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Lower-Extremity Biomechanical Characteristics of College American Football Starters: Examining the Squat, Lunge, and Vertical Jump

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Abstract

American football is a dynamic sport characterized by intense sporting actions such as blocking, tackling, jumping, and sprinting. Furthermore, these sporting actions often require athletes to repeatedly achieve extreme ranges of motion such as deep flexion and hyperextension. The aim of the present study was to assess select lower-extremity biomechanical characteristics and examine position-specific differences in those characteristics within a cohort of collegiate American football athletes. Sixteen NCAA Division-II American football starters volunteered to participate in this study. Biomechanical characteristics were assessed with a three-dimensional markerless motion capture system which examined each athlete's ability to perform bilateral and unilateral squats, lunges, and the countermovement vertical jump. Significant differences were observed in unilateral squat depth left (p=0.002), vertical jump height (p=0.033), net impulse (p=0.008), max ground reaction force (GRF) (p=0.034), right knee valgus at max loading (p=0.031), concentric left knee peak torque percent body weight (p=0.013), absorption right knee flexion (p=0.031), absorption left knee flexion (p=0.014), GRF absorption left (p=0.005), and GRF absorption right (p=0.015) between position groups. However, no significant differences were observed for measures of bilateral squat weight distribution, knee dynamic valgus, lunge characteristics, or peak power during jumping tasks. These findings, particularly unilateral squat and lunge characteristics, provide additional insight into the similarities and differences in foundational movement patterns across position groups within a cohort of NCAA Division-II American football starters. Sports performance professionals can utilize this information to develop and integrate resistance training programs that maintain and improve general as well as specific foundational movement patterns that may translate to athletic performance.

Keywords: flexibility, stability, movement screen, biomotor ability, athletic performance

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Introduction

American football is an extremely demanding sport involving violent collisions during plays for most positions during games and practice (Kerr et al., 2015; Rechel et al., 2008). During these collisions, an athlete's entire body can be exposed to ranges of motion that they are not typically exposed to, leading to both skeletomuscular and soft tissue injuries. Ensuring athletes can achieve and maintain optimal ranges of motion through compound, multi-joint exercises can be beneficial in aiding athletes in decreasing both contact and non-contact injuries (Clark et al., 2022; Edwards et al., 2019; Kiesel et al., 2011). In addition to performing movement and mobility routines, assessing an athlete's biomechanical characteristics (i.e., movement capacity) can be beneficial for quantifying and comparing kinetic variables throughout various planes of motion while also identifying potential areas of improvement. Collisions of great magnitude have led to high injury rates within the sport, where in college, the injury rate reached 39.9 per 1000 athletic exposure in competition (Kerr et al., 2015). These injury rates are ranked highest in all sports offered in high school and college (Kerr et al., 2015; Rechel et al., 2008). These high injury rates create challenges for teams with player availability at the high school and collegiate levels. Biomechanical analysis has become a common tool among sports performance professionals to assess athletes' mobility, flexibility, and stability, which plays a crucial role in the physical development of athletes as well as mitigating injury risk (Wiese et al., 2014). As part of a multidisciplinary team, sports performance professionals can collaborate to assess and address biomechanical characteristics in order to improve preparedness and optimize athletic performance while mitigating injury risks.

Coaches have used physical movement quality to assess athletes' technical skills, whereas, in a recent systematic review to establish optimal training session design, researchers investigated the relationship between physical movement quality and sport-specific technical skills in female athletes (Clark et al., 2022). From the articles in the systematic review, sport-specific technical skills in handball, volleyball, soccer, basketball, netball, lacrosse, and softball each showed significant correlations with several fundamental movement patterns (Farley et al., 2020). These findings further highlight the importance of biomechanical proficiency, motor control, and multi-joint coordination of the limbs as it relates to athletic performance, as well as its translatability across disciplines. The most common field-based movement capacity screening tools include the Functional Movement Screen (FMS) and the Y-Balance Test (YBT) (Cook et al., 2006a; Cook et al., 2006b). The FMS utilizes seven fundamental movement patterns to identify potential movement deficiencies and asymmetries (i.e., deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability), whereas the YBT uses three lower-body reaching tasks (e.g., anterior, posterolateral, and posteromedial) to identify possible deviations in dynamic balance (Clark et al., 2022; Wiese et al., 2014; Smith et al., 2015). Recent investigations using the FMS and YBT have reported correlations between poor movement capacity and increased risk for injury or re-injury, but it remains unknown how well these measures relate to sports performance ability (Smith et al., 2015; Chimera & Warren, 2015; Kiesel et al., 2011; Dorrel et al., 2018; Garrison et al., 2015; Kiesel et al., 2014; Lisman et al., 2018). Beyond sport, FMS can assess movement quality, particularly in tactical populations such as firefighters and law enforcement officers (Thompson et al., 2024; Farrokhi et al., 2008). As technology advances and becomes more available to sporting organizations and sport scientists, the careful integration of such can be utilized to understand the nuances of biomechanical characteristics. This detailed information can further guide athlete preparation, rehabilitation, and return-to-sport across disciplines and sport.

The use of markerless motion capture systems (MCS) in clinical settings has become commonplace, and it has been suggested that they can be utilized to assess flexibility, balance, and movement quality during dynamic motions while also assessing athletes' risk for injury or potential reinjury (Cabarkapa et al., 2022a; Hando et al., 2021). Several systems have developed valid and reliable analyzing software to perform such tasks (Martinez et al., 2018; Philipp et al., 2023; Sandau et al., 2014). Markerless MCS are becoming more popular than marker-based MCS primarily due to the task of placing markers on athletes being time-consuming and less practical due to constant or dynamic movement. Furthermore, markerless MCS has been shown to provide reliable kinematic characteristics of foundational movement patterns such as the squat, lunge, and vertical jump, as well as abduction and adduction of the upper-extremities (Philipp et al., 2023; Cabarkapa et al., 2022b). A recent study focusing on hip movements during baseball bat swings detected the range of motion of the lower body accurately (Sonnenfeld et al., 2021). A direct comparison between markerless MCS and marker-based MCS on baseball pitching kinematics observed similar results but suggested further testing of the markerless MCS (Fleisig et al., 2022). In basketball, research has been focused on shooting analyses as well dunking kinetics characters (Cabarkapa et al., 2023; Cabarkapa et al., 2020). Markerless MCS, more specifically, has developed movement screening programs that provide functions similar to those of both the FMS and the YBT and have been validated by several recent studies (Cabarkapa et al., 2022a; Cabarkapa et al., 2022b; Mundermann et al., 2006). Researchers found the intraclass correlation coefficient (ICC) to be above 0.8 for every component of the functional screen scores which prompted the authors to suggest using markerless MCS to assess various types of biomechanical motion of the human body (Cabarkapa et al., 2022a). Another study showed that markerless MCS could potentially analyze basic human movement with excellent reliability and 92% agreement of the analyzed movements (Philipp et al., 2023). When comparing it to the FMS directly, the markerless MCS's algorithm seemed to agree with the FMS score and could determine potential injury risk (Bird et al., 2022; Daggett et al., 2022).

Sports performance professionals commonly use motion analysis measures to assess flexibility, balance, and movement quality to identify areas of improvement from a physical development standpoint and the potential for injury or reinjury. However, current literature has primarily investigated highly competitive levels of sport (i.e., Professional and NCAA Division-I), while limited research has investigated other levels of competition (i.e., NCAA Division-II, NCAA Division-III), especially with regards to movement capacity assessed via markerless MCS within American football. In addition, current literature has primarily focused on using biomechanical analysis to identify athlete injury risk. Still, few focused on flexibility, balance, and movement quality in relation to athletes' level of play for their respective team. Therefore, the primary purpose of the present study was to profile biomechanical characteristics of NCAA Division-II American football starters. The secondary purpose was to examine similarities and differences in biomechanical characteristics between position groups. Findings from this investigation may be utilized as further evidence to support the rationale for programming general and position-specific exercises that are designed to enhance flexibility and stability at or around critical joints, as well as support the transfer of resistance training qualities to sports skills.

Methods

Experimental Design

This study used a cross-sectional design to examine the biomechanical characteristics of NCAA Division-II American football starters. Prior to the beginning of the season, subjects participated in a voluntary performance testing battery to assess baseline biomechanical characteristics of the lower-extremity. The markerless MCS assessment was included based on the value it could provide for sports performance professionals responsible for better understanding, as well as enhancing the preparation and performance of the American football athlete. Specific measures of biomechanical characteristics were selected in alignment with prior reported evidence and with the recommendation of an academically trained biomechanist (Cabarkapa et al., 2022a; Hando et al., 2021;

Philipp et al., 2023; Cabarkapa et al., 2022b). The successful development of the included research methods, organization and implementation of data collection, as well as data analysis, interpretation, and the writing of this manuscript are products of interdisciplinary collaboration that are critical for sport science initiatives with the purpose of supporting the health and safety of American football athletes.

Subjects

Sixteen resistance trained NCAA Division-II American football starters (age: 22.25 ± 1.1 years; height: 183.75 ± 7.8 cm; body mass: 97.22 ± 20.39 kgs) participated in the study. All subjects were free of musculoskeletal injuries, and prior to data collection, they regularly participated in resistance training sessions administered by their respective S&C coaches. Training sessions occurred three days per week and included exercises focused on developing football-specific muscular strength and power, explosiveness, sprinting speed, and agility. The athletes typically performed barbell squat, press, and deadlift variations to develop muscular strength. Meanwhile, they also performed Olympic weightlifting variations, plyometrics, and ballistic exercises to develop muscular power and explosiveness. The subjects who did not meet the criteria of being free of musculoskeletal injuries, regularly participating in training sessions, and being a starter were excluded from this study. According to McKay et al., this cohort of athletes would be classified as “Tier 3: Highly Trained/National”, which only includes approximately 0.014% of the global population (McKay et al., 2022). The testing procedures performed in this study were approved by the University of Nebraska-Kearney’s Institutional Review Board (#031022-1), and participants provided consent.

Procedures

This assessment was developed through collaboration between coaching, strength and conditioning, sports medicine, and academically trained sport scientists to provide a profile of lower-extremity biomechanical characteristics of offensive and defensive starters. Data were collected prior to the start of the football season and athletes were separated into offensive and defensive groups. Those within the offensive group were assessed on the first day (08:15 hr), while the defensive group was assessed on the second day (09:00 hr). The analysis procedures encompassed the data only from athletes who completed all relevant tests. Upon arrival at the athletic facility, subjects were familiarized with the testing procedures before having their body composition assessed. First, height was measured with a standard stadiometer (Cardinal; Detecto Scale Co, Webb City, MO, USA) and then body composition characteristics were measured utilizing a bioelectrical impedance analyzer (InBody 270, Cerritos, CA, USA). Lower-extremity biomechanical characteristics were assessed via a markerless three-dimensional motion capture movement screen (DARI Motion, Overland Park, KS, USA) that for the aim of this study assessed the functionality of the lower extremities during a bilateral squat, unilateral lunge, and countermovement vertical jump (18, 20-21, 23-24, 27). Movement capacity testing required approximately eight minutes per subject including a five-minute stationary cycle warm-up session.

Bilateral Squat

Subjects were instructed to stand at the center of the movement screening platform with their comfortable feet position (inside or at shoulder width with slightly externally rotated or straight foot position) to perform the squat movement, while maintaining upright trunk position and both arms and hands placed in front of the body. On the verbal command, subjects were instructed to perform the body squat as deep as they could and then return to the starting position. Subjects performed two bodyweight squat trials and the second trial was captured and analyzed. This method aligns with those previously published by Philipp et al., 2024.

Unilateral Lunge

Next, subjects were instructed to stand at the center of the movement screening platform with their feet in a comfortable position, similar to the squat exercise. On the verbal command, subjects were instructed to stride out with the right leg and to get as far and deep as possible. Then, return to the starting position in one fluid motion. Subjects were instructed to keep the arms out to the side for balance during the unilateral lunge movement. An identical movement was performed for the left foot. Subjects performed two trials and the second was captured and analyzed for the purpose of this investigation. This method aligns with those previously published by Philipp et al., 2024.

Bilateral and Unilateral Countermovement Vertical Jump

Then, subjects were instructed to stand at the center of the movement screening platform with their feet in a comfortable position, similar to the squat and unilateral lunge exercises. On the researcher's verbal command, subjects were instructed to load and jump as high as possible without stepping into the jump. Subjects were permitted to utilize an arm swing. For the unilateral CMJ, subjects were instructed to begin by standing on the right leg with the left foot off the ground behind the body and then load and jump as high as possible using an arm swing before ending the movement by landing on their right foot again. This method was repeated on the left leg. The depth of the squat, knee flexion, and amount of arm extension used during the CMJ was determined by each participant. Subjects performed two trials and the second was captured and analyzed for the purpose of this investigation. This method aligns with those previously published by Philipp et al., 2024.

Statistical Analyses

Descriptive statistics, means and standard deviations were calculated for each variable. Shapiro-Wilk's test corroborated that the assumption of normality was violated for 9/54 variables examined in the present study. Based on sample size, composition, and violation of normality, Kruskal-Wallis one-way analysis of variance by ranks test with Dunn test post-hoc adjustments were used to examine position group-specific differences in lower-extremity biomechanical measurements between Linemen (n=3), Big Skill (n=6), and Skill (n=7). Hedges g was used to calculate the measure of effect size [i.e., $g = 0.2$ is a small effect, $g = 0.5$ is a moderate effect, and $g > 0.8$ is a large effect] (Hedges, 1981). Statistical significance was set α priori to $p < 0.05$. To account for the sample size and to ensure accuracy, reported significance values were adjusted by the Bonferroni correction for multiple tests. All statistical analyses were completed with SPSS (Version 26.0; IBM Corp., Armonk, NY, USA).

Results

Descriptive statistics for each dependent variable are presented in Tables 1-2. As hypothesized, significant differences were observed between position groups for specific measures of lower-extremity biomechanical characteristics. However, unexpected similarities were observed within the bilateral squat and lunge tasks.

Table 1. Descriptive statistics, means and standard deviations ($\bar{x} \pm SD$), for specific bilateral and unilateral squat biomechanical variables available in DARI motion capture.

Variables (units)	Linemen	Big Skill	Skill	*p*	*g*
Bilateral Squat					
Weight Distribution Left (%)	51.05±1.22	50.24±1.36	49.88±1.79	0.388	0.46
Weight Distribution Right (%)	48.95±1.22	49.76±1.36	50.14±1.77	0.348	-0.47
Knee Dynamic Valgus Left (°)	-54.26±9.51	-55.12±12.67	-69.41±10.38	0.092	0.86
Knee Dynamic Valgus Right (°)	-62.78±2.74	-55.78±15.60	-63.84±20.24	0.861	-0.001
Unilateral Squat					
Squat Depth Left (cm)	32.35±4.92	42.01±2.71	54.76±7.47*⁑	0.002	-2.73
Squat Depth Right (cm)	31.64±3.48	42.10±4.09	50.37±14.97	0.078	-1.44
Dynamic Valgus of Left Hip and Knee (°)	11.58±6.53	23.29±12.40	30.05±27.35	0.363	-0.64
Dynamic Valgus of Right Hip and Knee (°)	6.85±13.64	24.71±8.14	37.45±20.93	0.079	-1.24
Lunge					
Stride Length Percentage of Lower-Body Left (%)	118.20±5.38	119.47±5.88	117.69±4.47	0.749	0.074
Stride Length Percentage of Lower-Body Right (%)	112.57±7.68	118.53±6.69	116.76±6.96	0.575	-0.35
Stride Length Max Left (cm)	123.61±6.50	118.45±4.36	112.70±5.71	0.089	1.20
Stride Length Max Right (cm)	117.77±8.45	117.56±7.07	111.83±6.73	0.416	0.51
Trail Hip Abduction Max Left (°)	48.20±3.57	54.25±8.25	59.36±5.09	0.056	-1.19
Trail Hip Abduction Max Right (°)	49.90±5.03	50.20±6.99	50.94±7.39	0.728	-0.091

Note: *significantly different when compared to the linemen position group ($p < 0.05$); ⁑significantly different when compared to the big skill position group ($p < 0.05$); and $g = 0.2$ is a small effect, $g = 0.5$ is a moderate effect, and $g > 0.8$ is a large effect.

Table 2. Descriptive statistics, means and standard deviations ($\bar{x} \pm SD$), for specific CMJ performance, eccentric, concentric, and landing variables available in DARI motion capture.

Variables	Line	Big Skill	Skill	*p*	*g*
Performance					
Jump Height (cm)	58.25±2.69	71.84±6.51	74.82±7.66*	0.033	-1.57
Jump Height Percentage of Lower-Body (%)	55.70±2.07	72.27±4.29	77.96±6.60*	0.010	-2.76
Peak Power (W)	5614.47±662.39	5395.87±603.09	4844.03±741.37	0.166	0.68
Net Impulse (N.s)	385.57±35.64†	304.65±35.60	262.44±26.77	0.008	2.36
Ground Reactive Force Max (N)	3391.40±746.36†	2717.02±271.57	2334.41±373.76	0.034	1.59
Eccentric Phase					
Hip Abduction Left (°)	14.40±2.89†	13.62±4.64	9.16±2.87	0.042	0.97
Hip Abduction Right (°)	18.17±7.19	11.88±4.01	8.40±5.16	0.136	1.11
Hip Flexion Left (°)	100.03±10.76	92.67±11.29	84.94±12.93	0.333	0.76
Hip Flexion Right (°)	99.83±14.83	90.70±9.89	85.23±14.15	0.333	0.68
Knee Flexion Left (°)	94.00±5.73	105.28±6.29	107.76±19.06	0.179	-0.84
Knee Flexion Right (°)	95.07±0.81	105.33±6.47	107.24±22.25	0.190	-0.78
Knee Valgus at Max Loading Left (°)	6.23±0.98	5.72±0.45	12.36±18.99	0.333	-0.02
Knee Valgus at Max Loading Right (°)	6.63±0.23†⁑	4.93±1.53	5.21±0.66	0.031	1.17
Ankle Flexion Left (°)	28.70±2.54	34.68±3.19	36.97±9.31	0.226	-0.99
Ankle Flexion Right (°)	32.20±5.40	33.45±3.23	38.46±11.39	0.647	-0.46
Concentric Phase					
Hip Peak Torque Percent Bodyweight Left (%)	15.47±1.45	15.22±4.05	22.91±10.05	0.259	-0.54
Hip Peak Torque Percent Bodyweight Right (%)	18.43±2.84	16.60±6.69	22.39±10.00	0.542	-0.25
Knee Peak Torque Percent Bodyweight Left (%)	10.03±2.75	14.32±2.17	20.20±6.31*	0.013	-1.46
Knee Peak Torque Percent Bodyweight Right (%)	11.33±2.31	16.07±3.88	23.21±13.13	0.060	-0.93
Ankle Peak Torque Percent Bodyweight Left (%)	1.93±0.67	1.88±0.52	2.33±0.45	0.497	-0.54
Ankle Peak Torque Percent Bodyweight Right (%)	1.87±0.85	1.52±0.50	2.14±0.76	0.316	-0.24
Hip Flexion at Peak Torque Left (°)	54.73±21.46	63.13±18.72	54.34±23.83	0.909	0.003
Hip Flexion at Peak Torque Right (°)	48.23±12.76	62.20±21.30	154.03±271.64	0.653	-0.49
Knee Flexion at Peak Torque Left (°)	79.90±11.92	99.03±7.68	102.37±21.95	0.192	-1.02
Knee Flexion at Peak Torque Right (°)	82.60±11.37	96.95±8.42	109.33±18.54	0.076	-1.19
Ankle Flexion at Peak Torque Left (°)	12.90±23.81	26.12±11.52	34.23±10.30	0.190	-0.91
Ankle Flexion at Peak Torque Right (°)	13.93±32.62	19.55±19.77	23.63±20.76	0.879	-0.25
Landing Phase					
GRF Takeoff Max Left (N)	1406.60±164.12†	1190.20±105.72	1105.49±138.41	0.049	1.35
GRF Takeoff Max Right (N)	1484.93±119.96	1226.57±129.28	1189.23±315.89	0.051	0.97
Absorption Depth (cm)	26.92±6.59	37.21±9.99	40.02±7.40	0.069	-0.98
Absorption Hip Flexion Left (°)	83.03±3.18	92.77±20.83	88.24±24.62	0.466	-0.18
Absorption Hip Flexion Right (°)	80.87±7.47	90.98±22.31	81.40±22.43	0.491	-0.03
Absorption Knee Flexion Left (°)	88.93±9.74	105.2±14.48	96.21±37.07	0.142	-0.33
Absorption Knee Flexion Right (°)	87.23±8.24	105.95±14.48	113.76±11.79*	0.031	-1.34
Absorption Ankle Flexion Left (°)	28.70±2.05	35.93±4.10	39.73±4.72*	0.014	-1.64
Absorption Ankle Flexion Right (°)	27.57±2.86	37.67±5.79	41.87±10.02	0.080	-1.23
GRF Absorption Left (N)	1684.80±394.54†⁑	1375.18±123.82	1027.83±203.88	0.005	1.76
GRF Absorption Right (N)	1706.60±352.04†	1333.22±206.58	1086.74±111.74	0.015	1.83
Absorption Knee Dynamic Valgus Left (°)	5.00±4.33	7.40±8.38	6.77±9.53	0.740	-0.14

Absorption Knee Dynamic Valgus Right (°)	3.03±3.80	6.33±7.74	5.67±8.99	0.710	-0.22

Note: GRF = ground reaction force; *significantly different when compared to the linemen position group ($p < 0.05$); ⁑significantly different when compared to the big skill position group ($p < 0.05$); †significantly different when compared to the skill position group ($p < 0.05$); and g = 0.2 is a small effect, g = 0.5 is a moderate effect, and g > 0.8 is a large effect.

Discussion

The purpose of this investigation was to assess specific measures of lower-extremity biomechanical characteristics within a cohort of college football starters. The primary findings of this investigation identified significant differences between position groups for measures of unilateral squat depth, bilateral CMJ height, and unilateral CMJ landing characteristics. However, no significant differences between position groups were observed for measures of sagittal plane lunge ability. Therefore, the results of the current investigation suggest that more careful observation of joint kinetics can provide sports performance professionals with critical information to support approaches for achieving and maintaining general and specific biomotor abilities relevant to the sport of American football. Furthermore, this information can also be utilized to support return-to-play and performance approaches for athletes who may have suffered a lower-extremity injury requiring sports rehabilitation.

Previous studies across sports have explored lower-extremity biomechanical characteristics (i.e., flexibility, range of motion, etc.) as assessed by the bilateral and unilateral squat tasks (Clark et al., 2022; Kiesel et al., 2011; Wiese et al., 2014; Kiesel et al., 2014; Lisman et al., 2018; Marchetti et al., 2018). Each task requires appropriate neuromuscular coordination, agonist-antagonist coactivation, dynamic joint stability, and mobility. The findings of this study observed no significant differences in weight distribution, dynamic valgus of the left and right hip or knee during the bilateral squat task as assessed via the utilization of the DARI motion capture system. These findings further highlight the similarities and apparent attention needed to develop and maintain foundational movement abilities regardless of stature, body mass, or playing position within starters. However, significant differences in unilateral squat ability between position groups were identified. Specifically, skill position groups achieved a greater range of motion in their left leg compared to both big skill and skill. These findings are especially novel and may be the first to profile these differences to this degree. Regarding American football, these findings may be due to body mass, the requirements of the sport in general, and each position-groups unique technical and tactical requirement specifically (e.g., accelerating and decelerating, joint kinetics and kinematics when doing so, changing directions to avoid opponents, etc.). Previous studies have shown that this asymmetry may be due to the stronger limb's unique force absorption characteristics or a loss of frontal plane stability (Paterno et al., 2010). Future investigations should aim to quantify and compare these characteristics between starters and non-starters and potentially by position group to enhance the current understanding of specific biomechanical similarities and differences that may contribute to optimal athletic performance.

The ability to coordinate one's lower extremities throughout dynamic ranges of motion to produce optimal levels of muscular power has been found to be a key characteristic of American football players (Lisman et al., 2018). Currently, scientific evidence suggests that lower-extremity muscular power is positively correlated with muscular strength, linear sprinting speed, change of direction speed, and agility (Farley et al., 2020; Johnson et al., 2024). As hypothesized, significant differences in CMJ ability were observed between position groups. However, upon further inspection beyond CMJ height, significant differences were observed for measures of jump height percentage of the lower body, net impulse, and maximal GRF between linemen and skill groups. Whereas the skill group jumped higher in absolute and relative terms, the linemen group produced a higher net impulse and GRF. These findings are likely to be due in part to differences in anthropometry as well as technical sporting demands unique to each position group. Whereas big skill and skill position groups are more likely to perform tasks that rely upon the stretch shortening cycle in game or practice scenarios, it is less common within linemen position groups. Furthermore, findings from this investigation can be utilized by sports performance professionals to develop specific training protocols that adequately prepare athletes for the demands of their sport and the demands of playing a starting role on the respective team.

The lunge exercise requires dynamic mobility, stability, and strength of the lower extremities primarily at the ankle, knee, and hip joints. Farrokhi et al. reported gluteus maximus and biceps femoris electromyography, as well as hip flexion angles, hip extensor impulse, and plantar flexor impulse were significantly different when trunk position was changed (i.e., forward lunge variations) (Farrokhi et al., 2008). Furthermore, adequate activation of agonist, antagonist, and synergist muscle groups such as iliopsoas, gluteus maximus, hamstrings, quadriceps, and gastrocnemius muscles have been found to contribute to the proficient completion of lunge tasks (Marchetti et al., 2018). Muscles in the abdominal region such as the transverse abdominal and in the back region such as the erector spinae provide stabilization when the body is in a split stance during both eccentric and concentric movement phases. However, this requires further exploration especially as it relates to the American football athlete. The results of the current investigation quantified and compared measures of stride length and hip abduction between position groups during the forward lunge exercise. No significant differences were observed for any measure of the lunge movement. Although biomechanical demands may differ based on position group, the ability to efficiently activate the hip extensor muscle groups seems to be a common characteristic within starters which should be maintained throughout a season, while knee extensors and ankle plantar flexors should also receive special emphasis throughout the season (Deneweth et al., 2014). These findings highlight the importance of dynamic mobility, stability, and strength of the lower body for American football athletes which may enhance their ability to block, accelerate and decelerate, and change direction in order to meet the specific demands of the sport.

An athlete's ability to decelerate their body mass during dynamic movements has been found to be related to reduced injury risk and increased athletic performance. Within CMJ tasks, it has been reported that athletes who decelerate their body mass more effectively transfer ground reactive forces during the contraction or propulsive phase of this task (Claudino et al., 2017). In addition to force production, this ability provides insight into neuromuscular fatigue and effective utilization of the lower-extremity's agonist, antagonist, and synergistic muscle groups (Claudino et al., 2017). Furthermore, eccentric loading of the hip flexors and ankle dorsiflexors, particularly the quadriceps muscle group, are also common within sport specific tasks such as cutting and change of direction (Merrigan et al., 2022). Significant differences were observed between linemen and skill groups for measures of knee valgus max loading right and concentric knee peak torque percent bodyweight left. Based on their uniqueness, these findings may be contributable to the sample tested, common loading mechanisms, and musculature contractile characteristics specific to the sport of American football but require further inquiry. An athlete's ability to contract their lower-extremity musculature to produce maximal vertical forces respective of time during the CMJ have been well-reported in the literature (Donahue et al., 2023). However, limited information is available as it relates to the function of the kinetic chain and how it may influence these abilities within the American football population.

Prior research has suggested that the landing phase of the CMJ produces 2-5x greater reactive forces when compared to that of the braking (1-3x) and propulsive phases (1-3x) across collegiate athletics (Donahue et al., 2023). Furthermore, when common mechanisms of injury are investigated it should be noted that an athlete's ability to effectively absorb ground reactive forces through proximal and distal tissues, ligaments, tendons, muscles, and bones is a primary predictor of lower-extremity injuries (Claudino et al., 2017). Significant differences were observed between linemen and skill groups for measures of GRF takeoff max left and right, absorption ankle flexion left, absorption knee flexion right, and GRF absorption right, while GRF absorption left was significantly different between linemen and skill groups, and skill groups and big skill groups. The authors posit that these findings may be influenced by body mass, loading mechanisms, and kinematic sequencing unique to each position group. However, no significant differences were observed between position groups for measures of absorption depth, absorption knee dynamic valgus left and right, and absorption hip flexion left and right. Altogether, these findings provide insight into task-specific functionality at the ankle, knee, and hip joints during the landing or absorption phase of the CMJ within the American football population. Consideration should be given to how these variables may vary by position group and throughout a competitive season. By utilizing this perspective, enhanced insights may be utilized to provide adequate sports performance or possibly sports rehabilitation approaches that support short- and long-term athlete development and performance by focusing on landing mechanics.

This study has limitations that should be noted. Due to the relatively small sample size of participants in this study, it may be beneficial for future research to include larger sample sizes by coordinating and collaborating with other teams and universities. In addition to providing a more robust sample, this would also allow for a more heterogeneous dataset than the one utilized in the current study. A second limitation of the current study involves information regarding the sample itself. In the future, it may be beneficial to account for biological age, training age, role on team, and playing experience, and to examine their interactions and influence on measures of physical performance. Not only will this assist research groups with providing more context to support their findings, but it may also assist practitioners in the field with determining the best approaches for developing their respective teams.

Conclusion

In conclusion, the findings of this study identified significant differences in the lower-extremity biomechanical characteristics of linemen, big skill, and skill position groups during squat, lunge, and jumping tasks. Specifically, differences between position groups for measures of unilateral squat depth, bilateral CMJ height, and unilateral CMJ landing characteristics were observed. These findings highlight the similarities and differences between position groups that may be due to physical characteristics or potentially the demands of the sport itself. Furthermore, insights gained can also be utilized to support specific strength and conditioning approaches to ensure athletes are prepared for the demands of their sport, or sports rehabilitation approaches to ensure athletes are prepared to return to play and performance. In the future, researchers may find it beneficial to expand the sample size but to also consider differences in age, grade classification, training status, and role (i.e., starter vs. non-starter).

Practical Implications

American football is a dynamic sport characterized by intense sporting actions such as blocking, tackling, jumping, and sprinting. Furthermore, these sporting actions often require athletes to repeatedly achieve extreme ranges of motion such as deep flexion and hyperextension. Findings from this study suggest that more similarities than differences exist in the lower-extremity biomechanical characteristics of college football starters from a successful team. Specifically, these similarities are observed during the bodyweight bilateral and unilateral squat, lunge, and CMJ exercises. However, unique differences were observed at the hip and knee during the eccentric and concentric phases of the CMJ, and at the ankle during the landing phase of the CMJ. Altogether, foundational lower-extremity movement patterns such as squats, steps, and lunges should be regularly integrated into strength training programs for football athletes. Furthermore, special attention should be given not only to lower-extremity muscular strength and power development, but also to the kinematic sequencing and biomechanical loading patterns during the development of such physical characteristics.

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