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The Influence of Peak Force, Rate of Force Development, and Countermovement Jump Metrics in Division II Collegiate Football Players

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Abstract

Introduction: Sports performance has been a widely discussed subject as the need for athletes to be not only more efficient but safer in their training and testing. While alternative methods for determining athletic performance have been used, the ability to appropriately test the athlete's peak force (PF) and rate of force development (RFD) can aid with the athlete's development. **Purpose:** The purpose of this study is to determine the influence of PF and RFD (early and late) within collegiate level football athletes, and to see if these performance measurements relate to playing time and/or offensive and defensive roles. Additionally, the present study examined the potential relationships between isometric force, RFD, countermovement jump metrics, and strength (bench, squat, power clean) in collegiate football players. **Methods:** Thirty-eight male collegiate football athletes (mean ± *SD:* 20.37 ± 1.62 years, height 185.37 ± 5.04 cm, and weight 101.89 ± 20.13 kg) participated in the study. All testing procedures were completed on wireless dual force plates. The first test consisted of three countermovement jumps (CMJ) with hands on hips, fifteen to thirty seconds of rest between attempts. The second part of the testing procedure was the isometric mid-thigh pull (IMTP). Participants were instructed to pull for three seconds, with three minutes of rest provided between the three attempts. **Results:** The present study observed significant differences with peak force, and peak force at certain time points of the force time curve, additionally there were differences seen for early RFD when comparing positions (line, big skill, skill). Specifically, line and big skill had greater PF and force at all time points compared to skill players (p = <0.001 – 0.028). Lineman had greater PF compared to big skill (p = 0.020). For rate of force development, differences were only seen for early RFD (RFD 0-50 ms), where big skill had greater RFD50 compared to line and skill (p = 0.006 - 0.029). For the countermovement jump, jump height, average and peak velocity were greater for skill

compared to line (*p* = 0.017 – 0.018), average power was greater for line vs. skill (*p* = 0.006) and peak power were greater for line and big skill compared to skill (*p* = <0.001 – 0.025). No differences were seen for any variables when comparing the offense vs. defense (*p* = 0.244 - 0.954). No differences were observed for any variable when comparing starters vs. non-starters (*p* = 0.167 – 0.757). No differences were seen for lower vs. upperclassmen (*p* = 0.490 – 0.995). Significant correlations were seen for strength and all force values (PF – PF250) (*r* = 0.490 – 0.947). For strength and RFD, RFD200 saw a significant correlation for the power clean (*r* = 0.348), RFD 250 had a significant correlation for bench press and power clean (*r* = 0.364 - 0.592). For maximum strength and countermovement jump metrics, significant correlations were observed for the strength with AP and PP (*r* = 0.695 – 0.769*, p* = <0.001). There were significant positive correlations for CMJH and the velocity variables (*r* = 0.877 – 0.998, *p* = <0.001). No differences were observed for power and CMJH (*r* = 0.257 – 0.258, *p* = 0.129 – 0.131).

Discussion: The aim of the present study was to examine the relationships between field tests and one repetition maximum strength for squat, bench press, and power clean. Additionally, another aim of the study was to determine the influence of PF and RFD on performance measurements between starters and non-starters, and offense vs. defense and lower vs. upperclassmen. Determining these aspects can help to further evaluate the athlete and make progressions accordingly. The main findings saw positive correlations with maximal strength values and force development (PF – PF250), correlations of bench press and power clean with RFD200, and RFD250, and positive correlations with strength values and average and peak power from the CMJH. Furthermore, for the IMTP, no differences were observed between playing status (starter vs. non-starter) or position (offense vs. defense), or class (under vs. upper). However, when breaking the groups down into position (line, big skill, skill) lineman and big skill players showed to have higher values of force production compared to skill players. Additionally, big skill players had better early RFD compared to other positions, and skill players possessing greater jump height and velocity compared to lineman.

Introduction

Background and Significance

The world of sports science is a continually growing field. The desire to train and perform better has placed added stress for those tasked with improving these skills. With the sports world in constant progression, the ability to train appropriately and efficiently for athlete safety and progression has become a major focus (Akehi et al., 2022). Although a multitude of variables have been suggested as primary factors for athletic performance during power based sports (strength, body fat percentage, height, weight, limb length, speed, agility, etc.), over the past ~25 years muscular force/torque, more specifically, the rate of force development (RFD), have added a specific variable of understanding to allow for greater comprehension of explosivity with muscle contractions. With athletic performance, it is vital for individuals to be able to produce a great amount of muscular force quickly (Andersen & Aagaard, 2006). Without the production of force, many of the explosive feats we often see athletes complete would not be possible. The window for this production of force is near milliseconds. Rate of Torque development (RTD) is the ability to rapidly develop muscular torque (Aagaard et al., 2002) and is assessed from the onset of the isometric contraction to 250 ms of the torque-time curve (Andersen & Aagaard, 2006). Although RTD/RFD can be specifically measured throughout an entire time-point segment, recent research has focused on assessing RTD/RFD at specific time points throughout the torque time curve, (i.e., 30, 50, 100, and 200 ms) (Aagaard et al., 2002; Jenkins et al., 2014; Peñailillo et al., 2015). These specific time points allow for a better understanding of early (0-100 ms), and late (≥100 ms) torque/force production, as well as the ability of the neuromuscular system to generate rapid force at the onset of contraction (Aagaard et al., 2002). Specifically, it is suggested that early RTD/RFD is intrinsically related to contractile properties of the muscle (i.e., cross bridge cycling rates, muscle fiber type, and calcium kinetics) (Aagaard et al., 2002; Andersen et al., 2010; Bottinelli et al., 1996; Brody, 1976; Larsson & Moss, 1993) while late RTD/RFD is considered to be more related to characteristics of maximal strength (i.e., muscle cross-sectional area, and neural drive to the muscle fibers) (Close, 1972; Häkkinen et al., 1985; Soriano et al., 2024). In addition to assessing rapid force/torque characteristics, previous research has also highlighted the importance of assessing peak torque (PT) which typically occurs ~500 ms (Thompson et al., 2013).

While a multitude of research on knee extensor and/or flexor profiles have been assessed through a variety of populations, most of the previous literature was assessed using isokinetic dynamometers and/or load cells that required lab-based testing. With advancements in technology, and portability, portable force plates are now becoming a reliable and safer way to assess athletic performance (Comfort et al., 2011; Kawamori et al., 2006). Specifically, assessment of PT/PF and RTD/RFD from the isometric mid-thigh pull (IMTP) has become a reliable and relatively quick assessment to assess these aforementioned variables (Comfort et al., 2019; Dos' Santos et al., 2017; Haff & Triplett, 2015; Townsend et al., 2019; Wang et al., 2016). Furthermore, it is also seen to be a safer alternative to assessment of these variables, as often a one-repetition max (1RM) would be completed to assess the overall current strength of the individual (Beckham et al., 2018; Comfort et al., 2019). During in-season sports, this is often not feasible for either the athletes or coaching staff as fatigue can cause a decrease in the athlete’s ability to produce force and power output (Mackey et al., 2020; Pääsuke et al., 1999). Knowing that injury prevention and overall safety for the athlete is of the highest importance, it is imperative that appropriate exercise programming from qualified strength coaching and medical professionals be implemented to assist with trying to decrease levels of fatigue for the athlete, so they are able to perform at their highest level.

Hypothesis and Purpose

The purpose of this study is to determine the influence of PF and RFD (early and late) within collegiate level athletes, and to see if these performance measurements relate to overall playing time and/or status (starter vs. non-starter).

Research Hypotheses:

1) Collegiate athletes that possess greater PF and RFD characteristics are more likely to play more minutes in a game.
2) Collegiate athletes that possess greater PF and RFD characteristics are more likely to be named a starter (whether offense, defense, or special teams).
3) Upper-classmen are more likely to possess greater PF and RFD compared to lower-classmen.

Null Hypothesis:

1) Weight room 1-RM strength (Squat, Bench, Power Clean) will not correlate to more playing time.

Limitations, Delimitations, and Assumptions

Limitations of the study include the primary testing site, which will be at the University of Central Oklahoma, specifically within the Sports Performance Center found on campus. An added limitation is the testing of a specific group of athletes (football) and sex (males). The ability to cross compare is difficult due to the individual nature of differing sports. Added considerations would include window of data collection time, season of sport, and the large volume of individuals that use the Sports Performance Center at various times. As with many studies that are completed, the individual's wanting to complete the test at a volitional effort could become a limitation to the overall data received.

Delimitations would include the preset positional groups due to the individualized sport. It provides a clear population to assess and a similar background for the individuals within the study. The testing site also provides an ideal situation where the participants typically perform similar athletic assessments and feats. The equipment (portable force plates) and tablet can also streamline data collection processes.

Literature Review

Introduction

The sports-performance field has been driven by the hope of producing the most well-rounded athletes for their specific needs within their chosen sport. While overall strength may have been a common goal with training programs in decades past, the sport-science field has become more comprehensive with overall force outputs, and what actual variables comprise force. In turn, this has brought about different training styles and differences within the strength and conditioning field. One aspect that is generally agreed upon is the importance of creating powerful and explosive athletes (Johnson et al., 2025; Thompson et al., 2013). The strides made within research have brought about the determination of the force time curve. This includes the rate of force development, peak force achieved, and the maximal muscular strength and/or force of the individual (Aagaard et al., 2002). The force time curve provides a picture of the individual's ability to exert force quickly. Although the proposed thesis project assessed an athletic population, the information received from a force time curve is a valuable assessment for a variety of populations (Thompson et al., 2013). While previous literature has assessed force time curves with isokinetic dynamometers, and load cells (Aagaard et al., 2002; Andersen & Aagaard, 2006; Andersen et al., 2010; Conchola et al., 2015; Thompson et al., 2013; Thompson et al., 2013), the present thesis project assessed peak force and rate of force development (early and late) from the isometric mid-thigh pull (IMTP) using portable force plates. Information from this mode of assessment, with the specific population being assessed, can allow for future researchers to have a better understanding of testing batteries and implementation of maximal force assessments when using portable force plates with athletic populations.

The Motor Unit and Rate of Force Development

Rate of force development (RFD) would not be possible without motor units, and the intricate process it plays in overall skeletal contractions. While overall force output (mechanical process) is frequently thought of as the most important variable when assessing athletic performance, the neural pathways [EMG amplitude, rate of EMG Rise (RER) neuromuscular junction, etc.] must occur before an actual skeletal contraction can begin. That said, due to efficient neural excitation it is suggested that the speed of the neural stimulus can directly relate to the overall force production (Wiegel et al., 2019). Specifically, it is suggested that an increase in motor unit speed can generate force in a shorter amount of time, allowing for greater early RFD (0-100 ms) within a force time curve (Aagaard et al., 2002; Andersen & Aagaard, 2006). In addition to the speed of motor unit activation, is the overall summation of motor units that are being recruited (Maffiuletti et al., 2016). While limbs, muscles, and differing contraction types (Maffiuletti et al., 2016) can impact neural activation, overall force outputs are directly attributed to the number and speed of the motor unit recruitment (Andersen & Aagaard, 2006; Maffiuletti et al., 2016; Wiegel et al., 2019).

In recent research, the ability to assess the force time curve has allowed the ability to differentiate neural and skeletal muscle fiber stimulus. Specifically, the maximal muscle strength characteristics within a specific contraction or output of movement type (Andersen & Aagaard, 2006; Conchola et al., 2015; Kawamori et al., 2006; Thompson et al., 2013). When discussing the ability of an athlete to react quickly, this is often related to the first stimulus rather than the athlete's overall capability to lift at a maximum level. As Anderson & Aagaard (2006) found, it is seen that higher levels of strength in relation to bodyweight allow for greater RFD production.

These findings are similar to Wang et al. (2016). Thus, it is plausible that differences within muscle fiber types can positively and or negatively impact RFD (Andersen & Aagaard, 2006).

Peak Force and Early and Late Rate of Force Development

The force time curve, as briefly mentioned, is the main area assessed when discussing time points of early and late RFD (Aagaard et al., 2002). The assessment of the force time curve is dependent on the first stimulation (early) and the later portions that are more closely related with maximal strength production. Regardless of the curve (early or late) all time points are assessed in milliseconds (ms). It is seen that the most amount of force that can be produced is within a (50-250 ms) time frame (Andersen & Aagaard, 2006). Times greater than (300 ms) is often related to the maximal strength/force (PF) capability of the individual (Andersen & Aagaard, 2006). Early and late RFD are seen to have differing time point opinions. The most standardized approach within the studies reviewed is early RFD defined as (< 100 ms), and late RFD defined as (>200 ms) with maximum muscular force commonly seen later in the curve (>300 ms) (Aagaard et al., 2002; Andersen & Aagaard, 2006; Andersen et al., 2010; Maffiuletti et al., 2016). These time points provide a visual explanation of the process of force production in the time curve. While peak torque/force (PF) and early and late RFD are important across a wide variety of needs (acts of daily living, athletic performance, general health), previous research has been able to suggest the importance of assessing said variables for athletes. For example, Thompson et al. (2013), found early RFD for the knee flexors was able to differentiate starter vs. non-starter for Division I football athletes. Additionally, Jenkins et al. (2013), found eccentric peak torque was greater for starters vs. non-starters for female soccer players.

Countermovement Jumping

American football consists of movements that require explosive strength (PF and RFD) and/or the ability to explosively perform vertical propulsive forces enabling the athlete to jump in the air for offensive or defensive purposes. Knowing this, assessing one's jumping metrics can allow coaches as well as strength and conditioning staff pertinent information relating to positional as well as differences within and between positions on the football team (skill, big skill, line, offense, defense). While vertical jump performance typically assesses one's vertical jump height (cm), other variables within the concentric portion (propulsive phase) are of interest (power and velocity) (Merrigan et al., 2022). For example, Merrigan et al. (2022) observed skill position athletes jumped the highest, and had greater velocity during the propulsive phase compared to lineman. Furthermore, previous literature also suggests that lineman produce greater average and peak power compared to skill players (Merrigan et al., 2022). Nevertheless, the ability to assess average and peak values for power and velocity, enable a greater comprehension and analysis of position and player specific metrics during the propulsive phase of a CMJ.

Discussion and Reliability of the Isometric Mid-Thigh Pull

As previously mentioned, when assessing force time curves using an isokinetic dynamometer, maximal voluntary isometric contractions (MVIC) have been the most common contraction type. However, while a multitude of populations and athletic capabilities have been assessed with strength and force capabilities within a laboratory setting, assessing populations (outside of the laboratory) could yield greater on-field or activities of daily living performance. Thus, assessing an isometric mid-thigh pull (IMTP), could yield a greater understanding of force capabilities during a field-based assessment. Performing field-based testing allows strength coaches and medical professionals real time assessments, which are vital for direct application and progression (Comfort et al., 2019; Haff & Triplett, 2015; Prajongjai et al., 2023; Rhodes et al., 2022). Due to good reliability (Comfort et al., 2019), and portability (portable force plates), force plates compared to isokinetic dynamometers are becoming a more cost-effective means to assess rapid and maximal force characteristics. Because of this mode of assessment, it is quickly becoming a more popular way to assess force time curves for a variety of populations.

The IMTP has been assessed through a variety of testing protocols. For example, Kawamori et al. (2006) performed a variety of comparison testing for mid-thigh pulls at loads of 30-120% of the participants one repetition power clean max. These comparisons of loads were tested in both dynamic and isometric assessments. Although the study's focus was assessing peak force, it was suggested that IMTP testing was comparable to dynamic peak forces exerted. Interestingly, Comfort et al. (2011), found that the midthigh power pull saw a higher RFD and peak force values when compared to power clean and hang power clean data. Their study suggests positioning (knee and hip joint angle) of the IMTP allows for loading of the ankle, knee, and hip joints which is in line with many required athletic tasks, as well as tasks of daily living. Additionally, Comfort et al. (2011) suggest that appropriate body position during these movements can alleviate any added stress on the shoulder girdle or lower back. Knowing that IMTP knee and hip angles can allow for safer testing protocols, it is plausible, that greater maximal strength/force outputs could occur due to alleviations of excessive movements during these assessments. Knowing that these variables (PF, early/late RFD, etc.) are vital for athletic and human performance, it is imperative that future studies follow the aforementioned IMTP protocol from Comfort et al. (2011), that way future studies, and the body of literature is assessing the same movements type (IMTP) with the same knee and hip joint angles.

Another important question when trying to assess athletic performance is the relation to strength (weight room or overall maximum strength), and if that carries over to on-field success. For example, Townsend et al. (2019) suggests the IMTP does have a positive relationship with athletic performance. Specifically, RFD is related closely with sprinting kinetics, power measurements, and agility aspects. Although most of the previous literature supports IMTP and being able to predict athletic performance, Wang et al. (2016), found no correlation with PF and sprint performance, however, they did see positive correlations with maximal strength, five-meter sprint times, and pro-agility times when correlating with RFD. Additionally, Beckham et al. (2013) found that weightlifting performance (maximal strength for Olympic lifts) had a positive relationship with early and late RFD metrics with competitive Olympic weightlifters. The aforementioned studies highlight the importance of one's RFD, and the ability of early and late RFD impact aspects of athletic performance. While more studies are needed to possibly support the idea of one's strength aiding with athletic performance, the IMTP has been continually recommended as a reliable, trouble-free assessment tool that is often a safer alternative for testing athletic markers to further understand needs and specifications of the individual (Comfort et al., 2019; Kawamori et al., 2006; Rhodes et al., 2022; Townsend et al., 2019; Wang et al., 2016).

Procedural Considerations

There have been differences in procedures that called for a broader standardization of the IMTP procedure (Comfort et al., 2019). The IMTP is most typically completed on a singular force plate, or a pair of force plates placed under each foot with a barbell placed in the middle position of the participant's knee and hip joint (Haff & Triplett, 2015; Rhodes et al., 2022). Many differences can be seen through procedures as research has also shown the importance of a “comfortable” position for the participant because it can greatly affect their overall force output and production.

Dos’ Santos et al. (2017), found that 145° range of motion was a more favorable position for the hip angle than the previously recommended 175° angle for the ability to exert the highest maximum force possible. This suggestion is similar to Beckham et al. (2018), who recommend a hip angle range of 140°-150°. As well as a 120°–135° range for the knee angle. An added consideration for the pull is the handgrip chosen by the researcher or athlete. Some studies have recommended the use of a pronated grip with the usage of lifting straps to eliminate limiting factors of grip strength (Beckham et al., 2018; Comfort et al., 2019; Dos' Santos, Thomas, et al., 2017; Rogers et al., 2023). This was contraindicated by Rhodes et al. (2022), when findings suggested that a greater consideration needed to be established for grip strength. Grip limiting factors could limit the athlete's ability to exert their maximum pull on the bar, regardless of straps or tape that has been previously recommended, it would become a large factor if working with younger and less experienced athletes as well (Rhodes et al., 2022). Prajongjai et al. (2023), found that the reliability to differing grip styles were consistent with PF outputs, but stated that a pronated grip was recommended for the IMTP. This was not recommended in the earlier studies (Beckham et al., 2018; Comfort et al., 2019; Dos' Santos, Thomas, et al., 2017) due to the use of lifting straps. Therefore, a recent publication by Comfort et al. (2019) proposed standardized protocols which suggest future studies measuring the distance between foot placement and handgrip if planning to reevaluate participants at a later date. It also recommends the use of a pronated grip with the use of lifting straps or tape.

Due to a paucity of literature who mimic the exact same IMTP protocols, Comfort et al. (2019), recommended considering these aspects so future research can relate results more accurately as well as a more universal understanding of results received. Therefore, the present thesis project intends to follow Comfort et al. (2019) recommendations for standardization of the IMTP. This will include the recommended knee angle range of (125-145°) and a hip angle of (140-150°) (Comfort et al., 2019; Haff & Triplett, 2015; Rhodes et al., 2022). A goniometer was used to accurately assess the two varying joint angles. The bar height was adjusted to the proper position for each individual athlete. Due to the study's nature, distance between feet and handgrip will not be assessed due to one trial period. It is further recommended for specific coaching procedures and encouragement throughout the test to encourage maximal exertion, which will be used in testing procedures. Specifically, during maximal IMTP attempts, the participants will be verbally encouraged with "pull-pull-pull-pull........."

Methodology

Participants

Thirty-eight male collegiate athletes participated in the study, (mean ± *SD:* age 20.37 ± 1.62 years, height 185.37 ± 5.04 cm, and weight 101.89 ± 20.13 kg). Participants will be later divided into three groups: lineman (offensive and defensive), big skill (tightened and linebacker), and skill (quarterback, kicker, punter, wide receiver, running back, defensive back, and safety). Specifications for positional groups is outlined in Table 1. Individuals were currently enrolled as students at the University of Central Oklahoma and were current football team members. Exclusion criteria for the study included any individuals that were currently injured or had not received physician release for a previous injury, chose to not participate, or did not successfully pass the PAR-Q+. Both coaching staff and participants were informed of the procedures of the study.

Table 1.

Mean and Standard Deviations (SD) of Demographic Data of Positions

	Line (n = 16)		**Big Skill (n = 9)**		**Skill (n = 13)**		**p-value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Age (yrs)	20.25	1.24	21.11	2.03	20.00	1.68	0.271
Height (cm)	188.43	3.15	185.71	4.22	181.38	4.93	<0.001*‡
Weight (kg)	121.00	11.15	99.07	9.20	80.33	6.38	<0.001*†‡
Academic Class	1.88	0.89	2.78	1.20	1.85	1.28	0.079

*Significantly greater (line vs. skill), †Significantly greater (line vs. big skill), ‡Significantly greater (big skill vs. skill)

Pre-Participation Screening

Prior to the informed consent, participants were informed of the purpose, testing procedure, and factors of the study that were going to be assessed. If participants agreed to take part in the study, they were asked to fill out an informed consent document (Appendix A) that explained purpose of the study, procedures, expected time for participation, potential benefits, potential risks, researcher contact information, explanation of confidentiality, assurance of voluntary participation, and a final affirmation of the participant. Participants were also asked to fill out a PAR-Q+ (Appendix B) to exclude any individuals with current injuries or medical history that would be negatively affected by the testing procedure. Participants were also asked to fill out a questionnaire about basic demographic and personal records information (Appendix C). After verification of their enrollment in the study, participants were coded in the research study and began testing.

Initial Procedures

Upon the completion of the paperwork, the participants' height and weight was assessed. Once that information was recorded, an online profile was created (Hawkin Dynamics Cloud), where each participant was assigned a participant number.

Testing Protocol

Participants arrived for testing and were familiarized with the testing procedures for the jumping and isometric mid-thigh pull protocols. Participants warmed up with their strength and conditioning coaches prior to testing. Upon completion of the warm-up, participants were taken through their countermovement jump assessment. This occurred before the IMTP trials. Participants were instructed to place their feet in a comfortable shoulder-width position while on the force plates. Hands were instructed to be placed on the hips, where their hands remained on their hips throughout the entire jumping process. Once set, the test administrator instructed the athlete to jump as high as possible. Ground reaction force data was collected via two sets of dual, unidimensional force plates, sampling at 1,000 Hz (Hawkin Dynamics, Westbrook, ME, USA), and force plates were zeroed/calibrated prior to each data collection. Fifteen to thirty seconds of rest were given between countermovement jump trials, a total of three jumps were attempted (Cabarkapa et al., 2024). Upon completion of the jumps, the IMTP attempts were assessed. Following the testing protocols recommended by Comfort et al. (2019), each individual participant was asked to take position on the force plates so proper placement of hip and knee angles (125° - 145°) could be assessed using a goniometer. The lifting rack and placement of the bar was assessed and properly placed for each participant. Once proper placement was found, the participant was asked to complete an IMTP attempt at a minimal level of exertion. At this time, any remaining questions were answered regarding the testing protocol and a rest was taken prior to the first assessment of the IMTP.

The participants were asked to take their placement on the force plate, keeping their hands in a mixed grip (pronated and supinated). Participants chose their preferred mixed grip. Once this body position was achieved, a final assessment by the researcher was conducted (using a goniometer), making sure the knee (125° - 145°) and hip joints were in appropriate ROM angles. For each IMTP attempt, the participant began by taking all the slack out of the barbell and leaving the body positioned in a locked manner. The test administrator began a three second countdown for the athlete. Once the participant begins the pull, the administrator used verbal encouragement throughout the exertion. The pull lasted approximately three seconds, and the participant was informed of when the test was completed. Three minutes of rest was allowed between each trial of the IMTP, with three total trials completed. If errors occurred within the testing protocol, an additional trial was completed for correct data results.

Variables

The independent variables included:

a) Status (Starter vs. Non-Starter)
b) Position (Lineman, vs. Big Skill vs. Skill)
c) Offense vs. Defense
d) Underclassmen vs. Upperclassmen

The dependent variables that were measured included:

a) Rate of Force Development (RFD)
    a. RFD 0-50 ms (RFD 0-50)
    b. RFD 0-100 ms (RFD 0-100)
    c. RFD 0-150 ms (RFD 0-150)
    d. RFD 0-200 ms (RFD 0-200)
    e. RFD 0-250 ms (RFD 0-250)
b) Peak Force (PF)
    a. Force at 50 ms (Force50)
    b. Force at 100 ms (Force 100)
    c. Force at 150 ms (Force 150)
    d. Force at 200 ms (Force 200)
    e. Force at 250 ms (Force 250)
c) Vertical Jump
    a. Vertical Jump Height

b. Average Propulsive Power

c. Peak Propulsive Power

d. Average Propulsive Velocity

e. Peak Propulsive Velocity

Statistical Analysis

All statistical tests were carried out by IBM SPSS Statistics Version 28 statistical analysis program with the level of significance measurement set at ($p<0.05$). All descriptive statistics were used according to the study objectives. A Pearson correlated coefficient analysis was used to examine the relationships between the field tests and one repetition maximum strength for squat, bench press, and power clean. Correlations between the variables were calculated using McGuigan and Winchester the Pearson product moment correlation coefficient. Cohen (1988) have ranked the meaningfulness of correlations as r = trivial (0.0), small (0.1), moderate (0.3), strong (0.5), very strong (0.7), nearly perfect (0.9), and perfect (1.0). The criterion for statistical significance of the correlations was set at $p \leq 0.05$. Additionally, descriptive statistics, means and standard deviations were calculated for each variable. A one-way ANOVA with Bonferroni post-hoc adjustments was used to examine the group-specific positions (lineman (n = 16), big skill (n = 9), and skill (n = 13)) for all dependent variables (PF, PF50 ms-PF250 ms, and RFD50 ms-RFD250 ms, VJH, AP, PP, AV and PV). The highest IMPT and CMJ attempt per participant was used for statistical analysis. Statistical analyses were performed using PASW software version 28.0 (SPSS Inc, Chicago, IL, USA), and an alpha level of $P \leq 0.05$ was used to determine statistical significance.

Results

Pearson Correlation

Pearson Correlation – Strength and Maximal Force

Strength (bench, power clean, and squat) and maximal force are illustrated in table 1. All variables within maximum force at certain time points of the force time curve (50ms, 100ms, 150ms, 200ms and 250ms) were positively and significantly correlated with maximum strength (bench press, power clean and squat) (r = 0.490 – 0.947, p = <0.001 – 0.019).

Table 2.

Correlations Among Strength and Force Variables

	IPF	IF50	IF100	IF150	IF200	IF250	Bench	PC	Squat
IPF	**1**	0.747*	0.730*	0.795*	0.826*	0.885*	0.775*	0.621*	0.745*
IF50	0.747*	**1**	0.904*	0.779*	0.876*	0.880*	0.585*	0.457*	0.543*
IF100	0.730*	0.904*	**1**	0.890*	0.879*	0.923*	0.517*	0.389*	0.49*
IF150	0.795*	0.779*	0.890*	**1**	0.928*	0.913*	.576*	.410*	0.558*
IF200	0.826*	0.876*	0.879*	0.928*	**1**	0.947*	0.601*	0.534*	0.578*
IF250	0.885*	0.550*	0.923*	0.913*	0.947*	**1**	0.650*	0.551*	0.630*
Bench	0.775	0.585	0.517	0.576	0.601	0.650*	**1**	0.714	0.895
PC	0.621*	0.457*	0.389*	0.410*	0.534*	0.551*	0.714*	**1**	0.720*
Squat	0.745*	0.543*	0.490*	0.558*	0.578*	0.630*	0.895*	0.720*	**1**

Note. IPF = Isometric Peak Force, IF50 = Isometric Force at 50 milliseconds, IF100 = Isometric Force at 100 milliseconds, IF150 = Isometric Force at 150 milliseconds, IF200 = Isometric Force at 200 milliseconds, IF250 = Isometric Force at 250 milliseconds, PC = Power Clean.
*Significant at $p \leq 0.05$

Pearson Correlation – Strength and Rapid Force

Strength (bench, power clean, and squat) and rapid force characteristics are illustrated in table 2. For maximum strength and rapid force characteristics, no significant correlations were observed for the squat (r = 0.093 – 0.309, p = 0.067- 0.589). No significant positive correlations were observed for RFD50-200 for the bench press (r = 0.186 – 0.2463, p = 0.230 - 0.278), however, a significant correlation was observed for RFD250 (r = 0.364, p = 0.029). No significant positive correlations were observed for RFD50-150 for the power clean (r = 0.178 – 0.210, p = 0.219 - 0.300), there was a significant correlation observed for RFD200 (r = 0.348, p = 0.0038) and RFD250 (r = 0.592, p = <0.001).

Table 3.

Correlations Among Strength and Rate of Force Development (RFD)

	IPF	IRFD50	IRFD100	IRFD150	IRFD200	IRFD250	Bench	PC	Squat
IPF	**1**	0.289	0.391*	0.424*	0.449*	0.592*	0.775*	0.621*	0.745*
IRFD50	0.747*	**1**	0.809*	0.519*	0.720*	0.718*	0.186	0.210	0.093
IRFD100	0.391*	0.809*	**1**	0.789*	0.762*	0.854*	0.203	0.184	0.146
IRFD150	0.424*	0.519*	0.789*	**1**	0.849*	0.815*	0.230	0.178	0.181
IRFD200	0.449*	0.720*	0.762*	0.849*	**1**	0.878*	0.246	0.348	0.186
IRFD250	0.592*	0.718*	0.854*	0.815*	0.878*	**1**	0.364*	0.405*	0.309
Bench	0.775	0.186	0.203	0.230	0.246	0.364*	**1**	0.714	0.895
PC	0.621*	0.21	0.184	0.178	0.348*	0.405*	0.714*	**1**	0.720*
Squat	0.745*	0.093	0.146	0.181	0.186	0.309	0.895*	0.720*	**1**

Note. IPF = Isometric Peak Force, IRFD50 = Isometric RFD at 50 milliseconds, IRFD100 = Isometric RFD at 100 milliseconds, IRFD150 = Isometric RFD at 150 milliseconds, IRFD200 = Isometric RFD at 200 milliseconds, IRFD250 = Isometric RFD at 250 milliseconds, PC = Power Clean.
*Significant at $p \leq 0.05$.

Pearson Correlation – Strength and CMJ Metrics

Strength (bench, power clean, and squat) and countermovement jump metrics are illustrated in table 3. For maximum strength and countermovement jump metrics, significant correlations were observed for the squat, bench press and power clean with average power and peak power (r = 0.695 – 0.769, p = <0.001). There were significant positive correlations for vertical jump height and the velocity variables (r = 0.877 – 0.998, p = <0.001). No differences were observed for power and VJH (r = 0.257 – 0.258, p = 0.129 – 0.131).

Table 4.

Correlations Among Strength Variables and Countermovement Jump

	CMJH	AP	PP	AV	PV	Bench	PC	Squat
CMJH	1	0.257	0.258	0.877*	0.998*	0.31	0.21	-0.062
AP	0.257	1	0.918*	0.407	0.266	0.725*	0.733*	0.695*
PP	0.258	0.918*	1	0.235	0.268	0.769*	0.703*	0.702*
AV	0.877*	0.407	0.235	1	0.884*	0.028	0.271	-0.018
PV	0.998*	0.266	0.268	0.884*	1	0.03	0.207	-0.059
Bench	0.031	0.725*	0.769*	0.028	0.03	1	0.714*	0.895*
PC	0.21	0.733*	0.703*	0.271	0.207	0.714*	1	0.720*
Squat	-0.062	0.695*	0.702*	-0.018	-0.059	0.895*	0.720*	1

Note. CMJH = Countermovement Jump Height, AP = Average Power, PP = Peak Power, AV = Average Velocity, PV = Peak Velocity, PC = Power Clean.
*Significant at $p \leq 0.05$

Playing Position

Peak Force - Lineman vs. Big Skill vs. Skill

There was a significant difference for PF (p = < 0.001; η_p^2 = 0.541), PF50 (p = < 0.001; η_p^2 = 0.503), PF100 (p = < 0.001; η_p^2 = 0.398), PF150 (p = < 0.001; η_p^2 = 0.489), PF200 (p = <

0.001; $\eta_p^2 = 0.500$), and PF250, (p = < 0.001; $\eta_p^2 = 0.467$). Post-hoc analysis revealed lineman and big skill had greater PF compared to skill players (p = < 0.001 – 0.028), additionally, lineman had greater PF compared to big skill ($p = 0.020$). Significant differences for PF50-PF250 were seen where greater force was seen for lineman and big skill compared to skill players (p = <0.001 – 0.005).

RFD - Lineman vs. Big Skill vs. Skill

There was a significant difference for RFD 0-50ms ($p = 0.006$, $\eta_p^2 = 0.253$), while no differences were seen for any other RFD metrics (p = 0.063 – 0.268). For RFD 0-50 ms, post-hoc analysis revealed big skill had greater RFD compared to skill players and lineman (p = 0.006 – 0.029).

CMJ Metrics - Lineman vs. Big Skill vs. Skill

There was a significant difference for VJH ($p = 0.015$; $\eta_p^2 = 0.213$), AV ($p = 0.021$; $\eta_p^2 = 0.198$), PV ($p = 0.018$; $\eta_p^2 = 0.206$), AP ($p = 0.008$; $\eta_p^2 = 0.243$), and PP (p = < 0.001; $\eta_p^2 = 0.378$). Post-hoc analysis revealed skill players jumped significantly higher than lineman (p = 0.017), AV and PV were greater for skill players compared to lineman ($p = 0.018$). Average power was greater for lineman compared to skill players ($p = 0.006$), while peak power was greater for lineman and big skill, compared to skill players (p = <0.001 – 0.025).

Table 5.

Mean (SD) Maximum Force (N) Values for All Time Phases for IMTP for All Grouped Positions.

	Peak Force	PF50	PF100	PF150	PF200	PF250
Line	3546.13 ± 416.65	2278.44 ± 294.48	2674.88 ± 458.46	2870.69 ± 377.96	2914.19 ± 287.46	2959.38 ± 367.67
Big Skill	3106.00 ± 324.68 †	2304.00 ± 318.57	2662.78 ± 340.86	2587.56 ± 249.53	2750.33 ± 366.69	2771.78 ± 336.04
Skill	2668.31 ± 322.93*‡	1730.00 ± 208.20*‡	2049.77 ± 273.24*‡	2202.85 ± 241.11*‡	2269.38 ± 254.93*‡	2294.31 ± 254.69*‡

Note. PF = Peak Force at varying time points in milliseconds (50, 100, 150, 200, 250).
*Significantly greater (line vs. skill).
†Significantly greater (line vs. big skill)
‡ Significantly greater (big skill vs. skill).

Table 6.

Mean (SD) Rate of Force Development ($N \cdot s^{-1}$) Values for All Time Phases for IMTP for All Grouped Positions

	RFD50	RFD100	RFD150	RFD200	RFD250
Line	9775.00 ± 4358.77∞	8851.88 ± 3984.13	7206.75 ± 2514.91	5622.50 ± 1481.01	4678.75 ± 1349.84
Big Skill	14717.78 ± 5618.95	10946.67 ± 3178.77	6796.22 ± 1586.20	5911.11 ± 1629.06	4814.67 ± 1192.77
Skill	8466.15 ± 3162.79 ‡	7430.77 ± 2319.89 ‡	5974.31 ± 1478.96	4813.46 ± 1134.97	3950.46 ± 893.72

Note. RFD = Rate of Force Development at varying time points in milliseconds (50, 100, 150, 200, 250).
∞ Significantly greater (big skill vs. line)
‡ Significantly greater (big skill vs. skill)

Table 7.

Mean (SD) Countermovement Jump Values for Power (w) and Velocity ($m{\cdot}s^{-1}$) for all Grouped Positions

	VJH (cm)	AP (w)	PP (w)	AV ($m{\cdot}s^{-1}$)	PV ($m{\cdot}s^{-1}$)
Line	41.24 ± 6.82 Φ	3767.73 ± 548.80	6673.08 ± 787.53	1.69 ± 0.13 Φ	2.95 ± 0.21 Φ
Big Skill	47.25 ± 9.71	3515.96 ± 438.94	6288.47 ± 625.61	1.77 ± 0.18	3.12 ± 0.30
Skill	49.30 ± 5.92	3093.41 ± 588.50*	5338.98 ± 868.04*‡	1.85 ± 0.14	3.20 ± 0.05

Note. VJH = Vertical Jump Height in centimeters, AP = Average Power in Watts (w), PP = Peak Power, AV = Average Velocity, PV = Peak Velocity.

*Significantly greater (line vs. skill).

‡ Significantly greater (big skill vs. skill).

Φ Significantly greater (skill vs. line).

Offense vs. Defense

No differences were observed for any variables when comparing offense vs. the defense (p = 0.244 - 0.954).

Starters vs. Non-Starters

No differences were observed for any variables when comparing starters vs. non-starters (p = 0.167 - 0.757).

Grade in College

No differences were observed for any variables when comparing underclassmen vs. upperclassmen (p = 0.490 – 0.995).

Discussion

The aim of the present study was to examine the relationships between field tests and one repetition maximum strength for squat, bench press, and power clean. Additionally, another research question wanted to assess PF and RFD (early and late) within collegiate level football athletes and if it related to overall playing status and aspects of performance. The main findings saw positive correlations with maximal strength values and isometric force (PF – PF250), correlations of bench press and power clean with RFD200, and RFD250, and positive correlations with strength values and average and peak power from the CMJH. For the IMTP, results of the study indicated that PF and RFD (early and late) were not significantly different between starters vs. non-starters and/or playing time, additionally, no differences were seen for the offense vs. defense or under vs. upperclassmen. Interestingly, when assessing said variables by position groups (line, big skill, and skill), significant differences were seen for all isometric force variables throughout a force time curve (Peak Force, PF50, PF100, PF150, PF200 and PF250) for line and big skill compared to skill players, peak force was greater for lineman compared to big skill athletes. When assessing RFD, big skill players possessed greater early RFD vs lineman at RFD50, and big skill players possessed greater early RFD vs. skill players for RFD50 and RFD100.

Correlation of Field Test and One Repetition Maximum

Often, athletic coaches will focus on weight room strength (one repetition maximum) and use that as their benchmark for human performance. However, when assessing common weight room lifts (bench, power clean, and squat) for American football players, only the power clean is performed with an explosive concentric phase, thus, a direct cross-over from weight room performance to athletic outcomes could be lacking. Previous literature suggests that a 1-RM correlates well with an IMTP (Dos' Santos et al., 2017; McGuigan & Winchester, 2008). Additionally, 1-RM has been shown to positively correlate with vertical jump performance (Haff et al., 1997). Thus, attempting to correlate 1-RM with dynamic functional assessments for collegiate football players could be of interest. For the present study, maximal force showed strong, to very strong correlations for power clean (r = 0.621), squat (r = 0.745), and bench press (r = 0.775). These findings are similar to previous literature which also agree that maximal force positively relates to 1-RM for bench, power clean, and/or squat (Dos' Santos et al., 2017; McGuigan & Winchester, 2008; Wang et al., 2016). Further, there were moderately strong correlations for all other specific force time points (50, 100, 150, 200 and 250) (r = 0.389 – 0.650). While sport type was different (rugby vs. American football), these findings are similar to Wang et al., (2016) who also saw positive correlations with 1-RM for the squat, and specific force time points (PF90 – PF250). Pertaining to RFD and 1-RM, there were significant correlations for bench press (r = 0.364) and the power clean (r = 0.405), when correlating to late RFD (RFD250). These findings are slightly dissimilar to McGuigan and Winchester (2008) who did not see a correlation with 1-RM and RFD. While the present study only saw differences for RFD250 and no other time points, potential differences between the studies could be related to athletic players (all players assessed together vs. grouping of player positions). Additionally, there were significant correlations for bench press, squat, and power clean for average power and peak power (r = 0.695 – 0.769) relating to CMJH. The correlation of 1-RM and CMJH is dissimilar to (McGuigan & Winchester, 2008) who did not see a significant correlation with 1-RM and CMJH performance. Differences between studies could be related to jumping equipment (Vertec vs. force plate), and hand placement (hands free vs. hands on hips).

Peak Force

For the present study, there were no differences observed for starters vs. non-starters, offense vs. defense, or under vs. upperclassmen, however, when grouped by positions, significant differences were seen for PF, where lineman and big skill players had greater PF compared to skill players. Additionally, PF was greater for lineman compared to big skill players. When comparing the present findings with an isokinetic dynamometer, the present findings (starter vs. non-starter) are dissimilar to Thompson et al. (2013), who observed differences in maximal force/strength for the hamstring between starters and non-starters. The differences in findings could be related to equipment type (isokinetic dynamometer vs. portable force plate), knee joint angle (120˚ vs. 125˚-145˚), and movement type (knee extension and knee flexion, vs. full body contraction). Although the present findings did not differentiate starter vs. non-starter, differentiation of positional performance (line, big skill, skill) is similar to Johnson et al. (2025). Their study also found that lineman and big skill players had greater PF compared to skill players. However, they did not see differences in lineman vs. big skill players. The differences could be related to the small sample size for lineman vs. big skill (3 vs. 6), while the present study has (16 vs. 9). Additionally, maximal IMTP testing protocols could also relate to the differences in findings (15-30 seconds of rest between attempts vs. 3 minutes rest). Be that as it may, there is a paucity of literature to compare the present IMTP findings to American football players (Johnson et al., 2025; McGuigan & Winchester, 2008), future research may want to assess IMTP with American football athletes across different collegiate levels (I, II, III, NAIA, JUCO), specifically, the athletes maximal force and rapid force characteristics, and if there are any differences within or between positions, playing status, etc.

Maximal Force at Specific Time Points

The present study observed no differences for starter vs. non-starter, offense vs. defense, or under vs. upperclassmen. When grouped by player positions, the present study observed significant differences for isometric force at specific time points of the force-time curve (PF50, PF100, PF150, PF200 and PF250), where lineman and big skill had greater force compared to skill players. Interestingly, there is no previous literature to compare the present findings to. Nevertheless, the present findings highlight the importance of being able to explosively apply forces, and to be able to attain the rapid and maximal force over the duration of the isometric contraction. While no direct comparisons (American football) can be made with previous literature, research does suggest that time specific force output does relate to dynamic performance (Dos' Santos et al., 2017). For example, Dos' Santos, Jones, et al., (2017) found maximum power clean strength positively correlates with PF100, PF150, PF200 and PF250 when assessing rowing, soccer, bicycle motocross, and hockey athletes. While the aforementioned study included a variety of sporting types, their findings, coupled with the present study, highlight the importance of athletes to be able to produce rapid force within a short time frame (0-250ms).

Rate of Force Development

Although the ability to produce peak force is crucial over the duration of a contraction, the speed at which the force is produced provides a valuable aspect to further assess specifics of the neuromuscular and musculature system (Maffiuletti et al., 2016). The present study observed no differences for starter vs. non-starter, offense vs. defense, or under vs. upperclassmen. When grouped by player positions, some significant differences were observed when comparing various RFD time points (50, 100, 150, 200, 250), specifically, big skill had greater RFD50 and

RFD100 compared to skill, and big skill had greater RFD50 compared to lineman. While different muscle groups (hamstring vs. full body), and status (starter vs. non-starter), Thompson et al. (2013) reported that American division I football starters had greater early RFD production for their hamstrings. The present study did not see any differences between any of the positions on late RFD (>100 ms). These findings are different than Johnson et al. (2025), who reported greater values for RFD250 for big skill compared to line and skill athletes. Differences could be attributed to the sample size of the big skill position (6 vs. 9), and IMPT assessment protocol (15-20 s rest vs. 3-minutes of rest between attempts).

Regardless of position, or status (starter vs. non-starter), RFD throughout a force-time curve can be advantageous for positions on the field and can aid with program design for strength coaches. Future studies may want to assess RFD throughout different portions of a season (In, Off, Post, Pre), how RFD is impacted within a competitive season, or pre- and post-testing of a training mesocycle.

Countermovement Jump and Strength Velocity Measurements

Although the purpose of the present study was not specifically focused on CMJ metrics, this data is still pertinent, as it provides movement patterns (power and velocity) that are important for athletic performance. The present study observed significant differences in CMJH, average velocity and peak velocity, where skill players jumped higher and quicker than lineman. These findings are similar to Merrigan et al. (2022) who also saw greater jump height and velocity variables for skill positions compared to lineman. While Johnson et al. (2025) did not assess velocity, they also found that skill players jumped significantly higher than lineman. The present findings, coupled with the aforementioned studies, suggest that absolute outcome (CMJH) and rate of speed (velocity) are more advantageous for skill players, regardless of one’s mass. However, when assessing power output, for the present study, lineman had greater power (average and peak) while big skill players only had greater peak power compared to skill players. These findings are similar to Merrigan et al. (2022) who also saw greater average and peak power differences for lineman vs. skill players. Interestingly, the present study (American football), has a handful of articles to reference, when assessing jumping profiles, specifically across specific athlete groupings (lineman, skill, big skill), additionally, the grouping of athletes can been seen differently as the present study and Merrigan et al. (2022) have different groupings of players. Regardless, the present study, coupled with previous literature (Merrigan et al., 2022; Townsend et al., 2019; Wang et al., 2016), highlight the importance of explosive-based measurements and athletic performance. CMJ variables have been seen to be a positive indicator of athletic performance and should remain a valuable aspect of assessment for positional and sport-specific progression and monitorization.

Conclusion

The objective of this thesis was to assess American football players weight room maximal strength (bench press, squat, power clean), maximal force, and rapid force characteristics, from an isometric mid-thigh pull using portable force plates. Additionally, countermovement jumps were also assessed using portable force plates. No differences were observed between starters and non-starters, offense vs. defense, nor under vs. upperclassmen. When assessing said metrics by positional grouping (line, big skill, skill), differences were seen, specifically where PF was significantly greater for line and big skill vs. skill players. Further, lineman had greater PF than big skill players. When looking at PF across specific time points (PF50-PF250), line and big skill players had greater force than skill players. When looking at RFD, big skill had greater RFD50 compared to lineman, and big skill had greater RFD50 and

RFD100 compared to skill players. For countermovement jumping, skill players jumped significantly higher than lineman and produced greater average and peak velocity compared to lineman. Lineman produced greater average and peak power compared to skill players, while big skill players produced greater peak power compared to skill players. The findings from the study indicate the value of testing both PF and RFD values by way of the CMJ and IMTP to further understand the force aspects of an individual and variations seen across a team with varying physical needs. It also provides insights into the physiological aspects of differing roles and the needs that each possess within their position. Although the equipment used would be ideal in all practical settings, this is not a practical purchase for all levels of strength and conditioning professionals. The findings from the current field of research and this study can help to further explain the connection that needs to be made with increasing force and rate of force production in the development, progression, and specificity of training competent athletes for their position needs.

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Appendix A – Informed Consent Document

Research Title: Assessment of Physiological Aspects of Division 2 Collegiate Football Players

Researchers:

Tatum Robertson, B.S.
Eric Conchola, Ph.D.

Purpose:

The purpose of this study is to look at the production of rate of force development and correlating factors of playing time and athletic performance.

Procedures:

Participants will be asked to read and complete the informed consent document (currently reading), a PAR-Q+, and basic demographic information form. Once paperwork is completed and agreement to enter the study is made, the individuals will be asked to have their height and weight taken.

Participants will be given a day and time for data collection availabilities that will work with current practice schedules. This will eliminate added time for participants and will ease data collection due to it being completed in the Sports Performance Center located at the University of Central Oklahoma.

On data collection days, after completing all paperwork, participants will complete a short warm-up. Following the warm-up, the participants will perform countermovement jumps. For all jumps, participants will stand on portable force plates, the protocol for each jumping attempt will ask for the participant to assume a comfortable jumping position with feet placed in approximately shoulder-width positioning and hands placed on the hips. Participants will jump as high as possible for three trials. Fifteen to thirty seconds of rest are provided between jump trials. After completing the jumps, each participant will be familiarized with the procedures for the isometric mid-thigh pull (IMPT) and finding proper placement for the individual's knee and hip joint while situated on the force plates with the barbell placed at their mid-thigh point with hands in an alternating hook grip. Participants will complete three total trials; additional trials will be completed if errors occur. Three minutes rest will be taken between each trial.

Permission to use your current strength values (squat, bench, power clean) of the Fall 2024 thru Spring 2025 (if you were on the team). By signing this form, you are consenting researchers to collect these values (1-RM, playing time, and playing status) from the current strength coach and staff. Initially, date will be identifiable by your name. The data will be received by email. Once received, the date will be added to your coded profile and will no longer be identifiable.

Expected Time for Participation:

Time for data collection should be approximately fifteen minutes. Participants are only asked to attend one data collection trial assessment.

Potential Benefits:

Participants within the study will receive instantaneous information of their overall performance and markers of their specific athletic makeup. This is useful for their personal knowledge and aspects that could further aid in their understanding of their capabilities.

Potential Risk:

The risk of the study consists of the general risk assumed when completing any athletic or daily task. Existing injuries should be disclosed prior to participation to discuss any increased risks. The testing procedure could result in a muscular strain due to isometric procedures but is a decreased risk due to the warm-up given for the participant. No physical risk is associated with height and weight measurements taken.

Researcher Contact Information:

The study has been approved by the University of Central Oklahoma Institutional Review Board (IRB), study (#2024-114). If you have any questions or concerns regarding the study, please contact Tatum Robertson, B.S. at trobertson10@uco.edu or Eric Conchola, Ph.D. at econchola@uco.edu. The UCO Institutional Review Board can be reached at irb@uco.edu or (405) 974-5497.

Explanation of Confidentiality:

All personal identifying information in regard to the participant will be kept confidential and unduplicated. The participant will be given an identifying number that will be used in place of their name for data analysis and release of the study results. The participants' online profile for the force plate data will consist of their identifying number and their weight. All remaining information will be kept on the original paper copies filled out by the participant and kept in a locked location that is only accessible by the advisor (Eric Conchola) and at the request of the IRB.

Assurance of Voluntary Participation:

Participation in this study is voluntary. The participant has the right to withdraw at any time and decline further participation within the study. The decision to leave the study is held solely with the individual participant. If the participant chooses to withdraw, information will remain confidential but will result in the beneficial aspects of the study to be discontinued.

Affirmation of the Participant:

I hereby volunteer to take part in the study listed above. I verify that I am at least 18 years of age. I understand the listed procedures and risks associated with my participation. I understand that I have the right to withdraw from the study at any point, but to understand that the benefits associated with the study will be discontinued at that time. I understand that my information will be kept confidential, and a copy of the informed consent will be provided to me. Any information received within the study will NOT be released with any identifying information to the public, coaching staff, or fellow participants within the study. In closing, I agree that I am participating based on my own free will and desire.

Participant's Printed Name: ____

Participant's Signature: __________________________ Date: ________________

Appendix B: PAR-Q+

PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

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

GENERAL HEALTH QUESTIONS

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

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

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ____________________ DATE ____________

SIGNATURE ____________________ WITNESS ____________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ____________________

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

Delay becoming more active if:

- You are currently experiencing a temporary illness, such as a cold or fever. It is best to wait until you feel better.
- You are pregnant. In this case, talk with your health care practitioner, physician, qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes. Answer the questions on Pages 2 and 3 of this document and/or talk to your health care practitioner, physician, or qualified exercise professional before proceeding with any physical activity program.

 1 / 4
01-11-2023

PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

PAR-Q+

6. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

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

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

PAR-Q+

If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

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

Delay becoming more active if:

- You are currently experiencing a temporary illness, such as a cold or fever. It is best to wait until you feel better.
- You are pregnant. In this case, talk to your health care practitioner, physician, qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes. Talk to your health care practitioner, physician, or qualified exercise professional before continuing with any physical activity program.

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

PARTICIPANT DECLARATION

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

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______________________________ DATE ______________________________

SIGNATURE ______________________________ WITNESS ______________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

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

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

Key References
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Appendix C: Background and Demographic Information

Please answer the following questions as accurately as possible:

1. What is your current academic classification? ___________________________

2. Current number of years of collegiate sports play. ________________________

3. What is your current offensive or defensive position? _____________________

4. Starter or Non-Starter, and approximate amount of playing time (if applicable).

   ____

<u>Researcher Will Collect These Values:</u>

Participant Number: ________________

Weight (kgs):	**Height (in):**

1. Current Squat 1RM Max: _________________________
2. Current Bench Press 1RM Max: ___________________
3. Current Power Clean 1RM Max: ___________________