Utility of Novel Rotational Load-velocity Profiling Methods in Collegiate Softball Players

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UTILITY OF NOVEL ROTATIONAL LOAD-VELOCity PROFILING METHODS IN COLLEGIATE SOFTBALL PLAYERS

by

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Learning Sciences and Educational Research
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Major Professor: David H. Fukuda
ABSTRACT

The purposes of this study were to determine the reliability of the bat swing (BS) and rotational medicine ball throw (RMBT) load-velocity profiling (LVP) methods and the relationships between LVP variables and batting performance in NCAA Division I softball players. Current NCAA Division I softball athletes participated in this study. Bat velocity was tracked with a swing sensor during the BS method. An inertial measurement unit (IMU) tracked forearm velocity during the BS and RMBT methods. Two-way intraclass correlation coefficients (ICC) were used for relative reliability and coefficient of variation (CV) was used for absolute reliability. For the BS method with the swing sensor, relationships between the multiple- and two-load models and between LVP variables and batting variables were examined using Pearson’s correlation coefficients. During the RMBT method and BS method using the IMU, no LVP variables were reliable (ICC ≤ 0.7; CV ≥ 15%). For the BS method with the swing sensor, all bat loads and $V_0$ had acceptable reliability using peak velocity (PV) and average peak velocity ($PV_{avg}$) (ICC > 0.7; CV < 15%). All LVP variables were highly related between the multiple- and two-load models when utilizing PV and $PV_{avg}$ ($r = 0.915$-$0.988$; $p < 0.01$). There were significant relationships ($r = 0.603$-$0.671$; $p < 0.05$) between PV using the 0.99 kg bat load and slugging percentage and on-base plus slugging, and between $V_0$ and doubles, runs batted in, and total bases. Neither the RMBT method nor the BS method using the IMU provided reliable LVP variables. All bat velocities were highly reliable during the BS method using the swing sensor, while only $V_0$ provided acceptable reliability. Practitioners may utilize the two-load model when utilizing the BS method using the swing sensor, although further research is needed to examine the relationship between LVP variables and batting performance.
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<th>Definition</th>
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<td>IRM</td>
<td>One-repetition maximum</td>
</tr>
<tr>
<td>BS</td>
<td>Bat swing</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of variation</td>
</tr>
<tr>
<td>$D_{RF}$</td>
<td>Rate of decrease in $RF$</td>
</tr>
<tr>
<td>ERA</td>
<td>Earned run average</td>
</tr>
<tr>
<td>$F_0$</td>
<td>Theoretical maximum force</td>
</tr>
<tr>
<td>F-v</td>
<td>Force-velocity</td>
</tr>
<tr>
<td>FVP</td>
<td>Force-velocity profile/profiling</td>
</tr>
<tr>
<td>$HZT-F_0$</td>
<td>Theoretical maximum horizontal force production</td>
</tr>
<tr>
<td>$HZT-V_0$</td>
<td>Theoretical maximum running velocity</td>
</tr>
<tr>
<td>IMU</td>
<td>Inertial measurement unit</td>
</tr>
<tr>
<td>$LD_0$</td>
<td>Theoretical load at zero velocity</td>
</tr>
<tr>
<td>LPT</td>
<td>Linear position transducer</td>
</tr>
<tr>
<td>LVP</td>
<td>Load-velocity profile/profiling</td>
</tr>
<tr>
<td>MBHT</td>
<td>Medicine ball hitter’s throw</td>
</tr>
<tr>
<td>MTU</td>
<td>Muscle-tendon unit</td>
</tr>
<tr>
<td>$PV_{avg}$</td>
<td>Average of the top two peak velocities</td>
</tr>
<tr>
<td>PAR-Q+</td>
<td>Physical Activity Readiness Questionnaire</td>
</tr>
<tr>
<td>$P_{max}$</td>
<td>Maximal power output</td>
</tr>
<tr>
<td>PV</td>
<td>Peak velocity (PV)</td>
</tr>
<tr>
<td>P-v</td>
<td>Power-velocity</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<td>----------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>RBIs</td>
<td>Runs batted in</td>
</tr>
<tr>
<td>RMBT</td>
<td>Rotational medicine ball throw</td>
</tr>
<tr>
<td>$RF$</td>
<td>Ratio of force</td>
</tr>
<tr>
<td>$RF_{\text{max}}$</td>
<td>Theoretical maximal ratio of force</td>
</tr>
<tr>
<td>RFD</td>
<td>Rate of force development</td>
</tr>
<tr>
<td>SEM</td>
<td>Standard error of measurement</td>
</tr>
<tr>
<td>$S_{\text{FV}}$</td>
<td>Slope of the line using least squares regression</td>
</tr>
<tr>
<td>$S_{\text{LV}}$</td>
<td>Slope of the line using linear regression</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
</tr>
<tr>
<td>$V_0$</td>
<td>Theoretical maximum velocity</td>
</tr>
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</table>
CHAPTER ONE: INTRODUCTION

Force-velocity profiling (FVP) of ballistic movements that are common across numerous sporting contexts has been utilized to understand the balance between the force and velocity capabilities of athletes. Due to the highly linear relationship between force and velocity during maximal multi-joint movements (Bobbert, 2012; Jaric, 2015, 2016; Morin et al., 2010; Samozino et al., 2012; Yamauchi & Ishii, 2007), simple FVP methods have been developed for several foundational ballistic movements, including jumping (Samozino et al., 2008) and sprinting (Samozino et al., 2016). Many sports, such as baseball, combat sports (e.g., boxing, judo, mixed martial arts, wrestling), cricket, golf, softball, tennis, and track and field throwing events, also require precise and powerful rotational movements to be successful. Although the kinetics and kinematics of the movement vary dependent on the sport (e.g. golf swing vs. softball swing) and type of movement (e.g., tennis forehand vs. backhand), rotational movements involve the ability of the athlete to coordinate body segments in order to transfer force from the ground through a stable midsection to another object, often at very high velocities. Assessing only force or only velocity may not be sufficient to fully understand rotational movements, therefore making FVP a relevant assessment for these athletes.

To the best of our knowledge, only one study has investigated a rotational movement using FVP. Paulovics (2018) analyzed the rotational FVP of elite golfers using a computerized robotic engine system able to measure power, force, and velocity (1080 Quantum) using three golf-specific tests: the thorax, pelvis, and full-body rotational tests. The author found that the test-retest reliability of peak power, peak force, and peak velocity were acceptable only in the
full-body rotational test. However, this test did not provide acceptable construct validity through correlational analysis with clubhead speed.

While the direct assessment of force, and consequently power, in order to develop FVPs using the technology described above is ideal to fully reveal the mechanical capabilities of an athlete’s neuromuscular system, purchasing this or other similar instrumentation is likely not realistic for many practitioners. Without this sophisticated instrumentation and/or the knowledge to create theoretical models (Ikeda et al., 2009), there are limitations to reliably assessing rotational FVPs. Consequently, rather than assessing force, or the vector quantity of push or pull placed on a mass causing acceleration, researchers have utilized an assessment of the total amount of mass of the object being accelerated, referred to as load. This simple assessment of load in relation to velocity is known as load-velocity profiling (LVP), which could be useful for practitioners and training staff. Primarily used to estimate one-repetition maximum (1RM) in traditional strength training movements, such as the back squat (Banyard et al., 2017; Dorrell et al., 2020), bench press (Jidovtseff et al., 2011), leg press (Conceição et al., 2016; Picerno et al., 2016), military press (Balsalobre-Fernández et al., 2018), and pullup (Muñoz-López et al., 2017), LVP can also be utilized as an assessment of the force and velocity capabilities of an athlete relative to various loads along the load-velocity spectrum. In the aforementioned LVP studies, the velocity of the movement was plotted as a function of the load, revealing a linear relationship between load and velocity (Balsalobre-Fernández et al., 2018; Conceição et al., 2016; García-Ramos, Pestaña-Melero, et al., 2018; Muñoz-López et al., 2017). Consequently, in plotting the load on the $x$-axis and velocity on the $y$-axis, the slope ($S_{LV}$) can be calculated using linear regression, whereas a more negative $S_{LV}$ represents greater velocity capabilities a less negative
$S_{LV}$ represents greater load capabilities (Morin & Samozino, 2016). Additionally, a mathematical estimation of theoretical maximum velocity ($V_0$) and theoretical load at zero velocity ($LD_0$) can be determined using LVP.

A large gap in the literature is the creation of a simple and reliable rotational LVP methodology using inexpensive instrumentation. In addition to the 1080 Quantum assessment utilized in the aforementioned study (Paulovics, 2018), previous literature examining rotational assessments have focused primarily on various seated and standing rotational medicine ball throws (RMBTs) (Gordon et al., 2009; Ikeda et al., 2007; Lehman et al., 2013; Read et al., 2013; Sell et al., 2015; Szymanski et al., 2007; Talukdar et al., 2015; Teichler, 2010), while other researchers have utilized various cable rotations (Andre et al., 2012; Schofield et al., 2021; Talukdar et al., 2015), rotationally-based machines (Ellenbecker & Roetert, 2004; Ikeda et al., 2007; Lephart et al., 2007; Sell et al., 2015; Szymanski, Mcintyre, et al., 2007), and strain gauges connected to a trunk strength tester (Ikeda et al., 2009). Although rotationally-based machines and the trunk rotation strength tester with accompanying strain gauge may have an advantage isolating an athlete’s movement, potentially increasing the level of reliability, these machines are not common within sports performance settings. Cable machines are more commonplace, but the variety of models available does not easily allow for the standardization of loads from machine to machine. Consequently, utilizing RMBTs for LVP is most practical for practitioners due to the relatively low cost, the standardization of MB masses between companies, and the frequency in which MBs can be found within sports performance settings.

While the RMBT LVP method has applicability to athletes from all rotationally-based sports, there is a lack of primary task of interest specificity as suggested for physical assessments
(Schofield et al., 2021). For softball athletes, the primary task of interest related to hitting performance is the bat swing. It is essential for softball athletes to have the ability to produce large muscular forces and the proper technical skill to apply these forces to the bat, and consequently, the ball. Therefore, an assessment that enables the athlete to perform an actual swinging motion would be most appropriate for these athletes. The assessment of peak velocities of maximum-effort swings utilizing bat jackets in order to create loads along the load-velocity spectrum could help establish a bat swing (BS) load-velocity relationship. The variables obtained using the BS LVP method could then be used to assess individual strength and velocity capabilities during the swing.

The literature examining changes in bat velocity after long-term training with overload or underload bats is sparse, with the majority of research focusing on acute strategies to create a potentiating effect (Dabbs et al., 2010; DeRenne et al., 1992; Gilmore et al., 2014; Mace & Allen, 2020; Montoya et al., 2009; Southard & Groomer, 2003). In NCAA Division I baseball players, Sergo and Boatwright (1993) examined the effects of six weeks of training with overload and underload bats on bat velocity, finding no significant differences between the groups utilizing the overloaded and underloaded bats and the control group. In contrast, DeRenne et al. (1995) examined the effects of 12 weeks of training with overload and underload bats on bat velocity in NCAA Division I baseball players, finding significant differences between the groups utilizing the overloaded and underload bats and the control group. Utilized by the former Soviet Union track and field coaches and scientists several decades ago (Kanishevsky, 1984; Konstantinov, 1979; Kuznetsov, 1975; Vasiliev, 1983), training with an overload implement slows the velocity of the movement, consequently allowing for greater force
production due to additional cross-bridge formation (Hill, 1938). In contrast, training with an underload implement allows for a movement pattern to occur under higher velocities but with lower force production as compared to normal implement training. Theoretically, using overload batting implements focuses bat swing training towards the force end of the force-velocity (F-v) spectrum, while using underload batting implements focuses training closer to the velocity end of the F-v spectrum. With the addition of LVP, training can potentially be enhanced by focusing on the specific deficiency of the individual. For example, a LVP for a softball athlete with a large $V_0$ and low $LD_0$ implies that the athlete can apply a low level of force during the swing but can effectively produce a high swing velocity. It may be recommended that this athlete focus on improving his/her force through the use of over-weight bats during training, although further investigation into the relationship between LVP variables and sport performance is necessary prior to specific recommendations.

Previous research has focused on bat velocity rather than either simulated or in-game batting performance (DeRenne et al., 1995; Higuchi et al., 2013; Liu et al., 2011; Montoya et al., 2009; Sergo & Boatwright, 1993; Southard & Groomer, 2003), with the overwhelming majority of research focusing on baseball athletes. Specific to softball players, researchers have examined the effects of various experimental procedures on bat velocity, such as assisted hip rotation (Rivera et al., 2018), a high-intensity isometric potentiating warm-up (Gilmore et al., 2014), jaw clenching (Mace & Allen, 2020), medicine ball training (Kobak et al., 2018), various warm-up devices (Szymanski et al., 2012), visual training (Szymanski et al., 2011), whole-body electromyostimulation (Hussain et al., 2019), and whole-body vibration (Dabbs et al., 2010). With regard to batting performance in softball athletes, researchers have examined the
relationships between in-game and/or controlled batting task performance and the use of analogy learning (Capio et al., 2020), anticipation timing (York, 1995), cognitive scores (Nasu et al., 2020), competitive anxiety and situation criticality (Krane et al., 1994), delta onset, or the difference in average time of swing onset between fastballs and slowballs (Nasu et al., 2020), multimodal modeling (DeRenne & Morgan, 2013), and visual-field size (Berg & Killian, 1995). To the best of our knowledge, only one study has examined the relationship between any measure of neuromuscular output and softball batting performance. York (1995) explored the contributions of anaerobic power as assessed using the Wingate Anaerobic Test to batting performance in slow pitch softball athletes, finding absolute peak power to be significantly correlated with batting average. Consequently, given the scarcity of literature examining the relationship between neuromuscular capabilities and in-game batting performance in softball players, further investigation is warranted.

Therefore, the purposes of this study were to determine the reliability of BS and RMBT LVP methods in NCAA Division I softball players and to establish the relationships between LVP variables and in-game batting performance. The findings of our research will provide several pieces of useful information for sports practitioners. The creation of a simple rotational LVP methodology will allow coaches to develop an enhanced picture of the mechanical capabilities of their athletes’ neuromuscular systems, specifically during movements more similar to those displayed within the sporting context. Additionally, by exploring any potential relationships between LVP variables and in-game performance metrics, a clearer insight into the factors that cause enhanced softball performance may be obtained. The combined information
gained from our research will allow coaches and researchers the ability to increase the efficacy of sports performance training.

**Purposes**

1. To develop a simple and reliable method of assessing rotational LVP.
2. To examine the relationship between LVPs and in-game batting performance in collegiate softball players.

**Hypotheses**

1. A simple and reliable method of rotational LVP can be developed using inexpensive, commercially-available pieces of technology.
2. A higher \( V_0 \) revealed during the LVP correlates with higher in-game batting performance in collegiate softball players.
CHAPTER TWO: REVIEW OF LITERATURE

Physiological Basis for Power Production

Many neuromuscular factors contribute to an individual’s ability to produce maximal power ($P_{\text{max}}$), including the mechanical properties of skeletal muscle, muscle architecture, the properties of tendons and the muscle-tendon unit (MTU), morphological factors, and neural factors.

Muscle Mechanical Factors

During concentric skeletal muscle contractions, there is an inverse relationship between force and velocity (Hill, 1938). The attachment and detachment of the actin and myosin filaments, known as cross-bridge cycling, takes place in a set amount of time. If a concentric muscle action occurs at a high contraction velocity, there is less time for cross-bridges to be formed, consequently leading to decreased force production. In contrast, if the velocity of contraction is slow, there is ample time to maximize the number of cross-bridges formed, leading to a large production of force. This fundamental F-v relationship of skeletal muscle is true during both single-joint and multi-joint concentric contractions, although the F-v curve is hyperbolic and linear, respectively (Bobbert, 2012; Thorstensson et al., 1976; Tihanyi et al., 1982). As power is the product of force and velocity, $P_{\text{max}}$ occurs somewhere along the F-v spectrum, at both a submaximal force and a submaximal velocity (Cormie et al., 2011b).

Another property of skeletal muscle that affects $P_{\text{max}}$ production is the length-tension relationship. During cross-bridge cycling in skeletal muscle, there is a sarcomere length that allows for an optimal overlap of actin and myosin filaments (Lieber et al., 1994). As is the case
in the F-v relationship, when the number of actin-myosin cross-bridges formed is maximized, a large amount of tension can be developed, consequently leading to large force production. The optimal length of a muscle fiber, and therefore sarcomeres, has been shown to be slightly longer than the length of the resting muscle fiber (Close, 1972). When muscle lengths are too short, the myosin filament comes in contact with the Z-disk, causing compression (Cormie et al., 2011b). In contrast, when muscle lengths are too long, the optimized amount of overlap between actin and myosin filaments does not occur (Lieber et al., 1994). In both cases, the number of cross-bridges that can be formed is less than optimal, leading to a lower amount of tension, force, and ultimately $P_{\text{max}}$, that can be developed.

**Morphological Factors**

Several morphological factors play a role in the expression of $P_{\text{max}}$, such as muscle cross-sectional area (CSA), muscle fiber fascicle length, and pennation angle. Many researchers have described the strong positive correlation between muscle CSA and force production (Ikai & Fukunaga, 1970; Maughan et al., 1983). Researchers have found that changes in maximal force production of a single skeletal muscle fiber are proportionate to the changes in CSA (Trappe et al., 2000; Widrick et al., 1996). Consequently, due to the large influence of maximal force production in the expression of $P_{\text{max}}$, there is also a positive correlation between CSA and $P_{\text{max}}$ production (Ackland et al., 2012; Davies, 1992; Miura et al., 2002; Palmer et al., 2014). Research has shown that improvements in $P_{\text{max}}$ production are typically seen with corresponding increases in muscle CSA (Malisoux et al., 2006; Widrick et al., 2002).
In addition to muscle CSA, both fascicle length and pennation angle play a role in $P_{\text{max}}$ production. While the maximal velocity of contraction of a muscle fiber varies greatly dependent on fiber type, the length of the muscle fiber is directly related to the velocity of contraction (Wickiewicz et al., 1983). The longer the fascicle length, the faster the contraction velocity (Abe et al., 2001; Kumagai et al., 2000) and consequently, higher $P_{\text{max}}$ production (Wickiewicz et al., 1983). While fascicle length primarily relates to velocity of contraction, pennation angle affects both force production and velocity of contraction. As the number of sarcomeres is directly related to the amount of cross-bridge formations that can occur, an increase in the number of sarcomeres that can be arranged in parallel with a concomitant increase in pennation angle leads to an increase in force production (Gans, 1982; Wickiewicz et al., 1983). In contrast, as the pennation angle decreases, there is an increase in the number of sarcomeres in series, consequently leading to an increase in the velocity of contraction. Researchers have found that the increase in maximal force production caused by an increase in pennation angle positively affects $P_{\text{max}}$ more so than an increase in velocity through a decrease in pennation angle (Cormie et al., 2011b). Due to the effect of the tendon compliance on fascicle length, the MTU plays a role in $P_{\text{max}}$ production as well, although the research is equivocal. Researchers have found that sprint performance correlates with an increase in tendon compliance (Kubo et al., 2000), while others have found that knee extension performance correlates with a decrease in tendon compliance (Bojsen-Møller et al., 2005).

Additionally, different measures of body composition have been found to correlate with $P_{\text{max}}$. Although the literature has primarily examined males, peak power has been found to correlate with peak fat-free mass (FFM) in many different populations. A weak positive
correlation was seen in untrained but physically active men (Patton et al., 1990), while a positive correlation was seen in adolescent male soccer athletes (Nikolaïdis, 2011), elite young male and female wrestlers (Vardar et al., 2007), professional male basketball players (Ribeiro et al., 2015), and obese men and women (Lafortuna et al., 2004). Researchers have also found a negative correlation between relative power and fat mass (Ribeiro et al., 2015). Additionally, different body composition measures have been found to correlate with performance measures relevant to the sporting context in athletic populations. Barbieri et al. (Barbieri et al., 2017) found a positive correlation with sprinting performance in 100m competitive male sprinters. Zaras et al. (Zaras et al., 2016) found significant correlations between the percentage increase in lean body mass (LBM) and increases in leg press rate of force development (RFD) in young track and field throwers after a 10-week periodized training program. Additionally, these researchers found that increases in muscle mass explained 37% of the variation in improvement in shot put test performance (Zaras et al., 2016). Researchers also revealed significant relationships between LBM and home runs, total bases, and slugging percentage in 343 professional baseball players (Hoffman et al., 2009).

As somatotyping includes both height and weight, several researchers have analyzed the relationship between somatotype and power output. Buško et al. (2017) found no significant relationships between somatotype components and $P_{\text{max}}$ during three different types of jumps, but found a significantly positive relationship between cycle ergometer power and mesomorphy and a significantly negative correlation between cycle ergometer power and ectomorphy in male basketball athletes. Lewandowska et al. (2011) found similar positive and negative correlations between cycle ergometer peak power and mesomorphic and ectomorphic somatotypes,
respectively, in judokas. Additionally, Buško et al. (2013) found a significant positive correlation and a significant negative correlation between maximal power during jumping and mesomorphic and ectomorphic components, respectively, in female volleyball athletes. These researchers also found cycle ergometer power to correlate positively with endomorphy and mesomorphy and negatively with ectomorphy (Buško et al., 2013).

**Neural Factors**

In addition to the intrinsic properties of muscles affecting power production, as the nervous system controls the activation of skeletal muscle, neural factors play a large role in the expression of $P_{\text{max}}$. In skeletal muscle, force is determined by the number and size of the motor units recruited. The size principle states that motor units are recruited in a systematic order according to size and recruitment thresholds during graded, isometric, and ballistic voluntary muscular contractions. At low force levels, the small $\alpha$-motoneurons that innervate the Type I muscle fibers are recruited. When higher levels of force are required, the larger $\alpha$-motoneurons that innervate the Type IIa and IIx muscle fibers are recruited. As Type IIa and Type IIx muscle fibers have a higher capacity for force production and faster contraction rates, the ability to recruit the larger $\alpha$-motoneurons is crucial during power production.

In addition to recruiting the larger $\alpha$-motoneurons, the rate and synchronization of recruitment plays a large role in $P_{\text{max}}$ production. Firing frequency refers to the rate of neural impulses being transmitted from the $\alpha$-motoneurons to the muscle fibers. Both the force of muscular contraction and the RFD can be increased by increasing the firing frequency (Enoka, 1995; Zehr & Sale, 1994). Motor unit synchronization refers to the activation of multiple motor
units at the proper time (Milner-Brown et al., 1975). Motor unit synchronization may cause increased force production and/or RFD, which has the potential to increase power production. Thus, for maximal power production, an individual must have the ability to recruit the high-threshold motor units, to recruit these motor units rapidly, and to recruit these motor units in a synchronized fashion.

The last main neural factor that affects $P_{max}$ production is inter-muscular coordination. Inter-muscular coordination refers to the activation and relaxation of the agonist(s), synergist(s), and antagonist(s) at the appropriate times and rates. While the activation of an antagonist may occur in order for the body to reduce its risk of injury, this will lower the level of overall force production. In order to produce optimal force, and consequently, optimal $P_{max}$, the agonist(s) and synergist(s) must be recruited while the antagonist(s) must be relaxed at the proper time and rate.

**Power-velocity Relationship**

The power-velocity (P-v) relationship is directly related to the F-v relationship described above. While the F-v relationship is highly linear during multi-joint contractions (Bobbert, 2012; Jaric, 2015, 2016; Morin et al., 2010; Samozino et al., 2012; Yamauchi & Ishii, 2007), the P-v relationship is parabolic (Hintzy et al., 1999; Sargeant et al., 1981; Sreckovic et al., 2015). Consequently, theoretical $P_{max}$ corresponds to the apex of the P-v curve, and can be calculated using a second-degree polynomial function (Dorel et al., 2005; Hintzy et al., 1999; Sreckovic et al., 2015).

The P-v relationship is affected by the properties of the cross-bridges within the sarcomeres (Fenwick et al., 2017). As detailed above, several factors affect cross-bridge
formation, consequently affecting the P-v relationship, such as the length-tension relationship, muscle fiber architecture, muscle fiber type, and tendon stiffness. Additionally, cross-bridge stiffness may play a role in $P_{\text{max}}$ by affecting the cross-bridge cycling that can occur with changes in concentric velocity (Fenwick et al., 2017).

**Power Within the Sporting Context**

There is a strong positive relationship between power and general ballistic movements within the sporting context, general athletic performance, and various measures of sport-specific performance. As such, an in-depth look at power in relation to the sporting context is warranted.

**Relationship with Ballistic Movements**

The goal during ballistic movements is to produce the highest possible velocity of an object in the shortest amount of time. The object may be the mass of the body, such as during jumping and sprinting, the mass of the body plus any additional added mass, such as during loaded squat jumps, or it may be an object unassociated with the body, such as a barbell during bench press throws or a shot during the shot put event. Regardless of the object, to maximize acceleration, force must be applied as rapidly as possible. Consequently, maximal power output has been found to have a positive correlation with several ballistic movements frequently occurring within the sporting context. Peak power during the countermovement jump (CMJ) (González-Badillo & Marques, 2010), squat (Ashley & Weiss, 1994), and Wingate Anaerobic Test (Kasabalis et al., 2005) has been found to be positively correlated with jump height. Additionally, average power during the CMJ was found to have a positive relationship with CMJ height (González-Badillo & Marques, 2010). Researchers have found positive correlations
between peak power during jumping and 5m (Sleivert & Taingahue, 2004), 10m, and 30m (Ingebrigtsen & Jeffreys, 2012) sprint times. Young et al. (1995) also found average relative power during CMJ and squat jumps to have a positive relationship with both 2.5m sprint time and maximum sprinting velocity. Additionally, researchers have found positive correlations between power and change-of-direction (Nimphius et al., 2010), as well as power and agility (Schaun, 2013).

Sport-specific ballistic movements have also been shown to be correlated with power output. Researchers have found positive correlations between upper- and lower-body power during the medicine ball toss and vertical jump, respectively, with baseball bat swing velocity and batted-ball velocity in both NCAA Division I baseball players (Spaniol et al., 2006) and adolescent baseball players (Spaniol, 2002). Bonnette et al. (2008) showed similar correlations between rotational medicine ball toss power and both baseball bat swing velocity and batted-ball velocity in NCAA Division I baseball players. Additionally, Lehman et al. (2013) showed positive correlations between lateral to medial jumps and throwing velocity in college-level baseball players. Furthermore, Marques et al. (2007) showed a positive relationship between peak power during a concentric bench press and handball throwing velocity in elite handball athletes, while Fett et al. (2020) showed a positive relationship between power assessed during medicine ball throws and tennis serve velocity in elite junior tennis players.

Relationship with Overall Performance

Research has shown positive relationships between power from a variety of different assessments and overall performance in numerous sports. Using an incremental-load jump squat,
James et al. (2017) revealed that higher-level mixed martial arts (MMA) athletes had greater average and peak power than their lower-level counterparts. Franchini and Takito (2005) revealed that elite judokas had higher absolute mean power, absolute peak power, relative mean power, and relative peak power in the upper body Wingate Anaerobic Test as compared to their non-elite counterparts. Schmidt (1999) found that power in the seated medicine ball put can differentiate starters from non-starters in NCAA Division III football athletes. Power can also differentiate sub-elite from elite athletes in a variety of sporting contexts, including basketball, futsal, soccer (Jiménez-Reyes et al., 2018), football (Hoffman et al., 2009), and weightlifters (Carlock et al., 2004).

The literature has also revealed positive relationships between power and sport-specific performance. Using the Monark cycle ergometer, Bouhlel et al. (2007) found javelin performance to have a positive correlation with both upper- and lower-body power. Kyriazis et al. (2009) found a positive relationship between power during the CMJ and shot put performance. Positive correlations were seen in both mean and peak power assessed during vertical jumps and home runs, total bases, and slugging percentage in professional baseball players (Hoffman et al., 2009). Additionally, these researchers also saw a correlation between mean power and stolen bases.

*Sports Performance Training to Improve Performance*

Due to the strong positive relationship between power and ballistic movements (Bonnette et al., 2008; Fett et al., 2020; Ingebrigtsen & Jeffreys, 2012; Kasabalis et al., 2005; Marques et al., 2007; Peterson et al., 2006; Sleivert & Taingahue, 2004; Spaniol et al., 2006;
Young et al., 1995), training with a goal of improving sport performance is typically focused on enhancing $P_{\text{max}}$. To enhance $P_{\text{max}}$, there are basic principles that should be followed. The first is due to the fundamental relationship between strength and power. In order to produce a high level of power, an individual must have an adequate level of strength (Cormie et al., 2011a, p. 2). As compared to weaker individuals, stronger individuals have been shown in the literature to produce higher amounts of power (Cormie et al., 2009; McBride et al., 1999; Stone et al., 2003; Ugrinowitsch et al., 2007). Consequently, athletes with low levels of baseline strength should develop adequate levels of strength prior to performing advanced training techniques (Suchomel et al., 2018).

As an individual becomes stronger, the rate of improvements in strength decreases (Kraemer & Newton, 2000; Newton & Kraemer, 1994), therefore necessitating advanced techniques to continue improving $P_{\text{max}}$. Research has confirmed this, as enhancements in $P_{\text{max}}$ using traditional resistance training becomes less effective as training level increases (Kraemer & Newton, 2000; Newton & Kraemer, 1994). Consequently, power-type training should be incorporated into an athlete’s training program once he/she has developed an adequate level of strength (Suchomel et al., 2018). The addition of plyometric training has been shown to augment improvements in $P_{\text{max}}$ (Adams et al., 1992; Fatouros et al., 2000; Kobal et al., 2017), while traditional resistance training movements performed in a ballistic fashion can also help improve $P_{\text{max}}$. Optimal loading to maximize power production during ballistic training movements varies not only between exercises, but also based on the training status of the athlete and the phase within the macrocycle (Kawamori & Haff, 2004). This has led to a debate regarding optimal loading patterns to improve $P_{\text{max}}$ (Kobal et al., 2017). Regardless, several general principles have
been found, including selecting loads and velocities that are most similar to the sporting context, selecting multi-joint exercises, and using a combination of ballistic, traditional, and Olympic weightlifting exercises sequenced in a logical order (Kawamori & Haff, 2004).

Ballistic Movements

Ballistic movements as defined by Samozino et al. (2012) are movements aimed at maximally accelerating an object. As acceleration is defined as the rate of change in velocity of an object, the goal during ballistic movements is to reach the highest possible velocity of an object in the shortest amount of time.

Relationship Between Movements

Newton’s second law of motion describes the relationship between impulse and momentum, referred to as the impulse-momentum relationship. Momentum is calculated as the velocity of an object multiplied by the mass of the object. Impulse is calculated as the amount of force placed on an object multiplied by the duration that this force is applied, assuming a constant force. Impulse is, therefore, equivalent to the area under the force-time curve. In order to change the momentum of an object, the mass of the object must be changed and/or the velocity must be changed. During ballistic movements such as unloaded jumping and sprinting, the mass of the object is the body weight of the individual, something not able to be dramatically changed in the short-term. Consequently, to change the momentum of the body, the velocity must be altered. In order to do so, a force must be placed on the body in a certain direction. Therefore, impulse directly affects momentum and causes the change in motion of an object. The
greater the impulse, the greater the change in momentum of an object. The impulse-momentum relationship can be shown as:

\[ F \Delta t = m \Delta v \] (1)

Where \( F \) = force, \( t \) = time, \( m \) = mass, and \( v \) = velocity.

During ballistic movements such as vertical jumping, performance is dependent on the ability to develop a high impulse (Knudson, 2009; McBride et al., 2010; Winter, 2005). Therefore, the amount of force and the time this force is applied in the vertical direction directly affects the body’s center-of-mass velocity at push-off (McBride et al., 2010; Samozino et al., 2012). An increase in vertical impulse, and consequently, push-off velocity, can occur with an increase in force in the vertical direction or a change in the time this force is applied.

**Rotational Movements**

As power is the product of force and velocity, several researchers have analyzed rotational strength, both concentrically and isometrically. Researchers have used advanced pieces of equipment such as the axial trunk rotation strength tester (Ikeda et al., 2007) and the Biodex System 3 Multi-Joint Testing and Rehabilitation System (Sell et al., 2015). Assessments have also been made using resistance training equipment commonly seen in commercial gyms such as the Cybex Torso Rotation Machine (Ellenbecker & Roetert, 2004; Szymanski, Szymanski, et al., 2007) and cable machines (Talukdar et al., 2015). Additionally, force/strain gauges (Ikeda et al., 2009) have been used.

Since ballistic movements occurring in different planes of motion are independent skills (Murtagh et al., 2018), assessments in the frontal or sagittal planes are not as relevant for
rotational athletes. Consequently, several general tests have been created to assess power output in the transverse plane. One of the simplest and most commonly used is the rotating medicine ball throw (Fukuda, 2018), also referred to as the side medicine ball throw (Ikeda et al., 2007, 2009; Raeder et al., 2015). This assessment can be done from a standing, seated, or kneeling position (Fukuda, 2018; Sell et al., 2015). Regardless of throwing position, this test is often performed with an intent to throw the medicine ball as far as possible, although the intent can be shifted to throw the medicine ball as fast as possible (Ikeda et al., 2007). The FiTRO Torso Premium system has also been used in the literature to analyze power during barbell trunk rotations (Zemková et al., 2017).

As segmental dynamics of rotational movements are sport-specific, rotational assessments of power output have also been created for specific sports. Similar to the rotating medicine ball throw mentioned above, the medicine ball hitter’s throw (MBHT) has been used for baseball athletes (Kohmura et al., 2008; Spaniol, 2009; Szymanski et al., 2007). The main differences between the standard rotating medicine ball throw and the MBHT are the mass of the ball (1 kg for the MBHT due to the similarity between masses of the medicine ball and the baseball bat), the stance, and the movement of the body. For the MBHT, participants are asked to use their normal batting stance, which has a large amount of individual variation. Additionally, biomechanical characteristics for a successful bat swing are reinforced during the MBHT (Szymanski, et al., 2007). In contrast, standardized procedures are used during the rotating medicine ball throw to ensure reliability. While the MBHT could easily be adapted to the softball swing, the literature has yet to use this assessment in softball athletes.
For golf, researchers analyzed three different golf-specific rotational tests using the 1080 Quantum, a computerized robotic engine system (Paulovics, 2018). Although the full-body rotational test was found to have acceptable test-retest reliability, this test did not provide acceptable construct validity when compared to clubhead speed. Consequently, this is the only study that has analyzed this golf-specific rotational test.

Swing velocity is another assessment tool that can be used in baseball and softball athletes, golfers, and tennis athletes. With advancements in technology, inertial measurement units (IMUs) have become more common. Swing sensors such as the Blast Motion, Diamond Kinetics, and Zepp Swing Sensor can attach to the end of the bat, club, or racket, giving instantaneous feedback regarding velocity. Although an indirect measurement of power output, by entering the mass of the bat/club/racket, power output can be calculated using the proprietary software.

**Biomechanical Analysis**

Velocity is a vector quantity, meaning it has components of both magnitude and direction. Linear velocity refers to the speed of movement of an object in a particular direction. The typical units for linear velocity are meters/second (m/s), while the formula can be shown as:

\[ V = \frac{x}{t} \]  

Where \( V \) = linear velocity, \( x \) = distance, and \( t \) = time.

Angular velocity refers to the rotating, spinning, or turning speed of movement of an object. In other words, angular velocity is the angle at which an object moves (rotates, spins, or
turns) about a fixed point per unit of time. The typical units for angular velocity are revolutions/second, radians/second, or degrees/second. The formula can be shown as:

$$\omega = \frac{\Theta}{t}$$  \hspace{1cm} (3)

Where $\omega$ = angular velocity, $\Theta$ = radians, and $t$ = time.

Through substitutions in variables, the relationship between angular and linear velocity can be described. Linear velocity is the product of the angular velocity of an object multiplied by the radius about which the object moves, and can be shown with the following formula:

$$V = r\omega$$  \hspace{1cm} (4)

Where $V$ = linear velocity, $r$ = radius, and $\omega$ = angular velocity.

There is a similar relationship between force and torque. Force is a vector quantity in which the direction of applied force causes acceleration of an object in the same direction. In other words, the application of force causes linear acceleration of an object. The typical units for force are Newtons (N), and can be shown with the following formula:

$$F = m \cdot a$$  \hspace{1cm} (5)

Where $F$ = force, $m$ = mass, and $a$ = acceleration.

Although torque is also a vector quantity, torque refers to the application of force to an object that causes angular acceleration. The typical units for torque are Newton meters (Nm), and can be shown with the following formula:

$$\tau = F \cdot r \sin(\Theta)$$  \hspace{1cm} (6)

Where $\tau$ = torque, $F$ = force, $r$ = length of the moment arm, and $\Theta$ = the angle between the force applied and the moment arm. The amount of torque that an individual can produce around a joint
is influenced by muscle length, the involved musculature, speed of contraction, leverage, and the type of joint (Frey-Law et al., 2012; Haff & Triplett, 2015).

The moment arm is the distance or length of force application from the axis of rotation, which may be of equal length or shorter than the lever arm. Due to the above relationships regarding linear and angular velocity, force, and torque, the length of the moment arm plays a large role in the expression of power output. Researchers have created a three-dimensional, upper- and lower-trunk theoretical model to calculate torque during the side medicine ball throw (Ikeda et al., 2009). This model necessitates the use of multiple cameras and a system to digitize anatomical landmarks. These methods require the finances, knowledge, and time to properly calculate torque, making this theoretical model impractical for many researchers and sport performance coaches.

**Force-velocity Profiling**

As power is the product of force and velocity, differing levels of force and velocity can produce the same power output. The production of $P_{\text{max}}$ can occur with varying levels of these capabilities, and one single assessment of $P_{\text{max}}$ does not fully reveal the mechanical strengths and limitations of an individual’s neuromuscular system. Consequently, a method of assessing these underlying components of $P_{\text{max}}$ has been developed, termed force-velocity profiling (FVP).

Although FVP can be performed in both single-joint and multi-joint exercises, the relationship between force and velocity differs between the two. The relationship is hyperbolic during single-joint exercises (Bobbert, 2012; Jaric, 2015) due to several factors, such as neural activation, kinematics, and the elapsed time of muscle excitation (Jaric, 2015). In contrast,
segmental dynamics cause a highly linear relationship during maximal multi-joint movements such as sprinting, squatting, and cycling (Bobbert, 2012; Jaric, 2015, 2016; Morin et al., 2010; Samozino et al., 2012; Yamauchi & Ishii, 2007). Due to the simplicity of the F-v relationship during multi-joint movements, combined with the relevance of these movements within the sporting context, FVP has become more researched and applied with increasing frequency within athletics.

To determine an individual’s FVP, researchers have utilized both the multi-point and the two-point methods. The multi-point method assesses the athlete at multiple points along the F-v spectrum, whereas the two-point method assesses the athlete at one high force, low velocity point, and at one low force, high velocity point. In several studies, the two-point method has been found to have high reliability (García-Ramos et al., 2018; Jaric, 2016; Rez-Castilla et al., 2017; Zivkovic et al., 2017). Furthermore, it has been found that the further these two points are away from each other along the F-v line, the higher the reliability as compared to the multiple-point method (García-Ramos, Pérez-Castilla, et al., 2018).

Vertical Profiling

Samozino et al. (2008) developed a computational method for using three simple parameters in order to calculate force, velocity, and $P_{max}$ during the squat jump. The three parameters were the individual’s body mass, lower-limb vertical push-off distance, and jump height. Lower-limb vertical push-off distance refers to the distance covered by the center of mass during the push-off phase of the jump and can be measured by subtracting the length of the lower-limbs in the extended position minus the length at the starting height. Previous to this, the
measurements of force and velocity during various ballistic movements required devices such as cycle ergometers (Arsac et al., 1996; Vandewalle et al., 1987), force plates (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007), or linear position transducers (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007).

Vertical FVP consists of the performance of maximal-effort jumps using at least two different loads. Although researchers have analyzed unloaded jumps of -30% body weight (BW) using a pulley system (Cuk et al., 2014), the vertical jumping loads typically range from 0 to 70% BW. In the early literature regarding vertical FVP, researchers opted for methods that involved jumping under five different loading conditions that covered a wide spectrum of the F-v curve, known as the multi-point method. To reduce testing time and the risk of injury, as well as to make FVP more practical, researchers analyzed the two-point method, which involved the athlete jumping under only two loading conditions. Researchers found comparable reliability and high concurrent validity with respect to the multiple-point method if the most distant pair of loads was selected (i.e., 0-75kg) as compared to more proximal loads (i.e., 0-30kg) (García-Ramos, Pérez-Castilla, et al., 2018; Rez-Castilla et al., 2017). In selecting the most distance loads, one load allows for the expression of low force and high velocity and another the expression of high force and low velocity.

For each loading condition, the force and velocity can be plotted. Due to the highly linear relationship between force and velocity, least squares regression can be used to calculate the slope of the line ($S_{FV}$), representing the individual ratio between force and velocity capabilities. Extrapolation of this line to the $x$-intercept yields an individual’s theoretical maximum velocity
(\(V_0\)) while extrapolation to the \(y\)-intercept yields the individual’s theoretical maximum force (\(F_0\)). Furthermore, \(P_{\text{max}}\) can be calculated as:

\[
P_{\text{max}} = \frac{F_0 V_0}{4}
\]

The computational method has been found to have high reliability, with coefficients of variation (CV) of 2.56%, 3.84%, and 6.35% for \(F_0\), \(V_0\), and \(P_{\text{max}}\), respectively (Samozino et al., 2008). These researchers also found the absolute bias to be less than 3% for \(F_0\), \(V_0\), and \(P_{\text{max}}\) between the computational method and the force plate method. Additionally, the Pearson correlation coefficients were 0.98, 0.96, and 0.98 for \(F_0\), \(V_0\), and \(P_{\text{max}}\), respectively. Giroux et al. (2015) analyzed the concurrent validity and reliability of \(F_0\), \(V_0\), and \(P_{\text{max}}\) using FVP during the squat jump using several methods, including Samozino’s method (Samozino et al., 2008), a linear position transducer (LPT), and force plates. In comparing Samozino’s method to the force plate method, Pearson correlation coefficients were 0.98, 0.88, and 0.89 and CV values were 3.7, 11.4, and 13.3% for \(F_0\), \(V_0\), and \(P_{\text{max}}\), respectively. In comparing the LPT and force plate methods, Pearson correlation coefficients were 0.98, 0.91, and 0.89, while CV values were 3.3, 6.4, and 14.5% for \(F_0\), \(V_0\), and \(P_{\text{max}}\), respectively. Samozino’s method provided the most reliable results with ICC values of 0.99, 0.97, and 0.97 and CV values of 2.7, 6.5, and 8.6% for \(F_0\), \(V_0\), and \(P_{\text{max}}\), respectively. LPT provided ICC values of 0.96, 0.86, and 0.89 and CV values of 5.0, 9.3, and 12.2% for \(F_0\), \(V_0\), and \(P_{\text{max}}\), respectively. In comparing CMJs performed on a force plate and analyzed by two observers using the MyJump iPhone app, Balsalobre-Fernández, Glaister, and Lockey (2015) found almost perfect agreement (ICC = 0.997 and \(r = 0.995\)). Additionally, the Chronbach’s alpha (\(\alpha\)) was 0.997 and 0.988 and CV was 3.4 and 3.6% for observer 1 and observer 2, respectively, for each CMJ performed by each participant.
**Horizontal Profiling**

Samozino et al. (2016) also developed a computational method using only anthropometric and spatiotemporal data to calculate force, velocity, and $P_{\text{max}}$, as well as mechanical effectiveness, in the sagittal plane of motion during a sprint. Horizontal FVP consists of the performance of at least one maximal 20-40m sprint, although it is typical to perform multiple trials and select the fastest for analysis. Anthropometric data necessary during horizontal FVP are body mass and height, while either distance-time or speed-time can be used as the spatiotemporal data. Timing gates, laser systems, or radar devices were originally used to measure the latter, but advances in video-capturing capabilities of smartphones have allowed spatiotemporal data to be captured and imported into apps such as *MySprint*.

Contrary to vertical FVP methods, horizontal FVP requires only one sprint to be performed in order to plot force and velocity data. The derivation of the speed-time curve leading to horizontal acceleration can be used to provide the power-force-velocity profile, where the $y$-intercept describes the individual’s theoretical maximum force ($HZT$- $F_0$), the $x$-intercept the individual’s theoretical maximum velocity ($HZT$- $V_0$), and $S_{\text{FV}}$ the individual ratio between force and velocity capabilities. Using the same equation as in vertical profiling, horizontal maximal power output ($HZT$- $P_{\text{max}}$) can be calculated as:

$$\text{HZT} - P_{\text{max}} = \frac{F_0 \cdot V_0}{4}$$

(8)

Horizontal FVP also provides the mechanical effectiveness of an individual’s sprint due to the linear relationship between the ratio of force ($RF$) and running velocity (Morin et al., 2011). The $RF$ represents the step-averaged ratio of antero-posterior-directed ground reaction forces (GRFs). Additionally, the rate of linear decrease in $RF$ as running velocity increases ($D_{RF}$)
can be calculated. This measurement, independent from the total force applied, describes an individual’s ability to maintain horizontally-directed GRFs despite the increase in velocity (Morin et al., 2011, 2012). The theoretical maximal $RF$ ($RF_{\text{max}}$) can also be found by extrapolating the line representing the $D_{RF}$ to the y-intercept.

In comparing Samozino’s method to the force plate method (Samozino et al., 2016), bias of less than 5% and narrow limits of agreement were found for $HZT\cdot F_0, HZT\cdot V_0, HZT\cdot P_{\text{max}}, SFV$, and $D_{RF}$, revealing high concurrent validity. High reliability for Samozino’s horizontal FVP method was also displayed, as standards of measurement between trials were less than 5% for all variables. In comparing outcome measures of 40m sprints measured with timing photocells, a radar gun, and the MySprint iPhone app, Romero-Franco et al. (2017) found almost perfect agreement between the 40m split times between the timing photocells and MySprint ($ICC = 1.0$, $r = 0.989-0.999$). Almost perfect agreement between the radar gun and MySprint were found for $HZT\cdot F_0, HZT\cdot V_0, HZT\cdot P_{\text{max}},$ and $D_{RF}$ ($ICC = 0.987-1.00$, $r = 0.9749-0.999$). Very low levels of CV revealed a high level of reliability for all performance variables when comparing MySprint to the radar gun (MySprint: CV = 0.14%; radar gun: CV = 0.11%) and when comparing MySprint to the timing photocells (MySprint: CV = 0.027%; timing photocells: CV = 0.028%).

**Force-velocity Imbalance**

Recent research has shown that training focused on an individual’s underlying deficiencies of $P_{\text{max}}$ production, can further improve the efficacy of training (Jiménez-Reyes et al., 2017, 2019) as compared to “non-optimized” training. As described by Samozino et al. (2012, 2014), for any given $P_{\text{max}}$, there is an optimal balance between force and velocity that
maximizes jump height. The optimal FVP depends on an individual’s push-off height characteristics, the $P_{max}$ produced by the lower limbs during the push-off, as well as the afterload (i.e., body mass plus additional loading, projectile mass) (Samozino et al., 2012).

Several researchers have quantified the difference between the optimal jumping FVP and an individual’s profile, termed the F-v imbalance ($FV_{imb}$). Using the $S_{FV}$ derived from the plotted force and velocity data, the $FV_{imb}$ can be calculated as:

$$FV_{imb} = 100 \cdot |1 - \frac{S_{FV}}{S_{FV \, opt}}|$$ (9)

While $P_{max}$ is the main determinant in jumping performance (Samozino et al., 2012), researchers have shown that jumping performance can be improved by lowering the $FV_{imb}$, with no corresponding change in $P_{max}$ (Samozino et al., 2014). These results have been experimentally confirmed by Jiménez-Reyes et al. (2017) who classified 84 participants into a traditional training group or one of three optimized training groups based on their $FV_{imb}$: force-deficit, velocity-deficit, or well-balanced. The deficit groups were further divided into high- or low-deficit categories (e.g., high force-deficit and low force-deficit). Each group performed a nine-week resistance training program that focused on reducing the $FV_{imb}$ with exercise selection and load assignments dependent on their deficiencies. For example, the high force-deficit group performed a ratio of three strength, two strength-power, and one power exercise each week, while the high velocity-deficit group performed a ratio of three speed, two power-speed, and one power exercise each week. While ten of the 18 participants in the traditional training group improved jump performance, all participants in the optimized training groups improved jump performance, with no significant change in $P_{max}$. In a follow-up study, Jiménez-Reyes, Samozino, and Morin (2019) followed a similar experimental design, dividing 66 participants
into force-deficit (high and low) or velocity-deficit (high and low) groups. Instead of a set training timeframe, the researchers allowed each participant to train until they reached their FV_{opt}. On average, it took individuals in the force-deficit group 12.6 ± 4.6 weeks to reach their FV_{opt}, while it took individuals in the velocity-deficit group 8.7 ± 2.1 weeks. The researchers also found a large range for individuals on either deficiency extreme, with one individual reaching their FV_{opt} in four weeks and another taking 25 weeks. As was the case in their previous study (Jiménez-Reyes et al., 2017), all participants improved jump height. The authors also noted that the change in FV_{imb} explained a greater variance in the improved jumping performance as compared to P_{max}.

Furthermore, Samozino et al. (2014) analyzed the squat jumping performance of 48 international and national-level athletes using P_{max}, FV_{imb}, and lower limb extension range as predictor variables. Although the quality of adjustment in the multiple regression model was good using only P_{max} and lower limb extension range as predictors, it increased with the addition of FV_{imb}. On average, the athletes experienced a loss of 6.49 ± 6.25% in jumping performance based on their FV_{imb}. In other words, for a particular P_{max}, an overreliance on force or velocity to produce power in the squat jump caused a decrease in performance in this group of athletes. The authors also noted that one individual lost nearly 30% in jump height based on an overreliance on force in the production of P_{max}.

Although researchers have established an optimal FVP for jumping (Jiménez-Reyes et al., 2017), the nature of specific sports and training methodologies may cause athletes to display vertical FVP much different than optimal. Marcote-Pequeño et al. (2019) found an average FV_{imb} of 64.5% in elite female soccer players, while Giroux et al. (2016) found that the FV_{imb} of world-
class taekwondo athletes can be as high as 35%. Escobar Álvarez et al. (2020) analyzed the FVP of 87 female ballet dancers and found that all 87 showed a force deficit. It is unclear if a decrease in the $F_{Vimb}$ of these athletes would lead to improved performance, or if these imbalances are necessary for successful performance in their respective sports, thus warranting further research examining the relationship between FVP and performance in a multitude of different sporting contexts.

Sex, Sport, and Competition-level Differences

Several studies have analyzed sex-based differences using vertical or horizontal FVP methods. In using the squat jump FVP methodology, Giroux et al. (2016) reported that female cyclists, fencers, sprinters, taekwondo athletes, and control participants had lower $F_0$, $V_0$, and $P_{max}$ as compared to their male counterparts. Jiménez-Reyes et al. (2018) analyzed the vertical and horizontal FVPs of over 553 athletes, noting several sex-based differences of sport- and level-matched athletes. These researchers found males to have higher levels of $F_0$, $V_0$, and $P_{max}$ using both vertical and horizontal profiling in the following sports/levels: mid-level basketball, elite-level gymnastics, elite-level handball, mid-level karate, elite- and mid-level soccer, high-level sprinting, mid-level volleyball, and high-level weightlifting. These researchers found elite-level rugby and high-level tennis males to have higher $F_0$, $V_0$, and $P_{max}$ in all categories except vertical $F_0$. Mid-level taekwondo males displayed lower horizontal $F_0$ and higher $F_0$, $V_0$, and $P_{max}$ in all other categories. Additionally, high-level male judokas displayed lower $F_0$ in both vertical and horizontal profiling, yet displayed higher $V_0$ and $P_{max}$ in both profiling methods. Haugen et al. (2019) analyzed the horizontal FVPs of 666 athletes from 23 sports that had trained at the
Norwegian Olympic training centre from 1995 to 2018. In terms of mean sex differences, these researchers found men to have 9.3% higher $F_0$, 11.9% higher $V_0$, and 21.9% higher $P_{max}$. Additionally, in all sports where both sexes were represented, men displayed higher $S_{FV}$ values than women.

While the research has yet to determine if athletes displaying a certain FVP gravitate towards one sport over another, or if the nature of the sport and the sport-specific training employed to create specific profiles, and potentially $FV_{inh}$, it is evident that athletes from different sporting backgrounds display different profiles. Samozino et al. (2014) found that rugby athletes display more force-oriented vertical profiles as compared to soccer athletes and sprinters. While Jiménez-Reyes et al. (2018) didn’t specifically report $S_{FV}$, the data revealed that male rugby athletes were more velocity-oriented, as these athletes had lower $F_0$ and higher $V_0$ as compared to level-matched soccer players. These researchers also found that female rugby and female soccer players of the same level had nearly identical vertical FVPs. In further support, Giroux et al. (2016) found that cyclists and sprinters display more force-oriented vertical FVPs as compared to soccer, fencing, and taekwondo athletes. Jiménez-Reyes et al. (2018) revealed that male sprinters had both higher $F_0$ and higher $V_0$ as compared to level-matched soccer athletes. Giroux et al. (2016) also revealed that cyclists displayed more force-oriented profiles as compared to soccer, fencing, and taekwondo athletes. In using a cycle ergometer for FVP, Vandewalle et al. (1987) found that rugby athletes displayed more force-oriented profiles as compared to gymnasts.

Additionally, athletes from different positions within the same sport have been found to display different FVPs. Ahmun et al. (2020) examined international cricketers, finding that
senior seam bowlers had a moderately higher $HZT\cdot F_0$ and $RF_{max}$ as compared to batters. In using the bench press throw for FVP, McMaster et al. (2016) found that rugby forwards had significantly greater $F_0$ and $P_{max}$ as compared to backs.

Jiménez-Reyes et al. (2018) examined the FVPs not only of athletes from varied sporting backgrounds, finding different profiles throughout, but of athletes from diverse levels (amateur up to elite) and sexes. These researchers reported that professional male basketball players had higher $F_0$, $V_0$, and $P_{max}$ as compared to semi-professional male basketball players, while semi-professional male volleyball athletes had higher $F_0$, $V_0$, and $P_{max}$ as compared to their female counterparts. Colyer et al. (2018) noted that elite-squad skeleton athletes displayed more velocity-oriented profiles as compared to talent-squad athletes. Furthermore, Edwards et al. (2020) examined the horizontal FVPs of local and state under 18’s Australian football athletes. These authors found the state under 18’s had significantly higher absolute and relative $F_0$ and more negative $S_{FV}$ (more force-oriented) as compared to the local under 18’s.

**Changes Over Time**

There have been several studies examining changes over time using FVP during compound movements. In one study, de Lacey (2014) assessed the vertical FVPs of professional rugby league players before and after a 21-day step taper, noting likely positive increases in $F_0$, unclear changes in $V_0$ and $S_{FV}$, and very likely positive increases in $P_{max}$. Also using vertical FVP, Simpson et al. (2020) placed male professional rugby league athletes into either an optimized or a general strength-power training group during pre-season, noting significant increases in $F_0$, 3RM back squat, vertical peak power, and squat jump height. Using horizontal FVP, Escobar
Álvarez (2020) examined female amateur rugby union athletes prior to and after an eight week resistance sled training program, noting increases in $F_0, P_{\text{max}}$ and $RF_{\text{max}}$, and decreases in 5 and 20m sprint times. In the longest FVP study to date, Colyer (2018) examined the changes in the FVPs of elite- and talent-squad skeleton athletes over an 18-month period, as well as changes in 15-m sled start performance. The authors noted profile changes corresponding with certain training blocks, such as an increase in $F_0$, a decrease in $V_0$, and a more force-oriented (steeper) $S_{\text{FV}}$ during the first maximum strength block. Interestingly, the authors also noted that there were no direct associations between changes in $P_{\text{max}}$ and changes in sled velocity. In other words, with no change in $P_{\text{max}}$, 15-m sled start performance can be improved with a change in the FVP. In these athletes, the authors noted an improvement in sled start performance with a shift towards more velocity-oriented profiles in year two.

**Relationship Between Vertical and Horizontal Profiling**

While $P_{\text{max}}$ is the main variable calculated using all methods of FVP and seems to be generalizable across lower-body tasks, the literature has shown that jumping and sprinting are independent skills (Marcote-Pequeño et al., 2019; Murtagh et al., 2018). Marcote-Pequeño et al. (2019) noted a strong correlation for $P_{\text{max}}$ between vertical jumps and 30-m sprints in elite female soccer players using FVP methods, yet there was no significant correlation for the $S_{\text{FV}}$ between tasks. Theoretically, the same athlete can, therefore, present a force-deficiency in one task while presenting a velocity-deficiency in another. In agreement, Jiménez-Reyes et al. (2018) noted that the correlations of the same variables (e.g. $F_0$ and $V_0$) between vertical and horizontal profiling in several hundred athletes ranged from trivial to small, and decreased as performance
level increased (e.g., leisure to elite). Therefore, the optimal FVP for one specific ballistic movement may not be an optimal profile for another. Consequently, expanding upon the current database of FVPs amongst athletes is essential for comparison purposes.
CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

Experimental Design

For the first study (Analysis #1), a repeated-measures design was used to evaluate the test-retest reliability of rotational LVP for the BS and RMBT methods. A follow-up study (Analysis #2) was conducted with any LVP method that had acceptable reliability. In Analysis #2, a correlational approach was used to determine the relationship between LVP variables and selected batting performance variables. All in-game batting performance data were acquired from the UCF Softball website (https://ucfknights.com/sports/softball/stats?path=softball; accessed 5/27/2021).

Participants for Analysis #1 completed two testing days separated by a minimum of 48 hours. Each testing day consisted of a general warm-up including visuomotor training, submaximal BSs and RMBTs, the BS method, and the RMBT method. As not all pitchers participate in hitting in practice and/or games, these participants did not perform the BS method. To mitigate the risk of post-activation potentiation, the RMBT method was performed second, as this method allows the use of heavier loads, and consequently muscular contractions that are closer to maximal. Figure 1 details the study design for positional players.
Figure 1. Analysis #1 design.
Participants for Analysis #2 completed one LVP testing day consisting of a general warm-up including visuomotor training, submaximal BSs, and the BS method. This testing occurred in the later part of the season prior to the conference championship.

Participants were instructed to refrain from any high-intensity exercise for 15 hours, to refrain from consumption of alcohol for 24 hours, and to refrain from consumption of caffeine for eight hours prior to the testing days.

**Participants**

For Analysis #1, eleven current NCAA softball athletes (mean ± SD: 21.09 ± 1.45 years, 1.70 ± 0.05 m, and 70.81 ± 11.71 kg) between the ages of 18 and 35 participated in this study. Participants were divided into positional players (n = 8; 1st, 2nd, and 3rd baseman, shortstop, catcher, outfielder, or utility) and pitchers (n = 3). For Analysis #2, eleven current NCAA softball positional players (mean ± SD: 21.36 ± 1.29 years, 1.71 ± 0.07 m, and 72.71 ± 11.10 kg) between the ages of 18 and 35 participated in this study.

Participants completed the PAR-Q+, a medical and activity history questionnaire, and the informed consent prior to all testing days. All participants were free from any recent musculoskeletal injuries. Power analysis using power analysis software (G*Power 3.1.9.4, HHU, Dusseldorf, Germany) revealed that for a paired-samples t-test with a power of 0.80, α-value of 0.05, and an effect size of 1.22 derived from the $V_0$ within a previous FVP study (Jiménez-Reyes et al., 2019), the minimum sample size was eight.
Anthropometrics and Body Composition

Height and weight was measured using a Health-o-meter Professional scale (Patient Weighing Scale, Model 500 KL; Pelstar, Alsip, IL, USA). Body composition, including total body mass, skeletal muscle mass, and percent body fat, was assessed using a multi-frequency bioelectrical impedance analyzer (InBody 770; Cerritos, CA, USA) according to the manufacturer’s guidelines. Participants were asked to be sufficiently hydrated and to have abstained from food consumption for a minimum of two hours prior to testing.

General Warm-up

A general warm-up was performed consisting of foam rolling, stretching, and visuomotor training. Participants used a conventional, commercially-available foam roller, following a rolling progression targeting the quadriceps/hip flexor region (rectus femoris, sartorius, psoas major, iliacus), the hamstring region (biceps femoris, semitendinosus, semimembranosus), the gluteal region (gluteus maximus, gluteus medius, gluteus minimus), the calf region (gastrocnemius, soleus), the adductor region (adductor brevis, adductor longus, adductor magnus, gracilis, and pectineus), the tensor fasciae latae, and the thoracic/lumbar region (erector spinae, multifidis). Two minutes were allocated per region/side.

Following the foam rolling, participants performed a ground-based static stretching progression, starting with a side quadriceps stretch, supine hamstring stretch, half-kneeling hip flexor stretch, pigeon stretch, and frogger stretch, holding for two minutes per stretch/side. Participants then performed a standing stretch targeting the calf region on a commercially-available slant board, holding a straight knee position and a bent knee position for three minutes.
each. Following the static stretching, participants performed visuomotor training on the Dynavision D2 Device (D2™; Dynavision International LLC, West Chester, OH, USA) using Mode A, which measures the participant’s ability to react to a stimulus as it changes positions on the board.

**Specific Warm-up**

After completion of the general warm-up, participants completed three submaximal bat swings with each bat load (0.65, 0.91, 0.99, 1.09, and 1.25 kg) and three submaximal RMBTs (swing side only) with each medicine ball (2.72, 3.63, 4.54, 5.44, and 7.26 kg) for Analysis #1. For Analysis #2, participants completed three submaximal bat swings with each bat load (0.65, 0.91, 0.99, 1.09, and 1.25 kg) after completion of the general warm-up. Participants were instructed to perform the submaximal BSs and RMBTs at an intensity of 75-95% of maximal effort.

**Rotational Medicine Ball Throw Method**

Each participant completed three trials of the RMBT method using medicine balls (Dynamax Standard and Dynamax Atlas, Dynamax, Inc., Austin, TX) with masses of 2.72, 3.63, 4.54, 5.44, and 7.26 kg (total repetitions = 15). Participants were given 20 seconds of rest between the three throws using the same medicine ball mass, while 2 minutes of rest was given between each of the five different medicine ball masses. The testing order for the five medicine ball masses was determined using a randomization procedure in a commercially-available spreadsheet software program (Excel, Microsoft Corporation, Redmond, WA, USA). Throwing velocity was measured with an IMU, the PUSH band (PUSH, Inc., Toronto, Canada), attached to
the back forearm of the participant (e.g., the right forearm for a participant throwing to the left). Exercise selected was “Side Throws – Standing – MB – [R or L]”, with the corresponding side (e.g., “Right” selected for a participant throwing to her right) selected. According to the manufacturer’s instructions, the mass of the medicine ball was input into the software on a mobile tablet computer (9.7-inch iPad Air 2 with Software Version 12.4, Apple Inc., Cupertino, California). The trial with the highest PV and PV$_{avg}$ for each medicine ball mass were used for modeling the load-velocity relationship.

Following the methodology used during the medicine ball hitter’s throw (Kohmura et al., 2008; Spaniol, 2009; Szymanski, Szymanski, et al., 2007), participants were instructed to use the same foot placement as used during the BS method. Participants were instructed to start the medicine ball at their back hip with the trail hand directly behind the medicine ball. To avoid countermovement, participants were required to hold this position for two seconds prior to the throw. Participants was instructed to generate maximum velocity while throwing the medicine ball. To account for any non-horizontal movement involved in the throw, participants were asked to perform a level throw aimed at a wall 5-10-ft away. In the event that any of these requirements were not met, the trial was repeated.

**Bat Swing Method**

Each participant completed three trials of the BS method using bats with masses of 0.65, 0.91, 0.99, 1.09, and 1.25 kg (total repetitions = 15). All participants used a standard aluminum bat (DeMarini FXN, 83.8 cm, 0.652 kg) for the unloaded bat swing with removable bat jackets (Super Slugger Hitting Jacket, Hitting Jack-it Weighted Bat Jacket Set [0.255, 0.340, 0.434, and
0.595 kg]) for the loaded bat swings. Participants were given 20 seconds of rest between the three swings using the same bat mass, while 2-min rest was given between each of the five different bat masses. The testing order for the five bat masses was determined using a randomization procedure in a commercially-available spreadsheet software program (Excel, Microsoft Corporation, Redmond, WA, USA). Bat swing velocity was measured with the swing sensor (Blast Motion, Inc., Carlsbad, CA) attached to the knob of the bat. According to the manufacturer’s instructions, bat brand, length, and mass of the bat was input into the software on a handheld tablet computer (9.7-inch iPad Air 2 with Software Version 12.4, Apple Inc., Cupertino, California). For calibration, a light shake was performed prior to the trial swings for each bat mass. Additionally, bat swing velocity was measured with an inertial measurement unit (IMU), the PUSH band (PUSH, Inc., Toronto, Canada), attached to the back forearm of the participant (e.g., the right forearm for a participant swinging from the left batter’s box). Exercise selected was “Side Throws – Standing – MB – [R or L]”, with the corresponding side (e.g., “Right” selected for a participant swinging to her right [from right side of the plate]) selected. According to the manufacturer’s instructions, mass of the bat was input into the software on a mobile tablet computer (9.7-inch iPad Air 2 with Software Version 12.4, Apple Inc., Cupertino, California). The trial with the highest peak velocity (PV) and the average of the top two peak velocities (PV_{avg}) using the swing sensor and the IMU for each bat mass were used for modeling the load-velocity relationship.

A batting tee was aligned with the participant’s pubic arch to simulate a fastball in the middle of their strike zone. Participants were instructed to generate maximum velocity while hitting the ball off of the tee. All BSs took place inside a covered, outdoor batting cage using
standard softballs with a circumference of 30.48cm and a diameter of 9.65cm. To avoid countermovement, participants were instructed to hold the coiling or loading position (Welch et al., 1995) for two seconds prior to the swing. To account for any non-horizontal movement, participants were asked to perform a level swing, attempting to drive the ball on a line towards centerfield. To increase consistency, participants were instructed to maintain the same foot placement and perform the same type of swing for all trial swings.

**Load-velocity Relationships**

The LVP relationships for the multiple-load method was determined by linear regressions. The slope of the load-velocity relationship ($S_{LV}$) was used for analysis. Additionally, the LVP $S_{LV}$ were extrapolated to the y- and x-intercepts to identify the theoretical maximum velocity ($V_0$) and theoretical load at zero velocity ($LD_0$), respectively.

**Batting Performance**

All in-game batting performance variables were collected during the 2021 NCAA Division I women’s softball regular and post-season conducted under NCAA rules and regulations. Twenty-six of the games were home competitions, 29 were away competitions, and six were neutral competitions.

Variables evaluated for correlational analyses included: batting average, hits, doubles, triples, home runs, runs batted in (RBIs), total bases, slugging percentage (total number of bases per at-bat), on-base percentage, and on-base plus slugging (on-base percentage plus slugging percentage). As the number of at-bats ranged from 12 to 182 (mean ± SD: 106.7 ± 61.1),
analyses were also performed with an inclusion criterion of greater than 45 at-bats over the course of the 2021 season (n = 9).

**Statistical Analysis**

Descriptive statistics were calculated to determine group demographics. For Analysis #1, the test-retest reliability of \( LD_0, V_0, \) and \( S_LV, \) and velocities at each load for the BS and RMBT methods were calculated using a two-way fixed intraclass correlation coefficient (ICC\(_{2,1}\)) for PV and a two-way random intraclass correlation coefficient (ICC\(_{2,k}\)) for \( PV_{avg} \) to determine relative reliability. The test-retest reliability was calculated using a coefficient of variation (CV) for absolute reliability. An ICC value > 0.7 and a CV < 15% was indicative of acceptable reliability (Atkinson & Nevill, 1998; Shechtman, 2013). Additionally, the standard error of measurement (SEM) was determined for absolute values (m·s\(^{-1}\)). Paired-samples \( t \)-tests were used to determine any significant differences in \( LD_0, V_0, \) and \( S_LV, \) PV, and \( PV_{avg} \) of each load utilized during the BS and RMBT methods between the first and second testing days. Two-way ANOVAs were used to analyze load velocities across testing days. Following significant interactions, one-way ANOVAs with Bonferroni post hoc tests were used and Cohen’s d effect sizes between groups were determined. Effect sizes of 0.2, 0.5, and 0.8 were considered small, medium, and large, respectively. Pearson’s correlation coefficient were calculated for the relationship between the multiple-load and the two-load models for the BS method, interpreted as follows: trivial (<0.1), small (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), very high (0.7–0.9), or practically perfect (>0.9) (Hopkins et al., 2009). Multiple-load and two-load models were created for each testing day individually using both PV and \( PV_{avg} \). For Analysis #2, relationships
between LVP variables and selected batting performance variables were examined using Pearson’s correlation coefficients with the interpretations described above.

Significance for all statistical tests was defined as an alpha level of $p \leq 0.05$. Data was presented as mean ± SD unless otherwise stated. Intraclass correlation coefficients were calculated using a custom Excel spreadsheet (Microsoft, Redmond, WA) while CV was calculated in a separate Excel spreadsheet (Hopkins, 2017). All other statistical analyses were conducted using were analyzed using an open-source statistical software program (JASP, Version 0.11.1, University of Amsterdam, Netherlands).
CHAPTER FOUR: RESULTS

Anthropometric Measurements

The anthropometrics (age, height, body mass, and body fat percentage) of participants included in the final analysis for Analysis #1 and Analysis #2 are presented in Table 1.

Table 1. Anthropometric measurements.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Age (yrs)</th>
<th>Height (m)</th>
<th>Body Mass (kg)</th>
<th>Body Fat Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis #1</td>
<td>11</td>
<td>21.09 ± 1.45</td>
<td>1.70 ± 0.05</td>
<td>70.81 ± 11.71</td>
<td>24.74 ± 4.84</td>
</tr>
<tr>
<td>Analysis #2</td>
<td>11</td>
<td>21.36 ± 1.29</td>
<td>1.71 ± 0.07</td>
<td>72.71 ± 11.10</td>
<td>24.51 ± 4.42</td>
</tr>
</tbody>
</table>

Values are presented as mean ± standard deviation.

RMBT Method Reliability – IMU

When utilizing PV obtained from the IMU for each individual load during the RMBT method, the 2.72 and 5.44 kg MB loads had acceptable relative reliability, but only the 2.72 kg load had acceptable absolute reliability as well (Table 2). In addition to the 2.72 and 5.44 kg MB loads, the 4.54 kg MB load also had acceptable relative reliability when utilizing PV$_{avg}$, but only the 2.72 kg load also had acceptable absolute reliability. For all MB loads, the SEM ranged from 0.19 to 0.49 m/s. Main effects were found for load using PV (F(4,40) = 16.825, p < 0.001, η$_p^2$ = 0.392) and PV$_{avg}$ (F(4,40) = 22.605, p < 0.001, η$_p^2$ = 0.469). Utilizing PV, there were no statistically significantly differences in forearm velocities between the 2.72 and 3.63 kg (p = 0.080), 3.63 and 4.54 kg (p = 1.000), 3.63 and 5.44 kg (p = 0.607), 4.54 and 5.44 kg (p = 1.000), and 5.44 and 7.26 kg (p = 0.373) medicine ball loads, while all other comparisons provided statistically significant differences (p < 0.05). Utilizing PV$_{avg}$, with the exception of the 3.63 and 4.54 kg (p = 1.000), 3.63 and 5.44 kg (p = 0.152), 4.54 and 5.44 kg (p = 0.324), and 5.44 and
7.26 kg \((p = 0.118)\) medicine ball loads, all comparisons provided statistically significant differences. No main effects for day or significant load*day interactions were found using PV or \(PV_{avg}\) \((p > 0.05)\).

When the LVP was calculated from PV and \(PV_{avg}\) as assessed using the IMU during the RMBT method, no variable had acceptable relative or absolute reliability (Table 3).
Table 2. Reliability of forearm rotational velocities during the rotational medicine ball throw method measuring using the inertial measurement unit*.

<table>
<thead>
<tr>
<th>Load (kg)</th>
<th>Day 1 (mean ± SD m·s$^{-1}$)</th>
<th>Day 2 (mean ± SD m·s$^{-1}$)</th>
<th>ICC$^+$</th>
<th>CV%</th>
<th>SEM (m·s$^{-1}$)</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.72</td>
<td>3.63 ± 0.47</td>
<td>3.59 ± 0.39</td>
<td>0.772</td>
<td>11.11</td>
<td>0.21</td>
<td>0.669</td>
</tr>
<tr>
<td>3.63</td>
<td>3.35 ± 0.52</td>
<td>3.27 ± 0.38</td>
<td>0.317</td>
<td>15.15</td>
<td>0.38</td>
<td>0.647</td>
</tr>
<tr>
<td>4.54</td>
<td>3.12 ± 0.53</td>
<td>3.34 ± 0.49</td>
<td>0.362</td>
<td>16.63</td>
<td>0.40</td>
<td>0.224</td>
</tr>
<tr>
<td>5.44</td>
<td>3.15 ± 0.54</td>
<td>3.02 ± 0.53</td>
<td>0.856</td>
<td>16.13</td>
<td>0.19</td>
<td>0.115</td>
</tr>
<tr>
<td>7.26</td>
<td>2.92 ± 0.53</td>
<td>2.75 ± 0.48</td>
<td>0.050</td>
<td>17.86</td>
<td>0.49</td>
<td>0.439</td>
</tr>
<tr>
<td>PV$_{avg}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.72</td>
<td>3.49 ± 0.48</td>
<td>3.48 ± 0.41</td>
<td>0.846</td>
<td>11.43</td>
<td>0.25</td>
<td>0.956</td>
</tr>
<tr>
<td>3.63</td>
<td>3.25 ± 0.52</td>
<td>3.16 ± 0.42</td>
<td>0.650</td>
<td>15.63</td>
<td>0.35</td>
<td>0.542</td>
</tr>
<tr>
<td>4.54</td>
<td>3.04 ± 0.5</td>
<td>3.17 ± 0.42</td>
<td>0.793</td>
<td>16.13</td>
<td>0.26</td>
<td>0.273</td>
</tr>
<tr>
<td>5.44</td>
<td>3.02 ± 0.51</td>
<td>2.89 ± 0.48</td>
<td>0.884</td>
<td>16.67</td>
<td>0.21</td>
<td>0.171</td>
</tr>
<tr>
<td>7.26</td>
<td>2.78 ± 0.5</td>
<td>2.63 ± 0.43</td>
<td>0.312</td>
<td>18.52</td>
<td>0.43</td>
<td>0.412</td>
</tr>
</tbody>
</table>

*ICC = intraclass correlation coefficient, CV = coefficient of variation, PV = peak velocity, PV$_{avg}$ = average of the top two peak velocities, SEM = standard error of measurement; $^+$ICC$_{2,1}$ used for PV, ICC$_{2,k}$ used for PV$_{avg}$.

Table 3. Reliability of load-velocity profile variables during the rotational medicine ball throw method measuring using the inertial measurement unit*.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 1 (mean ± SD)</th>
<th>Day 2 (mean ± SD)</th>
<th>ICC$^+$</th>
<th>CV%</th>
<th>SEM (m·s$^{-1}$)</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$LD_0$</td>
<td>14.66 ± 33.73</td>
<td>32.54 ± 30.02</td>
<td>0.069</td>
<td>135.17</td>
<td>30.73</td>
<td>0.202</td>
</tr>
<tr>
<td>$V_0$</td>
<td>4.03 ± 0.43</td>
<td>3.91 ± 0.8</td>
<td>0.399</td>
<td>15.00</td>
<td>0.50</td>
<td>0.598</td>
</tr>
<tr>
<td>$S_{LV}$</td>
<td>-0.14 ± 0.14</td>
<td>-0.18 ± 0.08</td>
<td>-0.017</td>
<td>-68.75</td>
<td>0.11</td>
<td>0.509</td>
</tr>
<tr>
<td>PV$_{avg}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$LD_0$</td>
<td>9.75 ± 45.18</td>
<td>26.18 ± 14.41</td>
<td>0.120</td>
<td>186.11</td>
<td>32.37</td>
<td>0.261</td>
</tr>
<tr>
<td>$V_0$</td>
<td>3.81 ± 0.79</td>
<td>3.92 ± 0.44</td>
<td>0.670</td>
<td>15.38</td>
<td>0.46</td>
<td>0.611</td>
</tr>
<tr>
<td>$S_{LV}$</td>
<td>-0.15 ± 0.13</td>
<td>-0.18 ± 0.07</td>
<td>0.100</td>
<td>-68.75</td>
<td>0.10</td>
<td>0.472</td>
</tr>
</tbody>
</table>

*ICC = intraclass correlation coefficient, CV = coefficient of variation, PV = peak velocity, PV$_{avg}$ = average of the top two peak velocities, SEM = standard error of measurement, $LD_0$ = theoretical load at zero velocity, $V_0$ = theoretical maximum velocity, and $S_{LV}$ = slope of the linear regression line; $^+$ICC$_{2,1}$ used for PV, ICC$_{2,k}$ used for PV$_{avg}$.
BS Method Reliability – IMU

When utilizing PV obtained from the IMU for each individual load during the BS method, the 0.91 kg bat load had acceptable absolute reliability, but no load had acceptable relative reliability (Table 4). No other loads had acceptable absolute reliability when utilizing PV. When utilizing $PV_{avg}$, the 0.91 kg load had acceptable relative and absolute reliability. All other loads except the 1.09 kg bat load had acceptable relative reliability, but none had acceptable absolute reliability. For all bat loads, the SEM ranged from 0.34 to 0.82 m/s. No main effects or significant load*day interactions were found using PV or $PV_{avg}$ ($p > 0.05$).

When the LVP was calculated from PV and $PV_{avg}$ as assessed using the IMU during the BS method, no variable had acceptable relative or absolute reliability (Table 5). There was a significant difference in $LD_0$ between days when calculated using PV ($p = 0.05$).
Table 4. Reliability of forearm rotational velocities during the bat swing method measured using the inertial measurement unit*.

<table>
<thead>
<tr>
<th>Load (kg)</th>
<th>Day 1 (mean ± SD m·s^{-1})</th>
<th>Day 2 (mean ± SD m·s^{-1})</th>
<th>ICC*</th>
<th>CV%</th>
<th>SEM (m·s^{-1})</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.65</td>
<td>4.67 ± 0.72</td>
<td>4.69 ± 0.96</td>
<td>0.619</td>
<td>17.02</td>
<td>0.54</td>
<td>0.929</td>
</tr>
<tr>
<td>0.91</td>
<td>4.62 ± 0.58</td>
<td>4.61 ± 0.59</td>
<td>0.666</td>
<td>13.04</td>
<td>0.36</td>
<td>0.957</td>
</tr>
<tr>
<td>0.99</td>
<td>4.49 ± 0.56</td>
<td>4.59 ± 0.86</td>
<td>0.621</td>
<td>15.56</td>
<td>0.46</td>
<td>0.674</td>
</tr>
<tr>
<td>1.09</td>
<td>4.44 ± 0.6</td>
<td>4.31 ± 1.01</td>
<td>0.363</td>
<td>18.18</td>
<td>0.68</td>
<td>0.721</td>
</tr>
<tr>
<td>1.25</td>
<td>4.43 ± 0.66</td>
<td>4.45 ± 0.91</td>
<td>0.686</td>
<td>18.18</td>
<td>0.46</td>
<td>0.917</td>
</tr>
</tbody>
</table>

- *ICC = intraclass correlation coefficient, CV = coefficient of variation, PV = peak velocity, PV_{avg} = average of the top two peak velocities, SEM = standard error of measurement; ^{*}ICC_{2,1} used for PV, ICC_{2,k} used for PV_{avg}.

---

Table 5. Reliability of load-velocity profile variables during the bat swing method measuring using the inertial measurement unit*.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 1 (mean ± SD)</th>
<th>Day 2 (mean ± SD)</th>
<th>ICC*</th>
<th>CV%</th>
<th>SEM (m·s^{-1})</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD_{0}</td>
<td>9.49 ± 10.48</td>
<td>3.61 ± 7.96</td>
<td>0.615</td>
<td>143.08</td>
<td>4.96</td>
<td>0.050</td>
</tr>
<tr>
<td>V_{0}</td>
<td>4.98 ± 1</td>
<td>5.04 ± 1.13</td>
<td>0.585</td>
<td>20.00</td>
<td>0.70</td>
<td>0.855</td>
</tr>
<tr>
<td>S_{LV}</td>
<td>-0.46 ± 0.68</td>
<td>-0.53 ± 0.89</td>
<td>0.497</td>
<td>-161.22</td>
<td>0.58</td>
<td>0.826</td>
</tr>
</tbody>
</table>

- *ICC = intraclass correlation coefficient, CV = coefficient of variation, PV = peak velocity, PV_{avg} = average of the top two peak velocities, SEM = standard error of measurement, LD_{0} = theoretical load at zero velocity, V_{0} = theoretical maximum velocity, and S_{LV} = slope of the linear regression line; ^{*}ICC_{2,1} used for PV, ICC_{2,k} used for PV_{avg}.
BS Method Reliability – Swing Sensor

When using the swing sensor for each individual bat load, all bat loads had acceptable relative and absolute reliability utilizing both PV and \( PV_{avg} \) (Table 6). For all bat loads, the SEM ranged from 0.41 to 1.12 m/s. There was a significant difference in PV of the 1.25 kg load between days \((p < 0.05)\). Main effects were found for load using PV \((F(4,28) = 93.944, p < 0.001, \eta_p^2 = 0.822)\) and \( PV_{avg} \) \((F(4,28) = 135.262, p < 0.001, \eta_p^2 = 0.855)\). With the exception of the 0.91 and 0.99 kg bat loads assessed using PV \((p = 1.000)\) and \( PV_{avg} \) \((p = 1.000)\), all other velocity comparisons between loads provided statistically significantly differences \((p < 0.05)\). No main effects for day or significant load*day interactions were found using PV or \( PV_{avg} \) \((p > 0.05)\).

When the LVP was calculated using the swing sensor, \( V_0 \) had acceptable absolute and relative reliability using both PV and \( PV_{avg} \) (Table 7). Neither \( LD_0 \) nor \( S_{LV} \) had acceptable reliability when calculated using PV or \( PV_{avg} \).
Table 6. Reliability of bat velocities during the bat swing method measured using the swing sensor*.

<table>
<thead>
<tr>
<th>Load (kg)</th>
<th>Day 1 (mean ± SD m·s$^{-1}$)</th>
<th>Day 2 (mean ± SD m·s$^{-1}$)</th>
<th>ICC$^+$</th>
<th>CV%</th>
<th>SEM (m·s$^{-1}$)</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.65</td>
<td>28.67 ± 2.67</td>
<td>28.51 ± 2.57</td>
<td>0.939</td>
<td>9.09</td>
<td>0.68</td>
<td>0.659</td>
</tr>
<tr>
<td>0.91</td>
<td>26.85 ± 2.91</td>
<td>26.44 ± 2.44</td>
<td>0.918</td>
<td>10.15</td>
<td>0.76</td>
<td>0.321</td>
</tr>
<tr>
<td>0.99</td>
<td>26.54 ± 2.5</td>
<td>26.51 ± 2.61</td>
<td>0.965</td>
<td>9.81</td>
<td>0.51</td>
<td>0.916</td>
</tr>
<tr>
<td>1.09</td>
<td>25.51 ± 2.59</td>
<td>25.38 ± 2.92</td>
<td>0.851</td>
<td>11.02</td>
<td>1.12</td>
<td>0.826</td>
</tr>
<tr>
<td>1.25</td>
<td>24.79 ± 2.71</td>
<td>24.3 ± 2.5</td>
<td>0.961</td>
<td>10.61</td>
<td>0.41</td>
<td>0.049</td>
</tr>
<tr>
<td>0.65</td>
<td>28.41 ± 2.68</td>
<td>28.24 ± 2.47</td>
<td>0.973</td>
<td>9.19</td>
<td>0.65</td>
<td>0.620</td>
</tr>
<tr>
<td>0.91</td>
<td>26.69 ± 2.89</td>
<td>26.29 ± 2.37</td>
<td>0.954</td>
<td>9.81</td>
<td>0.78</td>
<td>0.349</td>
</tr>
<tr>
<td>0.99</td>
<td>26.13 ± 2.46</td>
<td>26.21 ± 2.35</td>
<td>0.983</td>
<td>9.16</td>
<td>0.50</td>
<td>0.764</td>
</tr>
<tr>
<td>1.09</td>
<td>25.12 ± 2.5</td>
<td>25.09 ± 2.78</td>
<td>0.958</td>
<td>10.36</td>
<td>0.86</td>
<td>0.945</td>
</tr>
<tr>
<td>1.25</td>
<td>24.6 ± 2.6</td>
<td>24.12 ± 2.78</td>
<td>0.971</td>
<td>10.66</td>
<td>0.44</td>
<td>0.067</td>
</tr>
</tbody>
</table>

*ICC = intraclass correlation coefficient, CV = coefficient of variation, PV = peak velocity, PV$_{avg}$ = average of the top two peak velocities, SEM = standard error of measurement; $^+$ICC$_{2,1}$ used for PV, ICC$_{2,k}$ used for PV$_{avg}$.

Table 7. Reliability of load-velocity profile variables utilizing the multiple-load model during the bat swing method measured using the swing sensor*.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 1 (mean ± SD)</th>
<th>Day 2 (mean ± SD)</th>
<th>ICC$^+$</th>
<th>CV%</th>
<th>SEM (m·s$^{-1}$)</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>$LD_0$</td>
<td>5.28 ± 1.64</td>
<td>4.92 ± 1.04</td>
<td>0.245</td>
<td>27.45</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>$V_0$</td>
<td>32.95 ± 3.08</td>
<td>33.05 ± 2.74</td>
<td>0.780</td>
<td>8.79</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>$S_{LV}$</td>
<td>-6.63 ± 1.6</td>
<td>-6.98 ± 1.51</td>
<td>0.203</td>
<td>-22.91</td>
<td>1.40</td>
</tr>
<tr>
<td>PV$_{avg}$</td>
<td>$LD_0$</td>
<td>5.08 ± 1.11</td>
<td>4.87 ± 0.91</td>
<td>0.597</td>
<td>20.00</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>$V_0$</td>
<td>32.69 ± 3.06</td>
<td>32.74 ± 2.39</td>
<td>0.930</td>
<td>8.26</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>$S_{LV}$</td>
<td>-6.65 ± 1.3</td>
<td>-6.91 ± 1.25</td>
<td>0.519</td>
<td>-18.73</td>
<td>1.06</td>
</tr>
</tbody>
</table>

*ICC = intraclass correlation coefficient, CV = coefficient of variation, PV = peak velocity, PV$_{avg}$ = average of the top two peak velocities, SEM = standard error of measurement, $LD_0$ = theoretical load at zero velocity, $V_0$ = theoretical maximum velocity, and $S_{LV}$ = slope of the linear regression line; $^+$ICC$_{2,1}$ used for PV, ICC$_{2,k}$ used for PV$_{avg}$. 
Relationship Between Multiple-load and Two-load Models

The two-load model was created using the two most distinctive loads utilized during the BS method with the swing sensor (0.65 and 1.25 kg). Using this model, V₀ had acceptable absolute and relative reliability using both PV and PV\text{avg} (Table 8). Neither LD₀ nor S₁V had acceptable reliability when calculated using PV or PV\text{avg}. In comparing LVP variables obtained from the multiple-load and two-load models, all variables were highly related when utilizing PV during Day 1 (LD₀: \[r = 0.975; p < 0.001\], V₀: \[r = 0.982; p < 0.001\], and S₁V: \[r = 0.915; p = 0.001\]) and Day 2 (LD₀: \[r = 0.963; p < 0.001\], V₀: \[r = 0.988; p < 0.001\], and S₁V: \[r = 0.950; p < 0.001\]). Additionally, all variables were highly related when utilizing PV\text{avg} during Day 1 (LD₀: \[r = 0.986; p < 0.001\], V₀: \[r = 0.988; p < 0.001\], and S₁V: \[r = 0.957; p < 0.001\]) and Day 2 (LD₀: \[r = 0.963; p < 0.001\], V₀: \[r = 0.984; p < 0.001\], and S₁V: \[r = 0.942; p < 0.001\]).
Table 8. Reliability of load-velocity profile variables utilizing the two-load model during the bat swing method measuring using the swing sensor*.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 1 (mean ± SD)</th>
<th>Day 2 (mean ± SD)</th>
<th>ICC$^+$</th>
<th>CV%</th>
<th>SEM (m·s$^{-1}$)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$LD_0$</td>
<td>5.45 ± 1.83</td>
<td>4.77 ± 0.7</td>
<td>0.302</td>
<td>27.45</td>
<td>1.15</td>
<td>0.280</td>
</tr>
<tr>
<td>$V_0$</td>
<td>32.91 ± 3.04</td>
<td>33.12 ± 2.87</td>
<td>0.803</td>
<td>9.09</td>
<td>1.38</td>
<td>0.768</td>
</tr>
<tr>
<td>$S_{LV}$</td>
<td>-6.51 ± 1.71</td>
<td>-7.07 ± 1.23</td>
<td>0.384</td>
<td>-21.94</td>
<td>1.17</td>
<td>0.367</td>
</tr>
<tr>
<td>PV$_{avg}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$LD_0$</td>
<td>5.35 ± 1.37</td>
<td>4.81 ± 0.67</td>
<td>0.533</td>
<td>21.57</td>
<td>0.84</td>
<td>0.233</td>
</tr>
<tr>
<td>$V_0$</td>
<td>32.57 ± 3.06</td>
<td>32.75 ± 2.55</td>
<td>0.919</td>
<td>8.56</td>
<td>1.21</td>
<td>0.781</td>
</tr>
<tr>
<td>$S_{LV}$</td>
<td>-6.39 ± 1.48</td>
<td>-6.92 ± 1</td>
<td>0.536</td>
<td>-18.95</td>
<td>1.00</td>
<td>0.328</td>
</tr>
</tbody>
</table>

*ICC = intraclass correlation coefficient, CV = coefficient of variation, PV = peak velocity, PV$_{avg}$ = average of the top two peak velocities, SEM = standard error of measurement, $LD_0$ = theoretical load at zero velocity, $V_0$ = theoretical maximum velocity, and $S_{LV}$ = slope of the linear regression line; $^+$ ICC$_{2,1}$ used for PV, ICC$_{2,k}$ used for PV$_{avg}$. 
Performance Correlations

When analyzing individual bat loads, only the loads that provided acceptable reliability during the BS method with the IMU or the BS method with the swing sensor were utilized. During the BS method with the IMU, there was not a significant relationship between the 0.91 kg bat load calculated using PV_{avg} and any measure of batting performance in all participants or in participants with over 45 at-bats. During the BS method with the swing sensor, there was a significant relationship between PV using the 0.99 kg bat load and slugging percentage (r = 0.642; p < 0.05) and on-base plus slugging (r = 0.606; p < 0.05) in all participants. Using this method, there were no significant relationships between PV using the 0.65, 0.91, 1.09, or 1.25 kg bat loads or PV_{avg} using any of the bat loads and any measure of batting performance in all participants. Furthermore, during the BS method with the swing sensor, when participants with over 45 at-bats were analyzed, there were no significant relationships between PV or PV_{avg} using any of the bat loads and any measure of batting performance.

When analyzing LVP variables obtained from the multiple-load method, only those that provided acceptable reliability were utilized. When LVP was calculated using PV during the BS method with the swing sensor, there was a significant relationship between V_{0} and doubles (r = 0.671; p < 0.05), RBIs (r = 0.603; p = 0.05), and total bases (r = 0.634; p < 0.05) in all participants. When participants with over 45 at-bats were analyzed, there was a significant relationship between V_{0} calculated using PV and doubles (r = 0.680; p < 0.05). There was not a significant relationship between V_{0} calculated using PV_{avg} and any measure of batting performance in all participants or in participants with over 45 at-bats.
When analyzing LVP variables obtained from the two-load method, only those that provided acceptable reliability were utilized. Using the two-load model calculated using PV during the BS method with the swing sensor, there were significant relationships between: $V_0$ and doubles ($r = 0.661; p < 0.05$) and total bases ($r = 0.623; p < 0.05$) in all participants. There were no significant relationships between $V_0$ calculated using $PV_{avg}$ and any measure of batting performance in all participants. Additionally, there were no significant relationships between $V_0$ calculated using PV or $PV_{avg}$ and any measure of batting performance in participants with over 45 at-bats.
CHAPTER FIVE: DISCUSSION

The primary findings of this study revealed that (a) neither the RMBT method nor the BS method using the IMU provided LVP variables with acceptable reliability, (b) only $V_0$ provided acceptable reliability during the BS method using the swing sensor, although all individual bat velocities were highly reliable, (c) there were no significant differences between the LVP variables calculated using the two-load model and those calculated using the multiple-load model during the BS method using the swing sensor, and (d) relationships between the reliable bat loads and LVP variables and in-game batting performance were limited. Regarding the RMBT method, the 2.72 kg medicine ball load provided acceptable reliability using both PV and $PV_{avg}$, while only the 0.91 kg bat load had acceptable reliability during the BS method with the IMU utilizing $PV_{avg}$. No LVP variables provided both acceptable relative and absolute reliability during the RMBT method nor the BS method using the IMU. Regarding the BS method using the swing sensor, although there was a significant difference in PV of the 1.25 kg load between days, all individual bat swing loads provided acceptable reliability when utilizing PV or $PV_{avg}$. Additionally, $V_0$ had acceptable reliability when calculated using both PV and $PV_{avg}$ for the multiple-load and the two-load methods. Furthermore, $PV_{avg}$ produced higher reliability as compared to PV in the majority of the bat loads and in all LVP variables during the BS method using the swing sensor. Although our results should be considered exploratory due to the small sample sizes used in analyses, based on these findings, practitioners may utilize either the multiple-load or the two-load rotational LVP BS method with the swing sensor to calculate $V_0$ in collegiate female softball players.
Compared to bat velocity measured in softball athletes utilizing bats of equal length and mass, the swing velocities in the present study were faster than competitive fastpitch softball players (Gilmore et al., 2014), yet slower than other Division I female intercollegiate softball players (Szymanski et al., 2012). In comparing the swing velocities of the 1.09 kg bat load utilized in this investigation and that of Division I female intercollegiate softball players using a standard bat with a donut ring equating to 1.11 kg (Szymanski et al., 2012), the swing velocities in the current study were slower. In female collegiate softball athletes swinging a bat of equal mass but longer length (Hussain et al., 2019), the swing velocities in the present study were faster. These slight discrepancies seen in bat velocities may have been due to differences in bat brand and consequent weight distribution, which has been found to alter the kinematics of a swing (Laughlin et al., 2016), or simply due to differences in the technology used to assess bat velocity (e.g., swing sensor vs. motion analysis software). Additionally, the Blast Motion swing sensor has been found to have a 6.0 ± 2.0% measurement error as compared to 3D motion analysis, which may also explain the slight differences. While additional swing velocities utilizing overload and underload bats in female softball athletes have been reported (Szymanski et al., 2012), the large differences in bat masses do not allow for direct comparisons. As faster bat velocities have been observed in softball athletes with higher skill level (Smith et al., 2012) and higher bat velocities may lead to improved batting performance (Szymanski et al., 2012), it would be interesting to examine the correlation between bat velocity and in-game batting performance in the aforementioned studies utilizing other Division I intercollegiate softball players. Since bat velocity has been noted to be only one of the five most important components of batting performance (Breen, 1967), further research should examine potential upper limits to
bat velocity in which further increases do not lead to further improvements in batting performance.

There is a scarcity of studies that have examined the velocity of the forearm during a bat swing similar to the current study with the IMU during the BS method. Lapinski et al. (2009) placed IMUs on several body segments, including the forearm, of professional baseball players performing bat swings. Although it appears that the peak forearm velocities of collegiate softball are slower than those of professional baseball players, comparisons may be limited due to the fact that the velocity was presented in graphical form, thus only allowing for an estimation of forearm velocity. Cross (2009) examined the angular displacement of the bat and different body segments, including both right and left forearms, of one university baseball player performing a swing. While these researchers did directly report maximum angular velocities of both forearms, the units were radians/second. Without knowing the radius about which the forearm moves, consequently allowing for conversion to meters/second, direct comparisons with present forearm velocities cannot be made. While it can be hypothesized that faster forearm velocities would cause higher bat velocities, an in-depth biomechanical analysis of segmental dynamics during the bat swing in softball players should look to examine if this is the case. Furthermore, future research should look to investigate potential differences in forearm velocities based on competitive-level, as well as any potential correlations between forearm velocity and batting performance in collegiate softball players. Until then, practitioners should be cautious of attempts at increasing forearm velocities due to the full-body, sequential nature of the softball swing that leads to successfully batting a ball.
Several investigations have utilized various RMBT assessments in athletes from rotationally-based sports, including baseball (Lehman et al., 2013; Szymanski et al., 2007), golf (Gordon et al., 2009; Read et al., 2013), and softball (Teichler, 2010), but the aim of the throws in these investigations were to produce maximum distance rather than maximum velocity. In one study aiming to produce maximum throwing velocity during RMBTs, Ikeda et al. (2007) assessed participants using 2, 4, and 6 kg medicine balls, revealing that both males and females produced higher throw velocities with the 6 kg medicine ball as compared to the softball athletes’ forearm velocities for every load used in the current study. Specific to rotationally-based athletes, Talukdar (2015) assessed both fast and slow cricket-ball throwing male professional cricketers. Using a radar gun and a 2 kg medicine ball, these throwing velocities were also higher as compared to the IMU velocities of every load in the current study. The further away from the axis of rotation an object is, the higher linear velocity will be required to maintain the same angular velocity. Consequently, these higher velocities of the medicine balls in the aforementioned studies are to be expected, as the current study analyzed forearm rotational velocity rather than velocity of the medicine ball.

To the best of our knowledge, this is the first study to assess the reliability of rotational LVP methods, although several studies have assessed the reliability of LVP methods during different ballistic and sport-specific movements. In assessing LVP during the free-weight squat jump, Kotani et al. (2021) found moderate to excellent relative reliability and moderate to poor absolute reliability using PV (ICC = 0.83; CV = 10.7%) and poor to excellent relative reliability and poor absolute reliability using PV_{avg} (ICC = 0.77; CV = 15.1%). Furthermore, these researchers found no significant differences between sessions for the $LD_0$, $V_0$, or $S_{LV}$ when
calculated using PV or PV_{avg}, and noted that PV resulted in better reliability in creating LVPs and at the individual loads assessed. In assessing unresisted sprints and resisted sprints using an absolute load of 27 kg and relative loads of 20, 40, and 60% of body mass over the course of three testing days, Cahill et al. (2019) noted that S_{LV} was found to have acceptable reliability (ICC: 0.71-0.75; CV: 2.2-4.0%). Additionally, all sprint loads had ICC values ranging from 0.69-0.92 and CV less than 10%. Utilizing five 25 m resisted front crawl swimming sprints, Olstad et al. (2020) found ICC values of 0.980, 0.923, and 0.948 using the five-load method for LD_0, V_0, and S_{LV}, respectively, and ICC values of 0.981, 0.902, and 0.962 using the three-load method for LD_0, V_0, and S_{LV}, respectively. Furthermore, CV was less than 4% for all variables using both the five- and three-load methods. Although our results are most comparable to the aforementioned ballistic movements, the lack of consistency utilizing various LVP methods can also be seen in traditional resistance training movements. Researchers have found the free-weight back squat to have moderate or unacceptable reliability (Banyard et al., 2017; Thompson et al., 2021), while other investigations have found acceptable LVP reliability during the back squat (Banyard et al., 2017), deadlift (Chéry & Ruf, 2019), and power clean (Thompson et al., 2021).

An interesting finding from the current investigation is the acceptable reliability of V_0 during the BS method using the swing sensor with the concomitant low reliability of LD_0 and S_{LV}. These findings may be explained by the greater spectrum of feasible LD_0 values as compared to those of V_0 (Figures 2 and 3). Additionally, as reliability is affected by the range of possible values (Bruton et al., 2000), the lower reliability observed for LD_0 and S_{LV} may be partially explained by the smaller absolute values as compared to V_0 (Table 7). It is unclear whether particular movements such as the BS provide unreliable LVP variables or if the methodologies in
the current investigation need to be refined, such as utilizing different loads along the load-velocity spectrum or utilizing different pieces of technology in order to provide more reliable data.

Figure 2. Multiple-load model load-velocity profiles utilizing peak velocity during the bat swing method measuring using the swing sensor.

**Note:** Day 1 profiles are presented as dashed lines and Day 2 profiles are presented solid lines, while each color represents an individual participant.
Figure 3. Multiple-load model load-velocity profiles utilizing average of the top two peak velocities during the bat swing method measuring using the swing sensor.

**Note:** Day 1 profiles are presented as dashed lines and Day 2 profiles are presented solid lines, while each color represents an individual participant.
The small sample size utilized in the current study may have also affected low reliability values observed in some of the LVP variables and forearm velocities in the current investigation. While increasing the sample size may have strengthened the power of this investigation, research within high-level athletes inherently limits subject numbers. Due to the nature of the LVP assessments utilized in the current investigation, it was theorized that participants with little to no familiarity with these movements would require an extended learning period in order to provide reliable data. Particularly with the BS method, it is necessary to perform a swing with as small errors as possible due to the large variability in types of swings possible (e.g. home run vs. line drive swing). Consequently, researchers opted for smaller sample sizes as opposed to utilizing athletes from lesser competitive-levels.

Fatigue may have also played a role in the lack of reliability observed. Researchers examining the role of fatigue during LVP found moderate reductions in LVPs at both 24 and 48 hours after a free-weight back squat strength-oriented resisted training session (Vernon et al., 2020). Although the participants in this investigation were strength-trained males as opposed to females, it seems evident that LVP is sensitive to fatigue during free-weight movements. Indeed, fatigue was vocalized to the researchers by several participants during testing days, but researchers opted to continue to avoid smaller sample sizes. Furthermore, one of the primary findings from researchers examining the relationship between strength, power, speed, and change of direction performance in state Australian Institute of Sport female softball players was changes in the relationships of the aforementioned variables over the course of the season (Nimphius et al., 2010). As suggested by these researchers, accumulated fatigue and/or focus on other areas related to performance may have played a role. Since the testing days of the current
study occurred throughout the course of the 2021 season, accumulated fatigue and/or changes in focus may have negatively affected the LVP variables.

While fatigue may play a role in the daily fluctuations of LVP variables, the lack of reliability of forearm velocities during the BS method with the IMU cannot be completely explained by this, as the same swings measured using the swing sensor provided reliable bat velocities. A main issue may have been due to the selection of the “Side Throws – Standing – MB – [R or L]” exercise using the PUSH software during data collection. It can be hypothesized that algorithms are specific to each movement in the database of exercise selections within the software. Consequently, the selection of a movement that is biomechanically similar but has vastly different segmental dynamics may affect the reliability of the data, although further investigation would need to explore this hypothesis. In research that has utilized the PUSH IMU, researchers have found conflicting results. While Balsalobre-Fernández et al. (2016) found the PUSH to provide acceptable reliability during the Smith machine back squat (PV: CV = 6.0%, ICC = 0.981, r = 0.952; PV<sub>avg</sub>: CV = 5.0%, ICC = 0.978, r = 0.956), Pérez-Castilla et al. (2019) found unacceptable reliability during the bench press (PV<sub>avg</sub>: ICC = 0.46-0.78, CV = 5.02-19.1%). Furthermore, researchers have found unacceptable validity during the free-weight back squat (Banyard et al., 2017) and the deadlift (Chéry & Ruf, 2019), while others have found the PUSH to provide acceptable validity during the Smith machine back squat (Balsalobre-Fernández et al., 2016). Additionally, Sato et al. (2015) also revealed the dumbbell biceps curl and dumbbell shoulder press to have acceptable validity, although these movements were performed with light intensity. Given the results of the current findings and those of other investigations utilizing the PUSH IMU, it appears as though high-intensity, free-motion
exercises may provide lower reliability and validity as compared to low-intensity, movement-restricted exercises. Further research should examine the relationship between similar movements performed in restricted and unrestricted manners (e.g., Smith machine back squat vs. free-weight back squat), as well as the reliability of movements utilizing loads along the load-velocity spectrum. Additional research should also examine the effect of IMU placement on reliability (e.g., forearm vs. bar during a back squat).

Additional factors may help explain the low reliability of the RMBTs in the current investigation. As the researchers were unfamiliar with the specific biomechanical characteristics of each participant’s successful batting technique, verbal reinforcement was not given as suggested during the MBHT (Szymanski, et al., 2007). Additionally, the selection of loads may not have been appropriate within this sample of collegiate softball players. The lightest load used in the current investigation was 2.72 kg, higher than the 1.0 kg medicine ball utilized during the MBHT (Kohmura et al., 2008; Spaniol, 2009; Szymanski et al., 2007) and significantly greater than the 0.65 kg load of a standard bat. It can be hypothesized that the further the medicine ball load from the typical load utilized during the bat swing, the less similar the biomechanical movements are to the swinging motion, leading to lower reliability, although this is only partially supported by the data. Indeed, absolute reliability decreased as medicine ball load increased, yet the 5.44 kg load provided higher relative reliability as compared to the lowest load (2.72 kg). Future research should examine the reliability of rotational LVP using the RMBT method with lower loads and verbal feedback consistent with that given by the coaching staff.

In comparing the two-load model created using the most distinctive loads during the BS method using the swing sensor to the multiple-load model, the results of the current investigation
are consistent with previous FVP research. Pérez-Castilla (2017) examined the relationship between the multiple-load model and two-load models using various pairs of loads assessed during the ballistic bench press throw, finding that the two most distinctive loads provided the highest reliability (ICC = 0.89; CV = 5.5%). Zivkovic (2017) also examined the relationship between the multiple-load models and the two-load FVP models during the bench press throw, as well as during bench pulls, cycling, and vertical jumps, finding strong correlation coefficients (r > 0.952) for all movements using the most distinctive loads. Furthermore, researchers have found the correlation coefficients between $F_0$ and $V_0$ obtained during the multiple- vs. two-load models to be 0.994 and 0.995, respectively, during loaded and unloaded vertical jumps (Cuk et al., 2014), and 0.958 and 0.961, respectively, during bench press throws (Sreckovic et al., 2015).

Based on the results of this investigation and other studies comparing the multiple-load and the two-load models, it seems evident that practitioners can utilize the two-load method during FVP and LVP testing to obtain valid and reliable parameters. In doing so, practitioners can save time and reduce the risk of injury. Furthermore, the addition of one supplemental load to traditional one-load assessments (e.g., 1RM testing) through the use of the two-load FVP/LVP method allows the practitioner to obtain a more complete view of their athletes in a practical manner.

In partial support of our hypothesis that higher $V_0$ correlates with higher in-game batting performance in collegiate softball players, this investigation revealed that there was a significant positive relationship between $V_0$ calculated using PV and doubles, RBIs, and total bases, although the large range in total at-bats throughout the season may have altered the results. Indeed, when an inclusion criterion of greater than 45 at-bats over the course of the 2021 season was applied, the only significant relationship observed was between $V_0$ calculated using PV and
doubles. Furthermore, there were no significant relationships between $V_0$ calculated using $PV_{avg}$ and any measure of batting performance in all participants or in those with greater than 45 at-bats. Additionally, there was a significant relationship between the PV using the 0.99 kg bat load and both slugging percentage and on-base plus slugging in all participants, although when the aforementioned inclusion criterion of greater than 45 at-bats was used in analyses, there were no significant relationships between the PV using the 0.99 kg bat load and any measure of batting performance.

Based on the correlations observed between $V_0$ calculated using PV and the 0.99 kg bat load and various batting performance variables, it appears as though the PV at which collegiate softball athletes can swing a bat load approximately 50% above the standard bat positively correlates with batting performance. This may imply that collegiate softball athletes should have a sufficient level of rotational strength to be successful hitters. There is a scarcity of literature examining the role of strength in softball bat velocity and/or batting performance (Szymanski et al., 2009). In high school baseball players, researchers have found high correlations between torso rotational strength and linear bat velocity ($r = 0.81$-$84$) (Szymanski et al., 2010), while researchers have found no relationship between lower-body power, lower-body strength, or upper-body strength and bat velocity in NCAA Division I softball athletes (Albert, 2008). Future research should examine the relationship between strength, specifically rotational strength, and batting performance, in softball athletes of different competition-levels.

While this is the first study to assess the relationship between LVP variables and batting performance in any population, researchers have examined the relationship between LVP and swim performance (Gonjo et al., 2020, 2021). Using a tethered swimming apparatus to conduct
LVP, these researchers found significant correlations between $V_0$ and race velocity ($r = 0.885$), $LD_0$ and race velocity ($r = 0.556$), and $LD_0$ and 50 m time ($r = -0.624$) in butterfly swimming (Gonjo et al., 2020). Using the same LVP methodology, Gonjo et al. (2021) found significant correlations between mean race velocity and $V_0$ ($r = 0.698$), $LD_0$ ($r = 0.632$), and $S_L V$ ($r = 0.541$) in front crawl swimming. Previous research has also found a strong positive correlation between short-distance sprint performance and horizontal $HZT$-$V_0$ ($r = 0.84$). In research examining changes in FVP over time and the relationship between FVP variables and skeleton sled start performance, Colyer et al. (2018) noted that higher $V_0$ was associated with greater improvements in sled velocity ($r = 0.42$). Although outside of the scope of this investigation, assuming collegiate softball athletes have a sufficient level of rotational power, further improvements in batting performance may be observed with a shift towards more velocity-oriented LVPs. Further investigation examining potential relationships between batting performance and changes in $V_0$ over time are warranted.

In contrast to the findings of Kotani et al. (2021), the current investigation revealed that PV$_{avg}$ produced higher reliability as compared to PV in the majority of the bat loads and in all LVP variables during the BS method using the swing sensor. One potential reason why $V_0$ calculated using PV provided significant correlations while PV$_{avg}$ did not may be due to potential issues with the 1.25 kg bat load velocities. Although this load had acceptable reliability during Analysis #1, significant differences were found in bat velocity between days when analyzed using PV, whereas no significant differences were observed when analyzed using PV$_{avg}$. Consequently, higher reliability and lower SEM was observed in $V_0$ calculated using PV$_{avg}$ as compared to $V_0$ calculated using PV. As the participants for Analysis #2 were assessed in the
later part of the season prior to the conference championship, the use of the top two bat velocities in calculating $\text{PV}_{\text{avg}}$ may have led to more valid velocity assessments as compared to $\text{PV}$. As LVPs are based on individual load-velocity values, any significant differences in bat velocities between $\text{PV}_{\text{avg}}$ and $\text{PV}$ would lead to different LVP variables, and consequently, differences in performance correlations.

Since there were no significant relationships between $V_0$ calculated using $\text{PV}_{\text{avg}}$ and any measure of batting performance, practitioners should be cautious of aiming to improve batting performance in collegiate softball players based on the correlations reported in the current investigation. Additionally, many factors other than physiological output play a role in successful softball batting performance, such as coping strategies and trait anxiety (Finch, 1993; Krane et al., 1994). Moreover, as pitch type and location has been found to alter the swings of minor league baseball players (Fortenbaugh et al., 2011), it can be hypothesized that similar alterations in bat swings occur in softball athletes. Future investigations should examine correlations between reliable LVP variables and batting performance during a controlled setting with pitches of the same type and location, as well as in an increased sample of collegiate softball athletes and over multiple competitive seasons.

To the best of our knowledge, this study provides several novel examinations, including the reliability of one sport-specific and one general rotational LVP method utilizing simple and inexpensive pieces of technology, the assessment of forearm velocities during a bat swing in softball players, and the assessment of forearm velocities during a RMBT. Although individual bat loads produced acceptable reliability using the swing sensor during the BS LVP method, only $V_0$ produced acceptable reliability. No other method produced acceptable reliability in any LVP
variable. Furthermore, based on the results of the comparison between the multiple- and two-load LVP methods, practitioners can confidently utilize the two-load BS LVP method with the swing sensor. Based on the results of this study and other LVP methodology using free-weight ballistic movements (Cahill et al., 2019; García-Ramos et al., 2016; Kotani et al., 2021; Olstad et al., 2020), there appears to be a high degree of variability in LVP between days (Vernon et al., 2020). Whether low reliability values observed in the current study were due to natural variability in LVP or fatigue accumulated over the course of a competitive season warrants further investigation.

There were a number of limitations during this study that should be considered. As mentioned above, daily and weekly fatigue may have affected the findings. Furthermore, although all participants had extensive experience swinging softball bats and performing RMBTs, one or more familiarization sessions may have increased the reliability of the findings, particularly with the heavier loads. Additionally, during the BS method, the utilization of at least one underload bat may have produced a more realistic picture of the athletes’ force and velocity capabilities relative to various loads along the load-velocity spectrum. Furthermore, the selection of a different movement than was actually performed during the BS method within the PUSH software may have affected our findings. Finally, as the use of the swing sensor produced higher reliability over the IMU during the BS method, the addition of another inexpensive piece of technology during the RMBT method, such as a radar gun, may have produced better reliability.

The importance in investigating groups that are not well represented in the literature should not be understated. Future research should examine the reliability of LVP using the BS and RMBT methods during the off-season in collegiate softball players, as well as with a larger
sample of softball players. The kinematic parameters during a softball bat swing that might lead to increased batting performance might also be evaluated. Additionally, the reliability of rotational LVP methodologies in athletes from different competition-levels, sexes, and sporting backgrounds should be investigated.
APPENDIX A: APPROVAL OF HUMAN RESEARCH
January 19, 2021

Dear Chad Herring:

On 1/19/2021, the IRB reviewed the following submission:

<table>
<thead>
<tr>
<th>Type of Review:</th>
<th>Initial Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title:</td>
<td>Simplified Method for Assessing Rotational Force-Velocity Profiles in Collegiate Softball Players</td>
</tr>
<tr>
<td>Investigator:</td>
<td>Chad Herring</td>
</tr>
<tr>
<td>IRB ID:</td>
<td>STUDY00002603</td>
</tr>
<tr>
<td>Funding:</td>
<td>Name: GRADUATE STUDIES</td>
</tr>
<tr>
<td>Grant ID:</td>
<td>None</td>
</tr>
<tr>
<td>IND, IDE, or HDE:</td>
<td>None</td>
</tr>
</tbody>
</table>

Documents Reviewed:
- HRP-251 - FORM - Faculty Advisor Scientific-Scholarly Review fillable form F-v Rotational Profile Reliability DF201216.pdf, Category: Faculty Research Approval;
- Confidential Medical and Activity History Questionnaire.doc, Category: Survey / Questionnaire;
- HRP-502 - TEMPLATE CONSENT DOCUMENT Adult F-v Rotational Profile Reliability CH210117.pdf, Category: Consent Form;
- HRP-503-TEMPLATE-Protocol F-v Rotational Profile Reliability CH210117.docx, Category: IRB Protocol;
- PAR-Q+.pdf, Category: Survey / Questionnaire;

The IRB approved the protocol on 1/19/2021.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. Guidance on submitting Modifications and a Continuing Review or Administrative Check-in are detailed in the manual. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.
Sincerely,

[Racine Jacques, Ph.D.]
[Designated Reviewer]
APPROVAL

April 28, 2021

Dear Chad Herring:

On 4/28/2021, the IRB reviewed the following submission:

<table>
<thead>
<tr>
<th>Type of Review:</th>
<th>Modification / Update</th>
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</thead>
<tbody>
<tr>
<td>Title:</td>
<td>Comparison of Force-velocity Profiles in Female Collegiate Athletes: Sport-specificity Considerations</td>
</tr>
<tr>
<td>Investigator:</td>
<td>Chad Herring</td>
</tr>
<tr>
<td>IRB ID:</td>
<td>MOD00001835</td>
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<tr>
<td>Funding:</td>
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<td>Grant ID:</td>
<td>None</td>
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<tr>
<td>IND, IDE, or HDE:</td>
<td>None</td>
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</table>

Documents Reviewed:
- HRP-502 - TEMPLATE CONSENT DOCUMENT Adult F-v Profiling in Female Collegiate Athletes 210427.pdf, Category: Consent Form;
- HRP-503-TEMPLATE-Protocol F-v Profiling in Female Collegiate Athletes 210427.docx, Category: IRB Protocol;

The IRB approved the modifications to the protocol on 4/28/2021.

In conducting this protocol, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. Guidance on submitting Modifications and a Continuing Review or Administrative Check-in are detailed in the manual. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,
Racine Jacques, Ph.D.
Designated Reviewer
APPROVAL B: APPROVED INFORMED CONSENT
Permission to Take Part in a Human Research Study

Title of research study: Simplified Method for Assessing Rotational Force-Velocity Profiles in Collegiate Softball Players

Principal Investigator(s): Chad Herring, MEd
Co-Investigators or Sub-Investigator(s): Michael Redd, PhD
Faculty Supervisor: David Fukuda, PhD
Investigational Site(s): University of Central Florida
College of Health Professions and Sciences
School of Kinesiology and Physical Therapy

Key Information: The following is a short summary of this study to help you decide whether or not to be a part of this study. More detailed information is listed later on in this form.

Why am I being invited to take part in a research study?
We invite you to take part in a research study because you are a female between the ages of 18 and 35 years old, an NCAA softball player, and free of any physical limitations as determined by the Confidential Medical and Activity Questionnaire.

The following will be used as exclusion criteria for this research study:

- Participant is under the age of 18 years old.
- Participant is an amputee.
- Participant cannot complete all the testing visits.
- Participant is unable to participate in physical activity, as determined by the Physical Activity Readiness Questionnaire (PAR-Q+) and confidential Medical History and Activity Questionnaire (MHAQ).
- Participant has any chronic illness causing the individual to seek medical care.
- Participant has a pacemaker.
- Participant is unable to complete any of the exercise assessments on the familiarization day.
Permission to Take Part in a Human Research Study

Why is this research being done?
While simple methods have been created to determine force-velocity (F-v) profiles in jumping and sprinting, a simple method to assess F-v profiles during rotational movements has not been created. This research could help improve the physical training of athletes by utilizing individualized training based on their rotational F-v profile.

How long will the research last and what will I need to do?
We expect that you will be in this research study for approximately 2.5 hours total (0.5 hours for initial visit; 1.0 hours/visit for two testing sessions) over three separate visits. As a minimum of 48 hours is required between testing sessions in order to minimize fatigue, we expect that you will be in this research study for no more than two weeks.

If the second testing session cannot occur within 48 hours of the first testing session due to unforeseen circumstances, you may be asked to repeat the first testing session. In this scenario, the active participation time will be approximately 3.5 hours total (0.5 hours for initial visit; 1.0 hours/visit for three testing sessions).

More detailed information about the study procedures can be found under “What happens if I say yes, I want to be in this research?”

Is there any way being in this study could be bad for me?
No risks are associated with completing questionnaires, anthropometrics, or body composition testing.

The performance assessments carry the same inherent risks as participating in any physical activity, such as muscle soreness and fatigue and possibly muscle strains, and/or joint sprains. To minimize these risks, you will be instructed on appropriate technique for the performance assessments. You will be instructed to immediately stop and report any injury or discomfort associated with the performance assessments to a member of the investigative team. The extent of the injury/discomfort, as well as your ability to continue with the study, will be subsequently determined by the investigative team. If it is deemed that the discomfort/injury will prevent you from completing the study, or if the injury/discomfort may be exacerbated by further participation in the study, the investigative team will suspend your participation in the study.

Will being in this study help me any way?
We cannot promise any benefits to you or others from your taking part in this research. However, possible benefits include providing an additional assessment that may help individualize sports performance training and providing body composition testing.

What happens if I do not want to be in this research?
Your participation in this study is voluntary. You are free to withdraw your consent and discontinue participation in this study at any time without prejudice or penalty. Your decision to participate or not participate in this study will in no way affect your continued enrollment, grades, employment, playing time, or your relationship with UCF or the individuals who may have an interest in this study.
Permission to Take Part in a Human Research Study

**Detailed Information:** The following is more detailed information about this study in addition to the information listed above.

**What should I know about a research study?**
- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

**Who can I talk to?**
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team: Chad Herring, Doctoral Candidate, Education program/Exercise Physiology track, College of Health Professions and Sciences, School of Kinesiology and Physical Therapy at 607-435-1539 or chad.herring@ucf.edu; or Dr. David Fukuda, Associate Professor and Division Chair, College of Health Professions and Sciences, School of Kinesiology and Physical Therapy at (407) 823-0442 or david.fukuda@ucf.edu.

This research has been reviewed and approved by an Institutional Review Board (“IRB”). You may talk to them at 407-823-2901 or irb@ucf.edu if:
- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research subject.
- You want to get information or provide input about this research.

**How many people will be studied?**
We plan to recruit 31 people to be participants in this research study.

**What happens if I say yes, I want to be in this research?**
You will be asked to complete three visits to the UCF Softball Complex/Kinesiology Teaching Laboratory. The first visit (Visit #1) will be a preliminary visit for you to complete the informed consent form, physical activity readiness questionnaire (PAR-Q+), and the medical history questionnaire (MHQ), as well as the researchers addressing any questions you may have. Following Visit #1, the experimental trials (Visits #2 – 3) for positional players will consist of testing in the order outlined seen below:

**Figure 1. Study Design – Positional Players**
Permission to Take Part in a Human Research Study

Following Visit #1, the experimental trials (Visits #2 – 3) for pitchers will consist of testing in the order outlined seen below:

Figure 2. Study Design – Pitchers

Anthropometric testing will consist of measuring height, weight, arm length, and wingspan and will be completed by a member of the University of Central Florida’s Athletic Department. Body composition testing will consist of measuring muscle mass and body fat percentage and will be completed by a member of the research team.

For testing sessions, you will perform a general warm-up consisting of your typical pre-practice dynamic warm-up, and a specific warm-up. The specific warm-up will consist of three dry bat swings (positional players only) and three rotational medicine ball throws (both swing and non-swing sides) at an intensity of 75-95% of maximal effort.

For the bat swing method (positional players only), you will complete three batted balls using bats of five different masses (28, 35.8, 39.9, 43.6, and 49.4oz). You will be given 20 seconds of rest between each swing using the same bat mass, while 2-min rest will be given between each of the five different bat masses. A swing sensor will be attached to the knob of the bat and an inertial measurement unit will be attached to your back forearm to measure the velocity of movement throughout the swing. The inertial measurement unit will be attached by a member of the coaching or athletic training staff. Additionally, all testing swings will be recorded with a handheld camera for subsequent motion analysis. If you are a positional player completing both methods (bat swing and rotational medicine ball throw), you will be given three minutes of transition time between methods.
Permission to Take Part in a Human Research Study

For the rotational medicine ball throw method, you will complete three medicine ball throws on each side using five different medicine ball masses (4, 8, 12, 16, and 20lbs). You will be given 20 seconds of rest between each throw using the same medicine ball mass, while 2-min rest will be given between each of the five different medicine ball masses. An inertial measurement unit will be attached to your back forearm to measure the velocity of movement throughout the throw. The inertial measurement unit will be attached by a member of the coaching or athletic training staff. Additionally, a radar gun will record the velocity of the medicine ball during the throws and you will be recorded with a handheld camera for subsequent motion analysis.

The order of bat swing and medicine ball masses used during Visits #2 and 3 will be determined using a randomization procedure in Microsoft Excel. A minimum of 48 hours between experimental trials will be required to minimize fatigue.

What happens if I say yes, but I change my mind later?
You can leave the research at any time it will not be held against you.

What happens to the information collected for the research?
Efforts will be made to limit the use and disclosure of your personal information, including research study and medical records, to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization. The results of this study will be published as part of a scientific publication. Individual results will remain confidential and only be relayed to you upon your request. All MHQs, as well as data collection sheets will be kept in a locked cabinet during and following the study. Your names will be kept separately from the other study documents in a separate electronic file under password protection. This file will be stored on a computer in the Education Building and will be deleted upon completion of the study. All of the other study-related information will be destroyed five years from the end of the study. Folders will be marked with an I.D. number to protect against a breach of confidentiality and the I.D. number will be removed upon disposal. All of the medical information taken during the study will not be useful for you or cannot be used to supplement/replace medical care.

Can I be removed from the research without my OK?
The person in charge of the research study can remove you from the research study without your approval. Possible reasons for removal include refusal to adhere to any study requirements and/or failure to complete all visits.

What else do I need to know?
There is no monetary compensation for taking part in this research study. The results of the study will be provided to you upon request following completion of the study.
Permission to Take Part in a Human Research Study

Your signature documents your permission to take part in this research.

_________________________  ______________________
Signature of subject Date

_________________________
Printed name of subject

_________________________  ______________________
Signature of person obtaining consent Date

_________________________
Printed name of person obtaining consent
Printed name of person witnessing consent process
Permission to Take Part in a Human Research Study

Title of research study: Comparison of Force-velocity Profiles in Female Collegiate Athletes: Sport-specificity Considerations

Principal Investigator(s): Chad Herring, MEd

Co-Investigators or Sub-Investigator(s): Michael Redd, PhD

Faculty Supervisor: David Fukuda, PhD

Investigational Site(s): University of Central Florida
College of Health Professions and Sciences
School of Kinesiology and Physical Therapy

Key Information: The following is a short summary of this study to help you decide whether or not to be a part of this study. More detailed information is listed later on in this form.

Why am I being invited to take part in a research study?
We invite you to take part in a research study because you are a female between the ages of 18 and 35 years old, an NCAA golf, softball, or tennis player, and free of any physical limitations as determined by the Confidential Medical and Activity Questionnaire. The following will be used as exclusion criteria for this research study:

- Participant is under the age of 18 years old.
- Participant is an amputee.
- Participant cannot complete all the testing visits.
- Participant is unable to participate in physical activity, as determined by the Physical Activity Readiness Questionnaire (PAR-Q+) and confidential Medical History and Activity Questionnaire (MHAQ).
- Participant has any chronic illness causing the individual to seek medical care.
- Participant has a pacemaker.
- Participant is unable to complete any of the exercise assessments on the familiarization day.
Permission to Take Part in a Human Research Study

Why is this research being done?
Athletes of the same age and sex participating in different sports often display different force-velocity (F-v) profiles. Consequently, it is essential to examine the F-v profiles of different groups of athletes in order to expand upon the database for effective comparisons. Additionally, F-v profiles during different ballistic movements (e.g., jump vs. sprint) may reveal deficiencies that are not aligned (e.g., force-deficiency during jumping and velocity-deficiency during sprint). Therefore, this research could help improve the physical training of athletes by utilizing individualized training based on your vertical (jump), rotational, and horizontal (sprint) F-v profiles. We will also be comparing the F-v profiles of Softball athletes to on-field performance testing to examine potential relationships between F-v variables and performance.

How long will the research last and what will I need to do?
We expect that you will be in this research study for approximately 1.5 hours total (30 minutes for initial visit; 1 hour/visit for one testing sessions) over two separate visits. We expect that you will be in this research study for no more than two weeks.

More detailed information about the study procedures can be found under "What happens if I say yes, I want to be in this research?"

Is there any way being in this study could be bad for me?
No risks are associated with completing questionnaires, anthropometrics, or body composition testing.
The performance assessments carry the same inherent risks as participating in any physical activity, such as muscle soreness and fatigue and possibly muscle strains, and/or joint sprains. To minimize these risks, you will be instructed on appropriate technique for the performance assessments. You will be instructed to immediately stop and report any injury or discomfort associated with the performance assessments to a member of the investigative team. The extent of the injury/discomfort, as well as your ability to continue with the study, will subsequently be determined by the investigative team. If it is deemed that the discomfort/injury will prevent you from completing the study, or if the injury/discomfort may be exacerbated by further participation in the study, the investigative team will suspend your participation in the study.

Will being in this study help me anyway?
We cannot promise any benefits to you or others from your taking part in this research. However, possible benefits include providing three assessments that may help individualize sports performance training and providing body composition testing.

What happens if I do not want to be in this research?
Your participation in this study is voluntary. You are free to withdraw your consent and discontinue participation in this study at any time without prejudice or penalty. Your decision to participate or not participate in this study will in no way affect your continued enrollment, grades, employment, playing time, or your relationship with UCF or the individuals who may have an interest in this study.

UCF IRB-502 Template v 5/1/2020
Permission to Take Part in a Human Research Study

**Detailed Information:** The following is more detailed information about this study in addition to the information listed above.

**What should I know about a research study?**
- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

**Who can I talk to?**
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team: Chad Herring, Doctoral Candidate, Education program/Exercise Physiology track, College of Health Professions and Sciences, School of Kinesiology and Physical Therapy at 607-435-1539 or chadherring@ucf.edu; or Dr. David Fukuda, Associate Professor and Division Chair, College of Health Professions and Sciences, School of Kinesiology and Physical Therapy at (407) 823-0442 or david.fukuda@ucf.edu.

This research has been reviewed and approved by an Institutional Review Board (IRB). You may talk to them at 407-823-290 for irb@ucf.edu if:
- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research subject.
- You want to get information or provide input about this research.

**How many people will be studied?**
We plan to recruit 38 people to be participants in this research study.

**What happens if I say yes, I want to be in this research?**
You will be asked to complete two visits to a designated location based on your sport. Softball athletes will report to the UCF Softball Complex, while Golf and Tennis athletes will report to the Addition Financial Arena Weight Room/UCF Soccer and Track Complex. The first visit (Visit #1) will be a preliminary visit for you to complete the informed consent form, physical activity readiness questionnaire (PAR-Q+), and the medical history questionnaire (MHQ), as well as the researchers addressing any questions you may have. At least 24 hours following Visit #1, the experimental trial (Visit #2) will consist of testing in the order outlined seen below:

**Figure 1. Study Design**
Anthropometric testing will consist of measuring height, body mass (BM), arm length, leg length, squat position at a 90° knee angle, and wingspan and will be completed by a member of the University of Central Florida’s Athletic Department. Body composition testing will consist of standing on a bioelectrical impedance spectroscopy analyzer for approximately one minute. A member of the research team will enter your height and age, then you will be asked to stand still for approximately 20 seconds in order to assess your measuring muscle mass and body fat percentage.

For testing sessions, you will be asked to avoid any high intensity exercise 24 hours prior to the session. During these sessions, you will be asked to perform a general warm-up consisting of your typical pre-practice dynamic warm-up, and a specific warm-up. The specific warm-up for each profiling method will be completed immediately prior to that specific profiling method.

**Vertical Profiling**

- The specific warm-up for vertical profiling will consist of two bodyweight squat jumps (SJ)s and two SJs with an unloaded barbell weighing 45lbs at 75-95% of maximal effort.

- For testing, you will complete two SJ at body mass (BM) and two SJ at 65lbs (total repetitions = 4). For the jumps at BM, you will place a PVC pipe across the shoulders to replicate the arm positioning that will be used during the loaded SJ. For the loaded SJ, you will place the barbell across the shoulders. Prior to each jump, you will be asked to squat into a position of 90° knee angle and will be asked to maintain this position for about 2s. You will then be asked to jump for maximal height. Countermovement will be forbidden. In the event that any of these requirements are not met, any trial will be repeated.

- All jumps will be recorded in the frontal plane using a 9.7-inch iPad Air 2. Additionally, jump height will be measured with the PUSH band attached to the barbell. In the event that you cannot reach a jump height of 10cm with 65lbs, the loaded SJ mass will be reduced to 45lbs. You will be given 15-seconds of rest between jumps of the same load and 2-min of rest jump of different loads.

- Upon completion of the vertical profiling, you will be given 3-min of rest before starting the rotational profiling.

**Rotational Profiling — Softball Only**
Permission to Take Part in a Human Research Study

- Following the completion of the vertical profiling, you will complete a specific warm-up for rotational profiling consisting of three submaximal bat swings with five bat masses (33, 40.75, 44.9, 48.61, and 54.37 oz.) at 75-95% of maximal effort. You will be given 20 seconds of rest between each swing using the same bat mass, while 1-min rest will be given between each of the five different bat masses.

- You will be asked to stand in your normal batting stance during all swings. A batting tee will be used to maintain consistency. You will choose the height of the tee but will be instructed to imagine a fastball in the center of the strike zone. You will be instructed to generate maximum velocity for each swing.

- An inertial measurement unit will be attached to your back forearm using a sleeve that can be placed in the correct position by yourself without the need for additional assistance. The inertial measurement unit will measure the velocity of movement throughout the throw. You will be able to attach the inertial measurement unit yourself without additional assistance. The order of bat masses used during Visit #2 will be determined using a randomization procedure in Microsoft Excel. You will complete the rotational profiling from your swing side only.

- Upon completion of the rotational profiling, you will be given 3-min of rest before starting the horizontal profiling.

Rotational Profiling – Golf and Tennis Only

- Following the completion of the vertical profiling, you will complete a specific warm-up for rotational profiling consisting of two rotational medicine ball throws (RMBTs) for three of five different medicine ball masses (8, 12, and 16lbs) at 75-95% of maximal effort. You will be given 20 seconds of rest between each throw using the same medicine ball mass, while 1-min rest will be given between each of the five different medicine ball masses.

- You will be asked to stand with a comfortable foot placement approximately hip-width apart. You will be asked to hold the medicine ball with both hands with palms facing inwards towards each other, maintaining neutral shoulder and wrist position, as well as 90 degrees of elbow bend throughout the movement. You will be instructed to keep your elbow tight to your body throughout the movement. The medicine ball will be placed in a position as to line it up with your back hip when your trail hand is directly behind the ball. You will be instructed to generate maximum velocity while throwing the medicine ball, maintaining foot contact with the ground throughout.

- An inertial measurement unit will be attached to your back forearm using a sleeve that can be placed in the correct position by yourself without the need for additional assistance. The inertial measurement unit will measure the velocity of movement throughout the throw. You will be able to attach the inertial measurement unit yourself without additional assistance. Additionally, you will be recorded with a handheld camera for subsequent motion analysis. The order of medicine ball masses used during Visit #2 will be determined using a randomization procedure in Microsoft Excel. You will complete the rotational profiling from your swing/forehand side only.

- Upon completion of the rotational profiling, you will be given 3-min of rest before starting the horizontal profiling.

Horizontal Profiling

UCF HRP-502 Template v 5/1/2020
Permission to Take Part in a Human Research Study

- Following the completion of the rotational profiling, you will complete a specific warm-up for horizontal profiling consisting of two submaximal 30m sprints at an intensity of 75-95% of maximal effort.
- For testing, you will complete two maximal 30m sprints. You will be given 2-min of rest between sprints. Sprints will be recorded in the frontal plane using a 9.7-inch iPad Air 2 at 60 frames/second. All videos will be analyzed using a commercially available app (MySprint). You will be allowed to choose which leg will be the lead leg but will be instructed to maintain the same lead leg during both sprints.

Dynavision D2™ Data – Softball Only

- A member of the research team will analyze the Dynavision D2™ data that has been collected over the course of the 2021 season to determine any relationship with these data and your publicly available on-field performance batting performance (e.g., batting average, doubles/game, earned run average, etc.).

What happens if I say yes, but I change my mind later?
You can leave the research at any time it will not be held against you. If you decide to leave the research study, please contact the PI so that your data can be removed from the study results and destroyed.

What happens to the information collected for the research?
Efforts will be made to limit the use and disclosure of your personal information, including research study records, to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization. The results of this study will be published as part of a scientific publication. Individual results will remain confidential and only be relayed to you upon your request. All MHQs, as well as data collection sheets will be kept in a locked cabinet during and following the study. Your names will be kept separately from the other study documents in a separate electronic file under password protection. This file will be stored on a computer in the Education Building and will be deleted upon completion of the study. All of the other study-related information will be destroyed five years from the end of the study. Folders will be marked with an I.D. number to protect against a breach of confidentiality and the I.D. number will be removed upon disposal. All of the medical information taken during the study will not be useful for you or cannot be used to supplement/replace medical care.

Can I be removed from the research without my OK?
The person in charge of the research study can remove you from the research study without your approval. Possible reasons for removal include refusal to adhere to any study requirements and/or failure to complete all visits.

What else do I need to know?
There is no monetary compensation for taking part in this research study. The results of the study will be provided to you upon request following completion of the study.
Permission to Take Part in a Human Research Study

Your signature documents your permission to take part in this research.

______________________________   __________________________
Signature of subject                Date

______________________________
Printed name of subject

______________________________   __________________________
Signature of person obtaining consent Date

______________________________
Printed name of person obtaining consent

Printed name of person witnessing consent process
APPENDIX C: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q+)
**2017 PAR-Q+**

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

### GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th>NO</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Has your doctor ever said that you have a heart condition OR high blood pressure?</td>
<td>□</td>
</tr>
<tr>
<td>2) Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?</td>
<td>□</td>
</tr>
<tr>
<td>3) Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over breathing (including during vigorous exercise).</td>
<td>□</td>
</tr>
<tr>
<td>4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? PLEASE LIST CONDITION(S) HERE:</td>
<td>□</td>
</tr>
<tr>
<td>5) Are you currently taking prescribed medications for a chronic medical condition? PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:</td>
<td>□</td>
</tr>
<tr>
<td>6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer NO if you had a problem in the past, but it does not limit your current ability to be physically active. PLEASE LIST CONDITION(S) HERE:</td>
<td>□</td>
</tr>
<tr>
<td>7) Has your doctor ever said that you should only do medically supervised physical activity?</td>
<td>□</td>
</tr>
</tbody>
</table>

---

If you answered NO to all of the questions above, you are cleared for physical activity. Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

---

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

**Delay becoming more active if:**

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.aparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.
2017 PAR-Q+
FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems? If the above condition(s) is/are present, answer questions 1a-1c. If NO go to question 2
   1a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? YES NO
   1b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylosis/pars defect (a crack in the bony ring on the back of the spinal column)? YES NO
   1c. Have you had steroid injections or taken steroid tablets regularly for more than 3 months? YES NO

2. Do you currently have Cancer of any kind? If the above condition(s) is/are present, answer questions 2a-2b. If NO go to question 3
   2a. Does your cancer diagnosis include any of the following types: lung/breast/ovarian, multiple myeloma (cancer of plasma cells), head, and/or neck? YES NO
   2b. Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)? YES NO

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm. If the above condition(s) is/are present, answer questions 3a-3d. If NO go to question 4
   3a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? YES NO
   3b. Do you have an irregular heartbeat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction) YES NO
   3c. Do you have chronic heart failure? YES NO
   3d. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months? YES NO

4. Do you have High Blood Pressure? If the above condition(s) is/are present, answer questions 4a-4b. If NO go to question 5
   4a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments) YES NO
   4b. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure) YES NO

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes. If the above condition(s) is/are present, answer questions 5a-5e. If NO go to question 6
   5a. Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies? YES NO
   5b. Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness, or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness. YES NO
   5c. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, OR the sensation in your toes and feet? YES NO
   5d. Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)? YES NO
   5e. Are you planning to engage in weight loss or change lifestyle to manage your metabolic condition(s)? YES NO
2017 PAR-Q+

6. Do you have any Mental Health Problems or Learning Difficulties? This Includes Alzheimer’s, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome
   If the above condition(s) is/are present, answer questions 6a-6b
   If NO go to question 7

6a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?
   (Answer NO if you are not currently taking medications or other treatments)  YES  NO

6b. Do you have Down Syndrome AND back problems affecting nerves or muscles?  YES  NO

7. Do you have a Respiratory Disease? This Includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure
   If the above condition(s) is/are present, answer questions 7a-7d
   If NO go to question 8

7a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?
   (Answer NO if you are not currently taking medications or other treatments)  YES  NO

7b. Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?  YES  NO

7c. If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?  YES  NO

7d. Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?  YES  NO

8. Do you have a Spinal Cord Injury? This Includes Tetraplegia and Paraplegia
   If the above condition(s) is/are present, answer questions 8a-8c
   If NO go to question 9

8a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?
   (Answer NO if you are not currently taking medications or other treatments)  YES  NO

8b. Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?  YES  NO

8c. Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?  YES  NO

9. Have you had a Stroke? This Includes Transient Ischemic Attack (TIA) or Cerebrovascular Event
   If the above condition(s) is/are present, answer questions 9a-9c
   If NO go to question 10

9a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?
   (Answer NO if you are not currently taking medications or other treatments)  YES  NO

9b. Do you have any impairment in walking or mobility?  YES  NO

9c. Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?  YES  NO

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?
   If you have other medical conditions, answer questions 10a-10c
   If NO read the Page 4 recommendations

10a. Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?  YES  NO

10b. Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?  YES  NO

10c. Do you currently live with two or more medical conditions?  YES  NO

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE:

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.
2017 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:
- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:
- You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the ePAInmed-X+ at www.eparmedx.com and/or visit a qualified exercise professional to work through the ePAInmed-X+ and for further information.

Delay becoming more active if:
- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePAInmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePAInmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider or other designee) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

PARTICIPANT ID: ___________________________ DATE: ______________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ___________________________

For more information, please contact 
www.eparmedx.com
Email: eparmedx@gmail.com

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. J. Warburton with Dr. Norman Girard, Dr. Veronika Jarnik, and Dr. Donald C. Mc Manus (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References
APPENDIX D: CONFIDENTIAL MEDICAL HISTORY AND ACTIVITY QUESTIONNAIRE
Confidential Medical and Activity History Questionnaire

Participant #

When was your last physical examination? 

1. List any medications or herbal supplements you currently take or have taken the last month:

<table>
<thead>
<tr>
<th>Medication/Supplement</th>
<th>Reason for Taking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. List any nutritional supplements or ergogenic aids you currently take or have taken the last month:

<table>
<thead>
<tr>
<th>Supplement/Ergogenic Aid</th>
<th>Reason for Taking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Are you allergic to any medications? If yes, please list medications and reaction.

4. Please list any allergies, including food allergies that you may have?

5. Have you ever been hospitalized? If yes, please explain.

<table>
<thead>
<tr>
<th>Year of Hospitalization</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

1
6. List any chronic (long-term) illnesses that have caused you to seek medical care.

7. Have you undergone major surgery within the previous 16 weeks? If yes, please explain.

8. Have you ever had (or do you have now) active malignant disease or cancer. If yes, please explain.

9. Have you ever had (or do you have now) any of the following? Please circle questions that you do not know the answer to.
   
   Cystic fibrosis | yes | no
   Water retention problems | yes | no
   Epilepsy | yes | no
   Convulsions | yes | no
   Dizziness/fainting/unconsciousness | yes | no
   Chronic headaches | yes | no
   Chronic cough | yes | no
   Chronic sinus problem | yes | no
   High cholesterol | yes | no
   Rheumatic fever | yes | no
   Bronchitis | yes | no
   Hepatitis | yes | no
   Bladder problems | yes | no
   Tuberculosis (positive skin test) | yes | no
   Yellow jaundice | yes | no
   Anemia | yes | no
   Endotoxemia | yes | no
   Hyperprolactinemia | yes | no
### Institute of Exercise Physiology and Rehabilitation Science
University of Central Florida

<table>
<thead>
<tr>
<th>Condition</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anorexia nervosa</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Bulimia</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Stomach/intestinal problems</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Arthritis</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Back pain</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Gout</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Dementia</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Artificial limb</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Alzheimer’s</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

**Cardiovascular Diseases**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral vascular disease</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Arterial fibrillation</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>“Heart block”</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Myocardial infarction (Heart attack)</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Poorly controlled hypertension</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Heart pacemaker</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>High blood pressure</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Heart murmur</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

**Pulmonary Diseases**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Asthma</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Interstitial lung disease</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Emphysema</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

**Metabolic Disorders**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes mellitus (type 1, type 2)</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Diabetes insipidus</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Thyroid disorders</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>
Renal disease  yes  no
Liver disease  yes  no
Immunodeficiency disorder  yes  no
Any others (specify): ____________________________________________
______________________________________________________________
______________________________________________________________

Do you smoke cigarettes or use any other tobacco products?  yes  no
Do you smoke or ingest marijuana in any form?  yes  no
Have you taken any other street drugs (e.g., cocaine, heroin, meth, etc.) in the past 16 weeks?  yes  no
Do you have a history of drug or alcohol dependency?  yes  no
Has your doctor ever said you have a heart condition and that you should only do physical activity recommended by a doctor?  yes  no
Do you feel any pain in your chest when you do physical activity?  yes  no
Are you ever bothered by racing of your heart?  yes  no
Do you ever notice abnormal or skipped heartbeats?  yes  no
Do you ever have any arm or jaw discomfort, nausea, or vomiting associated with cardiac symptoms?  yes  no
Do you ever have difficulty breathing?  yes  no
Do you ever experience shortness of breath?  yes  no
Do you lose your balance because of dizziness or do you ever lose consciousness?  yes  no
Are you pregnant?  yes  no
Is there a chance that you may be pregnant?  yes  no
Have you ever had any tingling or numbness in
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your arms or legs? yes no
Has a member of your family or close relative died of heart problems or sudden death before the age of 50? yes no
Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? yes no
Do you have a bone or joint problem that could be made worse by a change in your physical activity? yes no
Has a health care practitioner ever denied or restricted your participation in sports for any problem yes no
If yes, please explain: ____________________________________________________________

____________________________________

Do you know any other reason why you should not do physical activity? yes no

10. Do you have any pain during exercise and/or sporting activities? If so, please explain.

11. I have answered these questions honestly and have provided all past and present health and exercise information to the best of my knowledge.

YES [ ] NO [ ]

____________________________________  ______________________________________
Participant Number                        Date
APPENDIX E: DATA COLLECTION SHEET
F-v Rotational Profiling

Participant # _______ Informed Consent ☐ PAR-Q+ ☐ MHQ ☐
Height _______ Age _______ Weight _______
Bat R or L Throw R or L
Upper Arm Length _______ Forearm Length _______ Wingspan _______
Height of Tee _______ Distance Btw Feet _______
Distance from Front Foot (side) _______ Distance from Front Foot (front) _______

Day 1

<table>
<thead>
<tr>
<th>General Warm-up</th>
<th>Specific Warm-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bat Swing Method
- Green
- Orange
- Black
- Blue
- Red

RMBT Method (Swing Side)
- 10
- 6
- 8
- 12
- 16

RMBT Method (Non-swing Side)
- MASS 1
- MASS 2
- MASS 3
- MASS 4
- MASS 5

Day 2

<table>
<thead>
<tr>
<th>General Warm-up</th>
<th>Specific Warm-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bat Swing Method
- Blue
- Black
- Green
- Orange
- Red

RMBT Method (Swing Side)
- 10
- 12
- 16
- 8
- 6

RMBT Method (Non-swing Side)
- MASS 1
- MASS 2
- MASS 3
- MASS 4
- MASS 5

20 seconds rest between swings/throws of same mass.
2 minutes rest between swings/throws of different mass.
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