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Association and Predictive Abilities of Jump and Throw Tests to Track Performance in Division I Athletes

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ASSOCIATION AND PREDICTIVE ABILITIES OF JUMP AND THROW TESTS TO TRACK PERFORMANCE IN DIVISION I ATHLETES

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Dedication

This thesis is lovingly dedicated to my mother, Denise Rebecca Cubillos. Her continuous support, encouragement, and continuous love has sustained me throughout my life.

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By

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THESIS

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Abstract

Sprinting jumping, and throwing are of the most vital abilities in track & field. Although various studies investigated relationships among these three aspects, there is limited empirical evidence as to how they may be correlated and predictive towards track performance. **Purpose:** To determine associations and predictive abilities of four field performance tests among a static (Accel30) and flying (Fly30) 30-meter sprint. This study also aimed to ascertain associations of kinematic and kinetic components of all field assessments to Accel30 and Fly30 sprint times. **Methods:** 23 subjects (18-25 years, 1.77 ± 0.10 meters, 78.67 ± 24.15 kg) performed two trials of a backward overhead medicine ball (BOMB) throw, unilateral and bilateral horizontal jump (HJ), vertical jump (VJ), Accel30 sprints, and Fly30 sprints. All field tests were performed on two force platforms (1000 Hz). Accel30 and Fly30 sprints were recorded with a video camera recording (120 fps) to obtain completion times. Spearman's rank correlation analysis was conducted for determining associations between jump and throw tests (VJ, HJ and BOMB throw) with athletic performance tests (Accel30 and Fly30 sprints). Series of Ordinary Least Squares regression analyses ($p < 0.01$) were conducted for track & field assessments to illustrate whether a particular jump or throw test predicted Accel30 and Fly30 completion time. The best predictive model was selected via forward-backward stepwise regression procedure. **Results:** Spearman's rank correlation analyses revealed the BOMB throw to be moderately correlated to Fly30 time ($r = -0.45$). Large correlations observed between unilateral HJ distance and Accel30 ($r = -0.61$) as well as towards Fly30 time ($r = -0.56$). Bilateral HJ distance exhibited very large associations between Accel30 ($r = -0.74$) as well as between Fly30 completion time ($r = -0.71$). Jump height from VJ test displayed moderate correlations in Accel30 ($r = -0.46$) as well as between Fly30 ($r = -0.34$). Both bilateral and unilateral HJ tests revealed to be most predictive of Accel30 ($R^2 =$

0.58 bilateral; R^2 = 0.49 unilateral) and towards Fly30 sprint times (R^2 = 0.59 bilateral; R^2 = 0.50 unilateral) compared to VJ for predicting Accel30 (R^2 = 0.31) and Fly30 (R^2 = 0.22). Lastly, BOMB throw assessment showed to be least predictive of Accel30 (R^2 = 0.19) and Fly30 completion times (R^2 = 0.18). **Conclusion:** Results suggest that the bilateral HJ assessment showed to contain very large correlations and predictions with Accel30 and Fly30 than the BOMB throw, unilateral HJ and VJ tests.

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Chapter 1: Introduction

IMPORTANCE OF SPRINTING, JUMPING AND THROWING IN TRACK AND FIELD

Sprinting jumping, and throwing are of the most vital abilities in various sports (e.g., basketball, soccer, baseball, football etc.) and are key determinants of competitive ability, especially in the sport of track & field. Track & field incorporates a high demand of sprinting at various distances (e.g. the 60 m, 100 m, 200 m, and 400 m), jumping (hurdles, long jumps, high jumps, etc.), and throwing (hammer throw, shot put, javelin throw, etc.) which are dependent on the events the athlete is competing in. Consequently, development of sprinting, jumping, and throwing is vital for their respective sport as well as strength and conditioning (S&C) programs which aim to enhance sport performance. Optimal modalities for aiming to develop these essential abilities include general resistance training, Olympic weightlifting, plyometric, and resisted sprint training interventions (Blazevich & Jenkins, 2002; Comfort et al., 2014; Cunningham et al., 2016; Hedrick, 2018; Markovic et al., 2007; Marques & González-Badillo, 2011). Although these forms of training programs are beneficial, strength coaches need to monitor the status of every athlete to ensure there is no indication of overtraining. Thus, implementing applicable physical assessments to track the progression of athletes and provide feedback to members of an athletic program are important (Lockie, Jeffriess, et al., 2012; Lockie, Murphy, et al., 2012; Spinks et al., 2007). Furthermore, it is imperative to assess athletes with the most appropriate tests that are reflective of the demands of the sport.

ASSOCIATION BETWEEN JUMPING AND SPRINTING

Various studies have been conducted to investigate relationships among muscular strength and power abilities and assessments of sport performance markers. Screenings that have been executed in previous studies include vertical (Bachero-Mena et al., 2017; González-Badillo

& Marques, 2010; Marques & Izquierdo, 2014; Requena et al., 2011) and horizontal jump variations (Habibi et al., 2010; Kale et al., 2009; Loturco, D'Angelo, et al., 2015; Maulder et al., 2006), isometric mid-thigh pull, (Brady et al., 2019), and throwing assessments (Aoki et al., 2015; Bourdin et al., 2010; Castro-Piñero et al., 2010; Stockbrugger & Haennel, 2003; Takanashi et al., 2020). However, one common approach in previous is the exploration of relationships between measures of jump and sprint performance. Results from previous literature have purported moderate to strong relationships between vertical jump parameters and sprint performance (Bachero-Mena et al., 2017; Markström & Olsson, 2013; Marques & Izquierdo, 2014; Young et al., 1995). Additionally, studies have examined the kinetics and kinematics of jump assessments (vertical and horizontal) and their associations between sprint performances. For instance, Marques and Izquierdo (2014) explored the relationships between 10-meter sprint time and several kinetic and kinematic parameters (displacement, instantaneous acceleration, instantaneous force, rate of force development, and instantaneous power output) during a weighted vertical jump using a linear transducer. Main findings from this study displayed significant associations between 10 m sprint time and peak velocity (r= -0.630). Thus, concluding that sprinting may be more correlated to the capability of moving a relatively light external resistance with maximum velocity. However, previous scholars have also suggested that the choice in jump variations when investigating correlations to sprint performance could be dependent on the running distances being analyzed. For example, previous authors have advocated that quantifications of horizontal jump variables could possibly be better associated for sprint performance in shorter distances (0-50 meters), whereas top maximal speed sprinting 100 meters (m) could display a stronger association to vertical jump parameters (Habibi et al., 2010; Holm et al., 2008; Loturco et al., 2018; Loturco, D'Angelo, et al., 2015; Loturco, Pereira, et al., 2015). The rationale being that short distance sprinting necessitates significant horizontal force production, whereas the vertical force production may have more of a predictive ability for maximum speed (Baumann, 1976; Hafez et al., 1985; Morin et al., 2015; Rabita et al., 2015). For example, one study in particular (Holm et al., 2008) investigated the relationship between the kinetics and kinematics (jump distance, reactivity coefficient, ground contact time, impulse, & ground reaction forces) of unilateral horizontal drop jump with 25 m sprint time, including five, 10- and 25-m splits. Main findings of this study exhibited strong correlations between all sprint times (five, 10, and 25 meters) and jump distance when normalized to subjects' height ($-0.44 < r^2 < 0.65$). Also, multiple linear regression analyses also suggested that the unilateral horizontal drop jump could account for a high level of variance in sprint time ($0.49 < r^2 < 0.68$) with a low standard error of estimate (0.02-0.10 seconds). However, it was concluded that future research should further investigate jump kinetics and kinematics and parameters of sprinting performance. Furthermore, Maulder and Cronin (2005) have indicated support for the claim, finding that horizontal jump variations (horizontal squat, countermovement and repetitive jumps) displayed superior predictive ability of 20 m sprint performance (r= -0.73 to -0.86) compared to vertical jump variations (r= -0.52 to -0.73). Additional empirical evidence found that horizontal jumps (single and triple hop assessments, standing long jumps) to be better correlated with short distance sprint performance (Habibi et al., 2010; Loturco, D'Angelo, et al., 2015). Lastly, one study indicated that vertical jump height had a stronger association (r= -0.85) with a 100 m dash times (Loturco, Pereira, et al., 2015). Thus, when deciding to implement vertical or horizontal jump variations, it is suggested to consider the possibility that sprinting distance can dictate the appropriate assessment being used. What is also noteworthy is that many of the previous studies have investigated these different jump variations (vertical and horizontal) largely in sprint acceleration performance (Dobbs et al., 2015; Holm et al., 2008; Maulder & Cronin, 2005; McCurdy et al., 2010; Schuster & Jones, 2016). These studies have not investigated the correlations to longer sprint displacements, which may differentiate between qualities of sprint performance (McCurdy et al., 2010). Additionally, more research is warranted in establishing the premise among the track & field populations. Since throwing is of importance in track & field, it would also be germane for investigating correlations between power assessments encompassing a throwing action and sports performance.

Association between Jumping, Sprinting, and Throwing Performance

Although throwing largely involves utilizing the upper extremities, the lower limbs are also known to be a contributor for optimal performance among various athletic populations like baseball (Lehman et al., 2013; McNally et al., 2015), handball (Chelly et al., 2010) as well as water polo (McCluskey et al., 2010). As stated, certain track & field events involve a high demand for throwing including the shot put, javelin, and hammer throw events. While the aforementioned sports do differ in their specific skill set and physical abilities required for success, the concept of enhancing, generating and transferring explosiveness in a kinetic sequence from the lower to the upper limbs remain consistent for superior throwing distance or velocity (Bourdin et al., 2010; McNally et al., 2015; Zaras et al., 2019). Previous research has supported that lower extremity power assessments (e.g. standing long jump) can be a useful tool for monitoring power capacity, whether it be in the lower or upper extremities (Castro-Piñero et al., 2010; Zaras et al., 2019). Another common assessment implemented for measuring full body power output is the backward overhead medicine ball (BOMB) throw test, showing moderate to strong correlations between sprinting and jumping performance (Lockie, Jeffriess, et al., 2012; Mayhew et al., 2005; Stockbrugger & Haennel, 2003). Although throwing abilities have shown to be associated with performance markers in track & field and other sports, the sole measurement computed and analyzed from these previous studies was throwing distance, which provides partial information for this explanation.

KNOWLEDGE GAP

Even though throwing distance exhibiting associations to sprint and jump performance is a noteworthy finding among the empirical evidence, further research analyzing the kinetics and kinematics of the BOMB assessment would be warranted to further clarify how these aspects could be associated with lower extremity explosiveness in other tests, such as the standing vertical and horizontal jumps and sprint performance. Furthermore, investigations that have been sought for correlations were among athletes of various sports background such as soccer and football, with little evidence conducted in track & field athletes. Moreover, one study investigated associations between throw and jump performance among various athletic groups (e.g. volleyball vs. wrestling), which may have an influence displaying a greater correlation in lower and upper limb strength and power variables (Stockbrugger & Haennel, 2003). Thus, further research is needed to investigate if relationships between jumping, sprinting and throwing have a high correlation among athletes specializing in track & field, as these three areas of power are of high importance. To the author's knowledge, there is limited data on understanding these correlations between all three lower extremity power assessments among Division I collegiate track & field athletes.

PURPOSE AND HYPOTHESIS

Therefore, this project had three primary purposes: 1) to analyze the association between field performance assessments and a 30 m acceleration and a 30 m flying sprint, 2) to determine the predictive ability of field performance tests on both sprint completion times, and 3) to analyze the association between the kinetic and kinematic components of field performance tests to 30 m acceleration and flying sprint. It is hypothesized that: 1) the BOMB test would have the greatest association with the sprinting tests compared to the vertical and horizontal jumps, 2) the BOMB test would have the greatest predictive ability with the sprinting tests compared to the vertical and horizontal jumps and 3) the kinetic and kinematic components of the BOMB throw test would display a greater association to the sprinting assessments compared to the vertical and horizontal jumps.

Chapter 2: Literature Review

Biomechanics of the Horizontal and Vertical Jump

The nature of the horizontal and vertical jump includes an individual to stand erect, with or without hands on the hips, initiating the jump with a preliminary swing (e.g. countermovement). This countermovement involves flexion of the hips and then immediately extending hips, propelling the body as far forward, or as high, as possible.

The biomechanics of the horizontal jump has not only been examined, but also compared to movement patterns of the vertical jump. Although both the standing horizontal and vertical jump are common in the aspect that they assess lower extremity explosiveness, it is clear that both jumps have their differences. When executing the horizontal jump, it has been reported that the motion of the hip joint is greater when compared to the vertical jump (Fukashiro et al., 2005; Nagano et al., 2007). This means that the orientation of the trunk segment in the vertical jump is near erect and its angular momentum shows to be reduced to near zero in order for the movement to be performed vertically (Nagano et al., 2007). Moreover, when investigating and comparing both force development and muscle activity in both jumps, empirical data has reported that hip extensor muscles (e.g. gluteal muscles & hamstrings) showed longer durations of activation when observed in the horizontal jump compared to the vertical jump (Nagano et al., 2007). Evidence therefore suggests that the hip joint appear to show a higher demand for execution in the standing horizontal jump compared to the vertical jump in terms of kinematics, kinetics and muscle activity (Eagles et al., 2016; Nagano et al., 2007).

Backward Overhead Medicine Ball Throw

In addition to assessments of lower extremity explosiveness, another method that has been proven to be useful is the backward overhead medicine ball (BOMB) throw test. Also known to demonstrate a high test-retest reliability ($r = 0.91$, $P < 0.01$; (Stockbrugger & Haennel, 2001), previous literature has implemented this power assessment in various athletic populations such as football (Lockie, Jeffriess, et al., 2012; Mayhew et al., 2005) as well as track & field (Aoki et al., 2015; Stockbrugger & Haennel, 2003; Zaras et al., 2019).

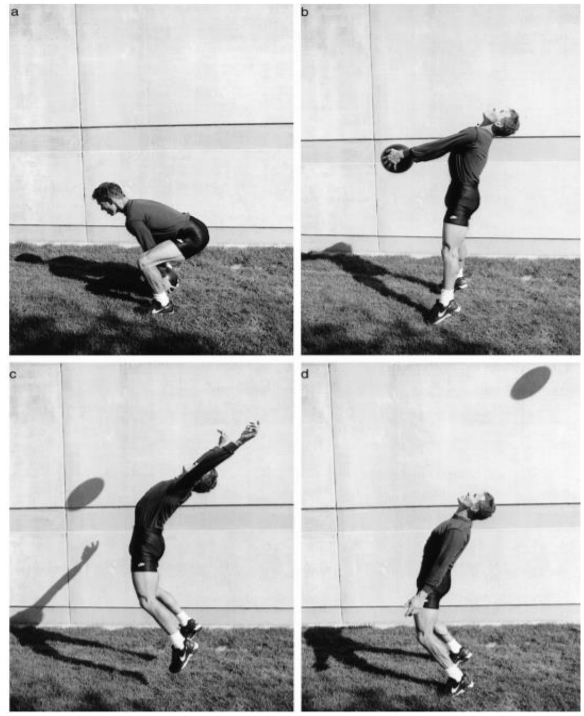

Figure 1. Backward overhead medicine ball (BOMB) throw

According to the findings discovered by Stockbrugger and Haennel (2001), the BOMB test consists of the following procedures in executing the movement: the individual starts by standing with the feet shoulder width apart, heels placed on the zero measurement line and the medicine ball held in the person's hands with the arms straight out in front at shoulder height. Once the individual is in position the action is initiated by a countermovement, consisting of flexion at the knees and hips while also flexing forward at the trunk to lower the medicine ball below hip height. Once the countermovement is achieved, the individual immediately thrusts forward at the hips followed by extension of the knees and trunk. Flexion of the shoulders occur, leading to elevation of the ball at shoulder height and beyond as they throw it back over the head.

The finishing point is also achieved with plantar flexion of the ankles, extension of the knees, hips, and trunk as well as flexion of the shoulders to above the head. See *Figure 1*.

Correlations between Jump and Sprint Performance

Some of the most prevalent movements implemented in previous studies consisted of the vertical jump, squat jump and drop jump, where studies have conducted either one or more of these variations (Dobbs et al., 2015; McCurdy et al., 2010). One study investigated relationships between speed, agility and vertical jump performances (squat jump and vertical countermovement jump), mainly finding moderate to strong correlations (r = -0.599, P = 0.02) between vertical jump ability and 30 m sprint times (Köklü et al., 2015). It was also further discussed that the relationships observed became increasingly stronger over increasing sprint distances (Köklü et al., 2015). Furthermore, previous literature has also sought to investigate relationships between short sprint time (5 m) and strength parameters of the vertical jump (VJ) using a linear transducer (Marques et al., 2011). Results indicated moderate to strong associations between time to peak bar velocity (r = -0.664), mean propulsive force (r = 0.801), mean propulsive power (r = 0.715) variables and 5 m sprint time (Marques et al., 2011). On the other hand, previous findings from other scholars such as Furlong et al. (2019) have reported somewhat differing results when conducting a correlation and regression analysis between measures of 30 m sprints, vertical jump, squat jump, and drop jump performance. Results illustrated a strong prediction between squat jump height and 30 m sprint time (standardized beta coefficient of 0.508), however the vertical jump height showed weakest in prediction between 30 m sprint time (beta standard coefficient of 0.339). A limitation in regards to using these jump assessment variations as a correlation and predictor for short distance sprint performance is that they only place an emphasis in the vertical aspect (Schuster & Jones, 2016). Lastly, although jump height exhibits value to a certain degree for practitioners and coaches, previous investigation has also advocated that these results would still warrant further research to seek the underlying mechanisms of performance in these particular movements related to sprinting speed (Holm et al., 2008; Maulder et al., 2006).

Vertical vs. Horizontal Jumps for Sprint Performance

Despite the widely utilized variations of the vertical jump, whether it is the squat jump, vertical jump, or drop jump, many sports involve a high demand for force production in both the horizontal and vertical plane (Maulder & Cronin, 2005; Meylan et al., 2009). Moreover, it has been advocated that horizontal jump assessments could be a more viable method compared to vertical jump for predicting sprint performance (Maulder & Cronin, 2005). Other empirical evidence has further investigated relationships between horizontal and vertical jump variations and sprint performance markers (Bishop et al., 2018; Davis et al., 2012; Dobbs et al., 2015; Lockie et al., 2016; Loturco, Pereira, et al., 2015; McCurdy et al., 2010; Schuster & Jones, 2016). These particular studies have sought this question at hand, examining correlations from various horizontal jumps such as: countermovement jump (standing horizontal jump), squat jump, and drop jump, performed either bilaterally, unilaterally or both. Results have shown to be in support of the premise, reporting moderate to very large associations of horizontal jump variations to sprint performance in distances at 10, 20 and 30 meters (Davis et al., 2012; Dobbs et al., 2015; Lockie et al., 2016; Loturco, Pereira, et al., 2015; Maulder & Cronin, 2005; McCurdy et al., 2010; Meylan et al., 2009; Schuster & Jones, 2016). Although horizontal jump assessments could be better correlated and a possible predictor for sprinting performance, it is still advised that both variations of jump assessments (vertical and horizontal, bilateral and unilateral) should still be incorporated as the majority of sports movements require force production in both planes of motion.

Correlations between Throw, Sprint and Jump Performance

As discussed, jump and sprint performance variables from prior investigations have been extensively sought and have, for the most part, concluded that correlations between the two show assuring results. However, another aspect of optimal athletic performance includes throwing, especially in track & field. Although the research appears to be limited, what is known is that previous studies have conducted examinations in discovering relationships between jump variables and throwing ability. Throwing ability, specifically the backward overhead medicine ball (BOMB) throw being a widely utilized upper and lower limb power test in various sports to ascertain associations between jumping and sprinting performance. For example, Aoki et al. (2015) sought to determine associations between power event scores and power/strength assessments by converting the values through utilization of the International Association of Athletics Federations (IAAF) scoring table, revealing that the standing triple jump, standing quintuple jump, and BOMB throw were positively correlated to IAAF scores in sprinting ($p < 0.05$) among the sprint athletes. In addition, sprint performance also displayed a correlation between BOMB throw assessments ($p < 0.05$) among sprinters. Furthermore when analyzing the data in throwers, it was reported that a forward medicine ball throw, backward medicine ball throw (BOMB throw), and clean lift showed significant correlations with IAAF scores ($p < 0.05$). Although the literature indicates moderate to strong correlations, these investigations that were sought have been through simple measurement of BOMB throw distance (Aoki et al., 2015; Lockie, Jeffriess, et al., 2012; Mayhew et al., 2005; Stockbrugger & Haennel, 2003). If BOMB throw distance does in fact display correlations with kinetic and kinematic variables of jumping, then it would be prudent to determine the explanation as to how throwing distance is related from a biomechanical standpoint. Aside from merely the BOMB throw test utilized in previous literature other scholars have included different throwing assessments such as a throw basketball test (Castro-Piñero et al., 2010), and medicine ball squat throws and scoop throws (Lehman et al., 2013). Results from these other throwing assessments in relation to jump performance have also shown a strong contribution to throwing capability (Castro-Piñero et al., 2010; Lehman et al., 2013). Castro-Piñero et al. (2010) displayed the standing horizontal jump being a strong contributor for throwing performance ($R^2 = 0.851$, $P < 0.001$). In addition, Lehman et al. (2013) found that throwing velocity was most strongly predicted by lateral to medial jumps ($R^2 = 0.688$) in college level baseball players. Although these results are of value to a certain degree, what is unknown is how these measures of performance are associated from a biomechanical standpoint, specifically exploring the kinematics and kinetics of these particular power assessments. Exploring the details of the specific factors (force, velocity, and power) contributing to these tasks would provide a further understanding to the underlying mechanisms of how these measures of performance are correlated. In addition, this would offer useful knowledge to coaches and practitioners for recognizing how their athletes can further be progressed in the athletic program. However, to the author's knowledge, the amount of literature investigating these specific tests of power and their relation is scarce. Furthermore, since track & field is a sport that encompasses all three aspects of power (sprinting, jumping and throwing), limited empirical evidence is also provided on determining correlations in the aforementioned variables.

Chapter 3: Methods

Experimental Design

This study used a cross-sectional study design in which all subjects attended one session to perform all assessments. Subjects performed a standardized warm-up involving general and specific warm-up drills. Subjects then performed all the following assessments: two trials of standing horizontal jump (HJ), two trials of a 30 m acceleration sprint, two trials of a 30 m flying sprint, two trials of standing vertical jump (VJ), and two trials backward overhead medicine ball (BOMB) throws utilizing force platforms to collect kinetic data for the jump and throw tests. Since subjects were regularly assessed using the aforementioned tests, no familiarization trials were implemented. All variables of interest that were collected include: relative peak force (VJ, HJ, and BOMB), peak velocity (VJ, HJ and BOMB), relative peak power (VJ, HJ, and BOMB), relative rate of force development (RFD), eccentric time, concentric time, modified reactive strength index (VJ only), jump distance and height, and BOMB throw distance. Moreover, for data analysis the best 30 m acceleration (Accel30) and 30 m flying sprint (Fly30) completion time was used.

Subjects

This study utilized a convenience sample of 23 male and female Division I collegiate jumpers and sprinters from the Track & Field program at the University of Texas at El Paso (see Table 1). These subjects were at least 18 years of age and volunteered to participate after having the study explained fully and signing an informed consent document prior to data collection. The study was approved by the UTEP Institutional Review Board. Subjects that did not participate in data collection was due to either an injury or participation in competition the week after data collection. The G*power software (version 3.1, Universität Kiel, Germany) indicated that with a sample size of 23 subjects using a correlation point biserial model design with power set at 0.80 and an alpha level at 0.05, a correlational strength of 0.52 was determined. According to Hopkins et al. (2009), this corresponds to a large correlation. Moreover, this also agrees with a previous study by Köklü et al. (2015) investigating relationships between vertical jump performance and 30 m sprint times (r = -0.59).

Table 1. Participant descriptives: Mean, standard deviation (SD), and median values for Height (m), Weight (kg), and BMI (kg/m^2) for males, females, and combined group subjects.

	Mean	SD	Median
Height (m)			
All	1.77	0.10	1.79
Male	1.66	0.09	1.66
Female	1.82	0.06	1.81
Weight (kg)			
All	78.67	24.15	73.17
Male	83.08	21.12	76.58
Female	68.74	28.94	59.65
BMI (kg/m^2)			
All	24.71	5.76	22.54
Male	24.37	7.25	21.87
Female	24.86	5.20	22.69

PROCEDURES

After explanation of the study from the principal investigator and signing informed consent document, subjects were first measured for height and weight using a Detecto scale and stadiometer. Subjects then performed lower extremity power assessments in the following order: two trials for the 30 m acceleration sprint, two trials of the 30 m flying sprint, two trials of the HJ, two trials of the VJ, and two trials of the BOMB throw test.

STANDING VERTICAL JUMPS

All VJ trials were performed with arm swing on two force platforms (1000 Hz; PASCO Scientific, Roseville, CA, USA) with one foot on each platform starting in an upright position.

Subjects were instructed to jump up for maximum height. Subjects performed two trials with 30 seconds of rest provided between attempts. Subjects were to repeat trials if their feet lost contact with the force platform prior to take off during the countermovement phase. After completion of data collection, all raw VJ data was then exported into MATLAB (MATLAB, MathWorks, Natick, MA, USA) for data filtering using a fourth-order low-pass Butterworth filter and smoothed at a cut off frequency of 50 Hz determined by a Fast Fourier Transform frequency analysis. A custom MATLAB script was utilized for computing the following measures of interest: jump height (JH), eccentric time (Teccentric), concentric time (Tconcentric), relative eccentric RFD (RFDeccentric), relative concentric RFD (RFDconcentric), relative peak force (PF), peak velocity (PV), relative peak power (PP), time to peak force (TtPF), time to peak power (TtPP), and modified reactive strength index (RSImod). Variables of interest such as velocity and vertical displacement were computed following the procedures of forward dynamics explained by McMahon et al. (2018). Consequently, these variables were integrated for computing the remaining variables of interest such as RSImod, relative RFDconcentric and RFDeccentric, Teccentric, Tconcentric, TtPF, TtPP, relative PF, and relative PP (see Table 2).

STANDING HORIZONTAL JUMPS

All standing HJ trials were also performed with arm swing on two force platforms, providing all subjects similar instructions to the procedures of the VJ, except subjects were asked to jump forward for maximum distance. HJ variations that were performed included both bilateral and unilateral HJs, each with arm swing. Each variation was performed for two trials with 30 seconds between trials and one minute’s rest provided between tests. Subjects were to repeat trials if their feet lost contact with the force platform prior to take-off during the countermovement phase. After testing session was complete, all raw resultant kinetic data (from y and z axis) obtained via Pythagorean theorem was transported to MATLAB for data filtering using a 4th order low-pass Butterworth filter using at a frequency cutoff of 50 Hz. Cutoff frequency was selected after a visual assessment of the Fast Fourier Transform frequency plot. A custom MATLAB script was also implemented for calculating the following variables of interest: jump distance, Teccentric (s), Tconcentric (s), RFDeccentric ($N \cdot s^{-1} \cdot kg^{-1}$), RFDconcentric ($N \cdot s^{-1} \cdot kg^{-1}$), PF ($N \cdot kg^{-1}$), PV (m/s), PP ($W \cdot kg^{-1}$), TtPF (s), and TtPP (s).

BOMB THROW TEST

Subjects stood in an upright position with their back turned towards the throwing area, both feet placed a force platform holding a shot weight of 7.256 kg for males and 4.004 kg for females. Once in position, subjects were instructed to raise the medicine ball over their head and then initiate with the countermovement, consisting of flexion of the hips and knees. At the same time, subjects were to flex forward at the trunk, lowering the medicine ball to just below hip height. The action was then followed by an explosive forward thrust at the hips and extension of the knees and trunk. Subsequently subjects finally flexed the shoulders, elevating the ball up to shoulder height to throw it backward over the head to achieve maximum horizontal distance (Stockbrugger & Haennel, 2001). The subjects were instructed to jump backwards off the force platforms upon release of the medicine ball throw (see Figure 1). Subjects were provided one minute of rest between trials. Subjects were to repeat the trial if the feet remained on the force platforms after release of the medicine ball throw. All raw resultant kinetic data was transported to MATLAB for data filtering and smoothing, using a 4th order low-pass Butterworth filter using a frequency cutoff of 50 Hz. Cutoff frequency was selected after a visual assessment of the Fast Fourier Transform frequency plot. A custom MATLAB script was also implemented for calculating the following variables of interest: throw distance (m), Teccentric (s), Tconcentric (s), RFDeccentric ($N\cdot s^{-1}\cdot kg^{-1}$), RFDconcentric ($N\cdot s^{-1}\cdot kg^{-1}$), PF ($N\cdot kg^{-1}$), PV (m/s), PP ($W\cdot kg^{-1}$), TtPF (s), and TtPP (s).

30 m Flying Sprint

The 30 m flying sprint (Fly30) was conducted consisting of a 20 m running start and an additional 30 m maximal sprint zone. Subjects started in a two-point stance at a starting point placed 20 meters from the 30-meter assessment zone. Subjects were then provided an auditory signal and sprinted as fast as possible through the finish line marked at 30 meters. Subjects were provided two trials with two minutes rest in between attempts. Trials were video recorded using a predetermined camera set up (120 fps) 10 meters away (perpendicular sprint lane) from the 15-meter mark of the 30-meter assessment zone. Completion time from the Fly30 test was recorded via visual assessment from the camera recording videos. The best Fly30 completion time for each subject was also used for data analysis.

30 m Acceleration Sprint

The 30 m acceleration sprint (Accel30) was executed by having subjects start in a two-point stance and were provided an auditory signal to sprint as fast as possible through the finish line marked at 30 meters. Subjects were provided two trials with two minutes rest in between attempts. Trials for each subject were also recorded using a predetermined camera set-up (120 fps), with the camera set-up in the same manner for the Fly30 sprint test. Completion time was recorded via visual assessment from the camera recording videos. For data analysis, the Accel30 sprint time started when the subject initiated first movement to reaching the 30 m marker (0-30 m). The best completion time for each subject was used for data analysis.

Table 2. Definitions of kinematic and kinetic variables

Variables	Metric	Definition
Eccentric time (Teccentric)	s	Time duration of the eccentric phase; period between the end of the unloading and braking phase.
Concentric time (Tconcentric)	s	Time duration of the concentric phase; period between the end of the braking phase and takeoff phase.
Time to peak force (TtPF)	s	Time period between the start of the jump and peak force achieved.
Time to peak power (TtPP)	s	Time period between the start of the jump and peak power achieved.
Peak velocity (PV)	$m \cdot s^{-1}$	The highest velocity achieved during the concentric phase.
Take-off velocity	m/s	Velocity at take-off phase. **Takeoff velocity = velocity attained when subject reaches < 20 N of force.**
Jump height (JH)	m	Highest height achieved during the jump using take-off velocity. **JH = take-off velocity^2 / (2 · 9.81)**
Relative peak force (PF)	$N \cdot kg^{-1}$	Force achieved during the concentric phase (end of braking phase to time at take-off) relative to bodyweight.
Relative peak power (PP)	$W \cdot kg^{-1}$	Power achieved during the concentric phase, relative to bodyweight.
Eccentric rate of force development (RFDeccentric)	$N \cdot s^{-1} \cdot kg^{-1}$	Relative maximum force increase during the eccentric phase (end of unloading phase to end of braking phase).
Concentric rate of force development (RFDconcentric)	$N \cdot s^{-1} \cdot kg^{-1}$	Relative maximum force increase during the concentric phase (end of braking phase to take-off phase).

Statistical Analysis

All statistical analyses were computed using RStudio (RStudio, PBC, Boston, MA, USA). Data normality was analyzed using QQ-plots, Density plots and the Shapiro-Wilk test. Descriptives for each variable were obtained through the "psych" package in R, which provided mean (Mean), standard deviation (SD), median (Median), trimmed means for estimation of central tendency (Trimmed), minimum value (Min), maximum value (Max), range (Range), skewness and kurtosis for data distribution, and standard error (SE) for each of the descriptive variables. Time data from Accel30 and Fly30 were non-normally distributed (Figures 2-3). Therefore, Spearman's rank correlation analysis was used to determine relationships between jump and throw tests (VJ, HJ, BOMB) with athletic performance tests (Accel30 and Fly30). The strength of correlations were interpreted as follows: an r between ±0-0.3 considered small; ±0.31-0.49 moderate; ±0.5-0.69 large; ±0.7-0.89 very large; ±0.9-0.99 near perfect for relationship prediction, and 1.00 as perfect (Hopkins et al., 2009). A series of Ordinary Least Squares regression analyses ($p < 0.05$) were conducted for the track & field specific assessments to illustrate whether a particular jump test predicted Accel30 and Fly30 sprint completion time. The best predictive model was selected via forward-backward stepwise regression procedure. Multicollinearity was also checked, and in the presence of multicollinearity, variables were removed from the model to improve the accuracy of the model. When the regression models were performed, performance along with kinetic and kinematic variables that best predicted Accel30 and Fly30 were included. This method was applied for all jump and throw tests (BOMB throw, bilateral/unilateral HJ and VJ). Finally, a post hoc power analysis was conducted (see Table 17) for determining statistical power from the correlations of all field assessments in relation to Accel30 and Fly30 sprint times. The most significant variables found for conducting the power analysis were jump distance and jump height.

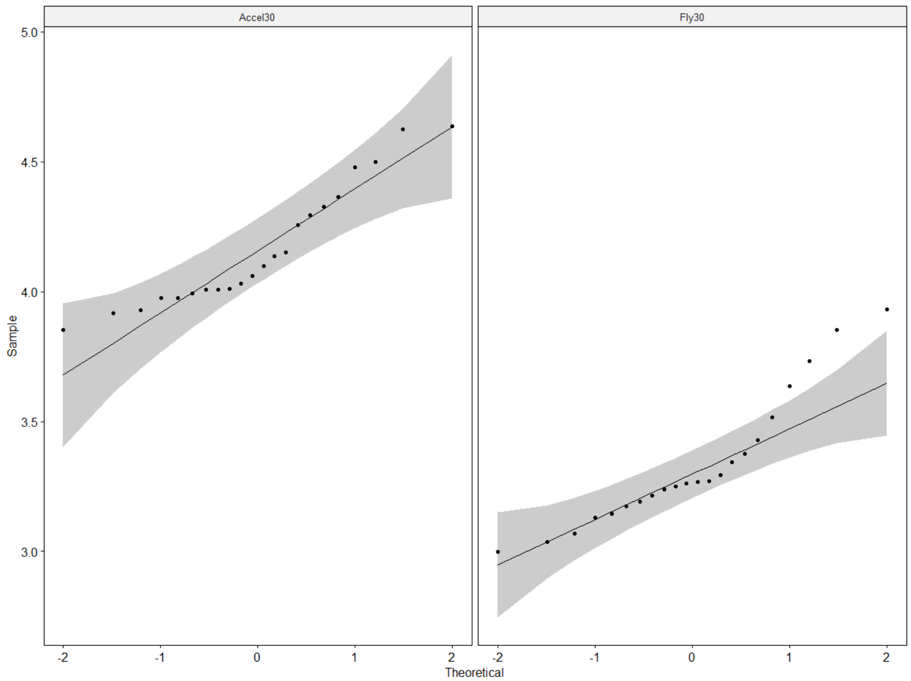

Figure 2. Q-Q probability plot of data normality

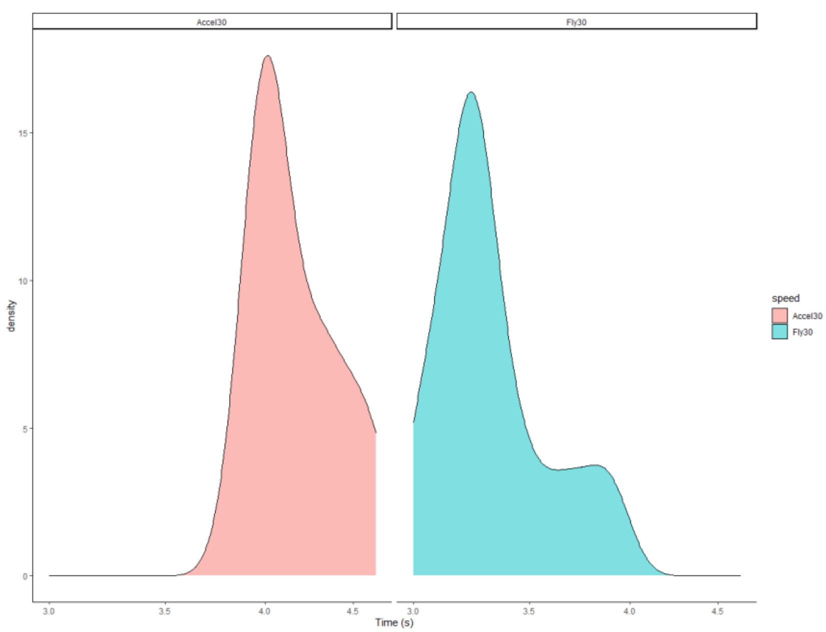

Figure 3. Density plot of data normality

Chapter 4: Results

ACCEL30 AND FLY30 TIME

On average subjects ran the Accel30 at 4.26 ± 0.36 seconds and the Fly30 at 3.42 ± 0.37 seconds (see Table 3). The Spearman's rank-order correlation indicated a near perfect correlation of 0.95 between Accel30 and Fly30 ($p < 0.01$).

Table 3. Performance data of Accel30 and Fly30 completion times

	Mean	SD	Median	Trimmed	MAD	Min	Max	Range	Skew	Kurtosis	SE
Accel30	4.16	0.24	4.08	4.14	0.19	3.85	4.64	0.78	0.67	-0.90	0.05
Fly30	3.33	0.25	3.26	3.31	0.17	3.00	3.93	0.93	0.94	-0.14	0.05

Mean, standard deviation (SD), median (Median), trimmed means for estimation of central tendency (Trimmed), mean absolute deviation (MAD), minimum (Min), maximum (Max), range (Range), skew, kurtosis, and standard error (SE).

BOMB THROW TEST

There was a moderate negative association (see Table 5) displayed between BOMB throw test distance and the Fly30 completion times ($p < 0.05$). Similarly, moderate negative associations were shown between the BOMB throw distance and Tconcentric as well as peak velocity (PV) and time to peak force (TtPF; $p < 0.05$). Additionally, large negative associations were observed between throw distance and Teccentric as well as among RFDeccentric and RFDconcentric ($p < 0.05$). Teccentric and TtPF from the BOMB throw showed to have a large positive correlation ($p < 0.05$). Furthermore, a moderate positive correlation was detected between BOMB throw Teccentric and TtPP, Tconcentric and TtPF, as well as between Tconcentric and TtPP ($p < 0.05$). Moderate positive associations were also shown between RFDeccentric and PF as well as RFDconcentric and PV ($p < 0.05$). Lastly, very large positive correlations (Table 5) were revealed between BOMB Teccentric and Tconcentric as well as TtPF and TtPP ($p < 0.05$).

Table 4. Descriptive of the performance, kinetic, and kinematic variables of the BOMB Test for all subjects combined

	Mean	SD	Median	Trimmed	MAD	Min	Max	Range	Skew	Kurtosis	SE
Distance (m)	11.09	1.63	11.18	11.07	1.45	8.09	14.45	6.36	0.16	-0.37	0.35
Teccentric (s)	0.48	0.08	0.49	0.49	0.07	0.30	0.65	0.34	-0.21	-0.29	0.02
Tconcentric (s)	0.36	0.07	0.33	0.35	0.06	0.28	0.59	0.31	1.70	3.63	0.01
RFDeccentric ($N \cdot s^{-1} \cdot kg^{-1}$)	2.40	0.30	2.36	2.37	0.27	1.95	3.24	1.29	0.96	0.69	0.06
RFDconcentric ($N \cdot s^{-1} \cdot kg^{-1}$)	1.79	1.47	1.28	1.58	0.98	0.16	5.57	5.41	1.13	0.38	0.31
PV (m/s)	1.93	1.17	1.80	1.80	0.98	0.39	4.76	4.37	0.73	-0.01	0.25
PF ($N \cdot kg^{-1}$)	2.14	0.19	2.08	2.11	0.13	1.87	2.60	0.73	0.97	0.04	0.04
PP ($W \cdot kg^{-1}$)	4.17	0.55	4.24	4.17	0.62	2.97	5.26	2.30	-0.11	-0.73	0.12
TtPF (s)	2.06	0.53	2.15	2.13	0.31	0.70	2.80	2.10	-1.05	0.77	0.11
TtPP (s)	2.22	0.50	2.36	2.27	0.22	0.88	2.82	1.93	-1.26	1.02	0.11

Mean, standard deviation (SD), median (Median), trimmed means for estimation of central tendency (Trimmed), mean absolute deviation (MAD), minimum (Min), maximum (Max), range (Range), skew, kurtosis, and standard error (SE).

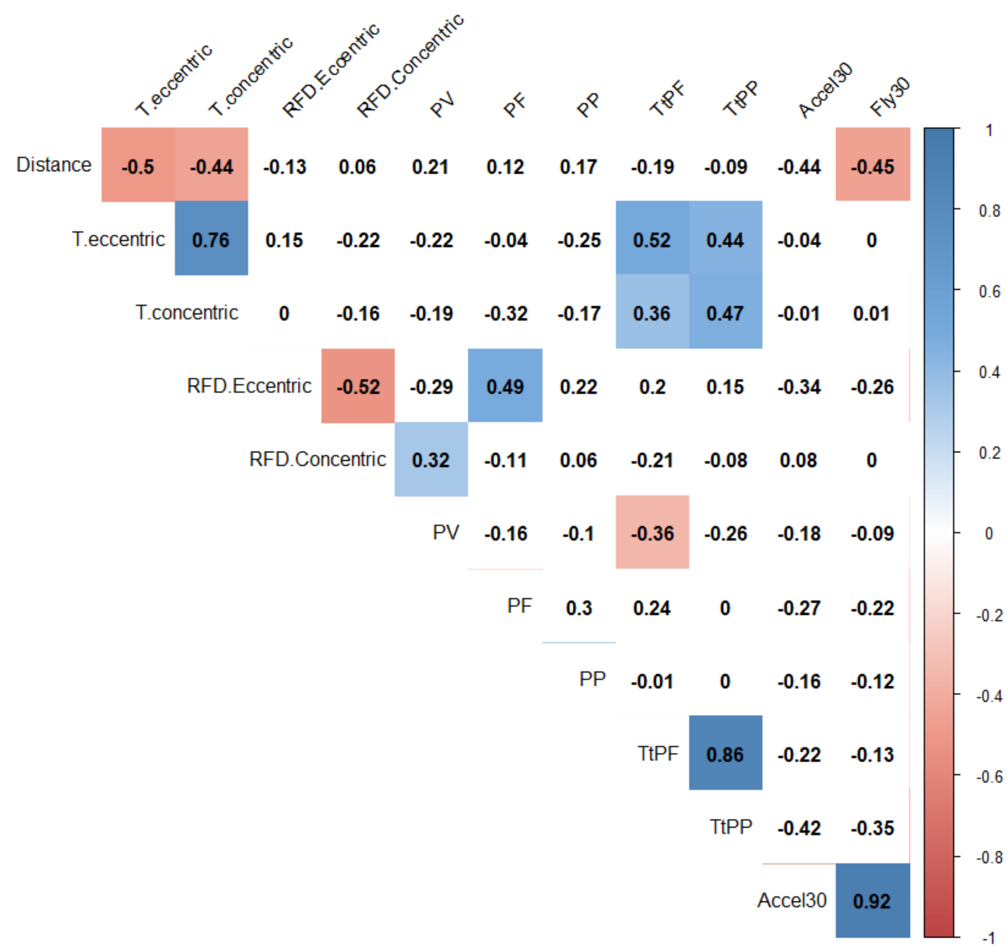

Figure 4. Correlogram between kinetic, temporal, and performance variables of the BOMB test, including completion times for Accel30 and Fly30. Red color-coding indicates a significant negative correlation and blue indicates a positive correlation ($p < 0.05$).

Table 5. Correlation matrix (r) between kinetic, temporal, and performance variables of the BOMB test including completion times for Accel30 and Fly30

	Teccentric	Tconcentric	RFD eccentric	RFD concentric	PV	PF	PP	TtPF	TtPP	Accel30	Fly30
Distance (m)	-0.50**	-0.45*	-0.13	0.06	0.21	0.13	0.17	-0.19	-0.09	-0.45	-0.45*
Teccentric (s)		0.76**	0.15	-0.22	-0.22	-0.05	-0.25	0.52**	0.44**	-0.04	0.00
Tconcentric (s)			0.00	-0.16	-0.19	-0.33	-0.17	0.36*	0.47*	-0.01	0.02
RFDeccentric ($N{\cdot}s^{-1}{\cdot}kg^{-1}$)				-0.52**	-0.29	0.49**	0.22	0.20	0.15	-0.34	-0.26
RFDconcentric ($N{\cdot}s^{-1}{\cdot}kg^{-1}$)					0.32*	-0.11	0.06	-0.21	-0.08	0.08	0.00
PV (m/s)						-0.16	-0.10	-0.36*	-0.26	-0.18	-0.09
PF ($N{\cdot}kg^{-1}$)							0.30	0.24	0.00	-0.27	-0.22
PP ($W{\cdot}kg^{-1}$)								-0.01	0.00	-0.16	-0.12
TtPF (s)									0.86**	-0.22	-0.13
TtPP (s)										-0.42	-0.35
Accel30											0.92**

Significance of tests is denoted as * for correlations $p < 0.05$ and ** for correlations $p < 0.01$.

Table 6. Best prediction models of the BOMB Throw Test, Accel30 and Fly30

	Est.	SE	t val.	p
Model 1: Accel30 ~ PF + PP				
Intercept	4.86	0.32	14.95	< 0.01
Distance	-0.06	0.29	-2.17	0.04
$F(1,20) = 4.74$, $p = 0.04$, $R^2 = 0.19$.				
Model 2: Fly30 ~ PF				
Intercept	4.06	0.35	11.42	< 0.01
Distance	-0.06	0.31	-2.06	0.05
$F(1,20) = 4.27$, $p = 0.05$, $R^2 = 0.18$.				

Each model is presented by the model [variable to be predicted by (~) predictors] with the estimated beta (β) coefficients (Est.), standard error (SE), t value test (t val.), and significance (p). Intercept, often labeled as constant, is the expected mean value of Y when all X=0.

As mentioned, performance along with kinetic and kinematic variables that best predicted Accel30 and Fly30 sprint times were included for conducting the best regression models. This method was also applied for all horizontal and vertical jump tests. Therefore, the best regression model indicated that the Accel30 times were best predicted by BOMB throw PF and PP with 19% of variance (Table 6). Moreover, best regression model involved BOMB throw PF for Fly30, which revealed to predict 18% of variance, respectively.

Unilateral Horizontal Jump

Findings from the unilateral HJ (see Table 8) showed large negative correlations between jump distance and Accel30 as well as distance and Fly30 sprint times ($p < 0.05$). Moreover, PV and Accel30 as well as PV and Fly30 completion times showed moderate negative associations ($p < 0.05$). Unilateral HJ results also detected a small negative association between peak power (PP) and Accel30 as well as between PP and Fly30 ($p < 0.05$). Additionally, a near perfect correlation was detected between TtPF and TtPP ($p < 0.01$) from the unilateral HJ assessment (see Table 8). Very large negative relationships were also demonstrated between Teccentric and RFDconcentric as well as between Tconcentric and PF ($p < 0.05$). Tconcentric and

RFDconcentric as well as RFDconcentric and TtPF from the unilateral HJ showed moderate negative associations ($p < 0.05$). Moderate positive correlations were displayed between Teccentric and Tconcentric, Teccentric and PV, as well as Teccentric and TtPF ($p < 0.05$). Similarly, RFDeccentric and RFDconcentric as well as PV and PP displayed moderate positive associations ($p < 0.05$). Finally, small positive correlations were detected between Tconcentric and TtPF as well as Tconcentric and TtPP from the unilateral HJ ($p < 0.05$).

Table 7. Descriptive of the performance, kinetic, and kinematic variables of the unilateral HJ test for all subjects combined.

	Mean	SD	Median	Trimmed	MAD	Min	Max	Range	Skew	Kurtosis	SE
Distance (m)	219.95	20.12	222.00	221.78	23.72	171.00	244.00	73.00	-0.61	-0.49	4.29
Teccentric (s)	0.47	0.14	0.49	0.47	0.13	0.25	0.69	0.44	-0.11	-1.26	0.03
Tconcentric (s)	0.31	0.05	0.32	0.31	0.07	0.22	0.39	0.17	-0.16	-1.43	0.01
RFDeccentric ($N \cdot s^{-1} \cdot kg^{-1}$)	2.79	2.51	1.47	2.59	1.65	0.15	7.86	7.71	0.61	-1.24	0.54
RFDconcentric ($N \cdot s^{-1} \cdot kg^{-1}$)	2.24	2.76	1.67	1.60	1.60	0.07	10.11	10.03	1.99	3.07	0.59
PV (m/s)	1.80	0.20	1.77	1.80	0.26	1.50	2.14	0.63	0.12	-1.58	0.04
PF ($N \cdot kg^{-1}$)	1.97	0.18	1.96	1.98	0.23	1.67	2.24	0.57	-0.13	-1.29	0.04
PP ($W \cdot kg^{-1}$)	2.94	0.51	2.97	2.95	0.64	1.90	3.85	1.96	-0.10	-1.02	0.11
TtPF (s)	0.91	0.14	0.93	0.91	0.15	0.60	1.13	0.53	-0.44	-0.76	0.03
TtPP (s)	0.97	0.12	0.99	0.97	0.13	0.72	1.18	0.47	-0.30	-0.98	0.03

Mean, standard deviation (SD), median (Median), trimmed means for estimation of central tendency (Trimmed), mean absolute deviation (MAD), minimum (Min), maximum (Max), range (Range), skew, kurtosis, and standard error (SE).

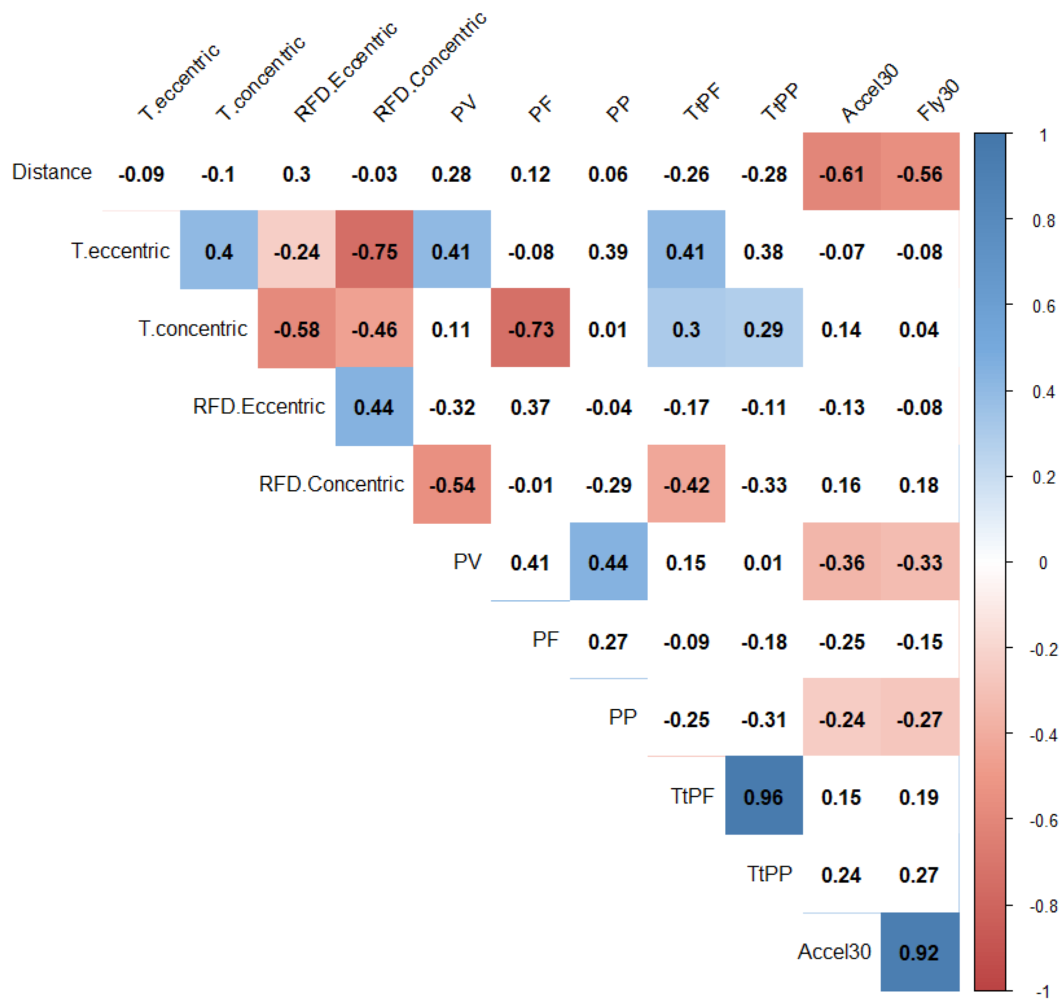

Figure 5. Correlogram between kinetic, temporal, and performance variables of the unilateral HJ test, including completion times for Accel30 and Fly30. Red color-coding indicates a significant negative correlation and blue indicates a positive correlation ($p < 0.05$).

Table 8. Correlation matrix (r) between kinetic, temporal, and performance variables of the unilateral HJ test including completion times for Accel30 and Fly30

	Teccentric	Tconcentric	RFD eccentric	RFD concentric	PV	PF	PP	TtPF	TtPP	Accel30	Fly30
Distance (m)	-0.09	-0.10	0.30	-0.03	0.28	0.12	0.06	-0.26	-0.28	-0.61**	-0.56**
Teccentric (s)		0.40*	-0.24*	-0.75**	0.41*	-0.08	0.39	0.41*	0.38	-0.07	-0.08
Tconcentric (s)			-0.58**	-0.46*	0.11	-0.73**	0.01	0.30*	0.29*	0.14	0.04
RFDeccentric ($N \cdot s^{-1} \cdot kg^{-1}$)				0.44**	-0.32	0.37	-0.04	-0.18	-0.11	-0.13	-0.08
RFDconcentric ($N \cdot s^{-1} \cdot kg^{-1}$)					-0.54**	-0.01	-0.29	-0.43**	-0.33	0.16	0.18
PV (m/s)						0.41	0.44**	0.15	0.01	-0.36*	-0.33*
PF ($N \cdot kg^{-1}$)							0.27	-0.09	-0.19	-0.25	-0.15
PP ($W \cdot kg^{-1}$)								-0.25	-0.31	-0.24*	-0.27*
TtPF (s)									0.96**	0.15	0.19
TtPP (s)										0.24	0.27
Accel30											0.92**

Significance of tests is denoted as * for correlations $p < 0.05$ and ** for correlations $p < 0.01$.

Table 9. Best prediction models of the unilateral HJ, Accel30 and Fly30

	Est.	SE	t val.	p
Model 3: Accel30 ~ Distance + PV				
Intercept	5.95	0.41	14.38	< 0.01
Distance	-0.00	0.00	-4.34	< 0.01
F(1,20) = 18.84, p = 0.00, ***R^2 = 0.49.***				
Model 4: Fly30 ~ Distance + PV				
Intercept	5.30	0.44	12.02	< 0.01
Distance	-0.00	0.00	-4.48	< 0.01
F(1,20) = 20.07, p = 0.00, ***R^2 = 0.50.***				

Each model is presented by the model [variable to be predicted by (~) predictors] with the estimated beta (β) coefficients (Est.), standard error (SE), t value test (t val.), and significance (p). Intercept, often labeled as constant, is the expected mean value of Y when all X=0.

Regression models computed for the unilateral HJ assessment displayed jump distance in addition to PV best predicted time to complete the Accel30 with 49% and Fly30 sprint time with 50% of variance (Table 9).

Bilateral Horizontal Jump

Results illustrated very large negative associations (see Table 11) between bilateral HJ distance and time to complete Accel30 as well as bilateral HJ distance and Fly30 time ($p < 0.01$). Moderate positive correlations were displayed between bilateral HJ TtPF and Accel30 time ($p < 0.01$) as well as bilateral HJ TtPF and Fly30 ($p < 0.05$). Similarly, findings exhibited a moderate positive association between bilateral HJ TtPP and Accel30 ($p < 0.01$) as well as bilateral TtPP and Fly30 completion time ($p < 0.05$). Nearly perfect association was displayed between TtPF and TtPP from the bilateral HJ assessment ($p < 0.01$). Additionally, very large positive correlations were observed between PV and PF, PV and PP, as well as PF and PP ($p < 0.05$). Similarly, bilateral HJ assessment demonstrated very large negative correlations between Tconcentric and bilateral HJ PF as well as between Tconcentric and PP ($p < 0.05$). A large positive correlation was also displayed between bilateral HJ RFDconcentric and PF ($p < 0.01$).

Moderate positive associations were observed between Teccentric and TtPF, Teccentric and TtPP ($p < 0.01$), as well as RFDconcentric and PP ($p < 0.05$). Furthermore, RFDeccentric and PV, RFDeccentric and PF, as well as RFDeccentric and PP ($p < 0.01$) showed moderate positive correlations. In addition, bilateral HJ Teccentric showed a large positive association with TtPF as well as bilateral HJ Teccentric and TtPP ($p < 0.01$). Similarly, Teccentric and RFDeccentric from the bilateral HJ assessment was largely correlated ($p < 0.05$). Moreover, large negative associations were detected between bilateral HJ distance and TtPF, distance and TtPP, Tconcentric and RFDconcentric, as well as Tconcentric and PV ($p < 0.01$). Lastly, moderate negative associations were exhibited among Teccentric and RFDconcentric as well as between Tconcentric and RFDeccentric ($p < 0.05$).

Table 10. Descriptive of the performance, kinetic, and kinematic variables of the Bilateral HJ test for all subjects combined.

	Mean	SD	Median	Trimmed	MAD	Min	Max	Range	Skew	Kurtosis	SE
Distance (m)	266.18	27.49	274.00	267.44	23.72	213.00	311.00	98.00	-0.49	-0.82	5.86
Teccentric (s)	0.50	0.19	0.47	0.49	0.19	0.19	0.94	0.75	0.42	-0.35	0.04
Tconcentric (s)	0.30	0.07	0.28	0.30	0.06	0.20	0.40	0.21	0.32	-1.44	0.01
RFDeccentric ($N \cdot s^{-1} \cdot kg^{-1}$)	2.29	2.13	1.97	1.89	1.59	0.13	9.44	9.31	1.85	3.54	0.45
RFDconcentric ($N \cdot s^{-1} \cdot kg^{-1}$)	3.16	2.91	1.87	2.84	2.42	0.03	10.54	10.51	0.87	-0.24	0.62
PV (m/s)	2.14	0.42	2.17	2.14	0.55	1.57	2.79	1.22	0.18	-1.47	0.09
PF ($N \cdot kg^{-1}$)	2.25	0.35	2.24	2.24	0.43	1.63	2.96	1.32	0.16	-1.02	0.07
PP ($W \cdot kg^{-1}$)	2.98	1.41	2.25	2.80	0.65	1.63	6.19	4.56	0.97	-0.61	0.30
TtPF (s)	0.98	0.16	1.01	0.98	0.19	0.74	1.24	0.50	-0.11	-1.34	0.03
TtPP (s)	1.03	0.16	1.04	1.03	0.19	0.79	1.29	0.50	-0.03	-1.24	0.03

Mean, standard deviation (SD), median (Median), trimmed means for estimation of central tendency (Trimmed), mean absolute deviation (MAD), minimum (Min), maximum (Max), range (Range), skew, kurtosis, and standard error (SE).

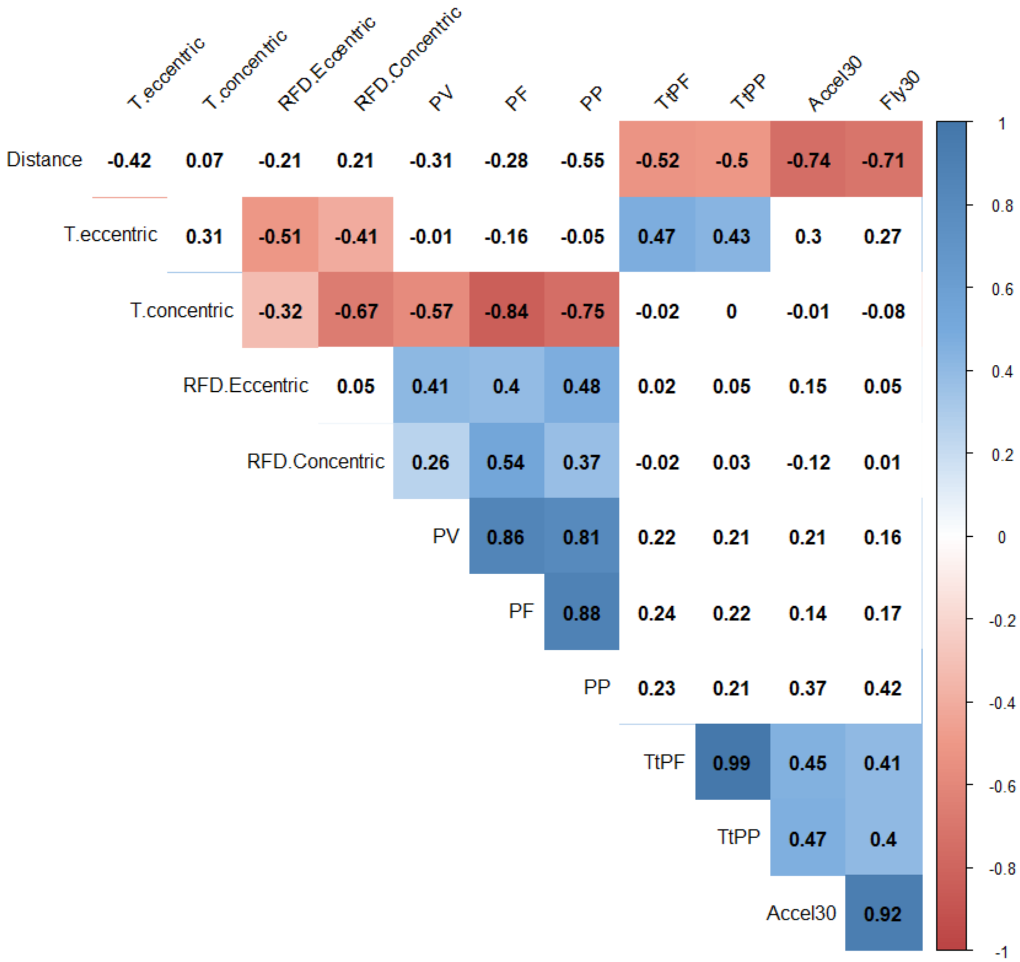

Figure 6. Correlogram between kinetic, temporal, and performance variables of the bilateral HJ test, including completion times for Accel30 and Fly30. Red color-coding indicates a significant negative correlation and blue indicates a positive correlation ($p < 0.05$).

Table 11. Correlation matrix (r) between kinetic, temporal, and performance variables of the Bilateral HJ test including completion times for Accel30 and Fly30

	Teccentric	Tconcentric	RFD eccentric	RFD concentric	PV	PF	PP	TtPF	TtPP	Accel30	Fly30
Distance (m)	-0.42	0.07	-0.21	0.21	-0.31	-0.28	-0.55	-0.52**	-0.50**	-0.74**	-0.70**
Teccentric (s)		0.31	-0.51*	-0.41*	-0.01	-0.16	-0.05	0.47*	0.43*	0.30	0.27
Tconcentric (s)			-0.32*	-0.67**	-0.57**	-0.84**	-0.75**	-0.02	0.00	-0.01	-0.08
RFDeccentric ($N·s^{-1}·kg^{-1}$)				0.05	0.41**	0.40**	0.48**	0.02	0.05	0.15	0.05
RFDconcentric ($N·s^{-1}·kg^{-1}$)					0.26*	0.54**	0.37*	-0.02	0.03	-0.12	0.01
PV (m/s)						0.86**	0.81**	0.22	0.21	0.21	0.16
PF ($N·kg^{-1}$)							0.89**	0.24	0.22	0.14	0.17
PP ($W·kg^{-1}$)								0.23	0.21	0.37	0.42
TtPF (s)									0.99**	0.45**	0.41*
TtPP (s)										0.47**	0.40*
Accel30											0.92**

Significance of tests is denoted as * for correlations $p < 0.05$ and ** for correlations $p < 0.01$.

Table 12. Best prediction models of the Bilateral HJ, Accel30 and Fly30

	Est.	SE	t val.	p
Model 7: Accel30 ~ Distance				
Intercept	5.89	0.33	17.71	< 0.01
Distance	-0.00	0.00	-5.22	< 0.01
F(1,20) = 27.29, p = 0.00, ***R² = 0.58.***				
Model 8: Fly30 ~ Distance				
Intercept	5.23	0.35	14.80	< 0.01
Distance	-0.00	0.01	-5.39	< 0.01
F(1,20) = 29.15, p = 0.00, ***R² = 0.59.***				

Each model is presented by the model [variable to be predicted by (~) predictors] with the estimated beta (β) coefficients (Est.), standard error (SE), t value test (t val.), and significance (p). Intercept, often labeled as constant, is the expected mean value of Y when all X=0.

The regression models that predicted Accel30 and Fly30 completion times included only jump distance of the bilateral HJ. These models were able to predict 58% of the variance for Accel30 and 59% of variance for Fly30 completion time.

Vertical Jump

Results of the VJ assessment (see Table 14) indicated that there were moderate negative associations between jump height (JH) and Accel30, JH and Fly30, RSImod and Accel30, as well as RSImod and Fly30 ($p < 0.01$). Additionally, moderate negative correlations were observed between PV and Accel30, PP and Fly30, PF and Accel30, as well as between PF and Fly30 ($p < 0.01$). Furthermore, PP and Accel30 from the VJ test showed to be largely associated ($p < 0.01$). Very large positive associations were also exhibited between JH and PP, RSImod and PP, Teccentric and Tconcentric, as well as PV and PP from the VJ ($p < 0.01$). Similarly, a very large negative correlation was discovered between VJ Tconcentric and PF ($p < 0.01$). Moreover, large negative correlations were detected between RSImod and Teccentric, RSImod and Tconcentric, as well as Tconcentric and RFDeccentric ($p < 0.01$). Large positive correlations were also shown between JH and RSImod, RSImod and RFDeccentric, RSImod and PV, RSImod and PF, as well as among PF and PP ($p < 0.01$). VJ assessment also displayed moderate positive associations between RSImod and RFDconcentric ($p < 0.05$), RFDeccentric and PF, RFDeccentric and PP, as well as between RFDconcentric and PF ($p < 0.01$). Likewise, moderate negative correlations were detected between Teccentric and RFDeccentric, Teccentric and RFDconcentric, Teccentric and PF, as well as Tconcentric and RFDconcentric ($p < 0.01$). Additionally, results from the VJ (Table 14) also exhibited moderate negative associations between Tconcentric and PP as well as RFDeccentric and TtPP ($p < 0.05$).

Table 13. Descriptive of the performance, kinetic, and kinematic variables of the VJ test for all subjects combined.

	Mean	SD	Median	Trimmed	MAD	Min	Max	Range	Skew	Kurtosis	SE
JH (m)	0.53	0.61	0.56	0.31	1.76	1.94	3.40	2.65	7.61	1.01	1.04
RSImod	0.62	1.03	0.30	0.31	3.07	5.95	3.64	2.62	8.11	0.60	0.66
Teccentric (s)	0.55	0.87	0.35	0.29	3.17	0.22	3.43	2.82	8.25	0.72	0.74
Tconcentric (s)	0.63	1.40	0.26	0.20	6.16	16.02	3.65	3.80	10.20	0.47	0.53
RFDeccentric ($N \cdot s^{-1} \cdot kg^{-1}$)	0.45	0.64	0.39	0.31	2.86	0.53	3.13	2.84	7.21	0.77	0.79
RFDconcentric ($N \cdot s^{-1} \cdot kg^{-1}$)	0.43	0.86	0.27	0.23	2.43	3.08	3.08	2.98	6.46	0.55	0.66
PV (m/s)	0.52	1.20	0.25	0.18	4.40	11.62	3.31	3.64	9.50	2.92	2.95
PF ($N \cdot kg^{-1}$)	0.52	1.20	0.25	0.18	4.40	11.62	3.31	3.64	9.50	2.92	2.95
PP ($W \cdot kg^{-1}$)	0.52	0.69	0.36	0.39	1.34	8.29	3.35	2.29	6.43	2.77	3.09
TtPF (s)	0.46	0.53	0.52	0.34	1.19	0.37	3.15	2.87	7.46	0.82	0.84
TtPP (s)	0.41	0.60	0.38	0.30	1.43	6.02	3.00	2.78	6.89	0.81	0.84

Mean, standard deviation (SD), median (Median), trimmed means for estimation of central tendency (Trimmed), mean absolute deviation (MAD), minimum (Min), maximum (Max), range (Range), skew, kurtosis, and standard error (SE).

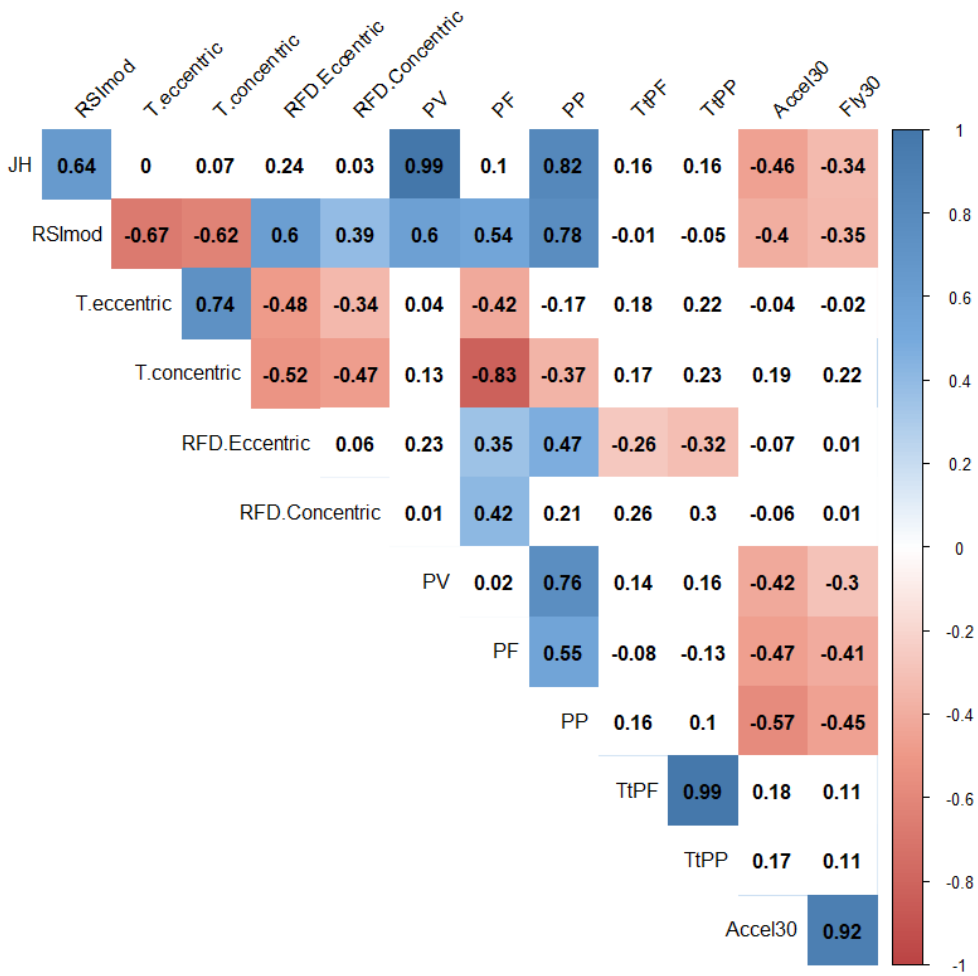

Figure 7. Correlogram between kinetic, temporal, and performance variables of the VJ test including completion times for Accel30 and Fly30. Red color-coding indicates a significant negative correlation and blue indicates a positive correlation ($p < 0.05$).

Table 14. Correlation matrix (r) between kinetic, temporal, and performance variables of the VJ test including completion times for Accel30 and Fly30

	RSImod	Teccentric	Tconcentric	RFD eccentric	RFD concentric	PV	PF	PP	TtPF	TtPP	Accel30	Fly30
JH (m)	0.64**	0.01	0.07	0.24	0.03	0.99**	0.10	0.82**	0.16	0.16	-0.46**	-0.34**
RSImod		-0.67**	-0.62**	0.60**	0.39*	0.60**	0.54**	0.78**	-0.01	-0.05	-0.40**	-0.35**
Teccentric (s)			0.74**	-0.48**	-0.35**	0.04	-0.42**	-0.17	0.19	0.22	-0.04	-0.02
Tconcentric (s)				-0.52**	-0.47**	0.13	-0.83**	-0.37*	0.17	0.23	0.19	0.22
RFDeccentric ($N \cdot s^{-1} \cdot kg^{-1}$)					0.06	0.23	0.35**	0.47**	-0.26*	-0.32*	-0.07	0.01
RFDconcentric ($N \cdot s^{-1} \cdot kg^{-1}$)						0.01	0.42**	0.21	0.26	0.30	-0.06	0.01
PV (m/s)							0.02	0.76**	0.14	0.16	-0.42**	-0.30**
PF ($N \cdot kg^{-1}$)								0.55**	-0.08	-0.13	-0.47**	-0.41**
PP ($W \cdot kg^{-1}$)									0.16	0.10	-0.57**	-0.45**
TtPF (s)										0.99**	0.18	0.11
TtPP (s)											0.17	0.11
Accel30												0.92**

Significance of tests is denoted as * for correlations $p < 0.05$ and ** for correlations $p < 0.01$.

Table 15. Best prediction models of the VJ, Accel30 and Fly30

	Est.	SE	t val.	p
Model 5: Accel30 ~ JH				
Intercept	4.87	0.24	19.93	< 0.01
JH	-1.37	0.47	-2.91	< 0.01
F(1,19) = 8.47, p = 0.01, $\boldsymbol{R^2 = 0.31}$				
Model 6: Fly30 ~ JH				
Intercept	3.98	0.28	14.09	< 0.01
JH	-1.25	0.54	-2.29	< 0.01
F(1,19) = 5.28, p = 0.03, $\boldsymbol{R^2 = 0.22}$				

Each model is presented by the model [variable to be predicted by (~) predictors] with the estimated beta (β) coefficients (Est.), standard error (SE), t value test (t val.), and significance (p). Intercept, often labeled as constant, is the expected mean value of Y when all X=0.

Regression model analyses indicated that both the completion times were best predicted using only JH and contained a predictive ability of 31% for the Accel30, whereas Fly30 completion time shown to be predicted with 22% of variance.

Table 16. Summary of correlations (r) and best regression analyses (R^2) for all tests with Accel30 and Fly30 time

	Summary of Correlations (*r*)		Summary of Regression Models (R^2)	
	Accel30	Fly30	Accel30	Fly30
BOMB	-0.44	-0.45**	0.19* (PF + PP)	0.18* (PF + PP)
HJ bilateral	-0.74**	-0.71**	0.58* (Distance)	0.59* (Distance)
HJ unilateral	-0.61**	-0.56**	0.49* (Distance + PV)	0.50* (Distance + PV)
VJ	-0.46**	-0.34**	0.31* (JH)	0.22* (JH)

Summary of the correlations and the R^2 of each of the regression models; Best regression models indicate performance variable of each test (i.e., distance for BOMB test, HJ bilateral and unilateral, and jump height for the VJ test), kinetic, and/or kinematic variables that predicted Accel30 or Fly30 time. * indicates significant at $p < 0.05$.

Table 17. Post hoc power analysis values of all field tests correlating to Accel30 and Fly30 sprint times

	Post hoc power analysis	
Assessment	Accel30	Fly30
BOMB Distance	Non-significant	Non-significant
Unilateral HJ distance	-0.61 = 0.94	-0.56 = 0.87
Bilateral HJ distance	-0.74 = 0.99	-0.70 = 0.99
VJ JH	-0.46 = 0.65	-0.34 = 0.38

Values expressed as correlation (*r*) = power

Chapter 5: Discussion

The purposes of this study were to ascertain associations and predictive abilities of field performance assessments on 30 m acceleration and 30 m flying sprints, in addition to analyze the association between the kinetic and kinematic parameters of field performance tests to said sprints. It was hypothesized that the BOMB test kinetic and kinematic variables would display a stronger correlation and prediction to the sprint assessments compared to the associations detected between the HJ and VJ tests and sprint performance. However, showing no support for the hypothesis, the BOMB throw distance was found to be least predictive of Accel30 and Fly30 sprint completion times. Moreover, regression models reported that the BOMB throw PF and PP best predicted Accel30 and Fly30 completion times with 19% and 18% of the variance. Aside from this fact, the findings of the present study align with previous literature. For instance, significant correlations as well as best predictions were observed in HJ (bilateral and unilateral) with Accel30 and Fly30 completion times. Furthermore, VJ assessment displayed weaker associations and predictions with Fly30 completion times compared to HJ variations, which is of interest.

HORIZONTAL JUMPS

The bilateral HJ test was more correlated and predictive of both Accel30 and Fly30 sprint times compared to unilateral HJ assessment. This is of interest as previous studies have advocated that unilateral HJ assessments have greater correlation and predictive ability of sprint performance due to force production during sprints being typically executed on one leg and largely in the horizontal direction (Dobbs et al., 2015; Holm et al., 2008; McCurdy et al., 2010). Moreover, significant associations and prediction models for completion time in Accel30 and Fly30 also included unilateral HJ jump distance. Based on the findings of the current study, unilateral HJ jump distance and PV revealed significant correlations and predictions for time completion of both Accel30 and Fly30. Results from previous studies have also indicated that horizontal (bilateral and unilateral) jump distance predict sprint performance times at distances ranging from 10-30 meters (Dobbs et al., 2015; Lockie et al., 2016; Maulder & Cronin, 2005; McCurdy et al., 2010; Meylan et al., 2009; Schuster & Jones, 2016). Although these studies differed in terms of jump variation utilized, such as unilateral drop jumps, squat jumps, and triple hops. Nevertheless, implementation of jumps performed in the horizontal direction appears to be of importance when selecting tests that pertain to the specificity of the activity, given the current findings and in accordance with prior literature that corroborates this premise (Dobbs et al., 2015; Lockie et al., 2016; Maulder & Cronin, 2005; McCurdy et al., 2010; Meylan et al., 2009; Schuster & Jones, 2016).

VERTICAL JUMPS

Main findings from the VJ assessments reported moderate negative associations between PV and Accel30 in addition to PV and Fly30. PP and Accel30 as well as PP and Fly30 also revealed negative correlations. Lastly, JH and Accel30 as well as JH and Fly30 were also noted as moderate negative correlations. Aligning with previous literature, Marques and Izquierdo (2014) found significant correlations between PV from VJ assessments and 10 m sprint time (r = 0.630). Another study by Maulder et al. (2006) also discovered correlations between VJ force and power (r = -0.70 to -0.79; p = 0.011 – 0.035) were strongly related to 10 m sprint performance. Although both sprint assessments in the present study displayed significant correlations with JH, PV, PF, PP and RSImod, regression models indicated that VJ was the jump assessment that exhibited the least predictive ability compared to the HJ variations. A notable difference in the current study involves the utilization of a 30 m fly-by sprint assessment in addition to a 30 m sprint, differing from similar studies investigating jump tests for determining associations and predictions towards merely one sprint assessment ranging from 30 meters or less (Dobbs et al., 2015; Lockie et al., 2016; Maulder & Cronin, 2005; McCurdy et al., 2010; Meylan et al., 2009; Schuster & Jones, 2016). To the author's knowledge, and aside from one study investigating jump variables between measures of a 50 m flying start (Loturco, Pereira, et al., 2015), this is the first study to investigate associations and predictions of jump parameters between a flying 30 m sprint test with the addition of a static 30 m sprint. The 30 m flying sprint was added due to the rationale that VJ assessments could be more associated and predictive of longer sprint displacements considered to be maximum speed phases (Harris et al., 2008; Loturco et al., 2018; Loturco, D'Angelo, et al., 2015; Schuster & Jones, 2016; Zafeiridis et al., 2005). Moreover, the 30 m flying sprint was implemented for its common use in track & field as an assessment for maximum speed. However, based on the findings of the current study, the VJ assessment showed to be least associated and predictive of Fly30 sprint time compared to both HJ assessments. Future research could investigate VJ tests and their possible correlations and predictive abilities among longer sprint displacements to solidify this premise. Also, it is evident that HJ variations could be better movements for implementation in a training program when intending to develop athletes in their sprint abilities, specifically for a static and flying 30 m sprint.

BOMB THROW

Significant results from the present study displayed a moderate negative association between throw distance and Fly30 time. Moreover, best prediction models conducted for the BOMB throw assessment included PF and PP for Accel30 but only PF for Fly30 time. However, regression models reported that these predictive variables from the BOMB test revealed to explain the variance of both sprint completion times by 18-19%. Although previous studies have sought to explore correlations between the BOMB throw distance and other measures of performance such as the VJ, HJ, and sprint performance among football and track & field players (Lockie, Jeffriess, et al., 2012; Mayhew et al., 2005; Zaras et al., 2019), this is the first study that conducts a kinematic and kinetic analysis in the BOMB throw to determine correlation and predictive abilities among other common power assessments used in track & field. Results from the current study demonstrates that force and power variables such as PF and PP are of high significance for optimal performance in throwing. However, the BOMB throw test may not be as specific towards other power tests to elicit a strong association and prediction (Terzis et al., 2003). Future research could replicate further investigations of associations and predictions in other performance markers for track & field. Other variations of medicine ball throws, such as a forward medicine ball chest pass, would also be of interest in finding associations and predictive abilities towards track performance markers.

LIMITATIONS

Although the current study provided insightful information, there were limitations involved. Although the sample size was not small, the study was composed of a heterogeneous sample such as jumpers and sprinters along with a mixture of males and females as this could possibly inflate correlations among variables measured in the current study. However, future studies could further replicate this study with a recruitment of a larger sample size to investigate if these correlations and predictions differentiate among various levels of performance and/or age groups (i.e., males vs. females, jumpers vs. sprinters, freshman vs. seniors/graduate students, etc.). Additionally, a standardized warm-up was not provided for the subjects, as they were instead permitted to perform their own warm-up to replicate preparation of a real-life competition day. Lack of a standard warm-up could have altered the results as different warm-up protocols could also have a possible effect on the magnitude of the subjects' performance. Future studies should also ensure to implement a standardized warm-up for all subjects for consistency and to account for athletes not conducting different warm-up protocols when engaging in these power assessments. Furthermore, although results of this study display correlations and predictions between the power assessments, these results do not imply causation. Nevertheless, HJ, VJ and BOMB movements used as training exercises may be of value to coaches and practitioners when aiming to incorporate explosive actions for developing sprint, jump, and/or throw performance. Finally, a post hoc power analysis was conducted with a sample size of 23 subjects. The post hoc power analysis revealed unilateral and bilateral HJ to contain a power between 0.87-0.99 for correlations with Accel30 and Fly30 time, whereas the VJ assessment displayed a power of 0.38-0.65 for associations with both sprint completion times. Future studies may desire to increase the sample size to obtain a sufficient power in the both the VJ and BOMB throw tests.

CONCLUSION

Results from this study suggest that the bilateral HJ assessment showed to contain very large correlations with Accel30 and Fly30 than the BOMB throw, unilateral HJ and VJ tests. Similarly, the bilateral HJ also contained a greater predictive ability through the regression model. It is noteworthy for strength coaches and practitioners to implement more horizontal jump variations as they may be more beneficial for improving sprint performance at distances such as static and flying 30 m sprints. Moreover, conducting HJ assessments under bilateral and/or unilateral conditions are encouraged as they are practical, time-efficient, and convenient tests. In addition, the BOMB throw assessment may have limited potential of peak power output for track and field athletes.

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Vita

Nicholas Ryne Cubillos, born and raised in El Paso, Texas, graduated from Americas High School in 2013 and pursued his bachelor's degree in Exercise & Sports Science at St. Mary's University of San Antonio, Texas.

After obtaining his Bachelor of Arts in 2017, Nicholas returned to El Paso where he acquired his certification as a strength and conditioning coach (CSCS) from the National Strength and Conditioning Association (NSCA) organization. During that time, he worked as a strength and conditioning coach and as a physical therapist technician. For a year and a half, Nicholas decided to return to school in the Spring of 2019 to pursue his Master's in Kinesiology at The University of Texas at El Paso. During his time as a graduate student, Nicholas gained experience and contributed to strength and conditioning research while working as a personal trainer. In addition, Nicholas worked as a teaching assistant in exercise physiology. Following his achievement of his master's degree, Nicholas will continue to further his practice and knowledge in strength and conditioning, with the possibility of returning to school to obtain a doctoral degree.