

Position-Specific Hip and Knee Kinematics in NCAA Football Athletes

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Background: Femoroacetabular impingement is a debilitating hip condition commonly affecting athletes playing American football. The condition is associated with reduced hip range of motion; however, little is known about the range-of-motion demands of football athletes. This knowledge is critical to effective management of this condition.

Purpose: To (1) develop a normative database of game-like hip and knee kinematics used by football athletes and (2) analyze kinematic data by playing position. The hypothesis was that kinematics would be similar between running backs and defensive backs and between wide receivers and quarterbacks, and that linemen would perform the activities with the most erect lower limb posture.

Study Design: Descriptive laboratory study.

Methods: Forty National Collegiate Athletic Association (NCAA) football athletes, representing 5 playing positions (quarterback, defensive back, running back, wide receiver, offensive lineman), executed game-like maneuvers while lower body kinematics were recorded via optical motion capture. Passive hip range of motion at 90° of hip flexion was assessed using a goniometer. Passive range of motion, athlete physical dimensions, hip function, and hip and knee rotations were submitted to 1-way analysis of variance to test for differences between playing positions. Correlations between maximal hip and knee kinematics and maximal hip kinematics and passive range of motion were also computed.

Results: Hip and knee kinematics were similar across positions. Significant differences arose with linemen, who used lower maximal knee flexion (mean \pm SD, 45.04° \pm 7.27°) compared with running backs (61.20° \pm 6.07°; $P < .001$) and wide receivers (54.67° \pm 6.97°; $P = .048$) during the cut. No significant differences were found among positions for hip passive range of motion (overall means: 102° \pm 15° [flexion]; 25° \pm 9° [internal rotation]; 25° \pm 8° [external rotation]). Several maximal hip measures were found to negatively correlate with maximal knee kinematics.

Conclusion: A normative database of hip and knee kinematics utilized by football athletes was developed. Position-specific analyses revealed that linemen use smaller joint motions when executing dynamic tasks but do not demonstrate passive range of motion deficits compared with other positions.

Clinical Relevance: Knowledge of requisite game-like hip and knee ranges of motion is critical for developing goals for nonoperative or surgical recovery of hip and knee range of motion in the symptomatic athlete. These data help to identify playing positions that require remedial hip-related strength and conditioning protocols. Negative correlations between hip and knee kinematics indicated that constrained hip motion, as seen in linemen, could promote injurious motions at the knee.

Keywords: hip kinematics; football biomechanics; knee kinematics; femoroacetabular impingement

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Hip injuries are a common cause of pain in athletes playing American football, and they can lead to movement restrictions, loss of playing time, and injury to other joints.⁸ Intra-articular injuries (eg, fracture, dislocations, and labral tears) represent approximately 5% of hip injuries in the National Football League, result in the longest time to recovery, and require surgical intervention more frequently than other hip injuries.¹⁰ Femoroacetabular impingement (FAI), in which osseous deformities of the acetabulum and proximal femoral morphology result in restricted terminal range of motion (ROM), often underlie or complicate these intra-articular injuries.^{19,30} In a recent

TABLE 1
Athlete Physical Characteristics and Hip ROM Measurements by Position^a

	Position					
	DB	L	QB	RB	WR	All
Height, m	1.83 ± 0.06 ^b	1.94 ± 0.06	1.87 ± 0.05	1.83 ± 0.09 ^b	1.83 ± 0.06 ^b	1.86 ± 0.08
Body mass, kg	94.3 ± 11.5 ^b	133.9 ± 7.3	95.8 ± 3.0 ^b	95.7 ± 12.7 ^b	82.1 ± 7.3 ^b	101.8 ± 21.4
BMI, kg/m ²	28.0 ± 2.1 ^{b,c}	35.6 ± 2.3 ^c	27.5 ± 1.3 ^b	28.6 ± 3.3 ^{b,c}	24.5 ± 1.2 ^b	29.2 ± 4.6
ROM, deg						
Flexion	104 ± 16	97 ± 9	96 ± 22	110 ± 18	103 ± 14	102 ± 15
IR	21 ± 10	26 ± 10	24 ± 8	30 ± 11	27 ± 8	25 ± 9
ER	22 ± 9	24 ± 7	28 ± 10	31 ± 10	25 ± 6	25 ± 8
iHOT ^d	92 ± 4	85 ± 10	79 ± 16	91 ± 8	83 ± 15	87 ± 11

^aValues are expressed as mean ± SD. All passive ranges of motion (ROMs) were measured by a single certified athletic trainer using a goniometer. BMI, body mass index; DB, defensive back/linebacker; ER, passive hip external rotation ROM at 90° of hip flexion; F, passive hip flexion ROM; iHOT, International Hip Outcome Tool; IR, passive hip internal rotation ROM at 90° of hip flexion; L, lineman; QB, quarterback; RB, running back; WR, wide receiver.

^bSignificant difference ($P < .05$) with lineman.

^cSignificant difference ($P < .05$) with wide receiver.

^diHOT scoring based on visual analog scale (range, 0-100); scores near 100 indicate better function/less pain.

study of 123 symptomatic hips of elite football players, 94.3% presented with cam- and/or pincer-type impingement.²⁷ Retrospective reviews of high-level athletes presenting with FAI indicated that football is a common sport for hip impingement.^{26,31}

FAI is associated with restricted hip joint ROM, particularly terminal internal rotation and flexion with typical deformity patterns.⁴ In a prospective study of 65 collegiate football players, alpha angle and head-neck offset (2 radiographic measures of FAI) were significantly correlated with clinically assessed hip internal rotation ROM deficits.² Loss of hip ROM can lead to repetitive bony collision and microtrauma during athletic activity, irreversible chondrolabral injury, and ultimate progression to hip osteoarthritis.^{12,17,28,29} In addition to damaging the hip joint, restricted hip ROM may lead to abnormal kinematics during athletic activities and compensatory injury in joints proximal and distal to the hip in the kinetic chain.³³⁻³⁵

The movement requirements of the hip and knee of elite football athletes during dynamic, game-like athletic tasks are not well quantified. However, detailed knowledge of the requisite hip ROM for elite football athletes is critical to recognize those athletes with FAI that may be more susceptible to injury with play. Furthermore, this information helps to establish practical targets for restoration of motion with surgical treatment or rehabilitation. While the compensatory mechanisms of injury secondary to restricted hip motion are being increasingly recognized, the impact of restricted hip motion on the knee is also not understood. Two studies have suggested a relation between radiographic indicators of hip impingement and an increased risk for anterior cruciate ligament (ACL) injury at the knee.^{13,14} Restriction of internal rotation at the hip may require athletes to achieve a greater range of internal rotation of the tibia to complete the athletic task successfully and thereby increase the likelihood of ACL injury.^{5,6} The extent to which hip and knee ROM requirements are

position specific is also unclear. An assessment of hip internal rotation and flexion ROM in National Collegiate Athletic Association (NCAA) football players found that offensive and defensive linemen were significantly more likely to test positively for reduced hip flexion ROM compared with other playing positions.¹⁶ Therefore, the objective of this study was to develop a normative database of hip and knee joint kinematics utilized by elite football athletes during common game-like movements. A secondary objective was to analyze the kinematic data by playing position. We hypothesized that kinematics would be similar between running backs and defensive backs and between wide receivers and quarterbacks, and that linemen would perform the activities with the most erect lower limb posture.

MATERIALS AND METHODS

Subjects

Forty healthy football athletes from 2 NCAA Division I programs volunteered to participate individually in 1 motion capture session. Athletes were selected such that there were 5 general positional categories represented: linebacker/defensive back (DB; $n = 10$), lineman (L; $n = 10$), quarterback (QB; $n = 4$), running back (RB; $n = 7$), and wide receiver (WR; $n = 9$). Subjects completed sections 1 (symptoms and functional limitations) and 2 (sports and recreational activities) of the International Hip Outcome Tool (iHOT-33).²¹ Scores were determined for each section and averaged to determine a hip quality of life (QoL) score, with 0 representing severe dysfunction and 100 representing perfect function. Athlete physical characteristics and hip QoL scores are presented in Table 1. The first 8 athletes included in this study (3 DBs, 1 L, 1 QB, 1 RB, and 2 WRs) did not complete the iHOT-33, as this portion was added after institutional review board approval and necessitated



Figure 1. Motion capture laboratory outfitted with synthetic turf. Turf was secured to force plates and decoupled from surrounding turf.

an amendment. The study was approved by the appropriate health sciences and behavioral sciences institutional review board.

Passive Range of Motion Assessment

Passive hip flexion, internal rotation, and external rotation terminal ROM were assessed using a goniometer by a single certified athletic trainer after a brief warm-up period at the start of the test session. Internal and external rotations were assessed at 90° of hip flexion with the athlete in a supine position. End ROM was determined to be the point at which the motion of interest induced pelvis motion. The same 8 athletes who did not complete the iHOT-33 also did not undergo passive ROM assessment because this portion was also added after institutional review board approval.

Biomechanical Assessment

The biomechanical assessment occurred in the motion capture laboratory, which was outfitted with synthetic turf (SYNTipede 321; SYNLawn) (Figure 1). All athletes wore the same model of turf cleat (adidas Response Mid; adidas AG). Prior to study initialization, a thorough video analysis of 10 NCAA Division I collegiate football games was undertaken to determine the most common movements performed by each playing position. From

this analysis, the 45° cut maneuver and the sidestep maneuver were selected for this study because of their frequency of execution and overlap among positions. For the 45° cut maneuver, the athlete ran forward approximately 9 m, cut at a 45° angle off of his dominant leg, and continued running for 4.5 m (Figure 2). Approach speed was monitored and required to be 5 ± 0.5 m/s. The sidestep required the athlete to shuffle sidestep (ie, no leg crossover) for approximately 5 m at an aggressive, self-selected speed with their dominant leg trailing, with respect to the direction of progression. The dominant leg contacted a force plate (AMTI OR6) for the cut step and 1 shuffle step of the cut and sidestep, respectively. Turf was secured to the surface of the force plate and decoupled from the surrounding turf. Athletes were required to complete 8 successful trials of each movement.

A lower-body retroreflective marker set was used to define the pelvis and bilateral thigh, lower leg, and foot segments in 3 dimensions.²³ Marker position data were collected at 240 Hz using 12 MX cameras (Vicon Corp), filtered with a zero-phase fourth-order Butterworth filter (12 Hz cutoff), and processed with Visual 3D software (C-Motion). Kinematic data were expressed relative to each subject's standing (neutral) posture⁷ and time-normalized to the stance phase of the movement, with heel-strike and toe-off defined by a threshold of above or below 10 N, respectively. Movement trials were averaged to create a



Figure 2. Exemplar cut maneuver performed by a wide receiver. The cut step occurred on a force plate.

representative kinematic cut and sidestep profile for each athlete.

Statistical Analysis

Passive ROM, physical, and kinematic measures were submitted to 1-way analysis of variance to assess differences between playing positions. Cut and sidestep kinematics were analyzed separately. The Levene test was used to test homogeneity of variances, and the Welch or Brown-Forsythe F -statistic was used when variances were non-homogeneous. Significance was denoted by $P \leq .05$. In the case of a significant main effect of position, post hoc pairwise comparisons were undertaken. A Bonferroni correction procedure was applied when variances were homogeneous, and a Games-Howell correction was used in the case of nonhomogeneous variances. Additionally, Pearson correlation coefficients (r) were computed between maximal hip and maximal knee rotations and maximal hip rotations and passive hip ROM measures. All statistical analyses were performed in SPSS 20 (IBM Corp).

RESULTS

Physical Measures and Hip Function

Athlete height, body mass, and body mass index (BMI) were significantly different across positions ($F[4, 35] = 5.15$, $P = .002$; $F[4, 35] = 41.8$, $P < .001$; and $F[4, 35] = 32.8$, $P < .001$, respectively) (Table 1). Linemen were significantly taller than defensive backs ($P = .007$), running backs ($P = .013$), and wide receivers ($P = .008$). Similarly, linemen were significantly heavier than other positions ($P < .001$ for all positions). Linemen also exhibited a significantly higher BMI compared with other positions ($P < .001$ for all positions). Additionally, wide receivers had significantly lower BMI than defensive backs ($P = .013$) and running backs ($P = .007$).

Hip function and pain scores as assessed by the iHOT questionnaire are tabulated by position in Table 1. No significant differences in iHOT score were present among positions ($F[4,26] = 1.55$, $P = .217$). Overall iHOT scores indicated very good hip function across subjects. Only 2 participants had scores below 70 (1 QB [score, 60]; 1 WR [score, 55]).

Hip Passive Range of Motion

Hip flexion, internal rotation, and external rotation passive ROM were not statistically different across positions. Mean values are presented by position in Table 1. ROM (mean \pm 1 SD) across positions were $102^\circ \pm 15^\circ$ for flexion, $25^\circ \pm 9^\circ$ for internal rotation, and $25^\circ \pm 8^\circ$ for external rotation.

Knee Kinematics

Cut. Tables 2 and 3 tabulate the means and SDs of each outcome variable for the cut and sidestep, respectively. For the cut, maximal knee flexion angle and knee range of flexion were significantly different across positions ($F[4, 35] = 6.09$, $P = .001$ and $F[4, 35] = 3.15$, $P = .026$, respectively) (Figure 3). Linemen had significantly lower maximal knee flexion (mean \pm SD, $45.04^\circ \pm 7.27^\circ$) compared with running backs ($61.20^\circ \pm 6.07^\circ$; $P < .001$) and wide receivers ($54.67^\circ \pm 6.97^\circ$; $P = .048$). Linemen also exhibited a reduced range of knee flexion ($28.90^\circ \pm 4.47^\circ$) compared with running backs ($38.76^\circ \pm 4.74^\circ$; $P = .034$). No other knee kinematical variables were significantly different across positions for the cut (Table 2).

Sidestep. For the sidestep, maximal knee flexion angle was significantly dependent on position (Brown-Forsythe, $F[4, 26.14] = 3.17$; $P = .030$) (Figure 4 and Table 3). Running backs displayed a higher maximal knee flexion angle ($73.09^\circ \pm 6.32^\circ$) compared with wide receivers ($61.32^\circ \pm 8.68^\circ$; $P = .048$). Range of knee internal/external rotation also exhibited a significant main effect of position ($F[4, 35] = 2.64$; $P = .050$), with defensive backs employing a lower rotational range ($13.25^\circ \pm 4.16^\circ$) relative to wide receivers ($20.23^\circ \pm 5.77^\circ$; $P = .054$). The remaining knee kinematical variables did not depend on position (Table 3).

TABLE 2
Kinematic Measures for the Cut Maneuver^a

Measure, deg	DB	L	QB	RB	WR	All
Knee						
Flexion						
At initial contact	25.20 ± 13.17	26.36 ± 9.71	27.11 ± 7.25	28.35 ± 4.72	27.03 ± 11.66	26.64 ± 9.91
Max	52.96 ± 6.29	45.04 ± 7.27	56.60 ± 9.19	61.20 ± 6.07 ^b	54.67 ± 6.97 ^b	53.17 ± 8.59
Range	36.13 ± 6.36	28.90 ± 4.47	37.22 ± 12.19	38.76 ± 4.74 ^b	32.70 ± 6.30	34.12 ± 7.09
Ad(+)/Ab(-)						
At initial contact	-0.65 ± 1.77	-0.62 ± 3.29	2.03 ± 3.76	-1.75 ± 2.84	-0.94 ± 2.91	-0.63 ± 2.87
Ad max	1.45 ± 1.35	0.16 ± 2.92	1.92 ± 3.62	-0.11 ± 1.83	1.02 ± 3.70	0.80 ± 2.69
Ab max	3.89 ± 2.29	5.41 ± 2.53	5.92 ± 4.23	5.19 ± 1.43	3.89 ± 3.67	4.70 ± 2.79
Ad/Ab range	5.34 ± 2.10	5.56 ± 1.79	7.84 ± 3.08	5.09 ± 1.03	4.90 ± 1.68	5.50 ± 1.98
IR(+)/ER(-)						
At initial contact	-3.34 ± 1.87	1.04 ± 5.08	-2.90 ± 5.19	-0.74 ± 4.76	-3.21 ± 4.64	-1.72 ± 4.49
IR max	6.60 ± 3.87	7.56 ± 4.01	8.08 ± 5.60	7.73 ± 5.53	8.05 ± 2.86	7.51 ± 4.04
ER max	7.98 ± 3.95	9.32 ± 2.42	6.49 ± 5.90	5.65 ± 6.27	8.64 ± 3.26	7.91 ± 4.20
IR/ER range	14.58 ± 1.73	16.88 ± 5.10	14.56 ± 0.99	13.38 ± 2.34	16.70 ± 2.93	15.42 ± 3.36
Hip						
Flexion(+)/extension(-)						
At initial contact	53.37 ± 7.90	43.36 ± 9.17	50.89 ± 6.51	50.98 ± 8.12	53.17 ± 6.24	50.15 ± 8.49
Flexion max	53.62 ± 7.92	43.36 ± 9.17	52.23 ± 8.76	51.26 ± 7.55	53.17 ± 6.24	50.40 ± 8.61
Extension max	8.42 ± 4.62	14.72 ± 8.70	11.50 ± 7.83	14.16 ± 4.63	7.32 ± 6.12	11.06 ± 6.95
Flexion/extension range	61.49 ± 8.45	57.56 ± 4.12	63.21 ± 10.09	64.97 ± 4.88	59.76 ± 5.99	60.90 ± 6.78
Ad(+)/Ab(-)						
At initial contact	-7.09 ± 7.95	-8.21 ± 6.11	-6.05 ± 4.89	-8.24 ± 2.98	-8.35 ± 5.72	-7.75 ± 5.80
Ad max	—	—	—	—	—	—
Ab max	22.97 ± 5.51	20.67 ± 3.90	20.99 ± 5.07	21.35 ± 4.72	19.07 ± 7.20	21.04 ± 5.33
Ad/Ab range	18.94 ± 6.52	14.52 ± 2.88	17.50 ± 4.92	13.53 ± 4.05	13.73 ± 5.31	15.57 ± 5.20
IR(+)/ER(-)						
At initial contact	9.97 ± 8.94	0.86 ± 9.67	4.17 ± 5.28	10.15 ± 11.98	6.40 ± 8.41	6.34 ± 9.64
IR max	16.92 ± 8.00	9.77 ± 7.77	7.40 ± 8.28	15.21 ± 10.15	12.79 ± 7.42	12.95 ± 8.47
ER max	4.38 ± 5.69	13.11 ± 7.31	12.11 ± 2.33	7.09 ± 8.99	7.48 ± 6.37	8.51 ± 7.26
IR/ER range	21.29 ± 4.62	22.87 ± 4.70	19.50 ± 9.63	22.30 ± 3.37	20.27 ± 8.20	21.46 ± 5.84

^aValues are expressed as mean ± SD. Ab, abduction; Ad, adduction; DB, defensive back/linebacker; ER, external rotation; IR, internal rotation; L, lineman; Max, maximum; QB, quarterback; RB, running back; WR, wide receiver.

^bSignificant difference ($P < .05$) with lineman.

Hip Kinematics

Cut. Hip flexion angle at initial foot contact significantly differed across positions ($F[4, 35] = 2.66; P = .049$) (Figure 3 and Table 2). Linemen exhibited significantly lower initial contact hip flexion ($43.36^\circ \pm 9.17^\circ$) relative to defensive backs ($53.37^\circ \pm 7.90^\circ; P = .07$). Maximal hip flexion angle also exhibited a significant effect of position ($F[4, 35] = 2.73; P = .045$) during the cut movement. Maximal hip flexion angle for linemen ($43.36^\circ \pm 9.17^\circ$) was lower than for defensive backs ($53.62^\circ \pm 7.92^\circ; P = .065$). All other hip kinematical measures were similar across positions for the cut (Table 2).

Sidestep. Several hip kinematical outcomes depended significantly on position for the sidestep movement (Figure 4 and Table 3). Similar to the cut, hip flexion angle at initial contact and maximal hip flexion angle showed a significant main effect of position ($F[4, 35] = 3.05, P = .029$ and $F[4, 35] = 3.62, P = .014$, respectively). Linemen experienced lower initial contact hip flexion ($48.54^\circ \pm 14.49^\circ$) and maximal hip flexion ($49.45^\circ \pm 12.74^\circ$) compared with defensive backs ($63.82^\circ \pm 7.73^\circ, P = .018$ and $64.45^\circ \pm 7.42^\circ, P = .010$,

respectively). Maximal hip abduction angle was also significant among position groups ($F[4, 35] = 2.59; P = .053$). Linemen exhibited a trend toward reduced hip abduction angle ($30.78^\circ \pm 3.78^\circ$) compared with wide receivers ($37.65^\circ \pm 3.70^\circ; P = .089$). Lastly, the range of hip abduction/adduction significantly differed by position (Brown-Forsythe, $F[4, 14.76] = 3.49; P = .034$), with linemen experiencing a reduced range ($21.37^\circ \pm 8.29^\circ$) relative to wide receivers ($32.41^\circ \pm 5.18^\circ; P = .022$). The remaining hip kinematical measures were similar across positions for the sidestep (Table 3).

Hip and Knee Correlations

Cut. For the cut, maximal knee flexion was significantly correlated with maximal hip flexion ($r = 0.60, P < .0001$), maximal hip extension ($r = -0.44, P = .005$), maximal hip internal rotation ($r = 0.41, P = .009$), and maximal hip external rotation ($r = -0.44, P = .004$). Maximal knee adduction was negatively correlated with maximal hip abduction ($r = -0.41, P = .008$) and maximal hip internal rotation ($r = -0.32, P = .046$). Maximal knee abduction was positively associated with maximal hip abduction ($r = 0.34$,

TABLE 3
Kinematics Measures for the Sidestep Maneuver^a

Measure, deg	DB	L	QB	RB	WR	All
Knee						
Flexion						
At initial contact	65.17 ± 7.53	57.85 ± 16.71	61.60 ± 5.59	66.41 ± 14.80	56.82 ± 13.46	61.32 ± 12.92
Max	67.72 ± 5.05	60.64 ± 12.15	63.50 ± 7.26	73.09 ± 6.32	61.32 ± 8.68 ^b	65.03 ± 9.35
Range	33.71 ± 11.48	42.13 ± 11.45	36.50 ± 17.24	43.28 ± 14.45	37.97 ± 9.13	38.73 ± 12.11
Ad(+)/Ab(-)						
At initial contact	7.95 ± 2.86	5.46 ± 5.32	4.27 ± 4.77	5.00 ± 3.44	5.28 ± 3.68	5.84 ± 4.05
Ad max	7.99 ± 2.83	5.67 ± 5.20	4.39 ± 4.57	5.44 ± 3.19	5.30 ± 3.70	6.00 ± 3.94
Ab max	4.14 ± 3.27	7.29 ± 3.31	6.36 ± 3.72	5.93 ± 2.97	5.44 ± 1.82	5.76 ± 3.07
Ad/Ab range	12.01 ± 3.40	12.87 ± 4.08	10.65 ± 2.12	11.30 ± 3.81	10.67 ± 3.96	11.66 ± 3.61
IR(+)/ER(-)						
At initial contact	3.73 ± 3.43	3.79 ± 3.28	9.52 ± 7.02	6.87 ± 6.90	6.33 ± 4.25	5.46 ± 4.87
IR max	5.39 ± 2.70	5.93 ± 2.77	10.19 ± 6.24	9.17 ± 6.29	8.55 ± 2.81	7.38 ± 4.17
ER max	7.94 ± 5.21	10.29 ± 5.04	8.95 ± 8.51	9.79 ± 6.35	11.72 ± 4.29	9.80 ± 5.43
IR/ER range	13.25 ± 4.16	16.18 ± 4.47	19.09 ± 7.36	18.85 ± 5.34	20.23 ± 5.77 ^c	17.12 ± 5.59
Hip						
Flexion(+)/Extension(-)						
At initial contact	63.82 ± 7.73	48.54 ± 14.49 ^c	60.55 ± 11.47	58.95 ± 8.41	56.98 ± 6.67	57.28 ± 11.16
Flexion max	64.45 ± 7.42	49.45 ± 12.74 ^c	60.97 ± 11.66	61.72 ± 9.03	58.63 ± 5.23	58.57 ± 10.55
Extension max	—	—	—	—	—	—
Flexion/extension range	25.94 ± 7.20	35.84 ± 9.19	38.28 ± 16.30	31.51 ± 16.21	37.43 ± 7.69	33.21 ± 11.27
Ad(+)/Ab(-)						
At initial contact	-5.39 ± 7.95	-10.00 ± 10.32	-4.53 ± 6.82	-6.44 ± 4.13	-5.51 ± 4.72	-6.67 ± 7.35
Ad max	—	—	—	—	—	—
Ab max	32.45 ± 7.59	30.78 ± 3.78	35.39 ± 4.90	36.65 ± 5.63	37.65 ± 3.70 ^d	34.23 ± 5.82
Ad/Ab range	27.62 ± 6.53	21.37 ± 8.29	31.56 ± 9.59	30.44 ± 4.37	32.41 ± 5.18 ^d	28.02 ± 7.71
IR(+)/ER(-)						
At initial contact	-7.85 ± 6.37	-6.15 ± 7.28	-9.37 ± 3.45	-10.02 ± 5.90	-8.32 ± 7.19	-8.06 ± 6.35
IR max	11.40 ± 11.66	5.96 ± 9.71	5.92 ± 8.98	11.16 ± 11.03	5.61 ± 10.20	8.15 ± 10.34
ER max	9.98 ± 7.50	10.41 ± 8.73	11.70 ± 3.12	11.61 ± 6.09	11.02 ± 8.44	10.79 ± 7.21
IR/ER range	21.27 ± 8.68	16.35 ± 6.71	17.62 ± 11.29	22.77 ± 5.48	16.62 ± 5.45	18.89 ± 7.45

^aValues are expressed as mean ± SD. Ab, abduction; Ad, adduction; DB, defensive back/linebacker; ER, external rotation; IR, internal rotation; L, lineman; Max, maximum; QB, quarterback; RB, running back; WR, wide receiver.

^bSignificant difference ($P < .05$) with running back.

^cSignificant difference ($P < .05$) with defensive back.

^dSignificant difference ($P < .05$) with lineman.

$P = .034$). Hip internal rotation ROM was negatively correlated with maximal hip abduction ($r = -0.38$, $P = .033$) and positively correlated hip external rotation ROM ($r = 0.37$, $P = .029$).

Sidestep. For the sidestep, maximal knee flexion was positively correlated with maximal hip flexion ($r = 0.65$, $P < .001$) and maximal hip internal rotation ($r = 0.50$, $P = .004$). Maximal knee abduction was negatively correlated with maximal hip internal rotation ($r = -0.32$, $P = .042$). Hip flexion ROM was significantly correlated with maximal hip abduction ($r = 0.40$, $P = .023$). Hip internal rotation ROM was significantly correlated with maximal hip internal rotation ($r = 0.39$, $P = .027$) and hip external rotation ROM ($r = 0.37$, $P = .037$).

DISCUSSION

This study is the first to define hip and knee kinematics of elite American football athletes as they performed dynamic

cut and sidestep athletic tasks with realistic turf and cleat conditions. Additionally, positional differences in kinematic profiles were identified. Defining requisite hip and knee ROM for these commonly performed game movements is critical for identifying athletes and their respective tasks that may increase susceptibility to hip and knee injury. Furthermore, these data help determine the goals for non-operative or surgical improvement of hip and knee ROM in the symptomatic athlete and inform hip-related strength, conditioning, and rehabilitation protocols.

A key finding of the study was that the majority of knee and hip kinematics for the movements analyzed were not statistically different across positions. Players in this study represented both offensive (quarterback, running back, wide receiver, offensive lineman) and defensive (defensive back/linebacker, defensive lineman) positions. Additionally, players spanned a wide range of physical characteristics, with linemen averaging 11 cm taller and 42 kg heavier than all other positions, in keeping with typical positional profiles.³² Despite the large differences in physicality among positions,

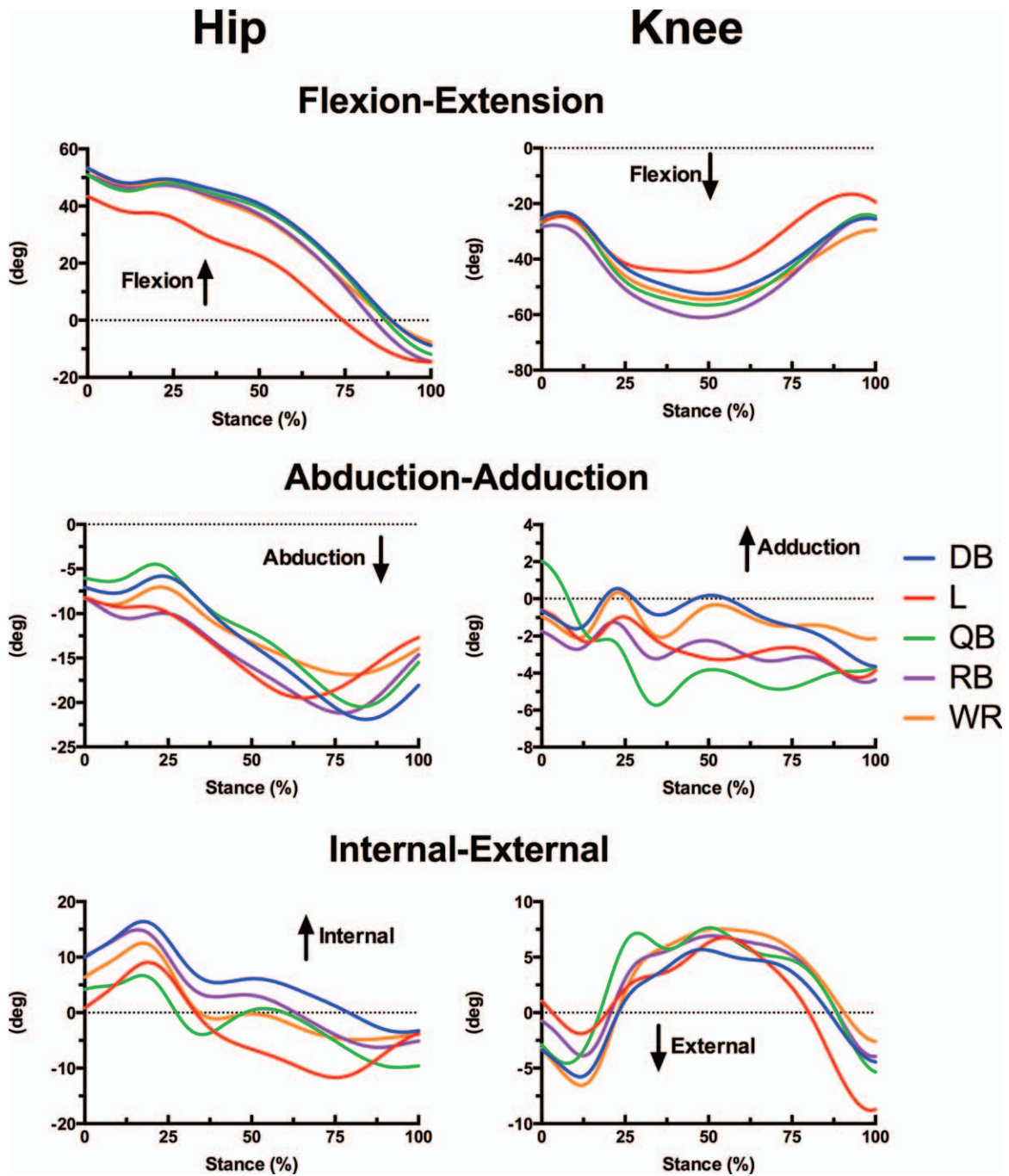


Figure 3. Mean hip and knee joint rotations for a 45° cut maneuver, stratified by playing position. Data were normalized from heel-strike (0%) to toe-off (100%), and 0° corresponded to the athletes’ standardized standing postures. Kinematic profiles were generally similar across positions. DB, defensive back/linebacker; L, lineman; QB, quarterback; RB, running back; WR, wide receiver.

the knee and hip showed similar ranges of motion overall. Hip internal/external rotation requirements were similar across positions for both movements examined in this study, suggesting that internal rotation ROM deficits may universally affect athletes required to perform cutting or sidestep maneuvers independent of position.

Although hip and knee kinematics were largely similar across positions, some position-specific patterns emerged in

the data. In the cases where significant differences were found, it was generally because linemen had smaller motions than other positions. The cut and sidestep movements were chosen for this study as they are common movements for all positions. They are also demanding movements that require good body control for proper execution. Since linemen were taller and heavier, they may employ smaller joint excursions to reduce the effort of performing the movement. However, a

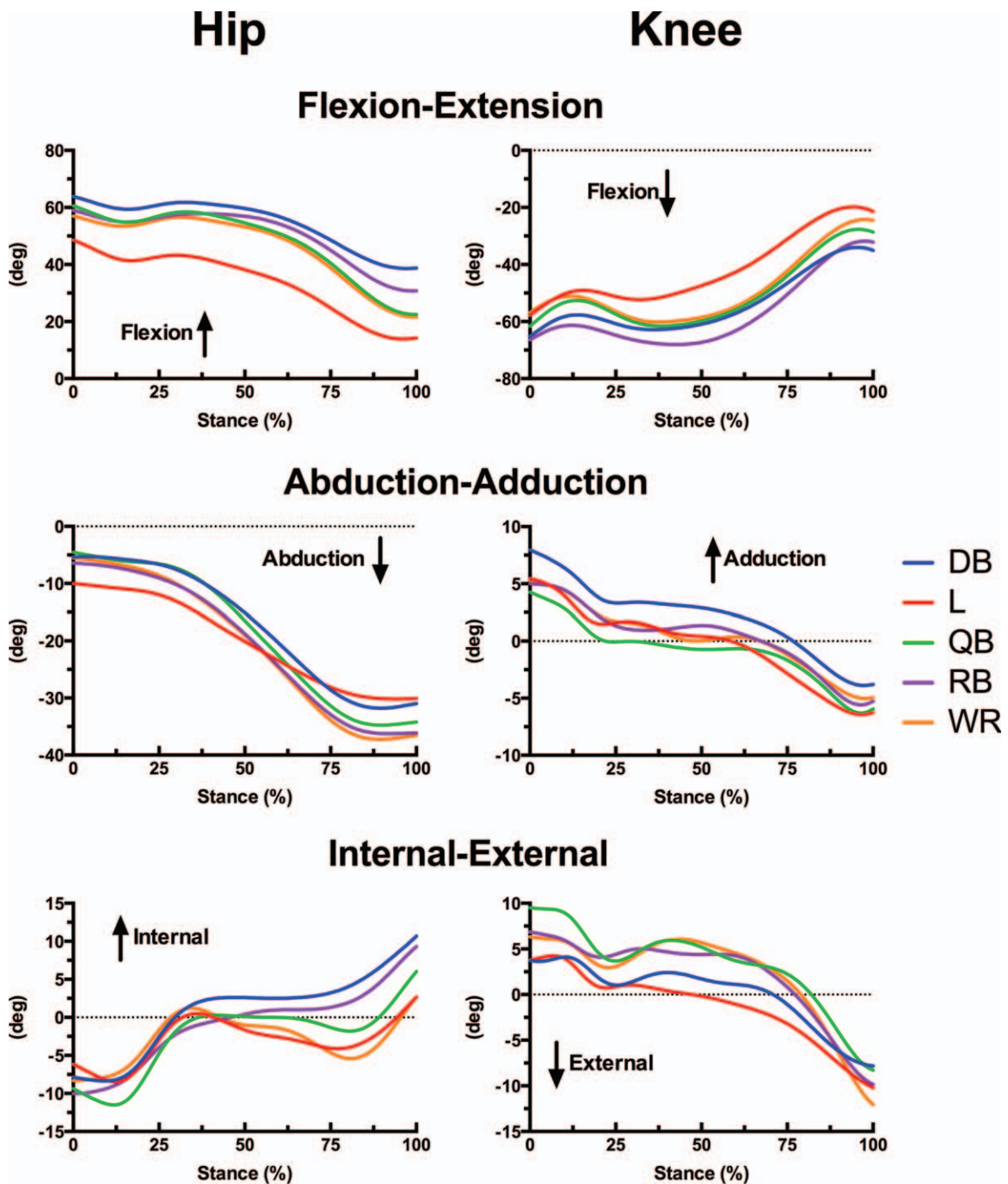


Figure 4. Mean hip and knee joint rotations for a sidestep shuffle maneuver, stratified by playing position. Data were normalized from heel-strike (0%) to toe-off (100%), and 0° corresponded to the athletes' standardized standing postures. As with the cut, kinematical profiles were generally similar across positions. DB, defensive back/linebacker; L, lineman; QB, quarterback; RB, running back; WR, wide receiver.

separate study that examined clinical hip flexion ROM in collegiate football athletes identified deficits in linemen compared with other positions.¹⁶ This suggested that linemen exhibit smaller motions because they have a significantly smaller ROM envelope. In the current study, however, no passive hip ROM differences were found among positions, suggesting that smaller joint rotations employed by linemen

during dynamic tasks resulted from a movement strategy rather than an anatomical constraint. Notably, all positions displayed endpoint passive hip flexion ROM below normal (120°).^{9,22} Internal and external rotation ROM were closer to normal values (30°-50°), but still on average low.^{2,9} Similar results have been noted in other studies of elite American football athletes.^{2,16} Less than normal ROM in otherwise

asymptomatic athletes may be indicative of a training regimen that emphasizes strength over flexibility. Further work is necessary to determine how reduced ROM relates to the presence of FAI in this population.

Several maximal hip and knee motions, which may predict joint injury risk, were found to correlate during the cut and sidestep movements. FAI is typically associated with reduced passive hip flexion and internal rotation. Smaller maximal hip flexion and maximal hip internal rotation angles were correlated with reductions in maximal knee flexion angle. Reduced knee flexion during dynamic loading of the knee has been associated with an increased risk of ACL rupture^{18,25} and knee osteoarthritis.^{20,38} Furthermore, a reduction in maximal hip internal rotation was associated with increased maximal knee adduction during the cut and increased maximal knee abduction during the sidestep. Increased knee adduction angle, particularly in combination with reduced knee flexion, has been identified in populations at risk for knee osteoarthritis.^{3,36,37} An elevated knee abduction angle during the execution of demanding movements was found to be a key predictor of ACL injury risk.^{11,15,24} Taken together, these findings indicate that abnormal hip kinematics may increase susceptibility to a knee injury, further emphasizing the importance of early detection of FAI. Likewise, the entire proximal and distal kinetic chain must be considered when diagnosing and treating FAI, as abnormal knee joint kinematics may indicate underlying hip issues.

Passive terminal hip ROM is a key diagnostic tool in assessing FAI and determining course of treatment. Surprisingly, no passive ROM correlated with its dynamic counterpart (eg, passive flexion ROM to maximal hip flexion), except for hip internal rotation ROM correlating with sidestep maximal hip internal rotation. While variability may account for lack of correlation, all assessments were performed by the same certified athletic trainer to reduce this variability. Given the lack of correlation, proper diagnosis and management may be aided by additional dynamic screening of hip range of motion.

Interpreting the results of this study is limited by several factors. While the athletes were encouraged to execute the cut and sidestep naturally, as in a game situation, the movements were performed in a controlled laboratory setting and may not translate equally to game play. Athletes did not wear pads because they blocked bony landmarks required for marker placement and obscured markers from the view of the cameras. The subjects may have moved differently if they had pads on, which also may limit the on-field translatability of the data. Passive hip ROM and hip QoL were not assessed for all athletes, so these measures must be interpreted with caution. While hip pain was assessed via questionnaires, radiographic imaging of the hip, which may have revealed more insight into the presence of FAI in the study population, was not obtained. Therefore, interpretation of these results as they relate to FAI must be done cautiously. Passive hip abduction/adduction ROM and knee ROM were not measured in this study, which would have assisted in interpreting the dynamic results. Nonetheless, the current protocol reflected standard

clinical assessments and thus provided valuable insight into the extent to which passive hip ROM translates to dynamic ROM. We sought to recruit equal numbers into each positional group, but the challenges of recruiting and maintaining an elite athlete population rendered the groups uneven. An appropriate multiple comparison correction was used to accommodate the lack of equal group sizes. We recruited this study size based on a priori power analyses. It remains possible, however, that non-significant results may occur due to underpowering of the study.

A novel database of hip and knee rotations typically utilized by elite football athletes while performing 2 dynamic and demanding football-relevant movements has been developed. These results provide an evidence-based reference to inform guidelines for range of motion goals after a surgical intervention. Furthermore, these data should guide postsurgical rehabilitation and return-to-play protocols by providing objective goals for hip and knee joint ROM. Positional analysis revealed that linemen exhibited significantly different dynamic kinematics compared with other playing positions but not statistically different passive hip ROM. This finding suggests that they may be at increased risk for injury that is not captured during clinical tests, and training linemen to utilize the same dynamic ROM during movements should be considered to reduce this risk. Correlation analysis between maximal hip and knee rotations during cutting and sidestepping revealed that reductions in hip ROM that commonly occur with FAI are associated with potentially injurious knee joint kinematics. The effect of hip injury on joints distal in the kinetic chain appears important to athlete health. Future work will examine proximal joints in the kinetic chain, as lower back injury is also common in collegiate American football,¹ and will additionally consider athletes with known hip injury for a more complete understanding of the effects of hip injury on dynamic joint range of motion.

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