as a real time strength training and evaluation tool.**
Researchers: Jake Frazier, Dr. Jae Pom Yom, Dr. Cheryl Howe, Erik Nykl

You are being asked to participate in research. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You should receive a copy of this document to take with you.

**Explanation of Study**

**Purpose of the Research**

The aim of this study is to confirm if the Microsoft Kinect can be used as a tool to accurately measure changes in distance between the hip, knee and ankle joint during activity.

**Procedures to be Followed**

First, you will complete a Physical activity readiness questionnaire. In order to be included in this study, you must be a male or female between the ages of 18-30 years, no personal history of metabolic (i.e., diabetes), heart or lung disease, as well as, no recent illness or limiting physical impairments and be a non-smoker. You must have a Body mass index between 18-29.9 kg/m².

The first day of the study you will participate in a screening to determine if you meet the criteria for inclusion in the study. You must agree to being video recorded while performing a squat exercise. You will be instructed how to position the simulated weightless barbell on your back as well as the desired squatting technique. You will be asked to report to the lab wearing tight fitting dark colored spandex material. Reflective markers will be place on your hips ASIS, outer leg or greater trochanter, knees on lateral tibial condyles and ankles or lateral malleoli.

The entire screening process should take approximately two hours over one week. If you meet all of the above requirements you will qualify for the experimental trials

**Experimental Trials**
You will be asked to stand in the frame of the camera and the Microsoft Kinect. You will perform 5 squatting movements in which your thighs become parallel with the floor and then return to an erect position. The recordings of the Kinect will be validated against the recordings of the camera after dartfish analysis.

**Risks and Discomforts**
Squatting with an extremely light load may be somewhat uncomfortable to those healthy individuals with poor flexibility. There should be very little discomfort if none at all due to the trials only consisting of 5 almost weightless squats.

**Benefits**
You will gain knowledge about your health by the BMI value. You will gain knowledge about the mechanics of your squat.

**Confidentiality and Records**
Your study information will be kept confidential by assigning codes to your information. Your information will be kept within a personal folder identified only by your respective code. A master list will be kept in a locked filing cabinet of the principal investigator and will be the only way to link your coded subject information to your identity following completion of all testing.

Following completion of the investigation, the principal investigator's faculty advisor will keep all files in a locked file drawer for a period of five years. Data will be compiled and analyzed with only group data being used for dissemination. After the data is compiled and you are provided with your individual results the master list will be destroyed.

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:
* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

**Contact Information**
If you have any questions regarding this study, please contact

* **Dr. Jae Pom Yom**
  Yom@ohio.edu
* **Jake Frazier**
  Jf890014@ohio.edu
* **Dr. Cheryl Howe**
  howec@ohio.edu
If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

By signing below, you are agreeing that:

- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered
- you have been informed of potential risks and they have been explained to your satisfaction.
- you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study
- you are 18 years of age or older
- your participation in this research is completely voluntary
- you may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you and you will not lose any benefits to which you are otherwise entitled.

Signature_________________________________________ Date__________