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Relationship Between Concentric Velocity at Varying Intensity in the Back Squat Using Wireless Inertia Sensor

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Relationship Between Concentric Velocity at Varying Intensity in the Back Squat Using Wireless Inertia Sensor

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by

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ABSTRACT

Relationship Between Concentric Velocity at Varying Intensity in the Back Squat Using Wireless Inertia Sensor

by

Kevin Michael Carroll

The purpose of this study was to determine the relationship between the Minimal Velocity Threshold (MVT) of 1RM and repetitions until failure testing conditions using the back squat exercise. Fourteen injury-free males with experience in the back squat volunteered to perform a 1RM and a submaximal (70% 1RM) repetitions until failure test, each during different testing sessions. Mean Concentric Velocity (MCV) was collected using a wireless inertia-measuring device. The last successful repetition in either condition was considered the MVT. A very small relationship between 1RM and repetitions until failure MVT was found (r=-0.135). There were no significant differences between testing sessions and the effect size was small (Cohen's d=0.468) between each testing session. The small relationship and the non-significant p-value might suggest there is individual variance with MVT. In conclusion, the results of this study do not support a general MVT for the back squat comparing 1RM and submaximal repetitions until failure.

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CHAPTER 1

INTRODUCTION

Neurological and skeletal muscle adaptations can occur when undergoing a resistance training program (Crewther, Cronin, & Keogh, 2006; Gabriel, Kamen, & Frost, 2006; McCall, Byrnes, Dickinson, Pattany, & Fleck, 1996). These adaptations may include- but are not limited to- increases in muscular size, strength, and power (Crewther et al., 2006; Gabriel et al., 2006; McCall et al., 1996). A variety of factors contribute to the training stimulus and potentially the adaptations that occur; some of which are intensity, volume, exercise order, and rest intervals (Kraemer & Ratamess, 2004). Traditionally, resistive exercise intensity has been shown to be the most vital factor in producing adaptations of muscular strength (Crewther et al., 2006; Kraemer & Ratamess, 2004). Another, less utilized, factor to consider is movement velocity. Concentric movement velocity is the velocity in which a lifter moves a resistance during the concentric phase of an exercise. Mean concentric velocity (MCV) when compared to peak concentric velocity seems to give a more comprehensive depiction of the concentric phase of an exercise (Judovtseff, Harris, Crielaard, & Cronin, 2011). Monitoring MCV during resistance training could be a valuable tool for a coach or participant (Gonzalez-Badillo & Sanchez-Medina, 2010; Izquierdo et al., 2006; Judovtseff et al., 2011; Sakamoto & Sinclair, 2006). Previous research suggests that there may also be velocity-specific adaptations in response to training (Jones, Bishop, Hunter, & Fleisig, 2001).

A specific exercise test, in the form of a one-repetition maximum (1RM) or a predictive method to 1RM, is usually administered before beginning resistance training to give an indication of baseline strength levels (Gonzalez-Badillo & Sanchez-Medina, 2010; Izquierdo et al., 2006; Jones et al., 2001; Judovtseff et al., 2011; Sakamoto & Sinclair, 2006). Exercise intensities/loads may then prescribed based on percentage of 1RM or predicted 1RM. Testing 1RM or reps until failure can require an impractical amount of time with larger groups (Braith, Graves, Leggett, & Pollock, 1993; Gonzalez-Badillo & Sanchez-Medina, 2010). Several studies have shown a relationship between exercise intensity (load) and velocity with r=0.98 (Gonzalez-Badillo & Sanchez-Medina, 2010), r=~0.95 (Judovtseff et al., 2011). Several other studies have found relationships between intensity and movement velocity also (Izquierdo et al., 2006; Sakamoto & Sinclair, 2006). Thus, collecting concentric velocity data of various exercises in relation to submaximal loads have been shown to be supportive in the prediction of 1RM (Judovtseff et al., 2011). This offers the strength and conditioning professional the opportunity to administer a regular strength monitoring program at submaximal loads routinely achieved in regular training.

Research conducted measuring concentric velocity in the bench press and back squat have suggested there is an exercise-specific minimal velocity threshold (MVT) regardless of load or individual differences (Izquierdo et al., 2006). The MVT in resistance training is the MCV achieved on the last successful repetition during a 1RM or repetitions until failure (Jovanovic & Flanagan, 2014). Izquierdo and colleagues (2006) found the MVT to be $0.15 \pm 0.03\ \mathrm{m \cdot s^{-1}}$ and $0.27 \pm 0.02\ \mathrm{m \cdot s^{-1}}$ for the bench press and back squat, respectively. At 1RM and 60%, 65%, 70%, and 75% there seems to be no statistical difference in MCV achieved during the last successful repetition, suggesting the presence of a minimal velocity threshold (Izquierdo et al., 2006). Another study confirmed the MVT found by Izquierdo and colleagues (2006) resulting in bench press MVT at 1RM to be $0.16 \pm 0.04\ \mathrm{m \cdot s^{-1}}$ (Gonzalez-Badillo & Sanchez-Medina, 2010). The MVT remained consistent after 6-weeks of training, despite gaining strength in the bench press. During the second 1RM trial, the MVT was found to be $0.18 \pm 0.04\ \mathrm{m \cdot s^{-1}}$.

Based on previous studies, there seems to be a MVT ranging from 0.12 $m \cdot s^{-1}$ to 0.22 $m \cdot s^{-1}$ for the bench press (Gonzalez-Badillo & Sanchez-Medina, 2010; Izquierdo et al., 2006). To the author's knowledge, there is only one study looking at the back squat which yielded a MVT ranging from 0.25 $m \cdot s^{-1}$ to 0.29 $m \cdot s^{-1}$ (Izquierdo et al., 2006). It is unclear if the standard deviation of these measurements were due to chance, measurement error, individual differences, or otherwise. More research is needed to determine what kind of variance can be expected in the MVT for strength and conditioning practitioners.

Definitions

1. 1-Repetition Maximum (1RM): In resistance training, the maximum load an individual can successfully complete 1 repetition for a given exercise
2. Exercise Intensity: The load of an exercise, or the load on the barbell. Typically notated as a percentage of 1RM
3. Exercise Volume: In resistance training, the total number of repetitions performed (or the number of sets multiplied by the number of repetitions per set)
4. Mean Concentric Velocity (MCV): The average velocity of a movement during the concentric phase of movement
5. Minimal Velocity Threshold (MVT): The MCV on the last successful repetition of a 1RM or repetitions until failure condition where maximal lifting effort occurs (Jovanovic & Flanagan, 2014)
6. Repetitions until Failure: In resistance training, the completion of continuous repetitions for a given exercise until muscular failure is reached

Purpose

The primary purpose of the current study is to examine the relationship between velocities during 1RM and repetitions until failure conditions in the back squat. The secondary purpose of this study will be to explore the use of PUSH (PUSH, Toronto, Canada) units for continuous monitoring of movement velocities in the practical setting of the weight room.

Assumptions

1. All subjects attempted to accelerate the bar as fast and with as much force as possible.
2. The linear position transducers used for data collection were accurate and reliable.
3. The subjects used in this research were representative of others who are familiar with the back squat exercise.

Delimitations

1. All subjects for this study were within the age of 25 ± 5 years old.
2. All subjects for this study were previously familiar with the back squat exercise.
3. All subjects squatted to a depth where the hip crease was parallel with the knee joint.

Limitations

1. There was no way to determine if subjects were accelerating the bar as fast and with as much force as possible.
2. Squat depth was standardized for all subjects.
3. The fatigued-state of subjects from outside training was not considered or controlled for in the current study.

CHAPTER 2

REVIEW OF LITERATURE

Resistance training for the enhancement of strength and sport performance has been developing for over half a century. Creating the correct training stimulus for the enhancement of those variables via monitoring of training variables has been the subject of a large portion of research in the past and the present. Thus, modern technology attempts to quantify training variables in order to further the understanding of resistance training.

Technology in Sport: Measuring Velocity

There are several variables that have been traditionally monitored in periodized strength training: a) exercise type and order, b) intensity, c) volume (sets and repetitions), and d) rest between sets (Gonzalez-Badillo & Sanchez-Medina, 2010). Intensity is generally considered to be the most important variable pertaining to strength levels and the further programming of loads (Kraemer & Ratamess, 2004). Recently, several studies have examined movement velocities as they relate to exercise intensity (Gonzalez-Badillo & Sanchez-Medina, 2010; Izquierdo et al., 2006; Sakamoto & Sinclair, 2006). A variety of different devices have been used to measure movement velocity during resistance training (Cronin, Hing, & McNair, 2004; Hori & Warren, 2009; Jovanovic & Flanagan, 2014; Stock, Beck, DeFreitas, & Dillon, 2011).

Linear Position Transducers

Linear Position Transducers (LPT) are devices which can measure displacement in a linear plane. An LPT consists of a measuring cable, spool, spring, and a sensor such as a potentiometer or rotary encoder (Harris, Cronin, Taylor, Boris, & Sheppard, 2010). The potentiometer or rotary encoder is what transduces, or converts, the change in distance of the cable to another variable such as voltage. It is from this voltage that displacement and eventually velocity and acceleration can be derived. Harris and colleagues (2010) go on to explain how the process of differentiation can be used to obtain values of velocity, acceleration, and eventually force. Basically, the change in displacement (transduced by the potentiometer or encoder to produce voltage) over the change in time can be used to derive velocity. The change in velocity over the change in time can be used to derive acceleration.

The ability to obtain accurate data via differentiation of data collected from an LPT is contingent on the sampling rate (Harris et al., 2010). The sampling rate, usually expressed in hertz (Hz), is the number of data points collected per second. Research suggests that the minimum sampling rate strength and conditioning professionals should consider using is 200 Hz but the ideal range should be above 500 Hz (Hori et al., 2009). This depends greatly on the type of test and the speed of the test. For example, any high speed movement such as sprinting, jumping, or throwing should be considered with a higher sampling rate as compared to relatively slow movements such as the back squat. It is important to note that some research done on sampling rate has been done using force plates and not LPTs (Hori et al., 2009).

There has been research on the reliability and validity of the LPT (Cronin et al., 2004). In this study, Cronin and colleagues (2004) used a force platform in an attempt to validate the LPT technology. They performed 3 jumping conditions (squat, countermovement, and drop) and compared values of average force, peak force, and time-to-peak force from the force plate to the values collect from the LPT. Using Pearson correlations and intraclass correlations for the average force ($r = 0.952–0.962$), peak force ($r = 0.861–0.934$), and time-to-peak force ($r = 0.924–0.995$) the researchers concluded that the use of LPTs could be considered both valid and reliable (Cronin et al., 2004). Using LPTs for measuring movement velocity may be considered a useful and accurate tool.

Hansen and colleagues (2011) examined the reliability of peak force and several force-time measurements (such as ground-reaction force) using a force plate and LPT. They also examined the reliability of measurement between the force plate and LPT technology. Each subject completed 2 testing sessions separated by 1 week and included 3 rebound jump squats with 40 kg external load. The force plate and LPT were both found to be reliable in the measurement of peak force (ICC = 0.88 – 0.96, CV = 2.3 – 4.8%). Values obtained from the force plate and the LPT had a strong relationship. However, the force-time variables obtained from the force plate were more reliable (ICC = 0.70–0.96, CV = 5.1–51.8%) when compared the LPT values (ICC = 0.18–0.95, CV = 7.7–93.6%). The LPT also had higher variation when compared to the force plate (Hansen, Cronin, & Newton, 2011). This is logical as the method of double differentiation from LPT technology to obtain acceleration values and subsequently force values has been shown to increase the likelihood of variation and error (Harris et al., 2010). The process of double differentiation takes displacement data and uses time data to derive velocity. The velocity data is again looked at with the time data to obtain acceleration data, hence the term "double differentiation." Overall, the LPT has been shown to be a valid and reliable way to measure velocity, acceleration, and force variables (Cronin et al., 2004; Hansen et al., 2011; Harris et al., 2010) which can be a useful tool for sport scientists and strength & conditioning practitioners.

TENDO FitroDyne and TENDO Weightlifting Analyzer

The TENDO FitroDyne and TENDO Weightlifting Analyzer (TENDO Sports Machines; Trencin, Slovak Republic) are devices which are used to measure certain variables such as average power and velocity of resistance training exercises. The TENDO units are comprised of a velocity sensor unit, which is attached to the resistance training equipment, mainly on a barbell, and a microcomputer to collect and analyze the data (Willardson, 2010). Willardson (2010) explains that the unit uses a linear position transducer to measure average vertical velocity of the movement. The unit also calculates average force using the summed mass of the barbell and the mass of the lifter and multiplying by acceleration due to gravity ($g=9.81\ m \cdot s^{-2}$). The average power may be calculated for each movement using the average force and average velocity.

Jennings et al. (2005) examined the reliability of the FitroDyne for muscular power during the squat jump and the bicep curl. To measure movement variables, the FitroDyne must be placed onto the resistance training equipment (i.e. barbell) using a cable and connected to a microcomputer. Average velocity and force values were obtained from the microcomputer's analysis of the linear position transducer data. Muscle power was then calculated. More specifically, peak power was obtained by calculating power from specific time points on the force-velocity curve. The ICC for the squat jump and bicep curl examining power were R = 0.97 and R = 0.97, respectively. These R-values demonstrate a very high reliability. However, the limits of agreement were approximately -17 ± 96 W and 0.11 ± 13.60 W for the squat jump and biceps curl, respectively. These fairly large limits of agreement may indicate that some of the values obtained may have been a result of variation due to unknown factors. The authors still concluded that the FitroDyne is a reliable measure of muscular power (Jennings, Viljoen, Durandt, & Lambert, 2005).

Mangine et al. (2014) used a TENDO unit to measure average and peak vertical jump power output as part of a study relating values from a variety of performance tests on a nomotorized treadmill and vertical jump testing. The TENDO unit was attached to each subject's waist during the vertical jump testing. Average and peak power were calculated from the velocity measurements obtained from the TENDO unit. According to this study, the TENDO units have consistently produced test-retest reliability of R > 0.90 when examining average and peak power (Mangine et al., 2014). The results of Jennings et al. (2005) and Mangine et al. (2014) show the TENDO unit's validity in measuring kinetic and kinematic variables. This can be a useful tool when examining movement velocities during resistance training.

Stock and colleagues (2011) examined the test-retest reliability of velocity measurements using a TENDO unit. Subjects performed 1 repetition of the flat bench press at 10% increments ranging from 10-90% of their 1RM during 2 separate testing sessions. Each repetition was performed with the intent to maximally accelerate the barbell. There were no significant differences in average movement velocity between trials 1 and 2. There was moderate reliability between trials 1 and 2 for velocity (test-retest ICC ranging from 0.564 to 0.811), but less reliability was observed when compared to Jennings et al. (2005) who looked at the reliability of power and reported test-retest ICC values of 0.97 for the TENDO units (Stock et al., 2011). Although the primary concern of the investigators was not to show reliability of the TENDO units, it was still observed there was acceptable reliability concerning velocity. The repeatability of measurement is essential especially when considering technology that may be used as a monitoring tool. Although statistically it may be acceptable to measure movement velocity with the TENDO units, it should be noted that there might be a certain level of variance in measurement values. One of the limitations in the Stock et al. (2011) study was the lack of multiple repetitions at each intensity. There was only one repetition performed during each trial at each intensity, so there is a possibility for other factors besides device error to have influenced the lesser ICC in this study.

It appears that there is some controversy regarding the method of calculating power using TENDO units and how values are being reported (Willardson, 2010). Research has shown the test-retest reliability to be very good regarding power measurements (Jennings et al., 2005; Mangine et al., 2014) as well as velocity measurements (Stock et al., 2011). Being one of the only studies regarding test-retest reliability of TENDO velocity measurements, it can be assumed that the TENDO units provide a large level of reliability of measurement (ICC > 0.7). It should also be noted that Stock et al. (2011) only looked at the flat bench press with subject instructions to move the bar as fast as possible. This research cannot be assumed to provide all of the answers regarding reliability of velocity measurements of the TENDO units.

In order to truly test the reliability of the TENDO units, movements should be measured with more than one TENDO unit simultaneously to discover the Intra- and inter-class Correlations between units and between sessions. This would provide practitioners with an answer on true repeatability of measurement. Without literature comparing TENDO variables to already established and valid methods it can’t be said with certainty whether the TENDO units are capable of accurate measurements, but they may be used for reliable measurements. With the current research, using a TENDO unit for the monitoring of velocity and power can be considered a useful tool when the TENDO units are used exclusively for measurement.

The price of TENDO units might not be considered expensive when compared to equipment such as force plates and linear position transducers, but considering the budgets of many laboratories and strength & conditioning practitioners within the field there are definite concerns about the price of the unit. For practitioners who typically train athletes in groups, this might not be the best tool for day-to-day monitoring for an entire group or team.

Motion Analysis Technology

Motion Capture (MoCap) Analysis has been used by a variety of different studies to examine kinematic (i.e. velocity) properties of movement (Chung, Yeung, Chan, & Lee, 2011; Leard et al., 2007; Windolf, Gotzen, & Morlock, 2008).

Chung et al. (2011) used an inertial tracking Xsens system (XSENS, Xsens Technologies 2007) to measure validity of the VICON motion analysis system (VICON, Oxford Metrics Group; Oxford, United Kingdom). Subjects who performed upper body movements as fast as they could had measurements drawn from both the Xsens and the Vicon systems simultaneously. The author concluded that Vicon performed with high level of validity (Chung et al., 2011).

Windolf et al. (2008) were interested in how several system parameters could influence the accuracy of motion analysis systems. The study used the VICON motion analysis system. The parameters examined included camera placement, calibration methods, reflective marker size, and the effects of smoothing and filtering. Each scenario consisted of 5 repeated periods of data collection. The study goes on to explain how there are any number of variables that can influence the accuracy of measurement. Marker roundness, reflection capacity, lighting conditions, calibration velocity, duration and technique can all affect the accuracy of motion analysis systems (Windolf et al., 2008). There is also an optimal set up regarding the three dimensional (3D) camera systems, but not all laboratories have the necessary dimensions to achieve such a set up. This also may have an effect on the accuracy of measurement. The author states the results indicate that motion analysis system can be used for a variety of situations but each individual laboratory should test for accuracy based on their specific set up (Windolf et al., 2008) rather than just assuming accurate and precise results.

Athlete Monitoring

Athlete monitoring is a term used to describe assessing an athlete’s progress periodically (S. Halson, 2014). Halson (2014) also describes athlete monitoring as an assessment that occurs more than once and with enough frequency to provide meaningful information back to the sport scientist or coach. There are a wide array of training variables that a sport scientist or coach might monitor. Some of these variables include external factors such as force or power output; and external factors such as heart rate or blood lactate (S. L. Halson, 2014). Other, more specific, training factors may also be looked at such as training volume, intensity, frequency, and barbell velocity.

Influence of Fatigue

Fatigue in athletes has been the subject of many research projects and books (Duffey & Challis, 2007; Edwards, 1981; S. L. Halson, 2014; Twist & Highton, 2013). Although there are many definitions of fatigue, a common definition states that fatigue is the “failure to maintain the required or expected force” (Edwards, 1981). Monitoring training loads has been described as a way to assess an athlete’s progress within a training program and to lower the risk for unplanned fatigue (S. L. Halson, 2014).

Halson (2014) provides a review of several methods of monitoring training load as it pertains to fatigue. When considering fatigue from an external and internal load perspective, it is essential to use external variables (Twist & Highton, 2013) and internal variables (Achten & Jeukendrup, 2003) to garner an understanding on the actual response to training (S. L. Halson, 2014). External vs. internal load variables are collected exclusively from one another in the sense that there are external variables (such as power output, speed, velocity, and acceleration), and there are internal variables (such as heart rate, blood lactate, and ratings of perceived exertion). Examining external variables (such as bar velocity) is an important step to understanding responses to training and fatigue. Fatigue has been described from the practical perspective as “an inability to complete a task that was once achievable within a recent time frame” (Pyne & Martin, 2012). In this sense, discovering an athlete’s or an exercise’s optimal range of velocity will allow sport scientist’s to monitor changes in that velocity over time to aid in understanding the training responses to a given program.

Fatigue has also been examined in regards to resistance training exercise in an acute sense (Duffey & Challis, 2007; Sakamoto & Sinclair, 2006). Duffey & Challis (2007) performed sets at 75% of 1RM until failure with 18 subjects. It was found that the mean concentric velocity (MCV) decreased as each subject neared failure. These findings indicate that acute fatigue contributes to the barbell velocity, or MCV, during resistance training but does not imply any chronic effects resulting from fatigue. To the author’s knowledge there is no currently published research regarding chronic fatigue and its effect on MCV.

Performance and Strength Characteristics

Several papers have examined the use of performance testing (i.e. jump testing) to monitor athletes in terms of physiological fatigue, preparedness, and even strength levels (Kraska et al., 2009; Twist & Highton, 2013). Testing sport-specific skills as a monitoring tool can be a useful way to identify training adaptations and fatigue (Twist & Highton, 2013). Twist & Highton (2013) outlined using subjective measures as monitoring tools such as questionnaires and ratings of perceived exertion might raise questions as to validity or reliability. Also, some objective measures such as blood lactate or other blood biochemical markers can be expensive and require a high level of expertise. Jump, sprint, or other performance testing might be an option for measuring performance and monitoring fatigue levels over time (Twist & Highton, 2013).

Kraska et al. (2009) related strength characteristics to variables obtained via weighted and unweighted jump protocols. Subjects in this study performed static and counter-movement jumps using 0kg and 20kg loads on force plates. Subjects also performed isometric mid-thigh clean pulls also on force plates. The results of this study indicated that strength characteristics were related to the force and rate of force variables obtained during the static and counter-movement jump testing (Kraska et al., 2009). The results of Kraska et al. (2009) research indicates that using jump testing on force platforms may be useful to assess strength characteristics in athletes. The use of force platforms are not always available in practical settings such as collegiate weight rooms and training facilities. Fatigue has been shown to affect barbell velocity acutely (Duffey & Challis, 2007). The use of velocity-measuring devices (such as linear position transducers) might allow practitioners to assess athletes more frequently to determine detriments to performance over the short and long-term.

Velocity-Based Resistance Training

Velocity-based resistance training, testing, and programming has been the subject of research (Jovanovic & Flanagan, 2014). The main idea behind the theory is that by tracking velocity with loads, there is a possibility to estimate strength levels and other monitoring variables without the need for constant maximal tests. It has even been proposed that a practitioner may be able to get instant feedback on daily preparedness by collecting resistance training velocities and comparing them with previous values (Jovanovic & Flanagan, 2014). Another proposed application by Jovanovic & Flanagan (2014) is using resistance training velocities real-time in order to select loads.

Concentric Velocity and Relationship to Maximal Strength

Examining and monitoring concentric velocity has been the subject of several recent research projects (Gonzalez-Badillo & Sanchez-Medina, 2010; Izquierdo et al., 2006; Jovanovic & Flanagan, 2014; Judovtseff et al., 2011; Sakamoto & Sinclair, 2006). It has been suggested that monitoring mean concentric velocity provides a more accurate depiction of the resultant velocity of a resistance training exercise (Judovtseff et al., 2011). Gonzalez-Badillo & Sanchez-Medina (2010) found there was a very strong relationship between MCV and load ($R^2=0.98$) when testing subjects in a 1RM bench press. The subjects in the aforementioned study also completed a second trial of 1RM after 6 weeks of training, and although there was a 9.3% increase in 1RM bench press the MCV remained stable at the maximal load (0.16 ± 0.04 m·s^{-1}) (Gonzalez-Badillo & Sanchez-Medina, 2010).

Velocities obtained from submaximal load-velocity profiles have been shown to correlate with 1RM very well (r=~0.95) (Judovtseff et al., 2011). In their study, Judovsteff et al. (2011) analyzed data from 3 bench press studies to determine the relationship between the submaximal load-velocity profile and the actual 1RM load. Their result show that MCV at submaximal loads have a linear relationship with the MCV at 1RM loads. Thus, there is a reasonable ability to predict 1RM bench press loads when only examining submaximal load-velocity profiles. It has been suggested that to get an accurate depiction of the load-velocity profile that MCV should be measured using at least 4-6 increasing intensities ranging from 30-85% of 1RM (Jovanovic & Flanagan, 2014).

Minimal Velocity Threshold

The idea of a minimal velocity threshold (MVT) has been suggested in several research studies as a way to test and monitor athletes (Gonzalez-Badillo & Sanchez-Medina, 2010; Izquierdo et al., 2006; Jovanovic & Flanagan, 2014). This term refers to the MCV on the last successful repetition of a 1RM or repetitions until failure condition where maximal lifting effort occurs (Jovanovic & Flanagan, 2014). These studies also suggest that there is an exercise-specific MVT. Izquierdo et al. (2006) performed a 1RM in the bench press and half squat with 36 physically active men as subjects. Every 10 days after the 1RM, subjects performed one set until muscular failure with different percentages of their 1RM (60%, 65%, 70%, and 75%). The MCV was recorded on both the 1RM and repetitions until failure conditions. In the bench press, the MVT was comparable between both the 1RM and repetitions until failure (0.15 ± 0.03 m·s^{-1}). In the half squat, the MVT was also comparable between both the 1RM and repetitions until failure (0.27 ± 0.02 m·s^{-1}) (Izquierdo et al., 2006). The results of the bench press portion of this study coincide with other research which has suggested that the MVT is the same in the 1RM bench press even after increases in strength (Gonzalez-Badillo & Sanchez-Medina, 2010). There is no other research to the author’s knowledge related to the MVT in the back squat exercise. More research is needed in order to determine if there is a MVT for the back squat exercise and to determine what factors might contribute to it.

CHAPTER 3

RELATIONSHIP BETWEEN CONCENTRIC VELOCITY AT VARYING INTENSITY IN THE BACK SQUAT USING WIRELESS INERTIA SENSOR

Original Investigation

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Abstract

The purpose of this study was to determine the relationship between the Minimal Velocity Threshold (MVT) of 1RM and repetitions until failure testing conditions using the back squat exercise. Fourteen injury-free males with experience in the back squat volunteered to perform a 1RM and a submaximal (70% 1RM) repetitions until failure test, each during different testing sessions. Mean Concentric Velocity (MCV) was collected using a wireless inertia-measuring device. The last successful repetition in either condition was considered the MVT. A very small relationship between 1RM and repetitions until failure MVT was found (r=-0.135). There were no significant differences between testing sessions and the effect size was small (Cohen's d=0.468) between each testing session. The small relationship and the non-significant p-value might suggest there is individual variance with MVT. In conclusion, the results of this study do not support a general MVT for the back squat comparing 1RM and submaximal repetitions until failure.

Introduction

The ability to quantify and monitor resistance training variables has been the subject of a large number of investigations [5, 13, 19, 21] and has been a topic for athlete monitoring and coaching in the practical setting [2, 4, 16]. Resistance training variables commonly quantified include exercise intensity, volume, exercise selection and frequency of training [11]. Several of these variables are straight-forward and simple to collect data on for monitoring purposes. For example, exercise intensity can be interpreted as the amount of resistance or load being used for a given exercise [5]. Volume can be interpreted as the total number of repetitions being performed within a given exercise, day, training phase, etc. [20]. Volume-load is often used as an approximation of work during resistance training and is the combination of volume and intensity (sets x repetitions) [14].

Resistance training variables that might not be as apparent as volume or intensity include acceleration, force, and velocity. Recently, more research has emerged that has measured the velocity of resistance training exercises [4, 6, 8, 10]. Velocity-based resistance training has also been reviewed in the literature [9]. Using a velocity-based training approach, a coach or practitioner could use the velocities of resistance training exercises to test and monitor factors such as strength, effort, and fatigue [9]. One-repetition maximum (1RM) testing has traditionally been used to measure strength and to determine training loads [8, 17]. Further research has shown that movement velocity of a submaximal load is highly related to maximal strength (1RM) [10]. The ability to predict 1RM based on submaximal velocities could be a useful method for coaches who want to monitor how their athletes are adapting to training without the need to perform maximal testing on a frequent basis. It is important to note that mean concentric velocity (MCV) has been shown to be a more reliable depiction of the propulsive velocity in a resistance training movement when compared to peak velocity measurements [10].

Research conducted measuring concentric velocity in the bench press and back squat have suggested there is an exercise-specific minimal velocity threshold (MVT) regardless of load or individual differences [8]. The MVT in resistance training is the MCV achieved on the last successful repetition during a 1RM or repetitions until failure test [9]. The relationship between MCV and intensity suggests that there is an inevitable “finite velocity” on the maximal end of intensity. If there is a relationship between the MVT during a 1RM and a repetitions until failure test, this could provide coaches with the opportunity to choose from a wider variety of tests for athlete monitoring purposes. Thus, the purpose of the current study is to examine the relationship of velocities in the back squat between 1RM and repetitions until failure conditions.

Methods

Subjects

Fourteen male subjects volunteered to participate in the current study (age= 25.0 + 2.6, height= 178.9 + 8.1, body mass= 88.2 + 15.8, body fat %= 15.8 + 5.8). Prior to beginning testing procedures, all subjects were required to have: no current or past injuries that affect their ability to back squat, at least one year of consistent experience with the back squat, the ability to perform a back squat to at least parallel, which was defined as the point at which the hip joint is level with the knee [3], and were at least 18 years of age. Subjects were also instructed not to perform any strenuous activity for 48 hours prior to each testing session. All subjects read and signed written informed consent documents as approved by the University’s Institutional Review Board.

Design

To investigate the presence of a MVT in the back squat, a repeated measures design was employed where each subject completed a 1RM during the first testing session and a set of repetitions until failure with a submaximal load during the second testing session. The MCV during the final successful repetition from each testing session were used to determine the minimal velocity in each loaded condition.

Methodology

A wireless inertia-measuring device (PUSH, Inc., Canada) was used to collect kinematic data. This device was attached to each subject's right or left forearm. Previous research has shown PUSH™ device-to-device reliability to be acceptable (r= 0.9), therefore the subjects attached the device on preferred side [18]. Kinematic data was displayed using a smartphone application connected via Bluetooth to the device.

All subjects performed 2 testing procedures at the laboratory with each testing session separated by 7 days. The first testing session involved a 1RM. The second testing session, involved performing a set of repetitions until failure using 70% of the 1RM load achieved in the first testing session. The back squat depth was defined as when the hip joint was in line horizontally with the knee [3].

Anthropometric Measurement and Warm-Up Procedure

Upon arriving to the laboratory for the first testing session, anthropometric measurements were obtained prior to testing. Subject height was collected to the nearest 0.5 cm using an electronic stadiometer (Cardinal Scale Manufacturing Co., Webb City, Missouri). Body mass was collected to the nearest 0.1 kg using a Tanita Body Composition Analyzer BF-350 (Tanita

Corporation of America, Inc., Arlington Heights, Illinois). ACSM 7-site skinfold procedures were used to estimate body fat % and were collected using a Lange Skinfold Caliper (Creative Health Products, Inc., Ann Arbor, Michigan).

Prior to performance testing, all subjects performed a standardized warm-up procedure. This procedure included 25 jumping jacks, 5 repetitions of dynamic mid-thigh pulls using a 20kg barbell, and 3 sets of 5 repetitions of dynamic mid-thigh pulls using 60kg [1].

1-Repetition Maximum Testing

Prior to beginning testing procedures, subjects reported an estimated 1RM for the back squat exercise to determine warm-up loads. During the first testing session, subjects performed a 1RM test of the back squat. The back squat depth was defined as when the hip joint is in line horizontally with the knee [3]. Subjects were instructed to move every repetition with maximal lifting effort during each testing session, including warm-up attempts, 1RM attempts, and all submaximal repetitions until failure. The eccentric portion of the squat was performed until the subject was verbally instructed to begin the concentric portion upon reaching the required depth. A resistance band was placed at the required depth for each subject as a visual aid for the tester to instruct the subject to begin the concentric portion of the lift. Subjects were also instructed to pause for 1-2 seconds between repetitions but were permitted to begin each repetition voluntarily. A modified 1RM protocol was used where subjects performed 65%, 75%, 85%, and 95% of their estimated 1RM for 5, 3, 2, and 1 repetitions, respectively, before attempting their 1RM [12]. Three minutes of rest were given between each warm-up and between each 1RM attempt [15]. Each subject achieved their 1RM within 4 attempts. After the initial 1RM attempt, subjects continued to increase the load on the barbell by a minimum of 2.0 kg and performed additional 1RM attempts until they failed to complete an attempt. The last successful repetition was considered the subject's 1RM. The MCV during the last successful repetition was considered the MVT.

Repetitions until Failure Testing

Subjects returned in 7 days for the second testing session during which they lifted 70% of their 1RM until they failed to complete an additional repetition. Subjects used the same depth as in the first testing session, and were reminded to move each repetition with maximal lifting effort and to pause in between repetitions. Two warm-up sets were performed prior to the repetitions until failure. These warm-up sets included 55% and 65% of 1RM for 5 repetitions each. Three minutes of rest were given between each warm-up and between the repetitions until failure set. Subjects then performed repetitions until failure with 70% of 1RM [8]. The MCV of the last successful repetition during this testing session was considered the MVT.

Statistical Analysis

Each subject's MVT was compared between the 1RM and repetitions until failure condition. The MCV was derived from the PUSH™ device's kinematic data. A Pearson product-moment zero-order correlation was used to identify the relationship between the two MVT. A paired t-test, typical error, and effect size using Cohen's d were used to explore differences between each testing session. The coefficient of variance (CV) was calculated between subjects at each warm-up load, during the first and last successful 1RM attempt, each successful repetition during the repetitions until failure session, and the last successful repetition during the repetitions until failure session. The criteria for statistical significance was set at $p<0.05$. ICCs were interpreted according to the scale developed by Hopkins: 0.0-0.1, 0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, and 0.9-1.0 were interpreted as trivial, small, moderate, large, very large, and nearly perfect, respectively [7]. Effect size using Cohen's d were interpreted according to a scale developed by Hopkins: 0.0-0.2, 0.2-0.6, 0.6-1.2, 1.2-2.0, and 2.0-4.0 were interpreted as trivial, small, moderate, large, very large, and nearly perfect [7].

Results

The MVT in the 1RM and the Repetitions until Failure conditions are outlined in Table 1. There was a small relationship (r= -0.135) between each condition. The MVT found during the 1RM testing session (0.32 + 0.06 m•s-1) and the Repetitions until Failure testing session (0.35 + 0.05 m•s-1) were not statistically different ($p>0.05$).

The mean, standard deviation (SD), and CV results of MCV for the 1RM and Repetitions until Failure are displayed in Tables 2 and 3, respectively. The mean set MCV decreased as the intensity (load) increased. The CV, in general, increased as the intensity increased with the exception of the last successful repetition in both testing sessions.

Each subject's 1RM was found within 4 attempts. There was an average increase of 2.68% + 1.04% in load from the last successful attempt to the failed attempt. Each subject's 1RM was an average of 125 + ~31 kg. An average of 22 + 7 repetitions were completed amongst the subjects with 70% 1RM in the repetitions until failure condition. Both the 1RM and repetitions until failure results yielded variances above 20%.

Table 1. MVT in 1RM vs repetitions until failure

Pearson's *r*	-0.135
Paired *t*-test *p*-value	0.266
Typical Error	0.062
Effect Size	0.468

Table 2. 1RM session: mean, SD, CV over several conditions

	Mean	SD	CV
First Warm-Up Set (65% 1RM 5 repetitions)	0.65	0.08	12.84
Second Warm-Up Set (75% 1RM 3 repetitions)	0.62	0.07	11.96
Third Warm-Up Set (85% 1RM 2 repetitions)	0.54	0.07	13.67
Fourth Warm-Up Set (95% 1RM 1 repetition)	0.47	0.08	17.57
First Successful 1RM Attempt	0.39	0.09	22.35
Last Successful 1RM Attempt	0.32	0.06	17.35

Table 3. Repetitions until failure session: mean, SD, CV over several conditions

	Mean	SD	CV
First Warm-Up Set (55% 1RM 5 repetitions)	0.73	0.11	14.77
Second Warm-Up Set (65% 1RM 5 repetitions)	0.66	0.10	14.62
All Successful Reps Until Failure	0.53	0.11	20.58
Last Successful Rep Until Failure	0.35	0.05	15.59

Discussion

The purpose of this study was to investigate the relationship between the MVT of 1RM and repetitions until failure in the back squat. The main finding of this study was a small relationship between the MVT during the 1RM and the repetitions until failure conditions (r= -0.135). This result indicates little evidence for the presence of an exercise-specific MVT in the back squat when measuring to associate two intensities. Based on the volunteer subjects in this study, there were some variances in physiological status such as strength and strength-endurance. This could be a potential reason for the disassociation between the two MVT data. This result suggests that there are individual or intensity differences that should be considered when examining MCV or MVT during exercise tests such as 1RM or repetitions until failure.

Although there was only a small relationship between sessions the two MVT data were not statistically different (p>0.05) and had a small effect size (Cohen's d= 0.468). There was also a small error (TE= 0.062) between each testing session. This indicates there are similarities between MVT in different conditions, meaning that although the two lifting conditions were a different stimulus physiologically, data output was not different. The differences in MVT obtained during the 1RM (MVT= 0.32 + 0.06 m•s-1) and the repetitions until failure (MVT= 0.35 + 0.05 m•s-1) seem to be small when considering the p-value and TE.

Previous research has suggested the presence of a MVT [6, 8, 9]. In this research, the MVT is considered exercise-specific (i.e. bench press and back squat have different MVTs) regardless of the individual's training status, training history, and levels of fatigue. The correlation results (r=-0.135) of this study do not support this theory. Although there seems to be a similarity between the MVT in maximal and submaximal training sessions until failure based on the paired t-test, (p>0.05; TE= 0.06), the concept of a MVT might not be as simple as previously suggested. It is possible that differences in MVT between 1RM and repetitions until failure might be resultant of individual physiological or intensity-related differences.

The depth of the back squat was standardized in the current study, which might not be indicative of each subject's natural squatting depth. It is unclear whether or not this standardized depth contributed or inhibited any subject's ability to move the barbell with maximal lifting effort. It was assumed that squatting until the hip crease was horizontally in-line with the knee would be sufficiently below each subject's sticking region. The 1RM warm-up protocol was modified from previous research [12] which may have affected the accuracy of the 1RM measurement. As previously mentioned the average percentage of increase from the last successful attempt until the failure attempt was 2.68 + 1.04% which may be interpreted as a reasonable increase in load.

Practical Applications

The results of this study have indicated a very small relationship between MVT at different intensities and an increased variance among tested subjects in MCV as intensity increases. These findings have several important benefits for practitioners interested in using MCV or MVT as a testing or monitoring tool:

1. Individual and intensity-related variance exists when considering MVT of the back squat. Not everyone fails if MCV falls below a certain point. This is important to keep in mind for coaches who may consider using MCV in training or especially when used during testing situations.
2. If a coach chooses to test his athletes in the weight room, via 1RM or repetitions until failure, it would be most beneficial to pick one of the tests (either 1RM or repetitions

until failure) to use exclusively as the tests yield different kinematic results and lifter responses.

3. When considering using submaximal repetitions until failure as a testing or monitoring tool in the practical setting, coaches should consider using a wireless inertia sensor such as PUSH to collect MCV during the test. Comparing MCV decrements throughout the test and at the point of failure has the potential to be a useful monitoring tool for coaches.

The subjects' strength or fatigue were not considered. It is unclear whether differences such as this, or others, may contribute to MCV and ultimately the MVT. Future research should consider how strength, fatigue, or other factors affect these 2 MCV measurements. Also, future research should consider how individuals change over time (i.e. after strength training) regarding MCV and MVT.

Conclusions

This study aimed to determine the relationship of MCV and MVT between 1RM and submaximal repetitions until failure. Overall, MCV decreased over time as intensity increased. Variance between subjects' MCV increased as intensity increased as well. This indicated that there was a relationship between MCV and intensity, but as intensity increased there was more variance between subjects. There was a small relationship between MVT at 1RM and submaximal repetitions until failure. Thus, the generalization that MVT is exercise-specific has been contraindicated by these results. The p-value and TE suggest that although there is a lack of a relationship between the 2 testing conditions there are similarities. Possibly, individual differences, intensity, volume, and possible fatigue should also be considered when testing MCV or MVT during the back squat. In conclusion, using MCV or MVT when testing 1RM or repetitions until failure could be a useful tool for practitioners, although considering the results of the current study it would be wise to use either of the tests exclusively of the other without comparing the two.

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CHAPTER 4

SUMMARY AND FUTURE DIRECTIONS

This study aimed to determine the relationship of MCV and MVT between 1RM and submaximal repetitions until failure. The results of this study indicated a very small relationship between the MVT during the 1RM and the repetitions until failure conditions (r= -0.135). The generalization that MVT is exercise-specific has been contraindicated by these results. Overall, MCV decreased over time as intensity increased. Variance between subjects' MCV increased as intensity increased as well. This indicated that there was a relationship between MCV and intensity, but as intensity increased there was more variance between subjects. There seems to be a similarity between the MVT in maximal and submaximal training sessions until failure based on the paired *t*-test, ($p \geq 0.05$; TE= 0.06) despite the poor *r*-value. The differences in MVT obtained during the 1RM (MVT= 0.32 ± 0.06 $m \cdot s^{-1}$) and the repetitions until failure (MVT= 0.35 ± 0.05 $m \cdot s^{-1}$) seem to be small when considering the *p*-value and TE. Based on the volunteer subjects in this study, there were some variances in physiological status such as strength and strength-endurance. This could be a potential reason for the disassociation between the two MVT data. This result suggests that there are individual or intensity differences that should be considered when examining MCV or MVT during exercise tests such as 1RM or repetitions until failure.

The dissociation between MVT at 1RM and repetitions until failure suggest that coaches who wish to use MCV in addition to a testing procedure would be best served to use one test exclusively. The MCV from 1RM should not be compared with MCV from repetitions until failure. Individual variance exists when considering MVT of the back squat. Not everyone fails if MCV falls below a certain point during 1RM or repetitions until failure. This is important to keep in mind for coaches who use MCV in training or especially when used during testing situations.

In the current study, the subjects' strength or fatigue were not considered. It is unclear whether differences such as this, or others, may contribute to MCV and ultimately the MVT. Going forward, future research should consider how strength, fatigue, or other factors affect MCV measurements. Also, future research should consider how individuals change over time (i.e. after strength training) regarding MCV and MVT.

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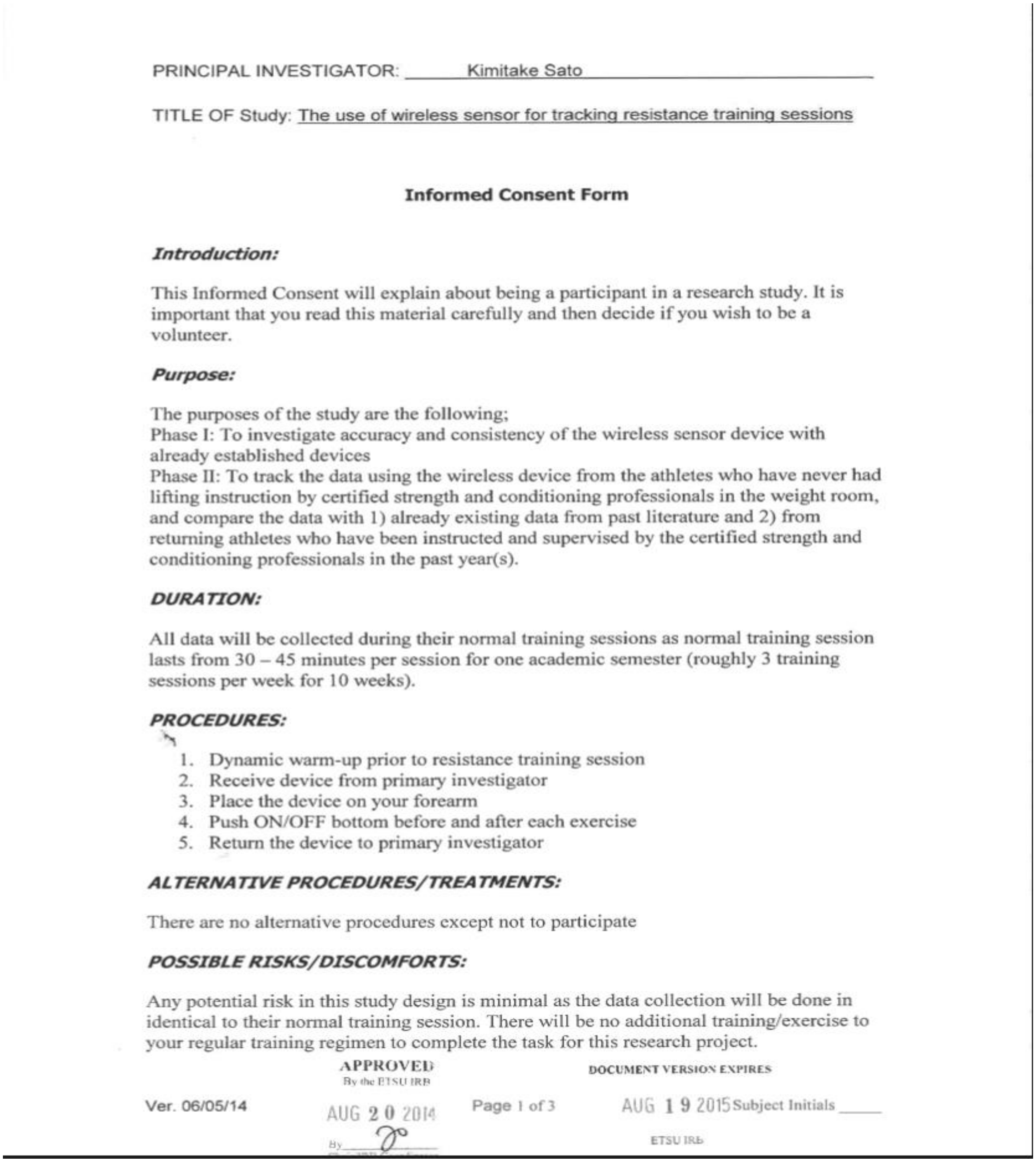
APPENDIX

Informed Consent Documents



PRINCIPAL INVESTIGATOR: Kimitake Sato

TITLE OF Study: The use of wireless sensor for tracking resistance training sessions

Informed Consent Form

Introduction:

This Informed Consent will explain about being a participant in a research study. It is important that you read this material carefully and then decide if you wish to be a volunteer.

Purpose:

The purposes of the study are the following;
Phase I: To investigate accuracy and consistency of the wireless sensor device with already established devices
Phase II: To track the data using the wireless device from the athletes who have never had lifting instruction by certified strength and conditioning professionals in the weight room, and compare the data with 1) already existing data from past literature and 2) from returning athletes who have been instructed and supervised by the certified strength and conditioning professionals in the past year(s).

DURATION:

All data will be collected during their normal training sessions as normal training session lasts from 30 – 45 minutes per session for one academic semester (roughly 3 training sessions per week for 10 weeks).

PROCEDURES:

1. Dynamic warm-up prior to resistance training session
2. Receive device from primary investigator
3. Place the device on your forearm
4. Push ON/OFF bottom before and after each exercise
5. Return the device to primary investigator

ALTERNATIVE PROCEDURES/TREATMENTS:

There are no alternative procedures except not to participate

POSSIBLE RISKS/DISCOMFORTS:

Any potential risk in this study design is minimal as the data collection will be done in identical to their normal training session. There will be no additional training/exercise to your regular training regimen to complete the task for this research project.

APPROVED
By the ETSU IRB
AUG 2 0 2014
By

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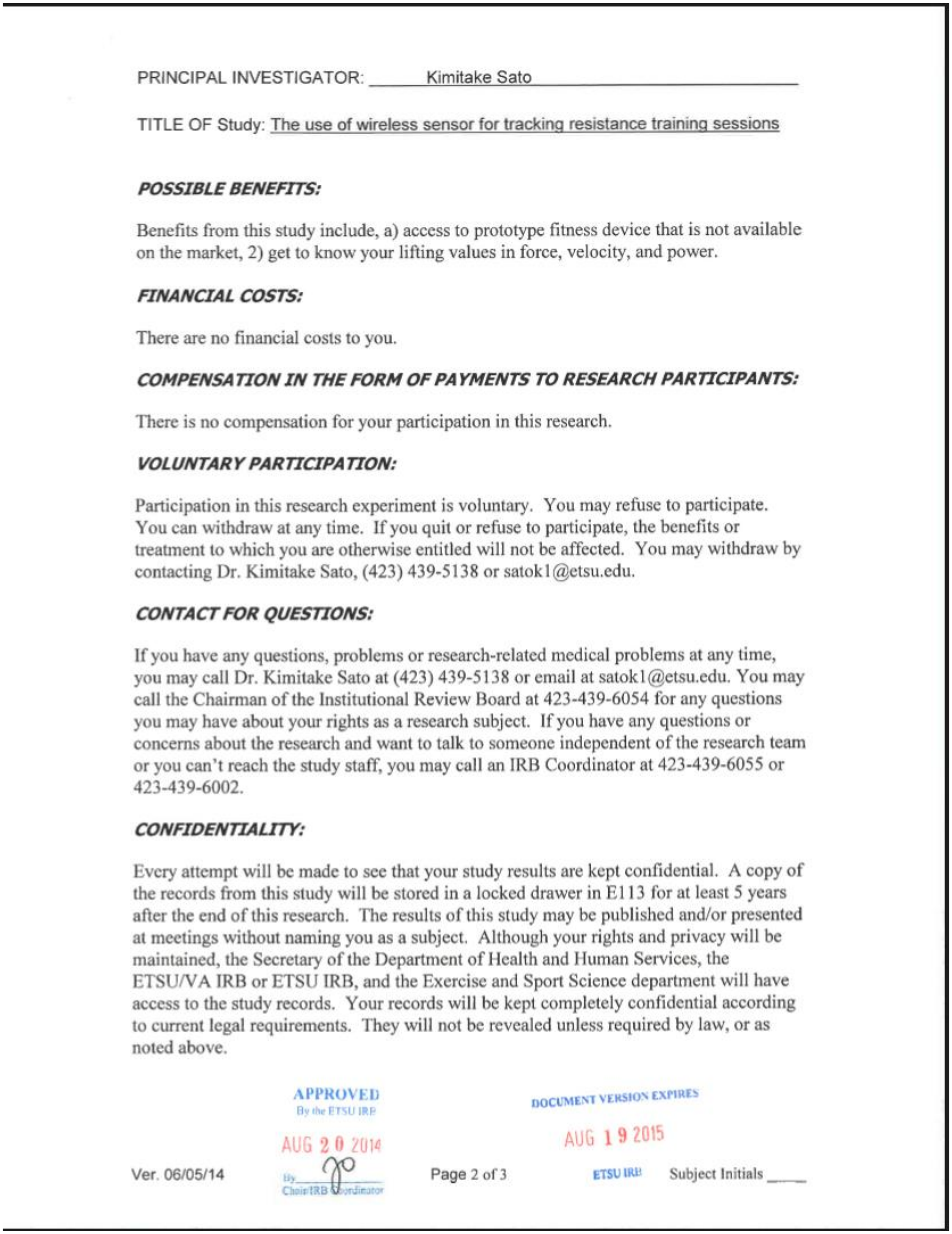
ETSU IRB

Ver. 06/05/14 Page 1 of 3 Subject Initials _____



PRINCIPAL INVESTIGATOR: Kimitake Sato

TITLE OF Study: The use of wireless sensor for tracking resistance training sessions

POSSIBLE BENEFITS:

Benefits from this study include, a) access to prototype fitness device that is not available on the market, 2) get to know your lifting values in force, velocity, and power.

FINANCIAL COSTS:

There are no financial costs to you.

COMPENSATION IN THE FORM OF PAYMENTS TO RESEARCH PARTICIPANTS:

There is no compensation for your participation in this research.

VOLUNTARY PARTICIPATION:

Participation in this research experiment is voluntary. You may refuse to participate. You can withdraw at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. You may withdraw by contacting Dr. Kimitake Sato, (423) 439-5138 or satok1@etsu.edu.

CONTACT FOR QUESTIONS:

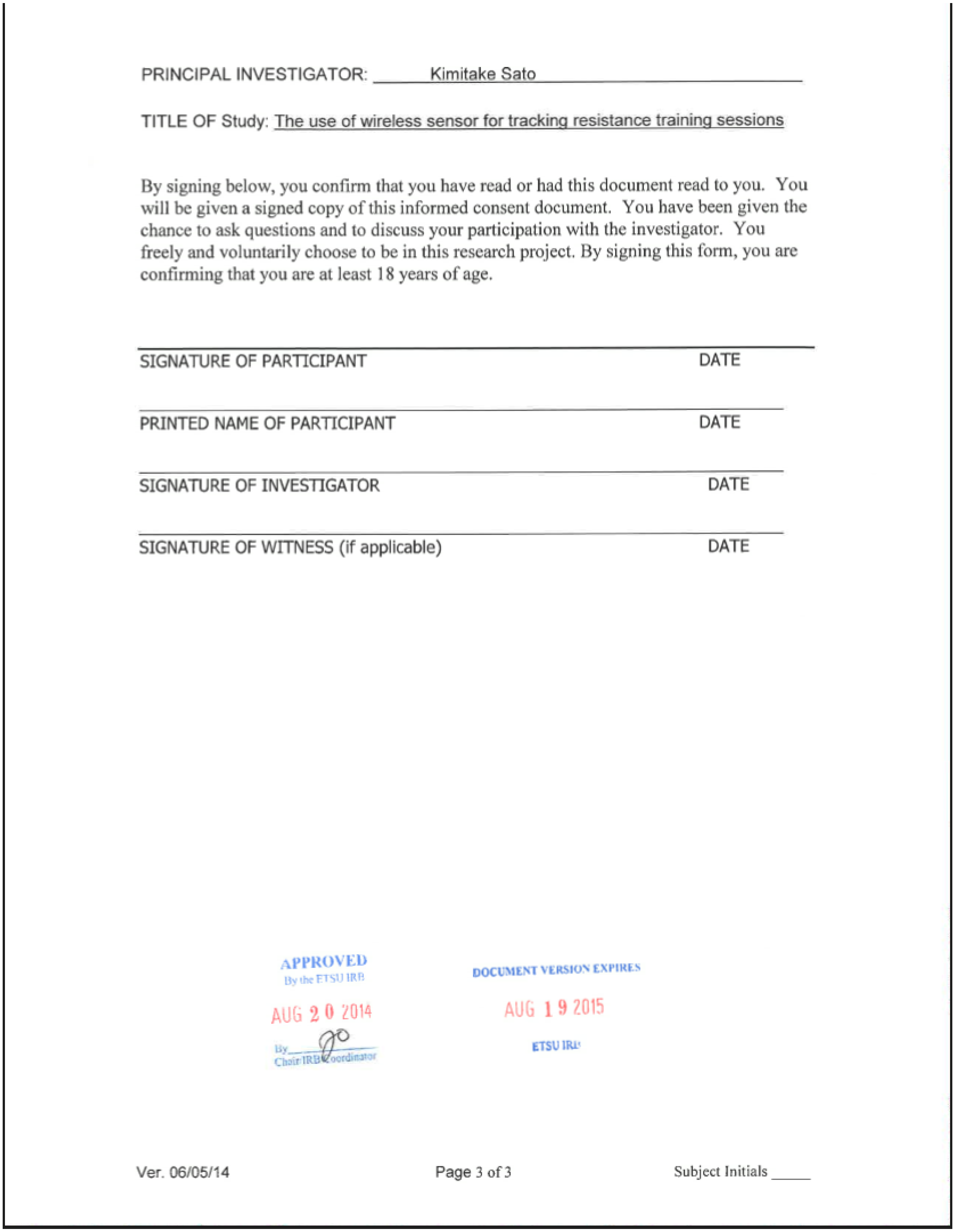
If you have any questions, problems or research-related medical problems at any time, you may call Dr. Kimitake Sato at (423) 439-5138 or email at satok1@etsu.edu. You may call the Chairman of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423-439-6055 or 423-439-6002.

CONFIDENTIALITY:

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in a locked drawer in E113 for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the ETSU/VA IRB or ETSU IRB, and the Exercise and Sport Science department will have access to the study records. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

APPROVED
By the ETSU IRB
AUG 20 2014
By Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES
AUG 19 2015
ETSU IRB



PRINCIPAL INVESTIGATOR: Kimitake Sato

TITLE OF Study: The use of wireless sensor for tracking resistance training sessions

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project. By signing this form, you are confirming that you are at least 18 years of age.

SIGNATURE OF PARTICIPANT DATE

PRINTED NAME OF PARTICIPANT DATE

SIGNATURE OF INVESTIGATOR DATE

SIGNATURE OF WITNESS (if applicable) DATE

APPROVED
By the ETSU IRB
AUG 20 2014
By ____
Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES
AUG 19 2015
ETSU IRB

VITA

KEVIN MICHAEL CARROLL

Education:

M.A., Sport Physiology and Performance, Expected 2015, East Tennessee State University, Johnson City, Tennessee

B.S., Exercise Science, 2013, Appalachian State University, Boone, North Carolina

Professional Experience:

Strength & Conditioning Coach; Sport Scientist, Women's Softball,

East Tennessee State University, Johnson City, Tennessee, 08/13-Present

Strength & Conditioning Coach; Sport Scientist, Women's Volleyball,

East Tennessee State University, Johnson City, Tennessee, 08/13-05/14

Strength & Conditioning Football Intern,

University of Texas, Austin, Texas, 05/13-08/13

Student Strength & Conditioning Intern,

Appalachian State University, Boone, North Carolina, 04/12-12/12

Publications and Papers

Sato, K., Beckham, G.K., Carroll, K., Bazyler, C., Sha, Z., & Haff, G. (2015) Validity of wireless device measuring velocity of resistance exercises. *Journal of Trainology,* 4(1), 15-XX.

Carroll, K. M., Christovich, J. D., Bazyler, C. D., Fiolo, N. J., Beckham, G. K., & Sato, K. (2014). *An exploratory study on the use of concentric velocities in the back squat as a monitoring tool*. Paper presented at the 9th Annual Coaches and Sport Science College, Johnson City, Tennessee, United States.

Honors and Awards:

Certified Strength & Conditioning Specialist, National Strength & Conditioning Association, November 2013

Chancellor’s List, Appalachian State University, Spring 2013

Dean’s List, Appalachian State University, Fall 2012

Chancellor’s List, Appalachian State University, Spring 2012

Chancellor’s List, Appalachian State University, Fall Semester 2011