MARKERLESS MOTION CAPTURE AND ANALYSIS SYSTEM TO ENHANCE
EXERCISE PROFESSIONAL EFFECTIVENESS: PRELIMINARY STUDY

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MARKERLESS MOTION CAPTURE AND ANALYSIS SYSTEM TO ENHANCE EXERCISE PROFESSIONAL EFFECTIVENESS: PRELIMINARY STUDY

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ABSTRACT

The Microsoft Kinect camera is a markerless motion capture and analysis system that offers tremendous promise for advancing the health and wellness services industry. Health and wellness providers can utilize such devices to improve the quality of care. However, the potential for the Kinect to be implemented for use in the health and wellness industry is still limited due to its reliability and validity in the domain of exercise error detection. The purpose of this investigation was to explore how the Kinect camera could be used to enhance exercise professionals ability to design and monitor interventions to improve wellness.

Ten experienced exercisers performed three exercises (body squat, reverse lunge, chair step-up) for 2 sets at 30 seconds per set. The exercise performances were recorded and analyzed by a single Microsoft Kinect camera and an experienced exercise professional. The participants were provided with no instruction or verbal feedback during the exercise performances. The quantitative data was collected by the Kinect and the qualitative data was collected by the exercise professional.

Analysis of the joint location data from the Kinect camera demonstrated that the system is best suited to detect finer details and non-intuitive parameters such as precise joint angles imbalances, and synchrony that the exercise professional cannot readily detect. The exercise professional outperformed the Kinect camera in detection of non-joint related movements such as muscle recruitment, performer fatigue, gaze, and overall
performer comfort. These results demonstrate the promise of systems such as the Kinect camera to enhance services provided by health and wellness professions.
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CHAPTER I
INTRODUCTION

It has been estimated that lifetime healthcare subsidy costs for sedentary individuals is $1,900 which is twice the amount compared to smokers (Keeler, Manning, Newhouse, Sloss, & Wasserman, 1989). The United States has the highest per capita health care costs in the world, about double the size of the other wealthy nations (Organization for Economic Cooperation and Development. OECD Health Statistics 2015). The United States currently spends 18% of the gross domestic product on health care (OECD/European Union, n.d.). Approaches to healthcare have shifted with current efforts focusing on pro-active preventative practices targeting increasing healthy lifestyle behaviors such as healthy eating and increasing physical activity. Research suggests it is financially important to focus on prevention strategies and interventions on both improving vitality and healthier lifestyles (Hartman, Van Dongen, Hildebrandt, & Strijk, 2016). Thus, considering the increased costs incurred from a sedentary lifestyle, healthy lifestyle modifications and intervention plans could reduce health care costs tremendously. These savings would be the result of prevention and treatment of common non-communicable diseases such as cardiovascular diseases, cancers, stroke, diabetes and depression (Blumenthal et al., 2007).

Looking at current data, about 20.2% of the United States citizens follows the Center for Disease and Control (CDC) exercise guidelines of achieving the recommended
amount of exercise per week. The CDC’s defining criteria is as follows, “Respondents were classified as active if they reported at least 150 minutes per week of moderate-intensity activity, or at least 75 minutes per week of vigorous-intensity activity, or a combination of moderate-intensity and vigorous-intensity activity (multiplied by two) totaling at least 150 minutes per week. Muscle-strengthening includes activities such as yoga, sit-ups or push-ups and those using weight machines, free weights, or elastic bands. Adults aged ≥ 18 years.” (CDC, Nutrition, Physical Activity and Obesity: Data, Trends and Maps, 2013). The question now remains what changes are necessary to promote healthy behaviors; initiatives such as Healthy People 2020 have been implemented nation-wide (“About Healthy People 2020,” 2010). This initiative has identified nationwide health improvement priorities, identified leading health indicators and tracks the progress to achieving relative benchmark goals. On a smaller scale it comes down to the individual and their own personal decision to exercise or not. The current culture is shifting in an unhealthy direction causing the everyday individual to sit more and move less. Technology has transformed our physical labor occupations to sedentary desk jobs. This suggests that the failure of the non-regular exerciser can be attributed to cultural, social and psychological factors (Iso-Ahola, 2013). Getting people to move more, even if they are not yet exercising regularly will provide health benefits. Some of the benefits from participating in moderate and light exercise include stress reduction, an improved self-esteem and as well as improved of body composition (De Bourdeaudhuij & Van Oost).

The first goal of getting individuals to be more physically active is to reduce sedentary time. There are many reasons why people choose not to exercise, some valid
while many are perceived such as a lack of time or resources. Research shows that planned exercise in conjunction with time management, results in improved adherence to an exercise program. Therefore, health educators and providers should assist clients in developing time management strategies to improve long-term exercise adherence (Kamal, 2016).

Recently, various wearable fitness technologies have been released such as the FitBit and the Apple Watch; they track the amount of exercise performed but do not provide instruction or how to safely and effectively perform exercise. The goal of health and wellness awareness and education is to improve and increase preventative steps to engage in a healthy lifestyle. A product on the market, the Microsoft Kinect camera, has been used for gaming purposes when combined with a gaming console such as the Xbox (Pathirana, Li, Trinh, & Seneviratne, 2016; Helios De Rosario, 2014). The Kinect is now being programmed to improve the health and wellness of individuals due to its capability of recording the movements of participants with a markerless joint tracking system (Pidaparthy, Narayan, & Sastry, 2015). No special clothing is required for the Kinect to track the body movements; thus is one of the reasons it has gained the attention of many health experts. The long-term vision is to have a device that can be implemented in a multitude of health-related services from rehabilitation in physical therapy clinics to personal training assistance.

Many research studies are being conducted looking the validity of the Kinect and its reliability when analyzing exercise performance. There have been no studies looking at the qualitative data interpreted by an exercise professional and comparing it to the quantitative data from the Microsoft Kinect camera in regards to exercise performance.
The closest related study was performed by Juvancic-Heltzel, Pidaparthy, Pinheiro, & Sastry (2015) in which the Kinect camera recorded individuals performing squats, forward lunges, jumping jacks and high knees. Then error detection was accomplished by analyzing the data provided by the Kinect. The data was not compared to qualitative collected data for comparison, thus differing the present study. A similar study examined the use of the Kinect camera for tele-rehabilitation services where therapists analyzed the live streaming data from the Kinect to determine if it was a reliable means of measurement where they could observe and prescribe exercise for patients in real-time (Yao, Xu, & Li, 2014).

According to the Bureau of Labor statistics (2014) there are currently 279,100 personal trainers working in the United States. They estimate that by the year 2024 this will increase to approximately 302,500 increasing personal training employment by eight percent. This demonstrates the increased need for competent preventative healthcare workers. According to the National Center for Health Statistics (NCHS) (National Health Interview Survey, September 15, 2016), “Adults aged 18 and over and within all age groups, women were less likely than men to meet the federal physical activity guidelines for aerobic activity (based on leisure-time activity).” The data also reported that, “Adult obesity is associated with increased risk of a number of health conditions, including diabetes, hypertension, high cholesterol, cardiovascular disease, stroke, arthritis, and certain cancers. The prevalence of obesity was 36.5% among U.S. adults during 2011–2014.” (National Health and Nutrition Examination Survey, May 9, 2016). These health conditions reported by the NCHS are considered preventable. Thus, a critical need exists for improving overall health and well-being to maintain and improve quality of life and
lower the national mortality rate. Allowing health care professionals to implement new technologies such as the Kinect will aid with future improvements in preventative healthcare and medical treatment.

The primary goal of this research study was to evaluate the potential of integrating the quantitative data collected using a single Microsoft Kinect camera with the qualitative observations of an exercise professional. Analysis of the data will establish the effectiveness and reliability of the Microsoft Kinect camera in a preventive wellness environment while performing commonly prescribed exercises. We hypothesized that the Microsoft Kinect camera can detect finer details and non-intuitive parameters not easily recognized by an exercise professional. Also, we hypothesized that the exercise professional will be able to determine the muscle recruitment and other non-joint related movements more efficiently than the Microsoft Kinect. We presume that the Kinect will serve to enhance the diagnostic and therapeutic capabilities of therapists, clinicians and trainers but will not totally replace the professional.
CHAPTER II

LITERATURE REVIEW

The use of technology in the health sciences field has gained prominence with one of the goals of wearable technologies and fitness trackers to improve an individual’s health and wellness. Preventative medicine is a generic term that covers the actions taken towards living a healthy lifestyle by engaging in healthy lifestyle behaviors such as regular exercise and eating a well-balance diet. These actions are preventive methods taken to reduce illness and to prevent adverse health complications. While exercise is not a new concept innovative technologies have been created to facilitate safe and effective exercise behavior. Implementing these technologies may enhance the effectiveness of health professionals working with clients/patients to improve/maintain health and quality of life.

Microsoft Kinect

A novel camera called the Microsoft Kinect was built for the Microsoft Xbox 360. The purpose of the camera was for gamers to be physically active and to participate in the game in which they were playing on the Xbox 360. An example would be for an individual to physically move while playing a dancing game. The camera follows the gamers dance moves and replicates them on the screen. The Kinect programming system has now been redeveloped and programmed to aid in the research and field of health sciences. It has now been used in both rehabilitation and clinical settings with the aim to improve the health services provided. The Microsoft Kinect camera uses range from
interactive gaming to facial recognition used for stroke victims and their rehabilitation exercises (Bamrunthai & Pleehachinda, 2015). The camera has a 3D vision-based marker-free system to monitor the human participant during the activity all in real time. Through a series of successive projects, a software system has been developed to detect exercise errors and mechanics by integrating expert domain knowledge (Pidaparthy, Narayan, Sastry, 2014; Juvancie-Heltzel et al., 2015, Gaddam et al., 2015; Vankamamidi, Sastry, et. Al., 2016).

As previously mentioned, the healthcare industry is gradually moving to a more proactive approach to maintaining and improving health. This preventative mindset begins with promoting healthy lifestyles through education of proper exercise and nutrition. The field of Exercise Science seeks to promote the benefits of exercise through behavior modification to be used both as prevention and therapy. Exercise physiologists develop exercise prescriptions in clinical settings, certified strength and conditioning coaches develop exercise prescriptions for athletic populations and personal trainers utilize exercise prescriptions based on their client’s health status and goals. The large undermining issue at hand is the lack of regulation of exercise professionals. To become a Clinical Exercise Physiologist (CEP) or a Certified Strength and Conditioning Specialist (CSCS), one must obtain a Bachelor’s degree or higher in the Exercise Science field before sitting for the certifications. To obtain a personal training certification, it can be done in as little as 48 hours and often times does not require a face-to-face skills assessment. This lack of regulation poses as a risk to integrity with minimal experience required to become active in the field of health services. The Microsoft Kinect camera provides a new level of reliability, validity and consistency that can be implemented within the health promotion and prevention fields. If a Microsoft Kinect camera can
detect errors equally or better than an expert trainer, the camera could potentially be approved for universal healthcare.

Future Benefits in Health Services

In the field of Exercise Science, there is no universally accepted nomenclature for specific exercises. Furthermore, many exercises have different modifications with inconsistencies in interpretation of safe and effective execution of individual exercises. This imbalance and inconsistency constitutes a weakness in the field. Therefore, integration of expert domain knowledge is recommended for the implementation of a Microsoft Kinect camera for health related activities. For example, the domain knowledge could be field specific such as physical therapists integrating appropriate body mechanics for performing their common therapeutic exercises. Another could be a strength coaches integrating their knowledge on how to properly perform Olympic lifts. The Kinect could collect and analyze the data in real time while the participant performs the movements. Data such as the duration of the exercise could be reported back to the physician or coach for approval.

Rehabilitation Use

Previous research has been conducted examining Kinect-based rehabilitation exercises for patient use. Therapists will often prescribe exercises to be performed in the client’s spare-time and offer little or no guidance (Yao, Xu, Li, 2014). Allowing patients to exercise and receive real-time feedback and suggestions provides instant ability for exercise mechanics to be altered immediately while being recorded for future reference and referral for both the patient and therapist.
In a study performed by Juvancic-Heltzel, Pidaparty, Pinheiro, & Sastry (2015), the exercise performance data from squats, forward lunges, jumping jacks and high knees was collected by a single Microsoft Kinect camera. The potential errors in the exercise performances were identified by a panel of experts reviewing the data provided by the Kinect. Their findings conclude that the Kinect is a low-cost effective tool in detecting exercise errors. They suggest that the technology may have value as a device in the teaching and assisting proper exercise performance.

As previously stated, the Microsoft Kinect camera was released as an additional piece of gaming equipment for the Microsoft Xbox gaming console. Several applications have been explored in the area of rehabilitation and therapeutic services.

One such study looked at using multiple cameras to assess lower body strength and balance. Two Microsoft Kinect cameras were used to record three leg-strengthening exercises and one balance test in healthy adult males. The researchers sought to determine if the Kinect camera could detect proper alignment and execution for the performed exercises. The participants read a description and saw an illustration of the exercises to ensure they understood the acceptable form of each movement. Results reveal that the Kinect is a suitable device which can be used for an easy self-diagnosis and measurement of kinematics for in-home therapeutic purposes (Choi, Kang, Seo, Kim, Yang, Tack, 2016). The study also concluded that the Kinect was a valid and reliable tool for assessing static and dynamic balance in patients.

In a non-clinical study, research was conducted to see the capabilities of a real-time automated feedback system from the Kinect camera with certain common exercises (Pidaparthy, Narayan, & Sastry, 2015). The participants performed either a jumping jack,
squat, high knee or forward lunge exercise for the Kinect camera. Analysis of the data collected by the Kinect concluded that the Kinect could be used as a low-cost piece of technology that improves exercise adherence and wellness but unfortunately there was no data supporting real-time feedback to the performer. However, other studies have been performed that actually do provide feedback to the user in real-time. Yao, Xu & Li (2014) concluded that the Kinect was a better option for tracking joint movements and providing feedback when compared to body suits because the Kinect does not limit the performer’s movements. It must be noted that the feedback provided in their study still required intuitive evaluation by a therapist. The findings of the studies by Pidaparthy, Narayan, & Sastry (2015) and Yao, Xu, & Li (2014) could be integrated to potentially develop a Kinect software program to improve health services with adequate assessment capabilities while functioning to provide proper feedback and exercise guidance.

Exercise performance observation is subjective causing a lack of reliability and consistency in error detection. What the Kinect camera can do is provide reliability and consistency in its measures with the integration of expert domain knowledge. The Microsoft Kinect camera can be programmed by computer engineers to analyze a human skeletal system and can measure very minuscule movements made by the performer. The Kinect camera can detect the multiple joints: head, neck, right shoulder, left shoulder, right elbow, left elbow, right hand, left hand, torso, right hip, left hip, right knee, left knee, right foot, and left foot. In total, the Kinect can detect 25 joint locations with an accuracy of millimeters (Pidaparthy, Narayan, Sastry, 2015). The camera can take individual joint locations and compare the volume, distance, speed in which the joint moves and even the weight between joints. This technology provides greater detection
capabilities than the human eye without requiring any joint markers while recording. With these features and capabilities, the device can capture an exercise being performed and can provide detail and insight on overall performance.

The Microsoft Kinect camera can be purchased at any major consumer chain such as Best Buy or Walmart for around $99.00. Comparable tracking systems such as the MT9 by Xsens Motion Tech and Vicon motion capturing system are available for purchase and are exponentially more expensive than the Kinect costing thousands of dollars. Not only is the Kinect camera more reasonable priced, it is also much more compact and transportable. The Kinect is a small camera that can be carried in a small book bag or in a small box. The counter systems are often too large to transport and require a larger area to be able to use the system correctly. The Kinect camera can be transported to and used in any household with access to a Windows PC or an Xbox gaming console device (Yao, Xu, Li, 2014). Overall, looking into the actual physical complexities of the Kinect and the fellow motion tracking devices, one can see that the Kinect is more economical and user friendly.

Cons to Markerless Recording System

Limb and motion tracking is unique to the Microsoft Kinect. The Kinect tracks the motion of the participant through a markerless system while the other systems rely on small inertial measurement units (IMU’s) to track movements in real-time. An example of a marker-based tracking system is the MT9 by Xsens Motion Tech. The participant wears the IMU’s and the system wirelessly tracks the movements in three dimensions (3-D). Another example of a marker-based tracking system is the Vicon motion capturing system. This system records 100 frames per second and provides a higher resolution rate
than the Microsoft Kinect camera (Gaddam et al., 2015). Current research suggests that one Kinect camera is less accurate in motion detection when compared to two Kinect cameras. As such more equipment will need to be purchased and for specific angles to be met for the optimal images to be captured correctly (Pathirana, Li, Trinh, & Seneviratne, 2016). Nonetheless, the two cameras are more economical than the IMU’s.

Another factor to consider with using the markerless system is the clothing what the participant wears while being recorded. The clothing worn for the systems that utilize IMU’s require specific clothing to ensure the IMU’s are in the correct position; improper marker placement can result in incorrect recording and interpretation. The Kinect guidelines recommend the participant to wear tight fitted clothing to ensure the camera accurately depicts the joint locations (Pathirana, Li, Trinh, & Seneviratne, 2016). This issue is comparable to human errors when attempting to locate a joint angle. However, a participant in loose clothing may cause the joint locations to be hidden, an exercise expert would be able to physically palpate or determine through recognition and anatomical knowledge the correct joint angles location. From current research, the comparison of human and Kinect joint assessment location has not been addressed.

Pros to Markerless Recording System

The Microsoft Kinect camera is versatile and easily transportable with no specific environmental performance guidelines. The low cost of the camera as well as its small compact size are great assets supporting why it is a great choice for typical consumers who can exercise in-home or in a confined clinical setting. The issue that arises aside from the tighter clothing requirement is the background of the participant. The camera uses a technology called randomized decision forests where the camera projects an
infrared mesh to determine distance and separate the objects of the recording environment (Helios De Rosario, 2014). The joint segment locations are found using a local model-finding approach (Pathirana, Li, Trinh, & Seneviratne, 2016). If the participant is in an ill-lit room, the camera may have a hard time detecting the distance and location of the participant. If the background is the same color as the participant, there may be an inaccurate reading of the participant’s body segments. These are not an issue with marker-based systems.

Research performed by Gaddam et al. (2015) was conducted comparing the marker-based Vicon system to the Microsoft Kinect camera for accuracy and reliability. The study concluded that the Microsoft Kinect camera for accuracy, agreed well when compared to the industry standard Vicon system. This indicates that the future standard of exercise error detection technology may become markerless motion capture and analysis systems as opposed to the marker-based systems previously used.

Comparison of Kinect and Human Error Detection

Further comparison between human and technology exercise error detection is warranted. The Kinect has additional capabilities beyond those of the human eye. The Kinect can detect precise joint angles, speeds, volume, distance traveled and more within fractions of a second while simultaneously computing feedback for guided corrections. An exercise expert can subjectively visually identify a single error and bilateral comparisons. A therapist, trainer or instructor would need to use assessment tools such as a goniometer to determine specific joint angles. Currently, contradicting research exists regarding the reliability of the Kinect comparing joint angles to an expert’s use of a goniometer. One such study states that shoulder range of motion measurements using a
Kinect show, “…excellent agreement with those taken using a goniometer. These results indicate that the Kinect can be used to measure shoulder range of motion…as an alternative to goniometer.” (Lee et al., 2015). On the other hand, another study revealed that the accuracy of the shoulder range of motion of the Kinect, although demonstrating good test-retest reliability, exhibited lower accuracy when compared to goniometer measurements. They posited that the Kinect needs to improve its accuracy through the use of patient positioning and measurement protocol standardization before being fully implemented into a clinical setting (Hawi et al., 2014).

The camera systems need to be connected to other technologies and require specific software to function accurately. On the other hand, an exercise expert could assess and evaluate a participant regardless of the physical location or type of clothing worn without additional technology. Furthermore, when one only camera is used with the Kinect, joint detection is less reliable than with multiple cameras (Pathirana, Li, Trinh, & Seneviratne, 2016). The main issue with using only one camera is the obstruction of body parts and angles, therefore, the Kinect has to estimate what it cannot see. A human can only visually see one angle of the participant at a time but can physically move around to visually get a 360° view of the participant. Utilizing a vantage point is an advantage over the Kinect camera. There are both pros and cons to utilizing a software system such as the Microsoft Kinect camera over an exercise expert.

There have been numerous studies that have involved using the Microsoft Kinect camera and detecting exercise errors (Choi, Kang, Seo, Kim, Yang, Tack, 2016; Pathirana, Li, Trinh, & Seneviratne, 2016; Pidaparthy, Narayan, & Sastry, 2015; Yao, Xu, & Li, 2014). However, none of the studies conducted have challenged the visual
capabilities of an exercise expert to the Kinect's capabilities. Some of the research has involved physical therapists prescribing exercises to their clients while observing how the Kinect performed in visualizing patient mechanics and progress (Yao, Xu, & Li, 2014). In one study, the therapists were introduced to software system that allowed them to prescribe select exercises clients, with no personal contact between the therapist and the client; everything was done online via software (Kurillo, Han, Nicorici, & Bajcsy, 2014). The goal of this system was to investigate the ability of therapists to prescribe rehabilitation exercises in an easier and faster way using technology. The research focused on comparing and evaluating patient’s movements in real-time while providing feedback and suggestions for the patient to correct their form immediately. The recommendation was implemented from the therapists’ personal experience in recognizing errors. Therefore, this study integrated domain knowledge but lacked a description as to how the exercises were expected to be performed. The team of researchers concluded that the system was useful and could allow therapists the ability to prescribe quick rehabilitation exercises with accurate measurement and feedback systems for patients (Yao, Xu, & Li, 2014).

Another comparable study examined tele-rehabilitation using the Kinect camera. The goal was similar to the previous study regarding allowing therapists to assess the performance of home-based exercises with personalized guidance from the Kinect while providing constructive feedback. This study differs from the rest in that not only clients’ exercise performance was evaluated by the Kinect but that they compared Kinect results using both one camera and two camera systems. Results revealed that using two Kinect cameras increased accuracy when compared to a single Kinect camera. A limiting factor
in this study is that only three participants were studied. However, this study appears to support other research that posits that the accuracy and validity of exercise evaluation improves when using multiple Kinect cameras. The degree of performance measured for a single Kinect camera was within 3° of the two Kinects measurements. While this is a minimal difference, it could potentially affect the reliability of using this technology in a clinical rehabilitation setting (Pathirana, Li, Trinh, & Seneviratne, 2016).

More research is warranted prior to adoption of this technology for rehabilitation applications such as focusing on defining proper execution of exercise mechanics. Additionally, the question arises as to the place of Kinect technology adoption in health and rehabilitation; should it assist or replace professionals? As previously stated, there is no universally accepted standard for proper exercise performance mechanics. Additionally, nomenclature of exercises is not standardized across exercise professions. Organizations such as the American College of Sports Medicine (ACSM) and the National Strength and Conditioning Association (NSCA) have guidelines for performing exercise safely and effectively. BodyBuilding.com is a free online site with a database with the exercise name, form and suggested skill level including videos of each exercise ("Exercise database," n.d.). With so many options available and no standardization this poses difficulty for both professionals and individuals to make informed decisions for practical, viable, safe and effective exercise programming choices.

Exercises

Exercise and movement is important across the lifespan and most paramount is executing exercise safely. Therefore, it is important to have a universal understanding of what defines safe and proper exercise. A personalized exercise prescription should be
designed to account for individual goals and health status. In the clinical setting, an exercise physiologist or physical therapist would prescribe exercises that they know are going to be beneficial for the patient accounting for their health status or rehabilitation goals. In many cases, exercises prescribed are related to activities of daily living (ADL’s); prescribed exercises target improvements in functional capacity. For example, an individual with a shoulder injury could struggle reaching overhead to grab an item from a shelf, so a therapist would be inclined to strengthen the muscles of the shoulder girdle and the upper back prescribing an overhead press to target these muscles. In conclusion, one of the goals of exercise is to improve health and well-being while ensuring safety and effectiveness of the exercise prescription.

Body Squat

Taking an exercise that is relative to everyday functional movements is a great way to start an exercise prescription. With the majority of people sitting in chairs throughout the workday, the execution of standing up and sitting down is equivalent to a body squat. With lower back and knee pain common complaints (Escamilla et al., 2008), teaching the correct mechanics of a body squat can be used as either preventative or rehabilitative. No clearly defined criteria for performing perfect squat exists, however, many exercise professionals do have recommendations.

The overall purpose of a squat includes building lower extremity strength, strengthening individual muscles of the lower body and back and promoting hip mobility. Over 200 muscles are involved while performing a squat (Solomonow et al., 1987). Proper form can yield the desired outcomes (Watkins, 1999), while with incorrect form, anatomical structures surrounding the knee such as the anterior cruciate ligament (ACL),
posterior cruciate ligament (PCL), medial cruciate ligament (MCL) and the lateral cruciate ligament (LCL) can all become severely damaged (Li, et al., 2004). Evaluating the squat begins with looking at the stance of the performer; the stance will indicate the load distribution among lower limb muscles as well as forces on the patellofemoral and tibiofemoral joints in the knee (Schoenfeld, 2010). Schoenfeld (2010) also reported that the foot placement, or stance, has affected squat kinetics with joint force differences of up to 15-16%. The force differences are positively correlated to the depth of the squat as well as the speed and load of the squat (Escamilla, Fleisig, Lowry, Barentine, & Andrews, 2001). All of the elements involved in performing a squat are not independent but instead interrelated.

The stance of the performer is closely related with the depth of the squat performed. The depth is referring to the angle of flexion that is measured at the knee joint (Schoenfeld, 2010). The knee joint is considered to have a range of motion of 0-160° of flexion (Schoenfeld, 2010; Li et al., 2004b; Signorile, Kwiatkowksi, Caruso, & Robertson, 1995; Van Eijden, Weij, Kouwenhoven, & Verburg, 1987). Research suggests that there are three categories of depth to consider. There are partial squats, half squats and deep squats (Schoenfeld, 2010). The partial squat can be classified as a knee flexion degree of around 40°. The half squats are around 70-100° of flexion. The most commonly recommended angle for executing a squat is to lower to about a 90° angle (half squat). Deep squats are considered anything greater than 100° of flexion (Schoenfeld, 2010). It is important to stress that there are no universal specifications for the proper exercise mechanics or standard terminology/vocabulary/names. The squat
option prescribed should depend on the health, functional abilities and goals of the individual.

The depth of a squat is important for a multitude of reasons including muscle activation levels, peak force pressures on anatomical structures and sport-specific goals. For general lower body strength, the squat is performed to 90° of flexion. Ample research has examined muscle activation at specific depths as well as the pressures that coincide with the depth and speed of the squat. Maximum anterior shear forces during a squat will develop with the first 60° of knee flexion. The peak forces on the ACL are between 15-30° of flexion which significantly drop at 60° (Li et al., 2004a; Isear, Erickson, & Worrell, 1997; Russell & Phillips, 1989). Posterior shear forces are higher at the lower end of the squat, specifically near 90° of knee flexion. It must also be noted that the posterior forces, specifically the PCL, are 30-40% greater during the concentric phase of a squat versus the eccentric phase. Research asserts that the greatest risk of injury from a deep, below 100° squat, would be more likely within the menisci and articular cartilage in the knee joint (Schoenfeld, 2010; Li et al., 2004a). These structures are put under the highest pressure at high knee flexion angles.

During a squat, the knees should maintain movement in the sagittal plane with no excessive medial or lateral movement in the transverse or frontal planes. When a knee joint translates medially this is called a valgus movement. When the knee travels laterally, it is considered varus. Valgus knees are more frequently seen in females than males (Hewett, 2010) and are thought to increase the risk of injury, specifically to the ACL (Markolf, Gorek, Kabo, & Shapiro, 1990). Therefore, any valgus movement should be avoided.
Squat mechanics often focus on the knee joint when in reality, the ankle joint, hip joint and spine are engaged as well. The spine could be considered the most delicate because it functions to protect the spinal cord (Toutoungi, Lu, Leardini, Catani, & O’Connor, 2000). If there is damage to this structure, severe paralysis or even death could occur; as such when performing the squat improper spinal alignment is the primary exercise error to correct. Each vertebrae in the spine has about a 3° range of movement. The 24 vertebrae together can produce a wide degree of flexion and extension as a whole (Schoenfeld, 2010; Signorile, Kwiatkowski Caruso, & Robertson, 1995). The deeper the squat, the spinal angle will increase to maintain balance. If additional weight is on the performer’s back, it is absolutely necessary to maintain a rigid spine to ensure lack of vertebral shearing. Without weight, although less likely, it is still very important to address. To maintain a neutral and rigid spine, the muscles of the back must be engaged. When a squat has lower depth and a lower knee angle lumbar flexion increases, resulting in significantly higher shear forces (Noyes, Butler, Grood, Zernicke, & Hefzy, 1984).

A study investigating the compressive forces on the spine, specifically the lumbar spines vertebrae L3 and L4 looked at the forces applied specifically to those two joints for a half squat (70-100° of knee flexion) with additional weight on the back of the performer. The added weight was between 0.8 to 1.6 times the participants bodyweight. They found that this equated to forces on the L3 and L4 joint to be 6-10 times greater than bodyweight forces. This suggests that it is common for athletes and advanced weight lifters to be squatting to a point above the considered threshold for spinal failure. They concluded that with regular training, an adaptation can occur within the structures which
allows for athletes to progress and ultimately heighten the threshold (Cappozzo et al., 1985; Schoenfeld, 2010).

Rigid and neutral positioning of the spine is required to maintain proper form while executing the squat. Not only should the spine be in a neutral position, it should also be as vertical as possible at the lowest point of the squat (Schoenfeld, 2010). If there is forward flexion, there is an extreme increase in lumbar forces which can ultimately lead to severe injury (Race & Amis, 1994). An interesting study examined the gaze of the performer while performing a squat and considered if it impacted the degree of forward spinal flexion. Three different gazes were studied: looking upward, forward and or a downward gaze. They concluded that the gaze and head positioning of the performer actually affected spine and trunk positioning. The upward and straight forward gaze were statistically similar, participants maintained a neutral spine and proper alignment. The downward gaze elicited different results demonstrating the increased likelihood of the performer exhibiting forward flexion of the spine. As forward flexion is considered poor form while performing the squat a downward gaze is not recommended (Donnelly, Berg, & Fiske, 2006).

During a squat, the weight of the performer should be distributed over the heels and mid-foot. This will aid in the recruitment of the gluteus maximus and decrease the chance of anterior translation of the knee past the toes of the foot. Gluteus maximus recruitment is desired for lower body exercises such as the squat, reverse lunge and chair step up. The increased recruitment of the gluteus maximus helps to inhibit the likelihood of lower back pain (Koh, Park, & Jung, 2016). Lawrence et al. (1998) reports that 80% of the United States population will experience lower back pain at some time in their lives.
Schoenfeld (2010) maintains that when a squat is performed from the ball of the foot the heels to rise off of the floor resulting in other joints such as the spine, knees and hips to compensate thereby increasing the chances of an injury. Other research studied the degree of mobility found in the ankle affirming that having an angle of $38.5 \pm 5.9^\circ$ is required in keep the heels down (Hemmerich, Brown, Smith, Marthandam, & Wyss, 2006). Sufficient ankle joint mobility is necessary for other joints to move correctly. Insufficient mobility of the ankle increases the chance of the torso having a higher degree of flexion in the hips increasing pressure on the lumbar spine (Race & Amis, 1994). Schoenfeld (2010) recommends that the most important error to identify and correct is any disadvantageous position of the lumbar spine which can promote lumbar shear. Lumbar spine errors should be addressed prior to other errors such as anterior tibial translation over the toes or valgus movements of the knees.

Lastly, the cadence of exercise is important to consider. The speed in which the movement is performed influences training adaptations and progressions. When programming for athletes, many fitness professionals will consider exercise cadence to stimulate the recruitment and development of specific muscle fibers. However, when performing large and complex movements such as the squat, it can quickly become dangerous when performed too quickly (Schoenfeld, 2010). Peak compressive forces on the spinal column can actually double if the squat is done too rapidly and under a load (Vakos, Nitz, Threlkeld, Shapiro, & Horn, 1994). Often times, when a squat is performed quickly, the transferring movement from eccentric to concentric phases, a bounce or bouncing motion can develop. This bounce can increase shear forces on the knee by an additional 33% (Donnelly, Berg, & Fiske, 2006). Consequently, the speed of the exercise
for the general population should be with a rather slow controlled tempo throughout the entire squat. A suggested squat cadence is a 2 to 3 seconds in the eccentric phase of the exercise (Schoenfeld, 2010; Donnelly, Berg, & Fiske, 2006; Hattin, Pierrynowski, & Ball, 1989).

In summary, the squat is a great exercise used for strengthening the lower body and for rehabilitation of the ACL (Smith, Weiss, & Lehmkuhl, 1996). The squat is performed by maintaining a neutral spine through the entire exercise. The weight should be distributed in the heels and should recruit the gluteus maximus. The knees should not translate anteriorly over the toes and the knees should not move medially (valgus) or laterally (varus). The eccentric phase should be controlled, 2-3 seconds in length. The squat depth is dependent upon the goals and health status of the performer.

Reverse Lunge

Many exercises can be performed with just body weight. The lunge is an exercise that is commonly prescribed for both recreational and therapeutic purposes (Comfort, Jones, Smith, & Herrington, 2015). There are multiple variations of the lunge including a reverse lunge, side lunge and curtsey lunge. Our research involves having participants perform a reverse lunge in lieu of a forward lunge. A reverse lunge is a unilateral exercise performed in the sagittal plane that is beneficial for increasing muscular capacity in the lower body. In a forward lunge, the lead foot will step forward and the back knee drops down. In the reverse lunge, the lead leg moves posteriorly while the other remains stationary with flexion in both knees. Similar to the body squat, the consequences of performing the exercise incorrectly can result in injury to joints, muscles and connective tissues. The joints involved in the reverse lunge are the same as the squat which include
ankle, knee, hip and spinal joints (Snarr & Eckert, 2014; Fischer, Walter, & Matovich, 2011).

The reverse lunge has not been as extensively researched as the squat however many of the same mechanics apply. The reverse lunge is unilateral; as such the lead leg should follow the same safety guidelines as the body squat related to depth, weight distribution and anterior translation of the patella over the toes. In similar fashion, a rigid and neutral spine should be maintained to ensure minimal shearing forces which may lead to injury (Schoenfeld, 2010; Signorile, Kwiatkowski Caruso, & Robertson, 1995). A team of researchers in the United Kingdom wanted to compare joint kinetics and kinematics in common lower body exercises used in rehabilitation (Comfort, Jones, Smith, & Herrington, 2015). The three exercises studied were the single legged squat, the forward lunge and the reverse lunge. The peak ground reaction forces, maximum joint angles and peak sagittal-joint movements between the three exercises were tested. Comfort, Jones, Smith, & Herrington (2015) concluded that the reverse lunge had lower peak relative eccentric and concentric ground reaction forces when compared to the forward lunge. The forward lunge had a greater knee-joint movement than the reverse lunge and lastly that the forward lunge also had greater ankle-joint dorsiflexion movements when compared to the reverse lunge. These findings suggest that the forward lunge may allow for greater errors when compared to the reverse lunge. Findings from the study fueled researchers to suggest that in a clinical setting if a patient has an injury to the knees or ankle, the reverse lunge is recommended due to lower ground reaction forces and limited anterior translation of the knee (Comfort, Jones, Smith, & Herrington, 2016). For this reason, we chose to use the reverse lunge in the current study.
Studies looking at the reverse lunge provide similar but conflicting instructions on
the proper performance of a reverse lunge (Liebenson, 2013; Fischer, Walter, &
Matovich, 2011). One main difference related to the lead foot. Liebenson (2013) studied
a reverse lunge in a rehabilitation setting where subjects were instructed to step as far
back as possible. Fischer, Walter, & Matovich (2011) had both knees flexed at 90° when
the leg stepped back. The rehabilitation specialists had the participant step back to the
starting position while the strength and conditioning team had their participants step
return to starting position and then immediately transition into a jump. Additionally, the
purpose of performing the lunge in both studies is very different, the former for
rehabilitative purposes, the latter for performance enhancement. Although there are no
specific guidelines for executing a safe and effective reverse lunge the kinematics are
similar to a body squat and as such many of the same guidelines can apply (Liebenson,

Chair Step-Up

The step up exercise is also a common exercise seen in rehabilitation centers
(Brand, 2009; Bynum, Barrack, & Alexander, 1995). It is beneficial for building the
lower body’s musculature and structures. It is similar to a forward lunge in movement
and mechanics with the addition of a step up onto a chair or platform. No defined step
height exists as it varies depending on the participant’s functional abilities and goals. An
elderly individual in rehabilitation center may focus on a step up being below 6 inches
while an athlete could see a significantly higher height. Many rehabilitation centers will
have patients walk on stair stepper machines to produce the same movement as a step up.
The rationale supporting the incorporation of the step up in prescribed exercise is that it
mimics functional movements and is beneficial in strengthening hip muscles for older individuals resulting in improved balance (Mercer, Gross, Sharma, & Weeks, 2009).

As with the other exercises, there is no universally standardized form. Similar to the lunge, minimal research on proper form and kinematics has been conducted. Both are lower body movements that engage the same muscle groups and joints, presumably many of the safety guidelines and joint alignment that apply to the squat can also apply to the step up and lunge. As with the squat and lunge, the recommended exercise prescription for performing the step up should be personalized to the individual’s health status, functional abilities and goals. An elderly person working on rehabilitating their lower extremity may have different mechanics than an athlete looking to promote hypertrophy in their lower legs. Thus it is important when prescribing the step up to consider the effect of forces on the joints to ensure proper mechanics.

The current research adds a new data to the ever-growing realm of preventative healthcare technologies. With physicians and therapists having limited time constraints to meet with patients, technology that is reliable and capable of performing visual assessments would save time and money for the industry. The Kinect could potentially assist therapists, physicians, rehabilitation specialists and personal trainers. Therefore, the purpose of this investigation was to explore how the Kinect camera could be used to enhance the abilities of exercise professionals to design and monitor interventions to improve wellness.
Hypotheses

1. The Microsoft Kinect camera can detect finer details (specific joint angles/consistency in repetition cadence) and non-intuitive parameters that are not easily recognized by an exercise professional during an exercise performance.

2. Measurements that are not related to joints and joint positions (muscle recruitment/fatigue/gaze/weight distribution/comfort) are better observed by an exercise professional than a Microsoft Kinect camera.

3. A Microsoft Kinect camera will enhance the practice capabilities of therapists, clinicians and trainers but will not be able to fully replicate the professional without intuitive evaluation by the health expert.
METHODS

Participant Selection

This study consisted of ten subjects (5 males and 5 females), ages 18-27 years old who have performed strength training regularly, at least two times per week, for the past year. Participants were recruited from The University of Akron’s Student Recreation and Wellness Center and the School of Sports Science and Wellness Education by word of mouth and by flyers (Appendix A). The study was a quasi-experimental study recruiting a convenience sampling of University of Akron students.

Procedures

Visit One

On day one, eligible participants individually attended an information orientation. During this time, participants were informed of the study procedures. Participants did not complete any instruments or have any assessments completed until they received all of the information about the study and read and signed the informed consent. Additionally, each participant was informed that they could withdraw from the study at any time. After completion of the informed consent (Appendix B), each participant completed questionnaires as well as a medical history form (Appendix C). These questionnaires included the PAR-Q & YOU (Appendix D) form to assess physical activity readiness and the International Physical Activity Questionnaire (IPAQ) (Appendix E) to assess current physical activity levels. Each participant was given a unique identifying number for all of data collected. For confidentiality, all data collected with the exclusion of the Informed Consent, Medical History and Par-Q only had the unique participant identification
number with no other identifying information. Next, the testing protocols were explained to the participants as well as establishing their eligibility to participate in the study. The exclusion criteria consisted of the following: not performing resistance training at least two times per week for at least the past year, participants’ inability to come to the Human Performance Laboratory at The University of Akron during testing and/or if they had physical limitations considered contraindications to physical activity: physical limitations including orthopedic, neuromuscular, metabolic, cardiovascular or cognitive disorders or if they were a pregnant female or if ruled ineligible to exercise as determined by the PAR-Q. All documents were reviewed prior to further instruction and upon testing to ensure each participant met the defining criteria and was fully eligible to participate in the study. The orientation and all day one assessments were held at least 48 hours before day two to allow the participants a rest period prior to performing the three exercises.

If the participant met the defining criteria and agreed to participate in the study, day one measurements began immediately after the information session. Prior to testing, anthropometric measurements were taken including height using a Detecto digital stadiometer while (Detecto Cardinal Scale Manufacturing Co., Webb City, MO) while weight was taken using a Detecto beam scale (Detecto Physician Scale, Cardinal Scale Manufacturing Co., Webb City, MO). Height and weight were measured as well as waist, hip and neck circumferences. Height was recorded to the nearest 1.0 millimeter and weight to the nearest 0.2 kilograms. Waist and neck circumference were measured to the nearest millimeter using a Gulick spring-loaded tape measure (Gulick Country Technology, Gays Mill, WI). Two measurements were taken at each site with a retest if the measurements did not agree within 5 millimeters. Waist circumference was measured
at the narrowest part of the torso above the umbilicus and below the xyphoid process. The hip circumference was measured, with the participant standing with feet together while the widest part of the buttocks was measured.

Upon completion of the anthropometric measurements participants performed a VO2max test using a metabolic cart (ParvoMedics, Sandy, UT). The purpose of the VO2max was to determine the participant’s cardiorespiratory fitness. Insight to the participant’s cardiovascular health is an important aspect in understanding their overall fitness level. This type of fitness is related to the ability to perform large muscle, dynamic, moderate-to-vigorous intensity exercise for prolonged periods of time. Cardiorespiratory fitness is considered a health-related component of physical fitness because high levels are associated with higher levels of habitual physical activity, which in turn are associated with many health benefits (Swain, 2014; Manson et al., 2002; Lee, Rexrode, Cook, Manson, & Buring, 2001; Ferrucci, Izmirlian, & Leveille, 1999). A VO2max test measures the maximal oxygen uptake which correlates with cardiorespiratory fitness level (Swain, 2014). The participant was asked to follow the Bruce treadmill protocol for the test (Bruce, Kusumi, & Hosmer, 1973). The treadmill was connected to a metabolic cart. The Bruce protocol is 7 stages in length with each stage lasting 3 minutes. Treadmill speed and grade increase at each stage. The first stage starts at 1.7 mph and at a grade of 10%. Each stage increases 2-3 METs. A MET is a metabolic equivalent which is used to describe the intensity of a variety of physical activities. One MET is relative to a resting VO2 measurement of 3.5 mL/kg/min. Light physical activity is defined as less than 3 METs, moderate as 3-5 METs and vigorous as 6 or more METs (Swain, 2014; Physical Activity Guidelines Advisory Committee Report,
The participant began walking and as the workload increased progressed to running. The test was terminated when three of the five defining criteria of a true VO\textsubscript{2}max test were met. The five criteria consists of: maximum achieved heart rate being within 10 beats of age-predicted heart rate maximum (220-age), respiratory exchange ratio of 1.15 or above, rating of perceived exertion of 9 or 10 (Borg, 1998) and other observations (e.g., participant can no longer give a thumbs-up sign, any irregular changes in treadmill gait, the participant voluntarily ending the test) (Swain, 2014). After the cardiorespiratory testing, the participants’ flexibility was assessed. Flexibility was measured using the Canadian Trunk Forward Flexion test (Novel Products Incorporated, Addison Il.) (Canadian Society for Exercise Physiology, 2003). It was important to test the flexibility of the participants to ensure they had adequate range of motion for performing the exercises in the study. The participant was asked to perform a brief dynamic warm-up to ensure the muscle was not damaged during the stretch. It was important that the flexibility was assessed post VO\textsubscript{2}max test because they were warmed up from the test. Once ready, they were asked to remove their shoes and to place their feet flat against the box. The participant was instructed to put their hands over one another, exhale and push the slider as far as possible towards their feet. Two warm-up tests were performed and then final two trials were performed. The better of two trials was recorded.

Visit Two

On day two, the participants were asked to perform a series of three pre-determined exercises after a brief uninstructed dynamic warm up. The warm up was unstructured and the participant was permitted to perform their normal warm-up routine.
The only instruction provided was that it consist of dynamic stretching. The participants were free to choose the duration of the warm-up. The three exercises include: body squats, reverse lunges and chair step ups. These exercises were chosen as they can be detected by the Microsoft Kinect camera and were easily executed by the sample population. Additionally, they are an accurate representation of lower body strength, balance and coordination. Each exercise requires a developed skillset for proper execution. Participants were not given instructions on how to perform the exercises. Participants performed each exercise at their own pace for thirty seconds. Data collected included the number of repetitions performed, assessment of participants form and alignment while performing the exercise, and the rate of perceived exertion using the Modified Borg Scale Rate of Perceived Exertion. The Modified Borg Scale Rate of Perceived Exertion is a measure of the participant’s perception of their effort during the exercise. The scale ranges from 1 to 10 with 10 being maximal exertion (Borg, 1998).

All of the exercises were performed in front of one Microsoft Kinect camera. The camera has the capability of measuring 25 joints non-invasively during exercise. The camera uses a markerless system to detect the participants joints. This allowed for the camera to capture what is considered “expert” form for the three exercises. The decision to use a single Kinect camera over multiple cameras was to determine the data detection capabilities in the simplest form. There was one exercise professional and therefore the data should be collected by only one Microsoft Kinect camera. It was understood that using multiple Kinect cameras was a more accurate means of analysis however, it was not appropriate for this specific investigation. The exercise professional observed the participant while performing the exercises and documented any errors such as knees over
toes during the squat or medial translation of the knees during any of the three exercises. These errors were documented on a criterion sheet developed by the exercise professional. The participants were instructed to turn to their right with the Kinect to their left once they were detected by the Kinect. The theory behind the camera being to their left was because it replicated the desired vantage point of the exercise professional during the exercise performance observations. The participants were instructed to perform two sets of each exercise with a minimum of five minutes rest between the two sets. This allowed for the participant to recover from the first exercise set. Both sets of data were recorded to gauge consistency between sets. Immediately after each exercise set participants were asked to rate their perceived exertion. The exercise professional is a certified personal trainer with the Athletics and Fitness Association of America (AFAA), has a Bachelor’s of Science degree in Exercise Physiology and has been personal training for over 4 years.

The exercise professional visually observed and scored each exercise performance. A performance point deduction system was implemented to quantify the quality of the exercise performance observed by the exercise professional. Each exercise performance was scored on a scale of 1-10 with a 10 being a perfect performance with no exercise errors occurring. The criteria for the quantity of points deducted can be seen in Table 1 below. The points deducted were based upon the frequency and severity of the error. The simplicity of error correction was also taken into consideration. A minimal error can easily be corrected through verbal cue. A moderate error can be corrected with consistent practice. This may take multiple repetitions to correct. An example is not reaching adequate depth in a body squat. A critical error is difficult to correct. This
requires practice and may take multiple exercise sessions to correct. An example would be a forward leaning torso due to a lack of mobility in the thoracic spine. Table 1 demonstrates the point deduction system for each exercise performance.

Table 1

**Manual Exercise Scoring**

<table>
<thead>
<tr>
<th>Points Deducted</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0</td>
<td>Error detected for fewer than 3 repetitions.</td>
</tr>
<tr>
<td>-0.5</td>
<td>Minimal Error - Simple to correct.</td>
</tr>
<tr>
<td>-1</td>
<td>Moderate Error - Difficult to correct.</td>
</tr>
<tr>
<td>-2 or more</td>
<td>Critical Error - Very difficult to correct.</td>
</tr>
</tbody>
</table>

Exercises

Body Squat

Starting position for a body squat is standing with feet shoulder width apart, shoulders flexed with elbows flexed or extended. Spinal alignment remains neutral throughout the body squat. The descent or lowering phase begins with synchronized flexion of the ankles, knees and hips in the sagittal plane. There should be no movement within the transverse or frontal planes. Hips are lowered until parallel to the floor. To ascend, drive through the heels to recruit the posterior chain, specifically the gluteus maximus. Synchronously extend ankles, knees and hips to return to starting position.

Within this exercise there are a multitude of errors that can occur at any phase. Beginning at the starting position, the performer should have their feet slightly wider than shoulder width apart. There is no universally identified foot placement that is deemed correct for all performers; it should be based upon their goal, mobility and anthropometrics. In this study we allowed the participant to self-select their starting position. If the starting position hampered correct performance of the body squat, this
was noted by the exercise professional. The performer is expected to have both shoulders flexed throughout the entire squat with elbows either extended or flexed. There were no point deductions if the performer extended their shoulders throughout the ascending phase or after completion of the repetition. However, if the performer had their shoulders extended through the entirety of the exercise, points were deducted by the observer. Posture was visually assessed in the starting position as well as throughout performance of the squat. Any poor postural mechanics and any physical deviations that might negatively influence the performance of the squat were documented. Table 2 illustrates potential errors when performing a body squat.
Table 2

*Manual Body Squat Error Criteria*

<table>
<thead>
<tr>
<th>Error ID</th>
<th>Error Criteria:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Knee angle at the beginning or completion of the squat is less than 175 degrees.</td>
</tr>
<tr>
<td>b.</td>
<td>Excessively fast at any phase (concentric or eccentric) of the repetition. – Defined as causing other mechanical errors due to speed.</td>
</tr>
<tr>
<td>c.</td>
<td>Spinal misalignment (flexion or twisting of the cervical/thoracic/lumbar spine).</td>
</tr>
<tr>
<td>d.</td>
<td>Lack of gluteus maximus recruitment during the repetition.</td>
</tr>
<tr>
<td>e.</td>
<td>Hip flexion at the conclusion of the concentric phase.</td>
</tr>
<tr>
<td>f.</td>
<td>Performer’s weight is distributed on the ball of the foot and/or their heels rise.</td>
</tr>
<tr>
<td>g.</td>
<td>Any unnecessary inversion/eversion/dorsiflexion or plantarflexion of the ankles.</td>
</tr>
<tr>
<td>h.</td>
<td>Any valgus or varus knee movement (medial or lateral) during either the concentric or eccentric phases.</td>
</tr>
<tr>
<td>i.</td>
<td>Downward or excessively upwards gaze.</td>
</tr>
<tr>
<td>j.</td>
<td>Shoulders elevated during any phase of the exercise.</td>
</tr>
<tr>
<td>k.</td>
<td>Lack of ankle, knee and hip synchronization throughout entire repetition.</td>
</tr>
<tr>
<td>l.</td>
<td>Torso positioning at the bottom of the squat is less than 45 degrees to the ground.</td>
</tr>
<tr>
<td>m.</td>
<td>Stance is shorter than shoulder width apart or excessively wider than shoulder width apart.</td>
</tr>
<tr>
<td>n.</td>
<td>Knees translate anteriorly over the toes.</td>
</tr>
<tr>
<td>o.</td>
<td>Performer appeared uncomfortable during exercise.</td>
</tr>
</tbody>
</table>

The squat recruits the muscles of the lower body including the gluteus maximus. The exercise professional surveyed the starting and ending stances to determine if the gluteus maximus was voluntarily engaged. The starting position should begin with an upright posture in with zero to minimal forward lean of the torso. Any forward leaning where a slight hip hinge was observed was documented. More importantly is the torso
positioning after the squat is completed. The exercise professional looked at the gluteus maximus and hip joint to determine if the participate voluntarily recruited the muscle. If the hips were not fully extended at the completion of the squat points were deducted. The gluteals are recruited minimally without voluntary contraction during the final phase the exercise; therefore voluntary recruitment is required. This can help to alleviate pressure on the anatomical structures of the knees which is optimal for injury prevention.

To begin the descending phase, the performer should flex the hips, knees and ankles in a synchronized motion. If the knees flex before the hips or vice versa, this is recorded as an error of asynchrony. Maintaining a synchronized joint movement pattern will translate to an even weight distribution and will limit unnecessary weight loading onto specific areas. If the knees begin the motion, the knee joint sustain much of the weight and pressures. If the hips begin the squat motion, the lumbar spine will bear more of a weight load. If the ankles begin the motion, the performer may fall forward which can increase lumbar spinal loading and possible excessive loading of the knees as well. Synchronization of the three joints is applied to the ascending phase as well. All three should be initiated, beginning joint extension at the same time to ensure an even distribution of weight and downward forces on the body. This will again help prevent injury.

Reverse Lunge

Starting position for a reverse lunge is standing with feet shoulder width apart with an upright posture. The shoulders should be flexed with the option of having the elbows flexed in a prayer-like position as well. To begin, step backwards with the lead leg in the sagittal plane while maintaining an upright torso. The step back should be synchronized
among the ankle, knee and hip joints. Step back to a comfortable distance allowing the hips to lower between the left leg and the right leg. The step back should be linear and should remain in the sagittal plane. The descent should continue until the participant cannot maintain balance or until adequate depth is reached with the hips being parallel with the left knee. The weight of the exercise should be focused primarily over the front foot, specifically through the heel and the lead foot should be used primarily for balance purposes. The knee on the front leg should maintain a vertical position and should not translate anteriorly over the toes. There should be no movement in the transverse plane by any joints. To ascend, drive through the heel of the front foot to recruit the muscles of the posterior chain, specifically the gluteus maximus. Synchronously extend the ankles, knees and hips while the back foot steps forward to the starting position. Begin the next repetition with the other leg.

The reverse lunge is unilateral meaning it predominantly works one side of the body at a time. Unilateral exercises are great for building strength in the abdomen and lower back as well as improving balance. Many errors develop in unilateral movements that are most often based around a lack of balance and coordination. There is no universally accepted form of the reverse lunge that applies to the general population. The performance speed, depth and frequency are determined by the performer’s goals, anthropometrics and mobility. In this study we allowed each participant to choose their own starting stance position and the length of which they stepped posteriorly. The length of the posterior step was observed and noted as an error if it had influenced other errors to occur. Arm positioning was also observed and monitored based on usefulness for balance during the performance. No arm swing movement throughout the entire exercise
was considered an error. Table 3 illustrates potential errors when performing a reverse lunge.

Table 3

*Manual Reverse Lunge Scoring Criteria*

<table>
<thead>
<tr>
<th>Error ID</th>
<th>Error Criteria:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Knee angle at the completion of the repetition is less than 175 degrees in both legs.</td>
</tr>
<tr>
<td>b.</td>
<td>Excessively fast at any phase (concentric or eccentric) of the repetition. – Defined as causing other mechanical errors due to speed.</td>
</tr>
<tr>
<td>c.</td>
<td>Spinal misalignment (flexion or twisting of the cervical/thoracic/lumbar spine).</td>
</tr>
<tr>
<td>d.</td>
<td>Lack of gluteus maximus recruitment during the repetition.</td>
</tr>
<tr>
<td>e.</td>
<td>Hip flexion at the conclusion of the concentric phase.</td>
</tr>
<tr>
<td>f.</td>
<td>Performer’s weight is distributed on the ball of the foot and/or their heels rise on the lead foot.</td>
</tr>
<tr>
<td>g.</td>
<td>Performer’s weight is heavily distributed over the back foot therefore putting excessive weight on back foot.</td>
</tr>
<tr>
<td>h.</td>
<td>Any unnecessary inversion/eversion/dorsiflexion or plantarflexion of the either foot aside from stepping upwards with the back leg.</td>
</tr>
<tr>
<td>i.</td>
<td>Any valgus or varus knee movement (medial or lateral) during either the concentric or eccentric phases.</td>
</tr>
<tr>
<td>j.</td>
<td>Downward or excessively upwards gaze. (Performers were not deducted points for looking where they were stepping.)</td>
</tr>
<tr>
<td>k.</td>
<td>Shoulders elevation during any phase of the exercise.</td>
</tr>
<tr>
<td>l.</td>
<td>Lack of ankle, knee and hip synchronization throughout entire repetition.</td>
</tr>
<tr>
<td>m.</td>
<td>Torso positioning at the bottom of the reverse lunge is less than 60 degrees to the ground.</td>
</tr>
<tr>
<td>n.</td>
<td>A loss of balance at any phase of the exercise.</td>
</tr>
<tr>
<td>o.</td>
<td>The lead foot crossed the midline of the body when stepping back or stepping out laterally from the stepping line.</td>
</tr>
<tr>
<td>p.</td>
<td>Distance of the back stepping leg is too far or too close based on their perceived comfort and anthropometrics. Considered an error if it influenced other errors to occur.</td>
</tr>
<tr>
<td>q.</td>
<td>Ipsilateral arm swing or no arm swing during the step back or forward.</td>
</tr>
<tr>
<td>r.</td>
<td>Knees translate anteriorly over toes.</td>
</tr>
<tr>
<td>s.</td>
<td>Performer appeared uncomfortable during exercise.</td>
</tr>
<tr>
<td>t.</td>
<td>Asynchrony between left to right side stepping movements.</td>
</tr>
</tbody>
</table>
Chair Step Up

Starting position for the chair step up, is standing with feet shoulder width apart and a straight back with shoulders and elbows extended. The stepping leg should lead the movement with the contralateral shoulder and elbow flexing in a synchronized motion. From the starting position, to ascend, the hip and knee of the lead leg are flexed to achieve a $90^\circ$ angle in both joints. The lead foot is placed on the chair or platform. Ensure that the thigh is parallel to the platform to prevent injury. Body weight should be on the lead leg. Extend the lead knee and hip while lifting and placing the other foot on the platform. Participant should be in the starting position on the platform. To descend, flex the lead hip and knee returning the foot to the ground. The other foot should follow to return to starting position. As the lead foot steps onto the chair in the sagittal plane, maintain a flat foot but drive through the heel to recruit the muscles of the posterior chain such as the gluteus maximus. The torso will be forward as the hips are flexed to transfer the weight over the stepping leg. For this study, we allowed the participants either step and match both feet on the chair or step and have the other leg come and flex up. This was the performer’s decision based on comfort and their interpretation of a proper chair step up. A straight and neutral spine should be maintained through the entire exercise. No movement should occur in the frontal or transverse planes.

The chair step up is a unilateral exercise and requires balance and coordination through the entire body. The exercise expert documented whether balance was lost during any phase of the exercise and noted if it was of the result of chair instability or the loss of balance from the performer. Each participant was observed from the frontal plane as well as the sagittal plane. Table 4 illustrates potential errors when performing a chair step up.
Table 4

*Manual Chair Step Up Scoring Criteria*

<table>
<thead>
<tr>
<th>Error ID</th>
<th>Error Criteria:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Knee angle at the top of the step is less than 175 degrees.</td>
</tr>
<tr>
<td>b.</td>
<td>Excessively fast at any phase (concentric or eccentric) of the repetition. – Defined as causing other mechanical errors due to speed.</td>
</tr>
<tr>
<td>c.</td>
<td>Spinal misalignment (flexion or twisting of the cervical/thoracic/lumbar spine).</td>
</tr>
<tr>
<td>d.</td>
<td>Lack of gluteus maximus recruitment during the repetition.</td>
</tr>
<tr>
<td>e.</td>
<td>Hip flexion \ at the conclusion of the concentric phase.</td>
</tr>
<tr>
<td>f.</td>
<td>Performer’s weight is distributed on the ball of the foot and/or their heels elevate on the stepping foot once planted on the chair.</td>
</tr>
<tr>
<td>g.</td>
<td>Any unnecessary inversion/eversion/dorsiflexion or plantarflexion of the either foot aside from stepping upwards.</td>
</tr>
<tr>
<td>h.</td>
<td>Any valgus or varus knee movement (medial or lateral) during either the concentric or eccentric phases.</td>
</tr>
<tr>
<td>i.</td>
<td>Downward or excessively upwards gaze. (Performers were not deducted points for looking where they were stepping.)</td>
</tr>
<tr>
<td>j.</td>
<td>Shoulders elevation during any phase of the exercise.</td>
</tr>
<tr>
<td>k.</td>
<td>Lack of ankle, knee and hip synchronization throughout entire repetition.</td>
</tr>
<tr>
<td>l.</td>
<td>Torso positioning at the top of the step is leaning forward and not upright.</td>
</tr>
<tr>
<td>m.</td>
<td>Ipsilateral arm swing or no arm swing during the step up or down.</td>
</tr>
<tr>
<td>n.</td>
<td>A loss of balance at any phase of the exercise (not due to chair instability).</td>
</tr>
<tr>
<td>o.</td>
<td>Uncontrolled and noisy downward step in the eccentric phase.</td>
</tr>
<tr>
<td>p.</td>
<td>Knees translate anteriorly over toes.</td>
</tr>
<tr>
<td>q.</td>
<td>Performer appeared uncomfortable during exercise.</td>
</tr>
<tr>
<td>r.</td>
<td>Asynchrony between left to right side stepping movements.</td>
</tr>
</tbody>
</table>
CHAPTER IV
RESULTS

The purpose of this investigation was to explore how the Kinect camera could be used to enhance the abilities of exercise professionals to design and monitor interventions to improve wellness. Upon providing written consent and meeting inclusion criteria, ten participants from The University of Akron completed two separate visits to human performance laboratory. Visit one assessed participant physical fitness levels and anthropometric measurements. Visit two assessed a series of exercise performances in front of the exercise professional, herein referred to as the exercise professional, and a single Microsoft Kinect camera. The exercises during visit two were a body squat, reverse lunge and a chair step-up. Each participant performed two sets of 30 seconds of each exercise at their own desired cadence with a 5 minute rest between sets. Data was collected by both the exercise professional and the Microsoft Kinect camera. The data from the Kinect camera was interpreted by the exercise professional once the data was processed.

Participant Characteristics

Physical Characteristics

Table 5 depicts participant demographic characteristics. Ten subjects (male, \( n = 5 \), females \( n = 5 \)) participated in this study. Males relative to females exhibited greater height and weight. Eighty percent of the males were classified as “overweight” according to the body mass index categories while none of the females were considered
“overweight” which is a BMI greater than or equal to 25 kg/m² ("Obesity and overweight: Body mass index," n.d.). BMI is calculated by taking a person’s weight in kilograms and dividing it by the square of their height in meters (kg/m²). The males scored a higher average VO₂ max by a difference of 3.34 ml·kg⁻¹·min⁻¹. Each participant was considered to be an expert exerciser as they had performed resistance exercise for ≥ 2 days per week for one year or more. All of the participants were in between the ages of 18-27 years. They were free of any medical conditions that prohibited them from exercising safely. Please note, participant PWMA04 was disqualified from the study due to having an unknown pre-existing medical condition.
Table 5

**Participant Demographics**

<table>
<thead>
<tr>
<th>Participant:</th>
<th>Sex</th>
<th>Height (cm)</th>
<th>Weight (Kg)</th>
<th>Body Mass Index (BMI)</th>
<th>BMI Category</th>
<th>VO2Max (ml.kg(^{-1}).min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWMA01</td>
<td>M</td>
<td>174 cm</td>
<td>77.27 kg</td>
<td>25.8</td>
<td>Overweight</td>
<td>52.1 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA02</td>
<td>M</td>
<td>170.2 cm</td>
<td>70.45 kg</td>
<td>24.3</td>
<td>Normal</td>
<td>49.4 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA03</td>
<td>F</td>
<td>163.8 cm</td>
<td>60.45 kg</td>
<td>22.8</td>
<td>Normal</td>
<td>36.8 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA04</td>
<td>xx</td>
<td>Xx</td>
<td>Xx</td>
<td>xx</td>
<td>xx</td>
<td>Xx</td>
</tr>
<tr>
<td>PWMA05</td>
<td>M</td>
<td>165 cm</td>
<td>70 kg</td>
<td>26.4</td>
<td>Overweight</td>
<td>50.5 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA06</td>
<td>F</td>
<td>171 cm</td>
<td>70.9 kg</td>
<td>24.4</td>
<td>Normal</td>
<td>49.2 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA07</td>
<td>F</td>
<td>165.1 cm</td>
<td>60.64 kg</td>
<td>22.2</td>
<td>Normal</td>
<td>51.9 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA08</td>
<td>F</td>
<td>154.9 cm</td>
<td>58.36 kg</td>
<td>24.3</td>
<td>Normal</td>
<td>43 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA09</td>
<td>M</td>
<td>170.2 cm</td>
<td>79.91 kg</td>
<td>27.5</td>
<td>Overweight</td>
<td>48.9 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA10</td>
<td>M</td>
<td>188.6 cm</td>
<td>88.64 kg</td>
<td>25.0</td>
<td>Overweight</td>
<td>44.8 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>PWMA11</td>
<td>F</td>
<td>161.3 cm</td>
<td>54.55 kg</td>
<td>21.3</td>
<td>Normal</td>
<td>48.1 ml.kg(^{-1}).min(^{-1})</td>
</tr>
</tbody>
</table>

**Total Mean:**

<table>
<thead>
<tr>
<th>Height (cm)</th>
<th>Weight (Kg)</th>
<th>Body Mass Index (BMI)</th>
<th>BMI Category</th>
<th>VO2Max (ml.kg(^{-1}).min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>168.4 cm</td>
<td>69.1 kg</td>
<td>24.4</td>
<td>Normal</td>
<td>47.5 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>+9.0</td>
<td>+10.8</td>
<td>+1.9</td>
<td></td>
<td>+4.7</td>
</tr>
</tbody>
</table>

**Mean of Males:**

<table>
<thead>
<tr>
<th>Height (cm)</th>
<th>Weight (Kg)</th>
<th>Body Mass Index (BMI)</th>
<th>BMI Category</th>
<th>VO2Max (ml.kg(^{-1}).min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>173.6 cm</td>
<td>77.3 kg</td>
<td>25.8</td>
<td>80%</td>
<td>49.1 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>+9.0</td>
<td>+7.7</td>
<td>+1.2</td>
<td>Overweight</td>
<td>+2.7</td>
</tr>
</tbody>
</table>

**Mean of Females:**

<table>
<thead>
<tr>
<th>Height (cm)</th>
<th>Weight (Kg)</th>
<th>Body Mass Index (BMI)</th>
<th>BMI Category</th>
<th>VO2Max (ml.kg(^{-1}).min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>163.2 cm</td>
<td>63.0 kg</td>
<td>23 +1.3</td>
<td>0%</td>
<td>45.8 ml.kg(^{-1}).min(^{-1})</td>
</tr>
<tr>
<td>+5.9</td>
<td>+6.1</td>
<td></td>
<td>Overweight</td>
<td>+6.0</td>
</tr>
</tbody>
</table>

**Data Interpretation**

This study used one Microsoft Kinect camera for recording and analyzing exercise errors. The camera was not moved between participants and was approximately 2-4 meters away from the participant during the performance. The camera recorded for 30 seconds and began analyzing the data once the body was detected. The participant turned
to their right once instructed to do so by the exercise professional so that the Kinect camera was located to the left side of the body. The exercise professional visually observed the exercise performance from a vantage point of choice without ever crossing the Kinects field of vision. The exercises analyzed were the body squat, reverse lunge and chair step-up. The data from the chair step-up and reverse lunge were difficult to interpret and therefore only general data comparisons between the Kinect and the exercise professional were analyzed.

The data recorded by the exercise professional was documented on a criterion sheet after a visual observation of each exercise. Concurrently, the Kinect camera was recording to collect the exercise performance data. The data from the Microsoft Kinect was sent to a cloud where the data was computed for visual analysis for interpretation. Due to a technological error saving the exercise data collection, Kinect data for participants PWMA05 and PWMA06 were not collected.

The Microsoft Kinect camera detects movement in 25 joint locations. For adequate interpretation the data should be visually consistent containing waves of the same height and distance. A consistent wave pattern typically represents a well performed exercise. The Kinect data recorded the following: the angle of the head, neck and spine, knee displacement in the y-axis, the angle of the hip, knee and ankle for each leg, any vertical movement in the y-axis of the ankle joint, synchrony of the shoulders and knees, synchrony of the hips and knees, synchrony of the ankle and foot, synchrony of the shoulders and spine, and spinal velocity.

This investigation focused on variances between errors detected by the exercise professional with those detected by the Kinect camera. Errors such as having valgus knees, forward leaning posture, unusual spinal flexion, improper repetition speed, uneven
weight distribution and excessive anterior translation of the knees are all easily identified visually by an exercise professional. The Kinect camera detects finer movement in each joint down to the millimeter which is not detectable by the human eye without additional technology. Therefore, the primary data in the current study examined the (1) angles of the ankles, hips, and knees, (2) distance of ankle movement, (3) hip and knee synchrony, and lastly (4) spine base velocity. These select areas were specifically chosen as they are frequently difficult to identify and document by the unassisted expert eye.

Exercise Professional Scoring Criteria

The exercise professional rated each exercise performance dependent upon the frequency and severity of the errors demonstrated. The highest available score was 10/10 meaning no errors occurred. To rate the severity of the error, the exercise professional determined how difficult the error would be to correct with verbal cueing or assistance. This was determined through personal experience and the subjective opinion of the exercise expert. A minimal error can easily be corrected through verbal cue. A moderate error can be corrected with consistent practice. This may take multiple repetitions to correct. An example is not reaching adequate depth in a body squat. A critical error is difficult to correct. This requires practice and may take multiple exercise sessions to correct. An example would be a forward leaning torso due to a lack of mobility in the thoracic spine. Table 1 demonstrates the point deduction system for each exercise performance.
Table 1

*Manual Exercise Scoring*

<table>
<thead>
<tr>
<th>Points Deducted</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0</td>
<td>Error detected for fewer than 3 repetitions.</td>
</tr>
<tr>
<td>-0.5</td>
<td>Minimal Error - Simple to correct.</td>
</tr>
<tr>
<td>-1</td>
<td>Moderate Error - Difficult to correct.</td>
</tr>
<tr>
<td>-2 or more</td>
<td>Critical Error - Very difficult to correct.</td>
</tr>
</tbody>
</table>

Body Squat Analysis

The exercise professional identified the top three most commonly observed errors in the body squat performance. They were as follows: spinal curvature (cervical/thoracic/lumbar) (12) (Schoenfeld, 2010; Race & Amis, 1994), forward weight distribution on the ball of the foot (9) (Hemmerich, Brown, Smith, Marthandam, & Wyss, 2006), and valgus knees (7) (Markolf, Gorek, Kabo, & Shapiro, 1990). Table 2 below contains the criteria used by the exercise expert to assess performance of the body squat.
Table 2

*Manual Body Squat Error Criteria*

<table>
<thead>
<tr>
<th>Error ID</th>
<th>Error Criteria:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Knee angle at the beginning or completion of the squat is less than 175 degrees.</td>
</tr>
<tr>
<td>b.</td>
<td>Excessively fast at any phase (concentric or eccentric) of the repetition. – Defined as causing other mechanical errors due to speed.</td>
</tr>
<tr>
<td>c.</td>
<td>Spinal misalignment (flexion or twisting of the cervical/thoracic/lumbar spine).</td>
</tr>
<tr>
<td>d.</td>
<td>Lack of gluteus maximus recruitment during the repetition.</td>
</tr>
<tr>
<td>e.</td>
<td>Hip flexion at the conclusion of the concentric phase.</td>
</tr>
<tr>
<td>f.</td>
<td>Performer’s weight is distributed on the ball of the foot and/or their heels rise.</td>
</tr>
<tr>
<td>g.</td>
<td>Any unnecessary inversion/eversion/dorsiflexion or plantarflexion of the ankles.</td>
</tr>
<tr>
<td>h.</td>
<td>Any valgus or varus knee movement (medial or lateral) during either the concentric or eccentric phases.</td>
</tr>
<tr>
<td>i.</td>
<td>Downward or excessively upwards gaze.</td>
</tr>
<tr>
<td>j.</td>
<td>Shoulders elevated during any phase of the exercise.</td>
</tr>
<tr>
<td>k.</td>
<td>Lack of ankle, knee and hip synchronization throughout entire repetition.</td>
</tr>
<tr>
<td>l.</td>
<td>Torso positioning at the bottom of the squat is less than 45 degrees to the ground.</td>
</tr>
<tr>
<td>m.</td>
<td>Stance is shorter than shoulder width apart or excessively wider than shoulder width apart.</td>
</tr>
<tr>
<td>n.</td>
<td>Knees translate anteriorly over the toes.</td>
</tr>
<tr>
<td>o.</td>
<td>Performer appeared uncomfortable during exercise.</td>
</tr>
</tbody>
</table>

The errors depicted were detected for each participant for both sets of the body squats performed and listed in Table 6 below.
Table 6

*Manual Body Squat (BS) Results*

<table>
<thead>
<tr>
<th>Participant</th>
<th>BS Score Set 1:</th>
<th>BS Set 1 Errors:</th>
<th>BS Score Set 2:</th>
<th>BS Set 2 Errors:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWMA01</td>
<td>9.5/10</td>
<td>c. (-0.5)</td>
<td>8.5/10</td>
<td>c. (-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>d. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>e. (-0.5)</td>
</tr>
<tr>
<td>PWMA02</td>
<td>9.5/10</td>
<td>c. (-0.5)</td>
<td>9/10</td>
<td>c. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>i. (0)</td>
<td></td>
<td>f. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>h. (0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWMA03</td>
<td>9/10</td>
<td>c. (-0.5)</td>
<td>8.5/10</td>
<td>b. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>h. (0)</td>
<td></td>
<td>c. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>l. (-0.5)</td>
<td></td>
<td>h. (-0.5)</td>
</tr>
<tr>
<td>PWMA04</td>
<td>xx</td>
<td>xx</td>
<td>xx</td>
<td>Xx</td>
</tr>
<tr>
<td>PWMA05</td>
<td>9/10</td>
<td>m. (-1)</td>
<td>9/10</td>
<td>f. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>j. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>m. (-0.5)</td>
</tr>
<tr>
<td>PWMA06</td>
<td>9.5/10</td>
<td>f. (-0.5)</td>
<td>9/10</td>
<td>f. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n. (-0.5)</td>
</tr>
<tr>
<td>PWMA07</td>
<td>8.5/10</td>
<td>b. (-1)</td>
<td>8/10</td>
<td>b. (-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. (0)</td>
<td></td>
<td>d. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. (0)</td>
<td></td>
<td>f. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>l. (-0.5)</td>
<td></td>
<td>l. (-0.5)</td>
</tr>
<tr>
<td>PWMA08</td>
<td>7/10</td>
<td>c. (-1)</td>
<td>8/10</td>
<td>a. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. (0)</td>
<td></td>
<td>c. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. (-1)</td>
<td></td>
<td>f. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>h. (-0.5)</td>
<td></td>
<td>h. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>l. (-0.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWMA09</td>
<td>7/10</td>
<td>h. (-2.5)</td>
<td>7.5/10</td>
<td>d. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>o. (-0.5)</td>
<td></td>
<td>f. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>h. (-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n. (-1)</td>
</tr>
<tr>
<td>PWMA10</td>
<td>8.5/10</td>
<td>c. (-1)</td>
<td>9/10</td>
<td>c. (-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d. (0)</td>
<td></td>
<td>m. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. (0)</td>
<td></td>
<td>n. (0)</td>
</tr>
<tr>
<td>PWMA11</td>
<td>9.5/10</td>
<td>b. (0)</td>
<td>9.5/10</td>
<td>b. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. (-0.5)</td>
<td></td>
<td>c. (-0.5)</td>
</tr>
</tbody>
</table>
In the following sections, some of the major errors detected in participant performance by the Kinect will be presented.

Angle of the Ankle, Knee and Hip (Body Squat)

The angles of the ankle, knee and hips were analyzed by the Microsoft Kinect camera comparing the joints bilaterally. For an error to be classified in this specific data set, variances in depth and speed between the left and right limb joint angles were detected. For the purpose of this study, the desired depth of the squat was at 90° in the knee joint (Schoenfeld, 2010). Additionally, any knee joint angle higher than 90° was considered an error. Inconsistent joint angle depths from each repetition were noted for the majority of the participants.

Multiple errors in the angles of the ankle, knees and hips in body squats performed by PWMA08 were detected by the Kinect. Inconsistent squat depths were detected between repetitions as well as a variance in left knee and right knee angles. Figure 1 represents set 2 of PWMA08’s body squat depicting the right knee angle consistently reaching about 80° in depth while the left knee reaches about 63° for the majority of the repetitions. The exercise expert documented that some of the squats were not at 90° knee flexion which contradicts the Kinect data. The Kinect detected that all repetitions were below 90° of knee flexion. This was documented in both sets of squats for PWMA08. The Kinect also depicted the left knee consistently having smaller knee angles than the right leg indicating unequal knee angles for each repetition.
Figure 1. PWMA08 Knee Angles Body Squat Set 2. Kinect Data Analysis of the Angle of the Ankle, Knee and Hips.

Distance of Ankle Movement (Body Squat)

In both sets of the squat performed by participant PWMA03, the Kinect recorded vertical movement in the y-axis of both ankle joints. This was not documented by the exercise professional for either sets of the squat. The data shows the ankle joint moving within a range of just less than 2 millimeters for set 2 (Figure 2). This can translate to a slight forward shift in weight on the ball of the foot causing the heel to rise 2 millimeters in height. That can be classified as an error as the squat should be performed with weight supported in the heels with zero vertical ankle movement in the y-axis (Hemmerich, Brown, Smith, Marthandam, & Wyss, 2006).
Vertical ankle movements were detected by the Kinect in 8 of the participants but not by the exercise professional. The exercise professional documented 9 total errors of forward weight distribution however this did not indicate the ankle moved vertically. This error was documented in the following participants: PWMA02 for set 2, PWMA05 for set 2, PWMA06 for both sets, PWMA07 for both sets, PWMA08 for both sets and PWMA09 for set 2. Both the Kinect and the exercise professional detected ankle movements in all the participants. Furthermore, data from the Kinect shows that the ankle distance traveled was consistently higher than in those participants that did not demonstrate this error.
Hip and Knee Synchrony (Body Squat)

Participant PWMA03 had a score of 9 out of 10 for squat set 1 according to the exercise professional. The errors detected were minor spinal curvature and a forward leaning torso positioning at the bottom of the squat. Additionally, valgus knees were documented for 2 repetitions or less thus did not affect the final subjective score. The Kinect camera detected a lack of synchrony between the hips and the knees for set 1 of squats in the z-axis (Figure 3). The left knee had a wider variance which can be interpreted as valgus movements. Therefore, both the Kinect and the exercise professional detected a valgus movement during the exercise performance. The Kinect also detected that the left knee and both hips were moving in the frontal plane as the hips were not level or synchronized during the squat. Hip and knee flexion should occur in the sagittal plane. The right knee was stable and consistently in the sagittal plane throughout the exercise. This imbalance between the left knee and both hips were not detected by the exercise professional but were detected by the Kinect. This asynchrony of hips can be seen in Figure 3.
Spine Base Velocity (Body Squat)

The Microsoft Kinect camera detected smooth wave-like consistencies in the performance speed for 5 participants (PWMA03, PWMA07, PWMA08, PWMA09, and PWMA10). However, analysis of squat Kinect data indicates that there appeared to be inconsistent speed between repetitions for 3 participants (PWMA01, PWMA02, and PWMA11). For a visual interpretation of a wave-like consistent speed see PWMA07’s set 1 body squat performance (Figure 4). For a visual interpretation of a non-wave-like inconsistent speed see PWMA01’s set 1 body squat performance (Figure 5). The exercise professional did not detect any variances in speed from repetition to repetition in any of the squat performance, however, an error was documented if the speed appeared to be too
quick. Participants PWMA07 and PWMA11 had documented speed errors by the exercise professional. According to the exercise professional, participant PWMA07 had an error in performing the squats too quickly although the Kinect showed consistent speeds between repetitions.

*Figure 4. PWMA07 Body Squat Set 1. Kinect Data Analysis of Spine Speed Velocity.*
Reverse Lunge Analysis

It was difficult to identify distinct errors using the Kinect when analyzing reverse lunge performances. Similar to the squat more consistent wave-like patterns of the graphic data demonstrated a more consistent reverse lunge. As for the exercise professional, the most common errors documented included forward weight distribution on the toes/ball of the foot (10), a loss of balance (8), and an excessively long step back (6). These errors include all 10 participants for both sets of reverse lunges totaling 20 sets. Table 3 below contains the criteria used by the exercise expert to assess performance of the reverse lunge.

Figure 5. PWMA01 Body Squat Set 1. Kinect Data Analysis of Spine Speed Velocity.
### Manual Reverse Lunge Scoring Criteria

<table>
<thead>
<tr>
<th>Error ID</th>
<th>Error Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Knee angle at the completion of the repetition is less than 175 degrees in both legs.</td>
</tr>
<tr>
<td>b.</td>
<td>Excessively fast at any phase (concentric or eccentric) of the repetition. – Defined as causing other mechanical errors due to speed.</td>
</tr>
<tr>
<td>c.</td>
<td>Spinal misalignment (flexion or twisting of the cervical/thoracic/lumbar spine).</td>
</tr>
<tr>
<td>d.</td>
<td>Lack of gluteus maximus recruitment during the repetition.</td>
</tr>
<tr>
<td>e.</td>
<td>Hip flexion at the conclusion of the concentric phase.</td>
</tr>
<tr>
<td>f.</td>
<td>Performer’s weight is distributed on the ball of the foot and/or their heels rise on the front foot.</td>
</tr>
<tr>
<td>g.</td>
<td>Performer’s weight is heavily distributed over the back foot therefore putting excessive weight on back foot.</td>
</tr>
<tr>
<td>h.</td>
<td>Any unnecessary inversion/eversion/dorsiflexion or plantarflexion of either foot aside from stepping upwards with the back leg.</td>
</tr>
<tr>
<td>i.</td>
<td>Any valgus or varus knee movement (medial or lateral) during either the concentric or eccentric phases.</td>
</tr>
<tr>
<td>j.</td>
<td>Downward or excessively upwards gaze. (Performers were not deducted points for looking where they were stepping.)</td>
</tr>
<tr>
<td>k.</td>
<td>Shoulders elevation during any phase of the exercise.</td>
</tr>
<tr>
<td>l.</td>
<td>Lack of ankle, knee and hip synchronization throughout entire repetition.</td>
</tr>
<tr>
<td>m.</td>
<td>Torso positioning at the bottom of the reverse lunge is less than 60 degrees to the ground.</td>
</tr>
<tr>
<td>n.</td>
<td>A loss of balance at any phase of the exercise.</td>
</tr>
<tr>
<td>o.</td>
<td>The lead foot crossed the midline of the body when stepping back or stepping out laterally from the stepping line.</td>
</tr>
<tr>
<td>p.</td>
<td>Distance of the back stepping leg is too far or too close based on their perceived comfort and anthropometrics. Considered an error if it influenced other errors to occur.</td>
</tr>
<tr>
<td>q.</td>
<td>Ipsilateral arm swing or no arm swing during the step back or forward.</td>
</tr>
<tr>
<td>r.</td>
<td>Knees translate anteriorly over toes.</td>
</tr>
<tr>
<td>s.</td>
<td>Performer appeared uncomfortable during exercise.</td>
</tr>
<tr>
<td>t.</td>
<td>Asynchrony between left to right side stepping movements.</td>
</tr>
</tbody>
</table>

The errors detected by the exercise expert for each participant for both sets of the reverse lunges performed are listed in Table 7 below.
Table 7

*Manual Reverse Lunge (RL) Results*

<table>
<thead>
<tr>
<th>Participant</th>
<th>RL Score Set 1</th>
<th>RL Set 1 Errors</th>
<th>RL Score Set 2</th>
<th>RL Set 2 Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWMA01</td>
<td>10/10</td>
<td>f. (0)</td>
<td>10/10</td>
<td>f. (0)</td>
</tr>
<tr>
<td>PWMA02</td>
<td>8.5/10</td>
<td>i. (-0.5)</td>
<td>8.5/10</td>
<td>m. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>m. (-0.5)</td>
<td></td>
<td>n. (-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>n. (-0.5)</td>
<td></td>
<td>r. (0)</td>
</tr>
<tr>
<td>PWMA03</td>
<td>9/10</td>
<td>d. (0)</td>
<td>9/10</td>
<td>b. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e. (0)</td>
<td></td>
<td>n. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>n. (-0.5)</td>
<td></td>
<td>o. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p. (-0.5)</td>
<td></td>
<td>p. (-0.5)</td>
</tr>
<tr>
<td>PWMA04</td>
<td>xx</td>
<td>xx</td>
<td>xx</td>
<td>Xx</td>
</tr>
<tr>
<td>PWMA05</td>
<td>8/10</td>
<td>f. (0)</td>
<td>8/10</td>
<td>c. (-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>g. (-1)</td>
<td></td>
<td>f. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s. (-1)</td>
<td></td>
<td>s. (-0.5)</td>
</tr>
<tr>
<td>PWMA06</td>
<td>9/10</td>
<td>f. (-0.5)</td>
<td>10/10</td>
<td>NONE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>n. (-0.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWMA07</td>
<td>9/10</td>
<td>b. (-0.5)</td>
<td>8.5/10</td>
<td>b. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f. (0)</td>
<td></td>
<td>d. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>m. (-0.5)</td>
<td></td>
<td>e. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>f. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>m. (-0.5)</td>
</tr>
<tr>
<td>PWMA08</td>
<td>8/10</td>
<td>c. (-1)</td>
<td>9/10</td>
<td>p. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>n. (0)</td>
<td></td>
<td>q. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>r. (-0.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>s. (-0.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWMA09</td>
<td>7.5/10</td>
<td>f. (-1)</td>
<td>7.5/10</td>
<td>f. (-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p. (-0.5)</td>
<td></td>
<td>p. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>s. (-1)</td>
<td></td>
<td>s. (-0.5)</td>
</tr>
<tr>
<td>PWMA10</td>
<td>7.5/10</td>
<td>o. (-1)</td>
<td>9/10</td>
<td>q. (-0.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p. (-0.5)</td>
<td></td>
<td>r. (-0.5)</td>
</tr>
<tr>
<td>PWMA11</td>
<td>9.5/10</td>
<td>n. (0)</td>
<td>9/10</td>
<td>f. (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>t. (-0.5)</td>
<td></td>
<td>n. (-0.5)</td>
</tr>
</tbody>
</table>
Angle of the Ankle, Knee and Hip (Reverse Lunge)

The angle of the ankles, knees and hips were analyzed by the Kinect. The data graphics show consistently that each participant had smaller knee angles than 170° at all times which does not make sense. During the reverse lunge, each individual returned to the starting position and therefore would have greater knee angles than what the data suggested. Participant PWMA08 had the largest knee angle at 115° for 2 repetitions while the remaining repetitions were consistently 100° or less. Refer to Figure 6 illustrating set 2 of participant PWMA08’s reverse lunge. Similar patterns for participants PWMA03 and PWMA07 depicted unrealistic knee angles. Therefore, the Kinect data may not be reliable for the reverse lunge.

Figure 6. PWMA08 Reverse Lunge Set 2. Kinect Data Analysis of the Angle of the Ankle, Knee and Hip.
Distance of Ankle Movement (Reverse Lunge)

The Kinect was unable to distinguish the left ankle from the right ankle in the reverse lunge performance. Therefore, the data cannot be interpreted as it is unclear which ankle is being recorded as well as which foot is stepping back. The front ankle should remain stationary during the performance of the reverse lunge. No ankle distance errors were detected by the exercise professional.

Hip and Knee Synchrony (Reverse Lunge)

The Kinect provided useful data in the interpretation of the hip and knee synchrony for the reverse lunges. A lack of bilateral knee, hip and shoulder synchrony was detected for each participant. No bilateral asynchrony was noted by the exercise professional. The Kinect data provided a clear representation of consistencies and inconsistencies while performing a reverse lunge as interpreted by either by the type of wave patterns. The exercise professional scored participant PWMA07 a 9/10 on set 1 of their reverse lunge. The errors were each considered minor and included a loss of balance and valgus knees. The Kinect data demonstrated an equal and balanced synchrony of both knees and both hips for set 1 which can be seen on Figure 7. In contrast, the exercise professional scored PWMA10 a 7.5/10 on set 1 of their reverse lunge performance due to the stepping foot crossing the midline of the body, the step was excessively far, and the knees moved anteriorly over the toes. The Kinect data demonstrated a lack of synchrony between the hips and knees for this participant as seen on Figure 8.
Figure 7. PWMA07 Reverse Lunge Set 1. Kinect Data Analysis of Hip and Knee Synchrony.
The data for the reverse lunge demonstrated that it was a difficult task for each participant maintain consistent speed while performing the exercise. Participants PWMA01 and PWMA07 were the most consistent in their repetition speeds during the reverse lunges. The remaining participants were inconsistent. The spine base velocity was evaluated by identifying an inconsistent wave pattern in the graphic which was interpreted as inconsistency in repetition speed. Inconsistencies in reverse lunge performance were not detected by the exercise professional for any of the participants. Having an irregular speed in performance may not directly be considered an error. The wave pattern is also used to track the number of repetitions performed. Refer to Figure 9 which represents participant PWMA07’s set 1 reverse lunge Kinect data. The exercise professional rated

Figure 8. PWMA10 Reverse Lunge Set 1. Kinect Data Analysis of Hip and Knee Synchrony.

Spine Base Velocity (Reverse Lunge)

The data for the reverse lunge demonstrated that it was a difficult task for each participant maintain consistent speed while performing the exercise. Participants PWMA01 and PWMA07 were the most consistent in their repetition speeds during the reverse lunges. The remaining participants were inconsistent. The spine base velocity was evaluated by identifying an inconsistent wave pattern in the graphic which was interpreted as inconsistency in repetition speed. Inconsistencies in reverse lunge performance were not detected by the exercise professional for any of the participants. Having an irregular speed in performance may not directly be considered an error. The wave pattern is also used to track the number of repetitions performed. Refer to Figure 9 which represents participant PWMA07’s set 1 reverse lunge Kinect data. The exercise professional rated
PWMA07’s set 1 of the reverse lunge a score of 9/10. The exercise professional counted 22 repetitions which is in agreement with the Kinect which visualized 22 wave peaks with each peak representing a repetition. Compare this to the performance of participant PWMA08. The exercise professional scored PWMA08’s set 1 performance of the reverse lunge an 8/10 due to spinal curvature, knees anteriorly over the toes, and a lack of comfort during the performance. The Kinect data represented in Figure 10 suggests that the participant had inconsistent speed between repetitions with difficulty distinguish a full repetition.

Figure 9. PWMA07 Reverse Lunge Set 1. Kinect Data Analysis of Spine Speed Velocity.
Chair Step-Up Analysis

It was difficult to detect errors in exercise performance of chair step ups using the Kinect data. The error detection criteria used by the exercise professional is depicted in Table 4.
## Table 4

**Manual Chair Step Up Scoring Criteria**

<table>
<thead>
<tr>
<th>Error ID</th>
<th>Error Criteria:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>Knee angle at the top of the step is less than 175 degrees.</td>
</tr>
<tr>
<td>b.</td>
<td>Excessively fast at any phase (concentric or eccentric) of the repetition. – Defined as causing other mechanical errors due to speed.</td>
</tr>
<tr>
<td>c.</td>
<td>Spinal misalignment (flexion or twisting of the cervical/thoracic/lumbar spine).</td>
</tr>
<tr>
<td>d.</td>
<td>Lack of gluteus maximus recruitment during the repetition</td>
</tr>
<tr>
<td>e.</td>
<td>Hip flexion \ at the conclusion of the concentric phase.</td>
</tr>
<tr>
<td>f.</td>
<td>Performer’s weight is distributed on the ball of the foot and/or their heels elevate on the stepping foot once planted on the chair.</td>
</tr>
<tr>
<td>g.</td>
<td>Any unnecessary inversion/eversion/dorsiflexion or plantarflexion of the either foot aside from stepping upwards.</td>
</tr>
<tr>
<td>h.</td>
<td>Any valgus or varus knee movement (medial or lateral) during either the concentric or eccentric phases.</td>
</tr>
<tr>
<td>i.</td>
<td>Downward or excessively upwards gaze. (Performers were not deducted points for looking where they were stepping.)</td>
</tr>
<tr>
<td>j.</td>
<td>Shoulders elevation during any phase of the exercise.</td>
</tr>
<tr>
<td>k.</td>
<td>Lack of ankle, knee and hip synchronization throughout entire repetition.</td>
</tr>
<tr>
<td>l.</td>
<td>Torso positioning at the top of the step is leaning forward and not upright.</td>
</tr>
<tr>
<td>m.</td>
<td>Ipsilateral arm swing or no arm swing during the step up or down.</td>
</tr>
<tr>
<td>n.</td>
<td>A loss of balance at any phase of the exercise (not due to chair instability).</td>
</tr>
<tr>
<td>o.</td>
<td>Uncontrolled and noisy downward step in the eccentric phase.</td>
</tr>
<tr>
<td>p.</td>
<td>Knees translate anteriorly over toes.</td>
</tr>
<tr>
<td>q.</td>
<td>Performer appeared uncomfortable during exercise.</td>
</tr>
<tr>
<td>r.</td>
<td>Asynchrony between left to right side stepping movements.</td>
</tr>
</tbody>
</table>
Table 8 depicts errors observed by the exercise expert while performing a chair step up.

**Table 8**

*Manual Chair Step Up (CSU) Results*

<table>
<thead>
<tr>
<th>Participant</th>
<th>CSU Score Set 1</th>
<th>CSU Set 1 Errors</th>
<th>CSU Score Set 2</th>
<th>CSU Set 2 Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWMA01</td>
<td>8.5/10</td>
<td>f. (-1.5)</td>
<td>8.5/10</td>
<td>f. (-1) m. (-0.5)</td>
</tr>
<tr>
<td>PWMA02</td>
<td>9/10</td>
<td>n. (0) o. (-0.5) p. (-0.5)</td>
<td>8.5/10</td>
<td>b. (-0.5) o. (-1)</td>
</tr>
<tr>
<td>PWMA03</td>
<td>8.5/10</td>
<td>d. (0) e. (-0.5) f. (-0.5) o. (-0.5)</td>
<td>8.5/10</td>
<td>b. (-0.5) m. (-0.5) q. (-0.5)</td>
</tr>
<tr>
<td>PWMA04</td>
<td>Xx</td>
<td>xx</td>
<td>Xx</td>
<td>Xx</td>
</tr>
<tr>
<td>PWMA05</td>
<td>8/10</td>
<td>f. (-0.5) h. (-0.5) m. (0) o. (-1)</td>
<td>8.5/10</td>
<td>f. (-0.5) h. (-0.5) m. (0) o. (-0.5)</td>
</tr>
<tr>
<td>PWMA06</td>
<td>10/10</td>
<td>None</td>
<td>10/10</td>
<td>None</td>
</tr>
<tr>
<td>PWMA07</td>
<td>9/10</td>
<td>e. (-0.5) f. (0) l. (-0.5)</td>
<td>9/10</td>
<td>f. (-0.5) l. (-0.5)</td>
</tr>
<tr>
<td>PWMA08</td>
<td>9.5/10</td>
<td>m. (0) o. (-0.5)</td>
<td>9.5/10</td>
<td>f. (0) m. (-0.5)</td>
</tr>
<tr>
<td>PWMA09</td>
<td>7.5/10</td>
<td>f. (-1) o. (-0.5) q. (-0.5) r. (-0.5)</td>
<td>8/10</td>
<td>p. (-1) r. (-1)</td>
</tr>
<tr>
<td>PWMA10</td>
<td>8.5/10</td>
<td>q. (-1.5)</td>
<td>9/10</td>
<td>c. (0) f. (-1) i. (0)</td>
</tr>
<tr>
<td>PWMA11</td>
<td>8/10</td>
<td>d. (-1) f. (-1)</td>
<td>8/10</td>
<td>d. (-1) f. (-1)</td>
</tr>
</tbody>
</table>
Angle of the Ankle, Knee and Hip (Chair Step-Up)

The Kinect provided knee joint angle data that was similar to the reverse lunge data. According to the Kinect data, the left leg for each participant appeared to underperform compared to the right meaning that the right knee and hip returned to near 180° while the leg hip and knees remained in slight flexion. Figure 11 illustrates participant PWMA02’s set 2 of the chair step up performance. PWMA02 had left knee joint angles that were consistently near 100° for the entire exercise performance. This conflicts with the observations of the exercise expert who found no errors. Consequently, the Kinect data may not reliably be able to detect errors while performing a chair step-up.

*Figure 11. PWMA02 Chair Step-Up Set 2. Kinect Data Analysis of the Angle of the Ankle, Knee and Hips.*
Distance of Ankle Movement (Chair Step-Up)

The Kinect data was unable to distinguish between the left and right ankles while performing chair step-ups. Data from the Kinect was unable to distinguish when the ankle is stepping up and when it is on the ground. The exercise professional did not indicate any errors in ankle movement distance.

Hip and Knee Synchrony (Chair Step-Up)

The Kinect data demonstrated a lack of knee and hip synchrony for all participants. Conversely, the exercise professional did not document asynchrony.

Spine Base Velocity (Chair Step-Up):

The spine base velocity was easily evaluated by identifying a consistent wave pattern in the graphics provided by the Kinect data indicating no inconsistencies in speed tempo. The exercise professional did not document any errors in the speed variances of any exercise performances. The data for the chair-step up was consistent with the reverse lunge indicating that a consistent wave pattern is preferred indicating the number of repetitions performed.

Errors Detected Only by Exercise Professional

Some errors were only detectable by the exercise professional. The errors not detected by the Kinect involved muscle recruitment, the estimated fatigue of the individual, the comfort of the performer while performing each exercise and the pressure of the weight distribution. The Kinect cannot detect muscular recruitment patterns and engagement. For the three exercises, the gluteus maximus should be recruited to extend the hips during the ascent phase. The Kinect cannot detect fatigue of the participant during the exercise performance. The exercise professional can visually determine if the participant is slowing the cadence due to fatigue, or if there is pain due to wincing or
facial expressions as well as verbally assessing rate of perceived exertion. These elements cannot be detected by the Kinect. This is similar to the observation of the level of comfort in which the performer demonstrated for the exercise. Some participants may not have been comfortable performing any of the three exercises and the exercise professional can determine this with visual observation, interpretation and speaking directly to the performer. The data collected by the Kinect did not address the exact speed of each repetition, only the differences in speed between each repetition. The exercise professional documented whether exercise performance speed appeared to be too fast for each exercise in addition to the overall comfort and fatigue level of the performer. The exercise professional can detect the gaze of the performer while this cannot be detected by the Kinect camera. Lastly, the Kinect cannot directly detect the weight distribution when exerting pressure to a specific muscle or joint segment. The Kinect was not programmed to analyze the curvature of the spine and therefore abnormal spinal deviations observed during exercise performance were recorded by the exercise professional alone. Forward flexion of the hips and trunk were documented by the exercise professional while the Kinect was not programmed to detect this.

Errors Detected Only by Microsoft Kinect

The Microsoft Kinect camera measured the movements in 25 joints. It measured distances traveled by specific joints, joint angles, and the speed of the joints moving. This produced a lot of visual data to interpret. Conducting the data analysis established that the Kinect detected finer movement details undetectable by the exercise professional. The Kinect detected movements in the ankle joints, a lack in synchrony among left and right shoulders, a lack in synchrony between left and right hip joint locations, a lack in synchrony between left and right knees, as well as asynchrony between knee and hip
movements. The spine base velocity was measured by the Kinect and while both the camera and the exercise professional documented errors in the speed of each exercise, the Kinect detected variances in each repetition while the exercise professional did not. All movements were measured in millimeters by the Kinect while none were documented by the exercise professional.
CHAPTER V
DISCUSSION

The purpose of this investigation was to explore how the Kinect camera could be used to enhance the abilities of exercise professionals to design and monitor interventions to improve wellness. Similar research conducted examined physical therapists intuitive capabilities in identifying errors from data provided by the Kinect (Yao, Xu, & Li, 2014). Unlike the current study, there were no qualitative versus quantitative comparisons in their research.

As technological advances continue to expand, it may adversely impact certain professions such as physical therapy assistants and personal trainers. By having the accessibility of reliable and state-of-the-art technology minimal costs, the likelihood of increasing health and wellness opportunities globally is exponentially greater. Physical therapists and other health service workers could potentially be competing with a relatively inexpensive a Microsoft Kinect camera which can perform assessments and exercise revisions while saving resources such as time and capital. The opportunity for this field of healthcare technology is immeasurable.

The technological advancements at such minimal costs could improve the healthcare industry immensely but it is necessary to establish the validity and reliability of data provided by the Kinect camera. We hypothesized that the Microsoft Kinect would detect finer details and non-intuitive parameters that are not easily recognized by an exercise professional. Also, we hypothesized that the exercise professional will be able to
determine the muscle recruitment and other non-joint related movements more efficiently than the Microsoft Kinect. We presume that the Kinect will be an adjunct device for therapists, clinicians and trainers but will not be able to fully replicate exercise professional input and evaluation.

Hypotheses

Hypothesis #1

The Microsoft Kinect camera can detect finer details (specific joint angles/consistency in repetition cadence) and non-intuitive parameters that are not easily recognized by an exercise professional during an exercise performance.

The Kinect measured the angle of segmented joint locations. In this study, the angles of the ankle, knee and hip were measured in each leg during the exercise performances. The exercise professional did not document any estimated joint angles however they did interpret whether adequate depth was reached (90° of the knee joint) during the exercises. Schoenfeld (2010) suggests that 90° is an appropriate knee joint angle when performing the body squat for general guidelines. During the body squat, the Kinect data evaluated inconsistent joint angle depths (left knee to right knee angles) from each repetition in the majority of the participants. The exercise professional did not document a single inconsistent joint angle depth. In set 2 of the body squat performed by participant PWMA08, the exercise professional documented minor errors in which adequate depth of 90° was not met. However, the Kinect data shows that every squat was below 90° and that the left leg had a smaller joint angle than the right leg. This inconsistency is considered an error due to the possibility of developing muscle imbalances. According to Croisier (2004), muscle imbalances can lead to injuries. The
Kinect data provides insight that the exercise professional cannot provide. This insight can help determine if a squat is being done correctly which will aid in injury prevention (Watkins, 1999). The data suggests that the Kinect can detect exact joint angles and the exercise professional cannot. Therefore, the quantitative data of the exact joint angles outperformed the exercise professional in exercise error detection.

The Kinect data also analyzed the hip and knee joint synchrony and movement in the z-axis during the exercise performances. For set 1 of body squats performed by participant PWMA03, the exercise professional documented minor valgus knee movements. There was no indication as to which knee moved. The Kinect data also detected the valgus movement and indicated that the left knee was moving while the right knee was not. This insight can be useful to health professionals attempting to minimize the chances of an injury to the anterior cruciate ligament (ACL) (Markolf, Gorrek, Kabo, & Shapiro, 1990). The Kinect data also revealed that both of the hip joints were deviating to the left and not maintaining linear movement in the sagittal plane. This was not indicated by the exercise professional. With a lack in synchrony between the left and right hips, this can develop muscular imbalances leading to injury (Croisier, 2004). Therefore, the Kinect outperformed the exercise professional in joint synchrony error detection.

The Kinect recorded each participant’s spinal speed velocity and cadence. The exercise professional did not document a single instance of speed imbalances, only excessively fast speeds in 8 performances amongst all three exercises. Through analysis of the Kinect data, the consistency of each repetition can be seen in each exercise performance. The Kinect data shows that specific participants were inconsistent in their exercise cadence and the exercise professional did not detect this. Again, the Kinect camera is useful in measuring non-intuitive parameters of the exercise performance such
as inconsistent repetition speeds. This data would be beneficial for rehabilitation specialists and sport-specific training programs focusing on time-under-tension (Schoenfeld, 2010; Donnelly, Berg, & Fiske, 2006). While the speed of a repetition is dependent upon a performer’s goals and health status, it’s advisable to perform the repetitions at a slower speed to inhibit injury from occurring (Hattin, Pierrynowski, & Ball, 1989).

Hypothesis #2

Measurements that are not related to joints and joint positions (muscle recruitment/fatigue/gaze/weight distribution/comfort) are better observed by an exercise professional than a Microsoft Kinect camera.

The exercise professional can visually observe changes in a participant’s fatigue while the Kinect cannot. The exercise professional can see where the participant is maintaining their gaze which is considered an error (Donnelly, Berg, & Fiske, 2006) because of the increased likelihood of lumbar flexion from occurring during the squat (Noyes, Butler, Grood, Zernicke, & Hefzy, 1984). The gaze cannot be determined by the Kinect. Gluteus maximus recruitment is desired during the concentric phase of all three exercises in this study (body squat/reverse lunge/chair step-up) (Koh, Park, & Jung, 2016). The Kinect camera cannot detect contraction of specific muscle groups while the exercise expert can somewhat visually determine if recruitment occurred. The squat has 200 muscles involved during each repetition (Solomonow et al., 1987) and therefore insight as to which muscles are predominantly being recruited is useful. The exercise expert looked for the shortening and tightening of the gluteus maximus muscle during the exercises. If the exercise expert did not detect any recruitment, an error was documented. Lastly, the exercise professional can determine where the weight of the performer is
located by observing torso positioning, the sole of the foot and by verbally asking the performer where they were distributing their weight. The Kinect cannot detect exact weight distribution and it would require intensive expert interpretation of the data to see any relationship to weight distribution and joint positioning. A forward trunk lean is unwarranted (Race & Amis, & 1994) as well as a forward weight distribution (Hemmerich, Brown, Smith, Marthandam, & Wyss, 2006) as they can cause injury to the lumbar spine (Noyes, Butler, Grood, Zernicke, & Hefzy, 1984) or anatomical structures of the knee joint (anterior cruciate ligament/posterior cruciate ligament) (Li et al., 2004a).

Therefore, the exercise professional outperformed the Microsoft Kinect in measurements that were not directly related to joints or joint positions.

Hypothesis #3

A Microsoft Kinect camera will enhance the practice capabilities of therapists, clinicians and trainers but will not be able to fully replicate the professional without intuitive evaluation by the health expert. As stated in hypothesis #1, the cadence of each repetition would be beneficial for physical therapists, rehabilitation specialists, and strength and conditioning coaches. The imbalance in repetition speed was detected by the Kinect and not by the exercise professional. The imbalance in speed is not necessarily an exercise error as speed is goal-oriented and based on health status. A strength and conditioning coach may want to see if any of the athletes are inconsistent in speed and may change a program based on specific cadences. Therefore, the Kinect shows promise as a system to enhance the practice capabilities of many health and wellness professions.

The distance of ankle movement was analyzed by the Kinect through all three exercises. The Kinect data did not specify which ankle was analyzed during the reverse lunge or during the chair step-up and therefore the data cannot be correctly interpreted.
For the body squat, there should be minimal ankle movement (Schoenfeld, 2010; Hemmerich, Brown, Smith, Marthandam, & Wyss, 2006) and the Kinect documented each participant having movement in the y-axis. This data suggests that the ankle joint was moving vertically during the squat performances. The exercise professional did not document any ankle movements; however it was documented if the heels were to rise which would cause the ankle to move vertically. Therefore, the Kinect data could be used in addition to visual observation in determining to what extent the ankle joint vertically moved and to what severity the error was. The Kinect data alone does not directly indicate that the heels were elevated or that a forward weight distribution occurred. The Kinect also does not indicate whether gluteus maximus engagement occurred during any exercise performance. The use of the gluteals reduces the chances of lower back pain from occurring (Koh, Park, & Jung, 2016). Again, the Kinect camera would be a beneficial tool is assisting health professionals in exercise error detection.

As stated in Hypothesis #1, both the exercise professional and the Microsoft Kinect camera detected valgus movement errors in set 1 of the squat performance of participant PWMA03. The Kinect data provided quantitative insight as to which knee experienced valgus movement and the distance moved. The exercise professional could only qualitatively indicate that a valgus movement occurred without supporting quantitative data. The Kinect camera also detected undesirable movements in both hip joints during the exercise performance which was not documented by the exercise professional. These results provide tangible possibilities as to how technology may aid exercise professionals. Errors detected by the software are not easily detected by the human eye. With the assisting device of a Kinect camera, a physical therapist or rehabilitation specialist could indicate the precise movements that occur in specific joints
such as the knee or hips.

For each exercise performance, the Kinect camera analyzed the joint angle of the knee (angle of the ankle, knee, and hip). The Kinect camera outperformed the exercise professional in precise joint angle interpretation; however the data from the Kinect appears to be questionable. For all three exercises and every participant, the left knee joint angle was performing at a lower angle than the right knee angle. For eight of the participants recorded, the probability that each set of each exercise performed resulted in the left leg maintaining a smaller angle than the right leg is minimal. In addition to each participant having the same result, the exercise professional did not document that the participant did not complete the repetition and never maintained a straight leg in all three exercises. In the instance that the Kinect was accurate, this would indicate that there is an increased chance in muscle imbalances from developing. Muscle imbalances can lead to injuries and therefore should be avoided (Croisier, 2004). Therefore, the Kinect data is useful in determining specific joint angles; however the additional assistance of an exercise professional also observing the exercise performance is warranted. The results from the visual observation by an exercise professional may be enhance by considering the additional quantitative data provided by the Kinect. The lack of reliability and validity of joint angles is consistent with the Hawi et al. (2014) study which concluded that the accuracy of the Kinect needs to improve before replace goniometers in a clinical setting. This research is inconsistent with the Lee et al. (2015) study which concluded that the Kinect was accurate and reliable in assessing joint angles when compared to a goniometer. Further investigation needs to be conducted.

Limitations

This study was not without limitations. One Microsoft Kinect camera was used to
record the exercise performances. Accuracy and validity of exercise evaluation improves when using multiple Kinect cameras (Pathirana, Li, Trinh, & Seneviratne, 2016). Using two Kinect cameras may have provided further insight in areas such as validating the left and right leg knee angles during the exercise performances. During the collection process, the data from participants PWMA05 and PWMA06 were not saved correctly and therefore data interpretation was not available.

The participants were expected to remain truthful in concluding that they fit the defining criteria. It is possible that a participant may not have been performing strength training exercises for over one year at a rate of at least 2 times per week.

The Kinect data was analyzed by the exercise professional. The Kinect data was also presented in a graphical form that is difficult to interpret. There were no anatomical references or positioning specified in the data. The Kinect evaluated by segmented joint locations and therefore the data had to be interpreted by single areas and not in its entirety. This proved to be difficult in comparing multiple errors documented by the exercise professional.

During the data collection process of visit 2, the participant should have been facing the camera and not turning to their right. The turning of the body caused specific joint images to be occluded from the field of vision of the Kinect and therefore could have caused a loss in accuracy of measurements. The rationale for having the participants turn to their right was to replicate the exercise professionals preferred vantage point for the exercise performance observations. For the reverse lunge and chair step-up data, the Kinect analysis did not indicate as to which ankle joint it was evaluating. This removed the ability to compare the Kinect data results of the ankle joint complex with the exercise professional’s documentation of errors.
The exercises performed in this investigation are strictly lower extremity movements. The data collected does not examine the capabilities of examining the errors of the upper body.

Lastly, the exercise error interpretation and documentation was a subjective process by the exercise professional. The educational background and training history of the exercise professional indicates that they are qualified to assess exercise performance; however there is always the ability of error to occur. Therefore, the qualitative data documented by the exercise professional was based on subjective interpretation and personal opinions and cannot be directly replicated.

Conclusions

The findings of the present study indicate that the Microsoft Kinect camera can detect finer details (specific joint angles/consistency in repetition cadence) and non-intuitive parameters more precisely than exercise professional can during an exercise performance. The present study further concludes that additional research needs to be conducted to determine the validity and reliability of joint angle measurements by a Microsoft Kinect camera. Lastly, results from the current study lead to the conclusion that the Microsoft Kinect camera is a useful tool that can enhance the ability of healthcare providers in determining non-intuitive parameters such as joint angle differences during an exercise performance and speed variances between repetitions. Implementing practice enhancing technology for exercise professionals may provide a means for enhanced feedback for clients thereby motivating and helping sedentary individuals adopt healthy behaviors. Feedback from both professionals and technology may decrease exercise injuries and overtime increase exercise adherence. The data provided by the Kinect
camera needs to be presented in a more holistic manner for interpretation by exercise professionals. The data is currently provided in graphical form and would be better understood if presented in anatomical terminology and visuals. The data collection analysis from the Kinect for this investigation is a preliminary step in exploring the practice enhancement capabilities in the health services field. Further research is warranted.

Future Directions

Based on the findings of the present investigation, the following recommendations are proposed for future research:

1. Further research should be conducted with more participants and more exercise professionals.
2. Future research should investigate examining more exercises including upper body, in determining validity and reliability of this system.
3. Future research should be conducted with participants at different skill levels.
4. Future research should examine anatomical and biomechanical deviations that may influence exercise performance.
5. Future studies should examine the use of this system with exercise performed in supine and prone positions.
6. Additional algorithms should developed to reduce data collection errors in occluded body parts.
REFERENCES


doi:10.1249/mss.0b013e31818e7ead


doi:10.1016/j.cmpb.2013.10.014


APPENDICES
APPENDIX A

STUDY FLYER
Personalized Wellness Management

Exercise Biomechanics Study

*Have your exercise biomechanics examined by experts and new-age technology*

*Exercise Research Program for Healthy Individuals*

*Volunteers are needed for an exercise biomechanics program*

Volunteers should be:

- UA students, males or females
- Ages 18-27
- Non-pregnant females
- Free of any medical condition that could prevent exercising safely
- Has performed resistance exercise >2 days per week for one year or more

If you meet these criteria you may be eligible for the Exercise Biomechanics Study.

For further information please contact:

**Andy Hanson, UA Graduate Assistant**

Phone: *(419) 906-0204* or by Email: **ath11@zips.uakron.edu**
APPENDIX B
INFORMED CONSENT
Title of Study: Can the Kinect Camera Detect Errors in Exercise Performance When Compared to the Analysis by an Exercise Expert?

Introduction: You are invited to participate in a research project being conducted by Andy Hanson, a graduate assistant in the School of Sport Science and Wellness Education and Professor Judith A. Juvancic-Heltzel, member of School of Sport Science and Wellness Education at The University of Akron.

Purpose: The purpose of this study is to use a Microsoft Kinect camera to analyze biomechanical errors in exercise. Developing software that could analyze biomechanical errors could be used in the health care industry from personal training to rehabilitation services.

Procedures:

Day 1: Once eligibility has been determined you will report to the Exercise Physiology Laboratory in InfoCision Stadium to complete a number of surveys, have biometric data collected and baseline fitness assessments conducted.

Baseline Measurements

You will complete a medical history questionnaire, an International Physical Activity Questionnaire (IPAQ) and a Physical Activity Readiness Questionnaire (PAR-Q) to rule out any safety concerns that would prohibit you from participating in the study.

Biometric Screening

Height, weight, waist, hip, and neck circumference measurements - Height will be recorded (to the nearest 1.0 mm) and weight (to the nearest 0.2 kg) will be measured.
using a balance beam scale (Health O Meter, Alsip, IL). Waist, hip, and neck circumference will be measured to the nearest mm using a Gulick spring-loaded tape measure (Gulick Country Technology, Gays Mill, WI). Two measurements will be taken at each site, with a retest if the measurements do not agree within 5 mm. Neck circumference is measured in the middle of the neck between the mid-cervical spine and the mid-anterior neck. Waist circumference will then be measured at the narrowest part of the torso above the umbilicus and below the xyphoid process. The hip circumference will be measured, with you standing with your feet together with the widest part of the buttocks being measured.

Body composition – Your body composition will be estimated using a DEXA bone densitometer (GE/Lunar Corp, Madison, WI). The DEXA uses tightly controlled x-rays to measure body composition. Bone mineral content, lean mass and body fat percentage can be determined. After removing all jewelry and metals, you will lay quietly, arms at your sides, on the scanning bed while the scanning begins at the head and moves slowly to the feet. Assessment will be completed in 10-20 minutes.

Fitness Assessments

Cardiorespiratory endurance – You will perform a VO$_2$max test using a metabolic cart (ParvoMedics, Sandy, UT). The VO$_2$max test measures your cardiorespiratory fitness. This type of fitness is related to the ability to perform large muscle, dynamic, moderate-to-vigorous intensity exercise for prolonged periods of time. Cardiorespiratory fitness is considered a health-related component of physical fitness because high levels are associated with higher levels of habitual physical activity, which in turn are associated with many health benefits. A VO$_2$max test measures the maximal oxygen uptake which correlates with cardiorespiratory fitness level. You will be asked to follow the Bruce treadmill protocol and will be connected to the metabolic cart. The Bruce protocol is 7 stages in length with each stage lasting 3 minutes. Every stage increases the speed and grade. The first stage starts at 1.7 mph and at a grade of 10%. Each stage increases 2-3 METs. You will walk/run until you meet three of the five criteria of a true VO$_2$max test. The five criteria consists of: within 10 beats of age-predicted heart rate maximum, respiratory exchange ratio of 1.15 or above, rating of perceived exertion of 18 or above, and other observations (e.g., you can no longer gives thumbs-up sign, changes in treadmill gait, you voluntarily ends the test).

Lower body flexibility – You will perform the Canadian Trunk Forward Flexion Test. You will remove your shoes and sit with the soles of your feet flat, without locking your knees, against a sit and reach box. You will lift your arms to shoulder height with hand over hand, and while exhaling reach forward sliding the measuring portion of the box as far forward as possible. Two practice runs are performed and then the best of two trials is recorded. Five minutes of rest time will be provided in
between each exercise set. You will be asked what your rate of perceived exertion is and your heartrate will be monitored using a Polar Heartrate Monitor.

**Day 2:** You will report to the Exercise Physiology Lab in Infocision Stadium. You will be asked to wear athletic clothing and to not exercise 24 hours prior to coming. You will be performing multiple exercises in front of a Microsoft Kinect camera while wearing a portable VO₂ mask. The exercises you will be performing are described below.

**Upper body muscular strength exercises** – You will perform tricep chair-dips for 30 seconds. There will be two trials in length with a minimum of a 5 minute rest period between exercise sets. You will be asked what your rate of perceived exertion is and your heartrate will be monitored using a Polar Heartrate Monitor.

**Lower body strength exercises** – You will be asked to perform the following exercises for 30 seconds in length; body squat, reverse lunge, jumping jacks, chair step-ups, and high knees. You will be asked to perform a wall sit for 45 seconds in length. There will be two trials of each exercise. Five minutes of rest time will be provided in between each exercise set. You will be asked what your rate of perceived exertion is and your heartrate will be monitored using a Polar Heartrate Monitor.

**Survey Instruments:**

**Exertion Measurement:**

You will be asked what your rate of perceived exertion during the exercises and VO₂max testing. The BORG Scale is rated 6 to 20. The highest exertion level is 20 and zero exertion is a 6. This scale is completely subjective to the participant’s fitness level.

**Organizing the Population:** In this study, 10 participants will be recruited and engaged in the two day program. All participants must satisfactorily complete the Physical Activity Readiness Questionnaire (PAR-Q), International Physical Activity Questionnaire (IPAQ) as well as a Medical History Questionnaire to rule out safety concerns. Participants will be required to be considered experts in exercising with the criteria being a regular strength training exerciser, performing resistance training at least 2 times per week, for over one year. Exclusion criteria will consist of: the participants inability to come to the Exercise Physiology Laboratory at The University of Akron during testing and/or if they have physical limitations that are considered contraindications to physical activity including: orthopedic, neuromuscular, metabolic, cardiovascular or cognitive disorders or if they are a pregnant female or if ruled ineligible to exercise as determined by the PAR-Q.
**Risks and Discomforts:**

For exercise sessions and fitness evaluations, you may experience mild muscle aches or joint discomfort. The DEXA scans utilize a small dose of radiation (1/10th of a typical medical X-ray and much less than a CAT scan); each participant will be asked for one such scan. DEXA scans are common in research and clinical settings and pose minimal risk (any radiation exposure theoretically carries some risk) and no discomfort. The VO$_2$max testing will require you to exercise at a vigorous intensity at which you should be nearly completely exhausted. This may cause some discomfort. It is expected that during the fitness testing, you may feel slightly fatigued or out of breath when performing each test. You also may experience nausea, dizziness or light-headedness, chest pain or shortness of breath. You will be cautioned to discontinue exercise if any adverse symptoms occur. Additionally, muscle soreness or muscle strains may be experienced at any time point through the fitness testing; though muscle soreness is normal when performing any kind of exercise. All baseline and post testing will be performed by trained exercise physiologists who are qualified and/or licensed to perform the testing.

**Benefits:** The possible benefits associated with this study include learning your body composition, cardiorespiratory fitness and flexibility levels as well as their relationship to overall health.

**Payments to Participants:** None.

**Right to refuse or withdraw:** Taking part in this project is entirely up to you, and no one will hold it against you if you decide not to do it. If you do take part, you may stop at any time.

**Anonymous and Confidential Data Collection:**

Any identifying information collected will be kept in a secure location and only the researchers will have access to the data. You will not be individually identified in any publication or presentation of the research results. Only aggregate data will be used. Your signed consent form will be kept separate from your data, and nobody will be able to link your responses to you.

**Confidentiality of records:** Will be maintained.

**Who to contact with questions:** Professor Judith A. Juvancic-Heltzel, 330 972 6273, Professor Shiva Sastry, 330 972 7646, or Andy Hanson, 419 906 0204.
This project has been reviewed and approved by The University of Akron Institutional Review Board. If you have any questions about your rights as a research participant, you may call the IRB at (330) 972-7666.

Acceptance & signature: I have read the information provided above and all of my questions have been answered. I voluntarily agree to participate in this study. I will receive a copy of this consent form for my information.

____________________________________
Participant Signature

____________________
Date
APPENDIX C
MEDICAL HISTORY FORM
MEDICAL HISTORY - ADULT

Participant #________________ Date ___/___/_____

Name_________________________________  Major (if college student) ___________________

Address_________________________________________________________________

______ Phone Number___________________________

Age________  DOB_____/_____/_____  Sex m f

Height ________ in  Wt _________ lbs

Height ________ cm (inches *2.54)  Wt _________ kg (lbs/2.2)

BMI _________ kg/m²  Weight

percentile_____________________

Which ethnic group do you most identify with (circle response):

American Indian or Alaskan Native  Asian or Pacific Islander  Black, not of Hispanic Origin

Hispanic  White, not of Hispanic Origin

Other___________________

Y/N

_____ Has a doctor ever said that your blood pressure was too high or too low?
___ Do you ever have pain in their heart or chest?

___ Do you ever notice extra heart beats, skipped beats or a racing heart?

___ Has a doctor ever said that you have heart trouble, an abnormal electrocardiogram (ECG or EKG), heart attack, or coronary?

___ Do you often have trouble breathing?

___ Have you ever been diagnosed with asthma?

___ Have you ever been diagnosed with diabetes?

___ Do you have any orthopedic limitations to physical activity?

Do you have any other medical conditions that affect your ability to safely participate in physical activity? If yes, explain.

________________________________________________________________________

________________________________________________________________________

________

Are you currently taking any medication(s)? Y N

If yes, please describe the medication(s)

________________________________________________________________________

___

Are you involved in any club or school sport teams? Y N

If yes, what sport(s) and how frequently each week?

________________________

Do you have any questions?
Does the participant seem eligible?  Y  N
APPENDIX D

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q & YOU)
PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

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

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 65 years of age, and you are not used to being very active, check with your doctor.

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

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

If you answered:

YES to one or more questions

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

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

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live activity. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.
- DELAY BECOMING MUCH MORE ACTIVE:
- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better.
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional.

Accept whether you should change your physical activity plan.

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

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

NAME ________________________________

SIGNATURE ________________________________ DATE __________

SIGNATURE OF PARENT
or GUARDIAN (for participants under the age of majority) ________________

WITNESS ________________________________

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

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (IPAQ)
INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health-related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of
IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

**Further Developments of IPAQ**

International collaboration on IPAQ is on-going and an *International Physical Activity Prevalence Study* is in progress. For further information see the IPAQ website.

**More Information**

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at [www.ipaq.ki.se](http://www.ipaq.ki.se) and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.
INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the vigorous and moderate activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ Yes

☐ Skip to PART 2: TRANSPORTATION

The next questions are about all the physical activity you did in the last 7 days as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, heavy construction, or climbing up stairs as part of your work? Think about only those physical activities that you did for at least 10 minutes at a time.
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3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

______ hours per day

______ minutes per day

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

______ days per week

---

☐  No vigorous job-related physical activity

☐  No moderate job-related physical activity

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Skip to question 4

Skip to question 6
5. How much time did you usually spend on one of those days doing moderate physical activities as part of your work?

___ hours per day

___ minutes per day

6. During the last 7 days, on how many days did you walk for at least 10 minutes at a time as part of your work? Please do not count any walking you did to travel to or from work.

___ days per week

☐ No job-related walking

Skip to PART 2:

TRANSPORTATION

7. How much time did you usually spend on one of those days walking as part of your work?

___ hours per day

___ minutes per day

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the last 7 days, on how many days did you travel in a motor vehicle like a train, bus, car, or tram?

___ days per week
9. How much time did you usually spend on one of those days traveling in a train, bus, car, tram, or other kind of motor vehicle?

____ hours per day
____ minutes per day

Now think only about the bicycling and walking you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the last 7 days, on how many days did you bicycle for at least 10 minutes at a time to go from place to place?

____ days per week
11. How much time did you usually spend on one of those days to bicycle from place to place?

_____ hours per day

_____ minutes per day

12. During the last 7 days, on how many days did you walk for at least 10 minutes at a time to go from place to place?

_____ days per week

☐ No walking from place to place

Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

13. How much time did you usually spend on one of those days walking from place to place?

_____ hours per day

_____ minutes per day

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the last 7 days in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time.
During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, chopping wood, shoveling snow, or digging in the garden or yard?

_____ days per week

☐ No vigorous activity in garden or yard ➞ Skip to question 16

15. How much time did you usually spend on one of those days doing vigorous physical activities in the garden or yard?

_____ hours per day

_____ minutes per day

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate activities like carrying light loads, sweeping, washing windows, and raking in the garden or yard?

_____ days per week

☐ No moderate activity in garden or yard ➞ Skip to question 18
17. How much time did you usually spend on one of those days doing **moderate**
physical activities in the garden or yard?

   _____ hours per day
   _____ minutes per day

18. Once again, think about only those physical activities that you did for at least 10
minutes at a time. During the **last 7 days**, on how many days did you do
**moderate** activities like carrying light loads, washing windows, scrubbing floors
and sweeping **inside your home**?

   _____ days per week

□ No moderate activity inside home

**Skip to PART 4:**
**RECREATION, SPORT**
**AND LEISURE-TIME**
**PHYSICAL ACTIVITY**

19. How much time did you usually spend on one of those days doing **moderate**
physical activities inside your home?

   _____ hours per day
   _____ minutes per day

**PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY**

This section is about all the physical activities that you did in the **last 7 days** solely
for recreation, sport, exercise or leisure. Please do not include any activities you
have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your**
leisure **time**?
21. How much time did you usually spend on one of those days walking in your leisure time?

_____ hours per day

_____ minutes per day

22. Think about only those physical activities that you did for at least 10 minutes at a time.

During the last 7 days, on how many days did you do vigorous physical activities like aerobics, running, fast bicycling, or fast swimming in your leisure time?

_____ days per week

□ No vigorous activity in leisure time

Skip to question 24
23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

   ____ hours per day
   ____ minutes per day

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

   ____ days per week

   [ ] No moderate activity in leisure

   *Skip to PART 5: TIME SPENT SITTING*

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?

   ____ hours per day
   ____ minutes per day

**PART 5: TIME SPENT SITTING**

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

   ____ hours per day
27. During the last 7 days, how much time did you usually spend sitting on a weekend day?

   _____ hours per day
   _____ minutes per day

This is the end of the questionnaire, thank you for participating.