Countermovement Jump Height as an Indicator of Sprint Performance in Female Division 2 Track and Field Athletes

by

Amanda Herrington

Submitted in fulfillment of the requirements for graduation as an Honors Scholar at

Point Loma Nazarene University, San Diego, California

April 23, 2021

Abstract

Sprint performance is influenced by a wide variety of factors such as muscle architecture and fiber type, metabolic characteristics, running mechanics and muscular strength (Abe et al., 2000, 2001; Hunter et al., 2005; Morin et al., 2012; Slawinski et al., 2010). The purpose of this paper is to identify monitoring variables that can be used as predictors of sprint performance in NCAA Division 2, female track and field athletes, while also suggesting a protocol for athlete monitoring specific to the sport of track and field. Athletes participated in a countermovement jump, 40-meter sprint test, and isometric mid-thigh pull to quantify variables related to power, speed and strength, respectively. A stepwise multiple linear regression model was used to identify significant predictors of 10- and 40-meter sprint performance utilizing countermovement jump and mid-thigh pull metrics. Relationships between the various dynamic and isometric measures were also identified to understand the carry over between strength and elastic power to sprinting performance. Jump height was determined to be the only significant predictor of both 10-($R^2 = 0.634, p < 0.001$)and 40-meter($R^2 = 0.704, p < 0.001$) sprint performance within this sample, suggesting that elastic explosive power is of great importance for sprint athletes.

Key terms: sprint performance, countermovement jump, mid-thigh pull, elastic power, strength, jump height

Introduction

Speed is a crucial fitness characteristic for athletes in sports such as track and field, soccer, football, and rugby (Barr & Nolte, 2011; Bellon, 2016; Markström & Olsson, 2013; Wang et al., 2016; West et al., 2011). Routine, evidence-based athlete monitoring can serve as a tool for quantification of athletic qualities such as speed, but also strength and power. When approaching athlete monitoring in the light of sprinters, where speed is the ultimate goal, it is important to recognize the factors that influence speed so proper monitoring methods can be prepared. There are many known factors that contribute to an athlete's speed, however the role in which a single characteristic creates differences in performance is not yet fully understood. High variability between athletes is partly influenced by genetic factors that predispose individuals to performance abilities through physical traits, cardiorespiratory and skeletal muscle function (Eynon et al., 2010; Macarthur & North, 2005). Some of the factors known to influence speed are the ability to produce and apply force as influenced by muscle architecture and fiber type, training experience and style, and running mechanics (Abe et al., 2000, 2001; Hunter et al., 2005; Morin et al., 2012; Slawinski et al., 2010). The purpose of this paper is to explore which monitoring variable is most indicative of 40-meter sprint time in Division 2 female track athletes, as well as to offer a protocol for athlete monitoring within the sport of track and field.

The sport of track and field is divided into twenty-three running, jumping, and throwing events, as described by the Olympic Committee. Each event places specific physiological demands on the body, and therefore, different fitness characteristics are considered favorable. The goal of the running events in track and field is to travel from start to finish in the shortest amount of time. For the purpose of this paper, the focus will remain on the events requiring some degree of sprinting with distances ranging from 60-meters to 400-meters. Short sprint events, such as the 100-meter and 200-meter, are limited by the anaerobic alactic system (phosphagen system) for energy production; whereas long sprint events, like the 400-meter, have a demand on the anaerobic lactic system or fast glycolytic system for metabolism (Baechle

& Earle, 2008, pp. 24–26). Successful performance in the sprinting events requires a variety of athletic characteristics including speed, strength, and power (Barr & Nolte, 2011; Bellon, 2016; Markström & Olsson, 2013; Slawinski et al., 2010; Wang et al., 2016; West et al., 2011).

Factors Determining Sprinting Speed

As previously mentioned, speed can be influenced by muscle architecture, elastic characteristics, fiber type, training experience and running mechanics (Abe et al., 2000, 2001; Hunter et al., 2005; Kuitunen et al., 2002; Morin et al., 2012; Slawinski et al., 2010). These factors are influenced by genetic factors, however specific training can also drive adaptations in the neurological, musculoskeletal, and endocrine systems -- all of which can play a role in athletic performance due to their effect on muscle contraction velocity, motor unit recruitment, force generation, fiber hypertrophy, fiber type ratios, and removal of metabolic waste products (Baechle & Earle, 2008, pp. 94–118). Muscle architecture and fiber type are associated with strength development for force application, while also preventing injury through hypertrophy of mechanically stronger resistant tissues (Baechle & Earle, 2008, pp. 94–118).

Muscle Architecture and Characteristics

Skeletal muscle is composed of groupings of contractile proteins, actin and myosin filaments, that allow for the shortening and lengthening of the muscle tissue. According to the sliding-filament theory, actin filaments are pulled inward by myosin cross bridging, causing a muscle to shorten or concentrically contract (Baechle & Earle, 2008, pp. 7–8). Shortening and lengthening of a muscle produces force, which in turn is used to generate movement through the musculoskeletal lever system. When applied to athletic performance, the architecture of skeletal muscle within the lower extremity is connected to performance ability (Abe et al., 2000, 2001). The speed at which a muscle can contract is known as the muscle shortening velocity, and it can be determined by fiber length, fiber number, myosin ATPase activity as determined by muscle fiber type (Abe et al., 2000, 2001; Kumagai et al., 2000). A muscle with a greater shortening velocity will be able to contract much faster than a muscle with a lesser velocity, thus will be able to produce forces at a greater rate. Sprint running requires the ability to reach high muscle shortening velocity so that rapid stride frequency can be achieved (Kumagai et al., 2000). Many of the architectural features of muscle are genetically predetermined; however with sport-specific training and resistance training, muscle fibers can hypertrophy and adapt to meet stimulus demands.

Muscle fascicle length is a determinant of contraction velocity which in turn affects sprinting speed by increasing muscle power production (Kumagai et al., 2000). The length of a muscle fascicle is determined by the number of sarcomeres, or contractile protein groupings, present within a single muscle fiber (Abe et al., 2000; Baechle & Earle, 2008, p. 5). When compared to distance runners, sprinters had greater average fascicle length and lesser muscle pennation angle in the vastus lateralis and bilateral gastrocnemius allowing for rapid muscle contraction (Abe et al., 2000). Greater fascicle lengths hold a greater capacity for force generation which increases power metrics and sprint performance ability (Abe et al., 2000, 2001; Kumagai et al., 2000). This is further explained by the increased opportunity for actin-myosin overlapping during cross-bridge cycling, allowing for greater force generation during contraction. Both male and female sprinters who had greater muscle fascicle lengths had better sprint performances over 100-meters than sprinters with lesser fascicle lengths (Abe et al., 2001).

Another characteristic of muscle is that it is extensible and elastic, meaning that the muscle fibers will return to original length following a stretching force. Elastin and titin are structures that provide elasticity to muscle fibers and their surrounding connective tissues, giving the tissue spring-like characteristics (Amerman, 2016, p. 344). Elasticity is controlled by proprioceptors, such as muscle spindles and golgi tendon organs, that are embedded within muscle tissue and tendons providing signals of stretch or tension to the central nervous system, triggering the stretched muscle to contract in order to prevent injury (Kuitunen et al., 2002;

Walker, 2016b). Kuitunen et al. (2002) determined increased stiffness of the knee joint during sprinting allows for the use of spring-like elasticity of the leg during sprinting (Kuitunen et al., 2002; Walker, 2016b). The stretch shortening cycle (SSC) uses this elastic quality of muscle tissue through a rapid countermovement action or change of direction, similar to that which occurs during plyometric and locomotive movements. Elastic properties allow for greater amounts of force to be involuntarily produced, resulting in increased movement speed (Ebben & Petushek, 2010; Walker, 2016b). This movement pattern includes an eccentric/lowering phase, transition, and a concentric explosion phase, similar to that of a countermovement jump. By loading the agonist muscles during the eccentric phase, the upward concentric contractions used to propel the body in the desired direction is potentiated via stretch forces; this is due to the series and parallel elastic components of the muscle fibers, connective tissues, and tendons that give the muscles a "spring-like" nature. Movements applying the SSC can further be classified as "slow-SSC" and "fast-SSC" determined by the amount of time required to fully complete a cycle (Walker, 2016b). Sprint running is classified as a fast-SSC movement given the minimal ground contact time and rapid turnover of each stride, whereas the countermovement jump is considered a slow-SSC (Walker, 2016b). Slow-SSC movement patterns, such as the countermovement jump, that have a longer eccentric and transition phase allow for increased muscle cross-bridging leading to greater force and power output (Walker, 2016b).

Muscle Fiber Type

Fiber type is connected to contraction time and force production as determined from metabolic capabilities (oxidative or glycolytic) and adenosine triphosphatase (ATPase) activity (fast or slow), and classified into the following types: Type I, Type IIa, and Type IIx (Baechle & Earle, 2008, p. 9). Type I fibers are oxidative cells that are dense in mitochondria, leading to their greater ability to utilize glucose and fat through oxidative phosphorylation for aerobic energy production. These fibers contain slow myosin ATPase, which result in slower contractions that can be sustained for greater durations at lower intensities, making these fibers ideal for endurance activity. Type IIa fibers contain fast myosin ATPase allowing for rapid, powerful contractions during high intensity exercise for shorter durations. These fibers typically utilize the anaerobic lactic energy system and have increased capillarization, as compared to Type IIx fibers, allowing them to utilize some oxygen for aerobic metabolism and fatigue resistance. Type IIx fibers contain fast myosin ATPase, resulting in rapid, powerful contraction; however with decreased capillarization, these fibers primarily utilize anaerobic alactic energy system. The quantity of each of these fibers can affect the shortening velocity of the entire muscle, thus affecting sprint performance ability. Type II muscle fibers are predominantly powerful and have a faster shortening velocity, making them ideal for sprinters. The recruitment of motor units depends on the physiological demands on that muscle during activity (Baechle & Earle, 2008, p. 11). With specific training, each of these muscle fiber types can be hypertrophied but they can also switch to a different fiber type to meet the demands of physical activity, via the SAID principle (Baechle & Earle, 2008, p. 379).

Kinematics of Sprinting

Sprinting can be divided into different phases: start, acceleration, transition, maximal velocity, and deceleration (Cunha, 2005). At the starting phase it is important to generate great amounts of force and power to reach high velocities leaving the starting blocks and while accelerating. Elite sprinters generally position their center of mass closer to the starting line during a block start, reducing the distance in which their center of mass must be displaced during the pushing phase of the start (Slawinski et al., 2010). By shifting the initial position of the center of mass closer to the starting, greater center of mass velocity during the pushing phase can be achieved, resulting in higher velocities when exiting the blocks. Sprinters with the ability to exit the starting blocks with high velocity have increased with sprinter performances over 100-meters (Slawinski et al., 2010). During the transition to constant/maximal velocity, it is important to maintain explosiveness and power while also maintaining mechanical efficiency to prolong the transition to deceleration (Mero et al., 1992). This takes the form of maintaining or increasing stride length and frequency. Stride length and frequency are determinants of horizontal velocity, thus by increasing one factor or both, velocity can be increased. Hunter et al. (2004) reported that among sprinters, as a group, step length was related to sprint velocity; however, individuals within the study experienced their fastest sprint trials when step rate was the highest (Hunter et al., 2004). This was most likely explained by the increase in stride frequency due to shorter ground contact times and greater muscle shortening velocity, while stride length remains constant (Hunter et al., 2004; Kumagai et al., 2000; Morin et al., 2012). Lastly, it is crucial to note that external factors including footwear, wind and ground resistance, may affect sprint performance (Mero & Komi, 1986).

Diving deeper, the specific joint moments can influence whole-body kinematic sprint performance. Stiffness in the knee joint increased during the transition from acceleration to maximal velocity, meaning the degree of flexion in the knee upon ground contact decreased (Kuitunen et al., 2002). Also, within the same study, peak joint moments stayed relatively constant in the ankle while increasing at the hip and decreasing at the knee, displaying that changes in knee stiffness as more influential on sprinting speed (Kuitunen et al., 2002). When comparing collegiate distance runners and sprinters, sprinters had lesser knee angle ranges, longer stride lengths and shorter ground contact times at equal running speeds (Cunningham et al., 2013). This could be mostly due to the influence of neurological components related to elastic explosiveness via the SSC that aid in force generation for rapid movement during sprint locomotion. Also, muscle activation time, force generation and stress load can be influenced by trunk orientation and joint moments during maximal sprinting. Nagano et al. (2014) reported the timing of peak biceps femoris force as synchronous with maximum biceps femoris length as well as peak forces in the gluteus maximus, ipsilateral and contralateral iliacus, and peak anterior pelvic tilt. It was concluded that the activation timing and force generation from the biceps femoris during maximal sprinting is influenced by other muscles that cross the hip joint (Nagano et al., 2014). During the late stance phase, the hamstring muscles (biceps femoris and semimembranosus) experience eccentric contraction and, when sprinting with forward trunk lean, the length of the hamstring tendons was significantly greater than when sprinting with an upright torso orientation. By sprinting with a forward trunk lean, excess elongation load is added to the hamstring muscles potentially increasing the risk of tissue injury (Higashihara et al., 2015).

Kinetics of Sprinting

For understanding sprint performance ability, it is important to note the role of force development and application. Sprinting requires large amounts of force production for powerful, explosive movement of body mass. Ground reaction forces are the result of a mass directing force into the ground and receiving equal and opposite forces in return, causing movement in the given direction that force was applied in. The magnitude of force applied is crucial to the power behind the initiation of the sprint start (Hansen, 2016). In addition to the magnitude of force, elite sprinters hold greater ability to apply the resultant ground reaction force vector in a forward-horizontal direction with minimal vertical displacement during sprint start, acceleration, and maximal sprinting, leading to greater horizontal sprinting velocities and superior sprint performance (Colyer et al., 2019; Hunter et al., 2005; Morin et al., 2012). From this, it is concluded that the strength of the sprinter becomes vital to their ability to reach greater velocities leaving the starting position.

Speed requires more than just the ability to apply large magnitudes of force, as it must be done quickly. The rate of force development (RFD) is the speed in which muscles can generate force and is used to measure explosive strength. RFD is displayed visually on a force-time graph where the rate is the slope of the force change during the given time period. In the literature, RFD is related to efficient starting and acceleration ability as it determines sprinting performance (Slawinski et al., 2010; Thomas et al., 2015; Wang et al., 2016; West et al., 2011). Elite sprinters had greater RFD with early muscle contraction, allowing for increased velocity leaving the starting blocks (Slawinski et al., 2010). RFD becomes crucial to sprinting performance as it relates to the length of time in which the foot is in contact with the ground, or ground contact time, during various phases of sprinting. During various phases of sprinting, ground contact times are similar to as follows in the graph below, but may fluctuate depending on the athlete's sex and skill level.

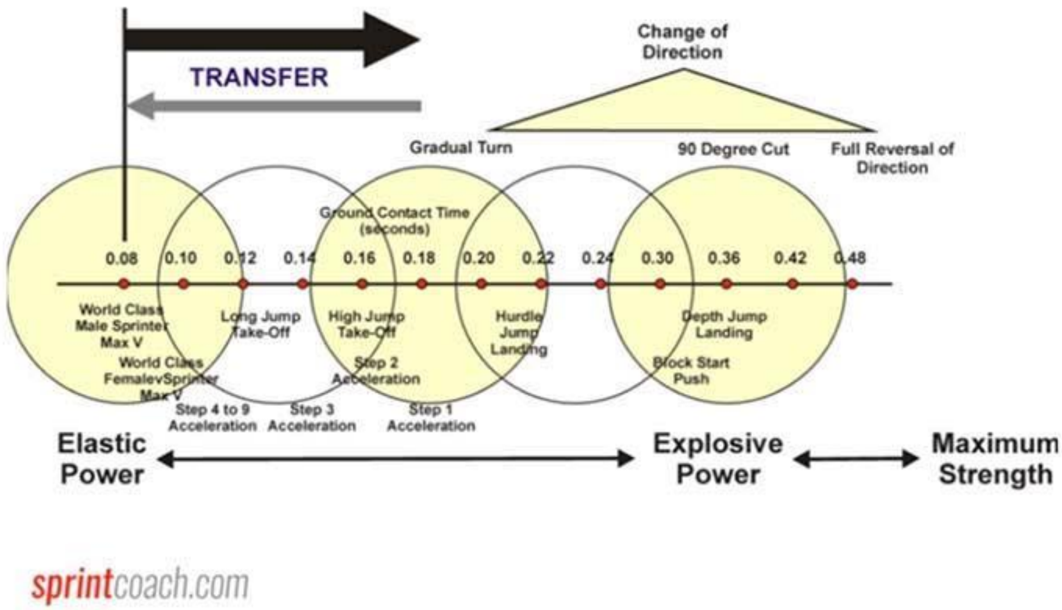

Figure 1: Various ground contact times across running and jumping movements up to World Class level sprinters (Valle, 2018).

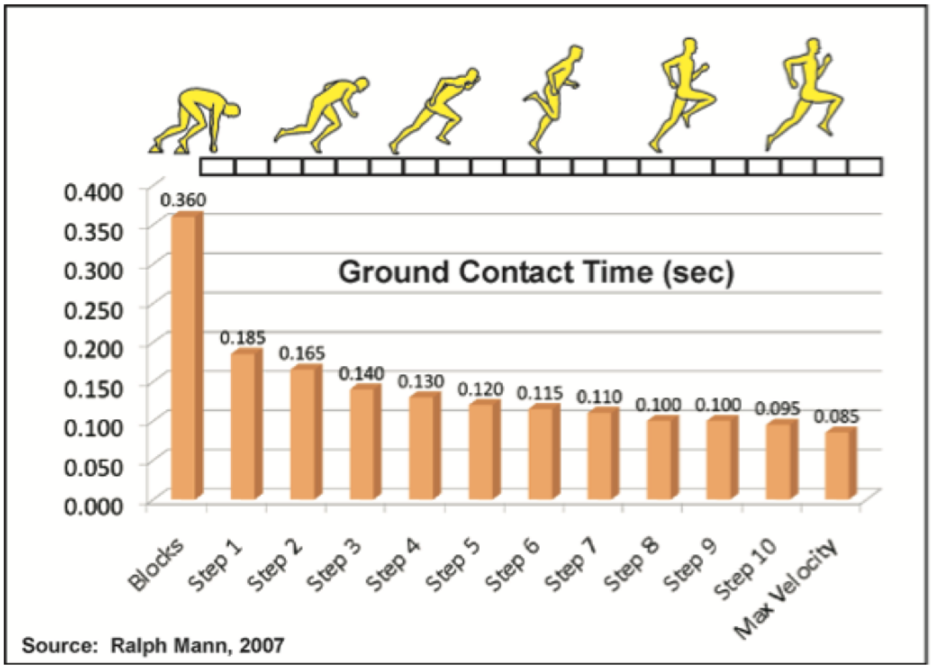

Figure 2: Ground contact times associated with sprint acceleration steps up to maximal velocity (Hansen, 2016).

It is important to note the spectrum for the ground contact times during acceleration steps of sprinting ranging from 0.18 to 0.10-12 (for elite level sprinters), with the contact time getting shorter as the sprinter reaches maximal velocity. As seen in Figure 1, the longer ground contact times are closer to the explosive power range of the spectrum, allowing greater time for force production and application. As the ground contact time is decreased, the spectrum shifts more towards elastic power, meaning that movements are more spring-like and no longer allow for as great of force application (Bellon, 2016). Also, as the step count progresses towards maximal velocity, the length of ground contact time continues to decrease, as displayed in Figure 2. During early acceleration, lengthened ground contact times allow for greater amounts of force to be applied, so RFD becomes crucial. As ground contact decreases and the sprinter approaches maximal velocity, the elastic power of the SSC is utilized.

Athlete Monitoring

Periodization in training programs is designed so that athletes will be at their performance peaks during their competition season while preventing injuries associated with overtraining. By introducing routine athlete monitoring programs, sports performance coaches have the ability to track their athletes' progress throughout their training programs. In addition, monitoring progress is important for identifying the gains an athlete is making throughout their training by comparing previous performances, while also aiding in the identification of weaknesses for the athlete or program. Monitoring initiatives are to benefit athletes and coaches by recognizing measures in which athletes have improved or diminished so that training may be adjusted accordingly. Other benefits of regular monitoring include use of daily readiness measures, such as the CMJ, which can be used to obtain insight to the preparedness for training on a given day. Lastly, for competitive purposes, routinely monitoring for progress gives opportunity for personal competition and feelings of accomplishment to athletes when they improve on a mark.

Evidence-based athlete monitoring programs utilizing technology and statistical procedures are relatively new, therefore the literature base supporting initiatives is small, and current studies primarily surround male athletes within the sports of rugby and soccer (Comfort et al., 2020; Owens, 2011; Wang et al., 2016). There are also few sports performance studies representing populations of athletes outside the professional to elite status, specifically within the NCAA Division 1 or Division 2 status (Hunter et al., 2004; Owens, 2011; Slawinski et al., 2010), so the aim was to focus on the well-trained to novice athlete training status that is encapsulated within this testing population. Furthermore, there appears to be minimal literature surrounding evidence-based athlete monitoring within the sport of track and field, more specifically, including female athletes. Lastly, the methods for athlete monitoring also vary based on the demands and athlete needs specified by each sport. Tailoring monitoring programs to the needs of each sport allows for the greatest yield of meaningful, usable data values, hence it was necessary to create a monitoring protocol specific to track and field athletes.

Countermovement Jump

The countermovement jump (CMJ) is a plyometric movement pattern consisting of an eccentric lowering phase, transition phase, and concentric explosion phase; however, it can further be broken down into standing bodyweight, unweighting, braking, propulsive, flight and landing phases (Chavda et al., 2017). Figure 3, included below, demonstrates the sequence of events for the CMJ as well as the force-time-velocity characteristics that correspond to each phase of the movement.

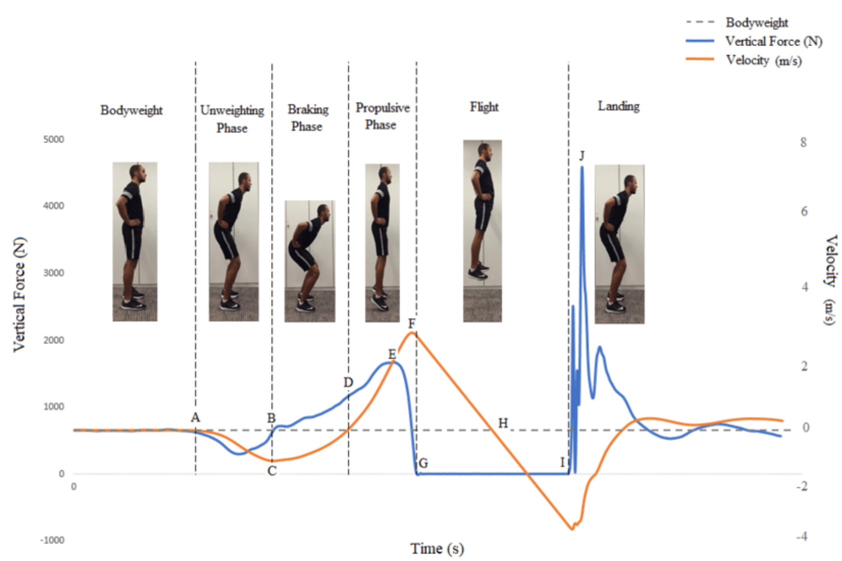

Figure 3: Force-time-velocity graph corresponding to the various phases of the countermovement jump (Chavda et al., 2017).

As previously described, the CMJ utilizes the reactive strength of the stretch shortening cycle for involuntary rapid force production and movement speed (Ebben & Petushek, 2010; Walker, 2016b). Due to the SSC aspects of CMJ, it may be used as a neuromuscular measure. Gathercole et al. (2015) had identified the CMJ as an efficient athlete-monitoring measure for neuromuscular fatigue immediately after, 24 hours and 72 hours after fatiguing exercise as various power metrics returned to baseline upon full recovery. Additionally, the CMJ has been used in various studies for the purpose of understanding explosive characteristics of athletes as it relates to athletic performance (Kale et al., 2009; Markström & Olsson, 2013; West et al., 2011). Other literature draws connections between the depth jump and sprint performance (Barr & Nolte, 2011), however for the purpose of this study and monitoring protocol, the CMJ was determined most appropriate as the movement is easily standardized and familiar to most athletes thus reducing risk of injury.

Jump height measured in the CMJ was found to be correlated with stride length during maximal sprinting (Kale et al., 2009). In addition, relative peak force from the CMJ was used by Markstrom & Olsson (2013) to predict 10- and 60-meter sprint time as it primarily relates to body mass velocity specific components. Similarly, West et al. (2011) stated that the CMJ and 10-meter sprint acceleration both rely heavily on the acceleration of body mass, because of this, it is predicted that these variables may be related to the rate of force development in the CMJ, thus the ability to accelerate rapidly during sprinting (West et al., 2011). Though peak force from the CMJ is connected to acceleration, track programs may not have access to force platforms; therefore, jump height was determined to be an acceptable alternative for a simple collection approach and relationship to the reactive strength of SSC components. Reactive strength is another component of plyometric stretch shortening cycle movements. The reactive strength index (RSI) is used to determine ability to change body mass direction from eccentric to explosive concentric action during plyometric movements (Ebben & Petushek, 2010; Walker, 2016a). RSI is primarily determined during the depth jump by dividing the jump height by the ground contact time; however, Ebben & Petushek (2010) introduced a modified version of the index that can be used and applied to the CMJ by dividing time to take off by the jump height. In the present study, RSI for the CMJ (RSImod) was calculated in the Hawkins Dynamics system using flight time divided by contact time, where contact time is the initiation of the countermovement up until the take off. Given the information displayed in the literature, the testing variables utilized from the CMJ for the present study include jump height and RSImod.

40-meter Sprint

The use of the 40-meter sprint test is to determine sprint performance ability, while also allowing for repetitive bouts without excessive fatigue, as demonstrated by Wang et al. (2016). Within the phases of sprinting, acceleration accounts for 0- to 30-meters and maximal velocity between 30- and 40-meters. This distance allows for optimal speed performance without excess deceleration or fatigue breakdown. Split marker cones are placed at every 10-meter increment to allow for analysis of early and late acceleration through the transition into maximal velocity. To quantify early acceleration as it relates to strength and power, previous literature has utilized the 10-meter split time from sprint tests (Barr & Nolte, 2011; Markström & Olsson, 2013; Slawinski et al., 2010).

Isometric Mid-Thigh Pull

The isometric mid-thigh pull (IMTP) is an assessment tool used to measure an athlete's maximal force production ability (peak force) and the rate at which the maximal force is applied (RFD) (Comfort et al., 2020; Wang et al., 2016). This testing technique has been used to extract force-time variables found to be connected to sprint, agility, and strength performance in sports like soccer, rugby, and track and field (Comfort et al., 2020; Owens, 2011; Thomas et al., 2015; Wang et al., 2016; West et al., 2011). The test places the athlete in a pulling position similar to the second pull position from the power clean, displayed below, where the athlete then pulls upwards with maximal effort on a immobile bar while standing on a force platform.

Literature surrounding the use and standardization of the IMTP is varied (Comfort et al., 2020; Wang et al., 2016). Studies surrounding the IMTP range from self-selected pull positions to set angles of knee flexion as represented by the literature. Body position is a crucial component to the IMTP, as it can be a limiting factor to an athlete's ability to effectively and safely produce force. When placed in an upright trunk orientation, athletes with weightlifting experience were able to produce greater magnitudes of force when compared to a "bent-over" trunk position (Beckham, 2015). This is due to the upright positions similarity to the second-pull of the power clean. The "bent-over" position has greater hip flexion and resembles the transition phase between the first and second pull, and it is during this transition in which force production is lowest. In regards to knee flexion angle, it was displayed that during an isometric leg press, the force produced during a maximal voluntary contraction and electromyography activity of the rectus femoris and vastus medialis was greatest at 120 degrees of knee flexion as compared to 90-100 degrees of flexion (Papadopoulos et al., 2008). However, pertaining to the IMTP specifically, the optimal angle of knee flexion is recommended to be 125-145 degrees (Beckham, 2015; Comfort et al., 2019). Optimal knee angle positioning should be determined in the light of the length-tension relationship for optimal force production during muscle contraction. The length-tension relationship refers to the degree of joint flexion that allows for the greatest amount of force production as a result of the optimal amount of myofilament cross-bridging. Applying this literature to the present study, the upright pull position was utilized with the optimal range of knee flexion between 125-145 degrees (135±10).

The literature is varied in the conclusions surrounding the relationship of force-time variables and dynamic sprint performance. In Rugby players, absolute peak force from the IMTP was not related to dynamic performance in the 10-meter sprint; however, peak force relative to body weight was determined to be related (West et al., 2011). Other findings contrasted with this claim and found peak force was related to sprint performance over 5-meter and 20-meter splits (Thomas et al., 2015). With this in mind, it is important to note that early sprinting requires the rapid acceleration of body mass, meaning that force production during dynamic performance is relative to the body mass of the athlete. Athletes with superior start and acceleration performance may also have superior sprint performances that carry over into maximal velocity. In collegiate athletes, peak force was utilized to quantify overall strength as it pertained to force development (Comfort et al., 2020). This comes back to the conclusion that exiting the starting position during sprinting requires large amounts of force for successful performance (Hansen, 2016). Furthermore, peak force relative to body mass is another variable to be considered as it can be more closely related to dynamic performance and acceleration of body mass. Markstrom & Olsson (2013) utilized relative peak force from the CMJ to understand sprinting ability; however, since IMTP is utilized for strength measures, absolute peak force and relative peak force will be used to understand the relationship of isometric strength and determine any carry over into dynamic performance. In addition, the rate of force development (RFD) collected from the IMTP can be utilized to understand acceleration ability as it correlates with 5-meter sprint time (Wang et al., 2016; West et al., 2011). Comfort et al. (2020) noted the benefit of quantifying and monitoring training adaptations to view the proportion of increase in either early force development or maximal force development. Based on the ground contact time metrics being between 100-180 milliseconds and use of RFD at 100 milliseconds by previous studies on elite level sprinters, the rate of force development time frame was determined (West et al., 2011).

Also, with consideration to the athlete population that was included in the present study, we can assume the ground contact time will be longer when compared to athletes at the elite level. Given the conclusions within the literature, the variables chosen for examination in the present study for the IMTP test include absolute peak force, relative peak force, and rate of force development at 0-150 milliseconds.

It was predicted that CMJ variables are most correlated to sprinting performance over 40-meters, while IMTP performance will have the strongest correlation with acceleration ability. With regard to the regression model, it is predicted that RSImod will be most indicative of 40-meter sprint time while RFD will be indicative of 10-meter acceleration time due to the neurological components of maximal sprinting and force generation for early sprint acceleration.

Methodology

Experimental Approach to the Problem

The purpose of this study is to determine which athlete monitoring variable is most indicative of sprint performance ability. To perform this retrospective analysis, a stepwise multiple linear regression was conducted. The independent variables used in this study are relative peak force, absolute peak force, and RFD 0-150ms from the IMTP, as well as jump height and RSImod from the CMJ. The dependent variables are the 10- and 40-meter sprint times from the sprint test. Relative peak force is the greatest force, in Newtons, applied to the force platform during the pull divided by the athletes system weight in kilograms, while absolute peak force is the greatest force applied to platform in Newtons. RFD 0-150ms is the rate of force development, in Newtons per second, over the 0 to 150 millisecond time frame. Jump height from the CMJ is the total height the athlete was able to jump in meters. RSImod is the flight time divided by the time to takeoff, indicated by the initiation of the countermovement until takeoff. By selecting these variables, it is possible to infer whether force generation or explosive elasticity is most indicative of sprinting performance

Subjects

The subjects included in this study are 16 female jump and sprint athletes (n = 16) on a collegiate NCAA Division 2 track and field team. There were 19 female athletes that participated in the data collection, as part of the Athlete Monitoring Initiative at the university, however 3 of these participants were excluded from this study as their event did not rely on sprinting ability. Selection of this sample stems from the physiological and specific skill demands of each event. Jump and sprint events require sprinting ability for successful performance; because of this, only the athletes that participate in these events were included in this study. Athletic ability and sport-specific skill ranges from beginner to well-trained experience levels, and widely varies across the heterogeneous sample. Use of this sample allows for inference on a population of athletes typically not included within the literature, as they are female and outside of professional skill level. Athletes are between 18 and 26 years of age (21.01±1.69 years) with body masses between 49 and 69 kilograms (60.47±6.01 kg). The present study was approved by the university's ethical review board and all subjects were made aware of the benefits and risks for participating prior to signing a written informed consent.

Procedures of Athlete Testing

The order of testing events was determined according to guidelines put forth by the National Strength and Conditioning Associations recommendations for exercise order (Baechle & Earle, 2008, p. 391). The CMJ was the first test because it is the least fatiguing and most powerful movement that also allows for explosive potentiation before the sprints. Next, the 40-meter sprint test, is speed and power focused while also being moderately fatiguing. Lastly, the IMTP was performed because this movement is strength focused and heavily fatiguing. The CMJ and IMTP tests were performed on dual force platforms and recorded on the Hawkins Dynamics mobile app, and sprint testing utilized the Freelap automated timing system to electronically collect times. Warm up activities, CMJ, and 40-meter testing was conducted on an all-weather track, while the IMTP was conducted within the university's Sports Performance

Center. All testing was completed in one 2 to 3 hour session, and replaced a day of practice for the athletes involved during their normal afternoon practice time slot.

Athletes performed their usual team warm up including 5 minutes of low intensity jogging, dynamic stretching, and sprint drills. Sprint drills included high-knee running, "butt-kick" emphasis running, A- and B-skips, and other cycling locomotive movements to potentiate for sprint testing. The goal of this warm up was for athletes to feel fully prepared for maximal effort sprinting and were encouraged to warm up how they saw fit, similar to a competition day.

Countermovement Jump

Athletes were instructed on how to perform the CMJ, keeping both of their hands placed on their hips at all times, unable to utilize arm swing. The hand placement on the hips serves to standardize the CMJ by eliminating the potential confounding effect of the arm swing and maintaining focus on lower body power. Athletes performed trial jumps at 50% and 75% effort, with 30 seconds rest between for familiarization with the testing commands and to allow for coaching before moving into a series of maximal effort jumps. For each jump, athletes were instructed to remain still on the force platform with their hands on their hips, on the command "3, 2, 1, JUMP!" to "jump as high as possible with a countermovement", and to remain still upon landing until it was indicated that the recording was finished. Maximal effort jumps were given between two and five attempts depending on the precision of jump height achieved with each trial. Athletes that continued to improve their maximal jump height were encouraged to jump again, so that top marks were within 0.02-meters of each other. Each maximal effort trial was followed by 30 to 60 seconds of rest between. Jump height was recorded to the 0.0001 meter via the force platforms and only maximal effort jumps were recorded.

40-meter Sprint

Athletes moved to the 40-meter sprint test after completing their CMJ trials. Freelap timing cones were placed at the start line, 10-, 20-, and 30-meters until the finishing cone at 40-meters to collect split and lap times at the respective meter marks. Sprint testing was conducted on an all-weather track surface and athletes were instructed to wear their sprinting spikes and start in the three-point start position. Athletes ran in self-selected pairs to encourage competition and maximal effort. Two warm up strides at 50% and 75% through the timing gates were completed before maximal effort trials. Athletes were instructed to start on the traditional track starting commands of “runners to your mark,” “set,” and to begin on a loud clap to simulate the starting gun. Lastly, athletes were instructed to sprint as fast as possible and completely through the 40-meter finish to ensure maximal effort was given for the entirety of the testing distance. Three maximal attempts were allowed for each athlete with 5 minutes rest between each trial. All times were measured to the nearest 0.01 second and only maximal sprints were recorded.

Isometric Mid-Thigh Pull

IMTP testing for the present study follows similar procedures used by Owens (2011), Comfort et al. (2019), Comfort et al. (2020), and Beckham (2015) as it pertains to warm up, body positioning, and standardized commands. Prior to IMTP testing, athletes performed an additional warm up consisting of the following exercises, respectively: 1 minute on a fan bike at rate of perceived exertion “5 out of 10,” 10 bodyweight squats, 1x5 mid-thigh pulls at 20kg, then 3x5 mid-thigh pulls at 40kg. This warm up procedure, prior to the IMTP, was modified from those used by Owens (2011). Fan biking promotes increased circulation while body weight squats promote complete, dynamic range of motion before additional loads are added. Warm up procedures vary within the literature, but most utilize body weight movements such as squats or lunges then a weighted exercise that mimics the IMTP position -- either cleans or mid-thigh pulls (Beckham, 2015; Comfort et al., 2019, 2020; Owens, 2011). Body position for the IMTP mimics the second pull of the power clean movement with torso upright in a slight flexed position, knee and hip flexed slightly, dorsiflexed ankles, hands gripping the bar in pronation just outside the thighs (similar to the power clean grip), shoulder girdle retracted and depressed, elbows extended, and feet centered under the bar at approximately shoulder width distance (Comfort et al., 2019). Utilizing a standardized upright body position and pronated hand grip agrees with

Beckham (2015), Comfort et al. (2019, 2020), and Owens (2011); however, differs from self-selected positioning used by Wang et al. (2016). Upon addressing the bar, athletes were coached into the upright mid-thigh pull position so the correct bar height could be adjusted and recorded. Bar height was adjusted so that athletes' knee angle was between 125-145 degrees (135±10 degrees) (Beckham, 2015; Comfort et al., 2019; Owens, 2011).

For each of the IMTP trials, athletes were instructed to "assume the power position," place steady "tension on the bar" to prevent countermovement on the initiation of the pull, and on the countdown "3-2-1-PULL!" to "pull upward as fast and hard as possible" until motioned to stop. Each pull should last the duration of about four seconds (Beckham, 2015; Comfort et al., 2019; Owens, 2011). IMTP warm up trials at 50% and 75% were utilized similar to Beckham (2015) and Owens (2011) however only one trial at each effort percentage was performed to prevent excess fatigue. The 50% warm up trial was followed by thirty seconds of rest before moving to the 75% trial, then one minute before the maximal effort trials. In order to eliminate the limiting factor of grip strength, lifting straps were utilized for maximal effort trials. Between two to four maximal effort pulls were recorded so that the top two pulls had peak forces that were less than 200 Newtons apart. Only maximal effort pulls were recorded.

Statistical Analysis

Maximal effort trials from each of the tests were recorded in either Freelap or Hawkins Dynamics before auto-calculated variables were exported into Excel for cleaning and organization. Top trials for the sprint test were determined by 40-meter sprint time; top trials for CMJ were determined by jump height in meters; top trials for IMTP were determined by absolute peak force achieved. Each athlete's top two trials for IMTP and CMJ were averaged and utilized for analysis to increase reliability, while the single best effort trial from the sprint test was used. The specific variables of interest for this study are 10- and 40-meter time from the sprint test, jump height and RSImod from the CMJ, as well as relative peak force, absolute peak force, and RFD for 0-150ms from the IMTP. A stepwise multiple linear regression model was created in

SPSS Software (IBM) to predict sprint performance ability given the athletes' strength and power metrics, as well as identify relationships between performances in the various testing measures. This approach is similar to regression models used by Markstrom & Olsson (2013), where sprint performance was predicted using CMJ variables.

Results

Summaries of the data from this sample are displayed in Table 1. Pearson correlations displaying the relationships between jump and pull metrics with early and late sprint performance can be found in Table 2. Jump height displayed statistically significant correlations with 10-meter ($r = -0.796, p < 0.001$) and 40-meter ($r = -0.839, p < 0.001$) sprint performances. RSImod displayed statistically significant correlations with 10-meter ($r = -0.576, p < 0.05$)and 40-meter ($r = -0.510, p < 0.05$)sprint performances. In addition, relative peak force displayed statistically significant relationships with 10-meter ($r = -0.581, p < 0.05$) and 40-meter ($r = -0.594, p < 0.05$) sprint performances. Pearson correlations displaying the relationships between jump and pull performances can be found in Table 3. Jump height has a significant correlation between RSImod ($r = 0.636, p < 0.01$)and relative peak force ($r = 0.630, p < 0.01$). All other relationships were insignificant.

Table 1: Data collection summary

	Sample Size	Age (years)	10-m (s)	40-m (s)	Jump Height (m)	RSImod	RFD 0-150 ms	Relative Peak Force (N/kg)	Absolute Peak Force (N)
Mean ± SD	n = 16	21.01 ±1.69	2.0925 ±0.1052	5.8963 ±0.2766	0.3317 ±0.0480	0.7324 ±0.1547	3116.4063 ±1816.7542	258.5292 ±44.3906	2165.9531 ±262.9645

Table 2: Pearson correlations and significance for jump, pull, and sprint metrics.

	10-m	40-m
Jump Height (m)	*r* = -0.796 ** *p* < 0.001	*r* = -0.839 ** *p* < 0.001
RSImod	*r* = -0.576 * *p* < 0.05	*r* = -0.510 * *p* < 0.05
Relative Peak Force (N)	*r* = -0.581 * *p* < 0.05	*r* = -0.594 * *p* < 0.05
Absolute Peak Force (N)	*r* = 0.142 *p* = 0.600	*r* = 0.008 *p* = 0.978
RFD 0-150	*r* = -0.054 *p* = 0.842	*r* = 0.142 *p* = 0.600

Table 3: Pearson correlations and significance for jump and pull metrics.

	Jump Height (m)	RSImod
Absolute Peak Force (N)	*r* = -0.035 *p* = 0.897	*r* = -0.206 *p* = 0.444
RFD 0-150	*r* = -0.044 *p* = 0.870	*r* = 0.363 *p* = 0.167
Relative Peak Force (N)	*r* = 0.630 ** *p* < 0.01	*r* = 0.386 *p* = 0.14
Jump Height (m)	------------	*r* = 0.636 ** p < 0.01

* significant at the p < 0.05 level (2-tailed). **significant at the p < 0.01 level (2-tailed).

A stepwise multiple regression was run to predict sprint performance ability from jump and pull metrics -- specifically jump height, RSImod, relative peak force and RFD. Jump height was found to be the only statistically significantly predictor of 10-meter sprint performance, $F(1,14) = 24.291, p < 0.001, R^2 = 0.634$. This regression resulted in 63.4% of the variance in sprint performance within the sample explained by the independent variable, jump height($R^2 =$

$0.634, p < 0.001)$. Equation 1 refers to the regression equation created to predict 10-meter sprint time, using jump height.

Equation 1: 10-meter prediction equation

$$10\ meter\ sprint\ time\ =\ 2.673 - (1.750\ \times jump\ height)$$

When 40-meter time was used as the dependent variable, jump height was also found to be the only statistically significantly predictor 40-meter sprint performance, $F(1,14) = 33.259, p < 0.001, R^2 = 0.704$. This regression resulted in 70.4% of the variance in sprint performance within the sample explained by the independent variable, jump height $(R^2 = 0.704, p < 0.001)$. Equation 2 refers to the regression equation created to predict 40-meter sprint time, using jump height.

Equation 2: 40-meter prediction equation.

$$40\ meter\ sprint\ time\ =\ 7.499 - (4.833\ \times jump\ height)$$

In both models, RSImod, relative peak force, and RFD 0-150 were excluded and not found to be significant predictors of sprint performance ability over 10- or 40-meters.

Discussion

Sprinting ability is highly influenced by strength and power abilities as it relates to dynamic performance. In the present study, CMJ was found to be a useful tool for assessing sprint ability in heterogeneous, female track and field athletes whose event requires a degree of sprinting. The hypothesis that CMJ metrics would be most related to 40-meter sprint performance was confirmed through the present analysis, however CMJ variables also were most related to 10-meter sprint performance. Findings of this analysis are consistent with those of Barr & Nolte (2011), Markstrom & Olsson (2013), and West et al. (2011) as it pertains to the importance of power development for dynamic movements such as sprinting. As displayed in Equations 1 and 2, jump height from the CMJ is a significant predictor of 10- and 40-meter sprint performance. Also, there is a strong negative relationship between CMJ height and 10-meter sprint time, similarly to Markstrom & Olsson (2013) and Barr & Nolte (2011), as well as with 40-meter sprint time. In addition, RSImod has a significant negative relationship to both 10- and 40-meter times. This can be used to understand the importance of lower body power and explosive elasticity that is required for dynamic movement.

It is inferred that improvements made to jump height could be used to predict changes in sprint performance during early acceleration and top speed phases. This finding may be explained by the familiarity of the CMJ movement and stretch shortening cycle aspects as they relate to explosive elasticity and rapid acceleration of body mass during sprinting, suggesting elastic explosiveness could be of greater significance than overall strength within the sport of track and field. Sprinting requires explosive power to accelerate body mass and maintain maximal velocities utilizing neurological and stretch shortening cycle elastic components. Elastic properties contribute to increased movement speed and force production through involuntary stretch reflexes during locomotion. Both parallel and series elastic components found in muscular membranes and tendons aid in the creation of spring-like energy for force production during sprint locomotion. With this in mind, the CMJ would be a useful tool for coaches hoping to gauge seasonal changes in sprinting ability by monitoring power and explosive strength capacity as developments could result in improvements to jump height. In addition to this, CMJ testing can be a safer measure for quantifying sprinting ability during offseason or preseason training periods, as it isolates lower body power capabilities in a controlled environment without introducing intense sprinting stimulus. CMJ testing may also be conducted routinely as a daily readiness measure to quantifiably gauge where an athlete is physically on a given day.

It was predicted that IMTP variables would be indicators of early sprint acceleration due to the ability to rapidly apply large magnitudes of force during brief ground contact times of sprinting. This prediction was not supported within the present study; however, findings are consistent with West et al. (2011) as it pertains to the IMTP and dynamic performance in jumping and sprinting movements. Similar to West et al. (2011), peak force values from the IMTP were not significant predictors of sprinting ability. It is important to note that relative peak force has a significant negative correlation with 10- and 40-meter sprint ability and a significant positive correlation with jump height. This relationship between force and dynamic performance suggests that force generation as it relates to body mass is of greater importance for explosive movements, like sprinting and jumping, than the greatest achievable magnitude. Sprinters are required to propel their mass across the track efficiently so necessary force production is that which is used to rapidly move their mass.

The purpose of utilizing IMTP for force generation was to determine total body strength capabilities outside of dynamic movements to determine a carry-over of absolute strength into explosive movements. Because of the difference in dynamic versus isometric force measures, comparisons between findings pertaining to the relationship of force development and sprinting as displayed in Markstrom & Olsson (2013) is difficult. Previously, relative peak force from CMJ was found to have greater relationship strength and significance when compared to the model utilizing jump height (Markström & Olsson, 2013). Relative peak force from IMTP was not found to be a significant predictor within this sample, as it was in Markstrom & Olsson (2013) using the CMJ. Differences may be explained by the variance in collection techniques, mostly since CMJ is a dynamic movement utilizing dynamic explosive strength measures while IMTP is a isometric absolute strength measure. Another explanation for the possible exclusion of the IMTP variables from the predicting equations could be the lack of athlete familiarity with the IMTP testing method. A lack of a pilot or familiarization session could have resulted in unreliable results from the IMTP leading to the exclusion of these variables from the model. Replication and athlete familiarity with the IMTP for future studies could result in changes to the predictability of sprint performance utilizing IMTP within this population. Lastly, IMTP may still be used for safe monitoring for strength changes during periodized training programs, as it eliminates potential confounding factors of 1-repetition maximum lifting testing like inefficient lifting technique and psychological barriers. Various literature supports the benefits of strength training as it relates to sprinting ability (Barr & Nolte, 2011; Bellon, 2016; Wang et al., 2016; West et al., 2011). Significant correlations between relative peak force with jump height, 10-meter, and 40-meter sprint times display the importance of strength for dynamic performance. Strength with respect to body mass is an important athletic characteristic as it relates to power production and injury prevention. Greater muscular strength also promotes resistance to tissue damage and can aid in injury prevention.

Jump height accounts for 63.4% of variance in 10-meter sprint ability and 70.4% of variance in 40-meter sprint ability within the present study. With this in mind, there are factors that could potentially explain the percentage of variance not represented within the models, which may include: genetic differences, differences in training backgrounds, as well as variance in events and the training prescribed per that event. Genetic factors influence physical traits, cardiorespiratory function, as well as skeletal muscle features and function (Eynon et al., 2010; Macarthur & North, 2005). Genetics may predispose athletes to successful sprint performance, although sport specific training backgrounds and programing can also create variance. It is crucial to note varying levels of performance could be explained by the wide variety of fitness characteristics spread across this heterogeneous sample. Athletes training for short sprint, long sprint, and jump events may undergo different training adaptations geared toward success in their particular event, creating variance within the sample.

CMJ is an effective tool that can be used to predict changes in sprint performance abilities in track and field athletes, as jump height from the CMJ can be used to predict 10- and 40-meter sprint performances (see Equation 1 and 2). Evidence suggests elastic power and explosiveness plays the greatest role in determining sprinting ability for track and field athletes. Though force measures were not direct predictors of sprinting ability, there is evidence suggesting a relationship between force production and dynamic performance in sprinting and jumping. Findings within this study were utilized to provide evidence for quantifiable techniques used to determine relationships between strength, power and speed for athlete monitoring initiatives within the sport of track and field.

Practical Implications

The suggestion of an evidence-based protocol specific to the sport of track and field encourages regular monitoring of athletes for tracking training adaptations, like strength and power, for the purpose of injury prevention and program modification. Utilizing the CMJ as a monitoring tool allows for inference on explosive, elastic power capabilities in a controlled and easily standardized environment. CMJ testing can be conducted without dual force platforms by using jump height alone to determine sprint ability. This is especially useful for programs without access to force platform technology, as evidence-based monitoring initiatives can still be applied. Routine athlete monitoring can identify potential signs of decreased performance due to overtraining for injury prevention and/or readiness for return-to-play. Collection of baseline marks allow for comparison for increases or decreases in performance as well as inference on athlete readiness to return to full intensity training following an injury. Lastly, routine monitoring can be used for program enhancement and modification to training, so coaches can quantifiably determine the needs of each athlete and the effectiveness of the training program in accomplishing the desired training adaptations.

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