

# American Football Position Does Not Influence Symmetry in Joint Power During High-Speed Running

Original Research

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## Abstract

**Introduction:** The distinct physical and tactical roles of American football positions may influence interlimb symmetry of ankle, knee, and hip power distribution during high-speed running. This study examined differences in joint power distribution symmetry between position groups and joints using inverse dynamics.

**Methods:** Sixty-eight draft-eligible American football players (Big n=18; Skill n=24; Skill n=26) completed a single high-speed running trial (6.4 m/s) on an instrumented treadmill synchronized with a motion capture system. Joint powers were computed via inverse dynamics and expressed as positive (generation) and negative (absorption) percent contributions to total limb power. Interlimb differences were quantified using the Asymmetry Index ( $AI = |left-right| / [(left+right)/2] \times 100\%$ ). Group differences were analyzed using Kruskal-Wallis tests with Bonferroni-adjusted post hoc comparisons ( $\alpha = .017$ ).

**Results:** No significant differences in AI were found among position groups for positive ankle ( $p = .868$ ), knee ( $p = .082$ ), or hip power ( $p = .846$ ), nor for negative ankle ( $p = .222$ ), knee ( $p = .181$ ), or hip power ( $p = .496$ ). AI differed significantly among joints for both positive ( $F(2,134)=33.4, p<.001, \eta^2=0.332$ ) and negative power ( $F(2,134)=15.7, p<.001, \eta^2=0.19$ ). Knee AI was highest for positive power ( $31.9 \pm 24.5\%$ ), followed by hip ( $18.1 \pm 28.9\%$ ) and ankle ( $9.6 \pm 6.9\%$ ). Negative AI was lowest at the ankle ( $11.9 \pm 14.1\%$ ) compared to knee ( $22.4 \pm 16.6\%$ ) and hip ( $22.8 \pm 19.5\%$ ).

**Conclusions:** Player position does not influence the symmetry of joint power contributions during high-speed running. The ankle demonstrates the greatest symmetry, whereas the knee shows the largest asymmetry.

**Key Words:** biomechanics, gait, inverse dynamics

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## Introduction

American football is a contact sport involving brief high-intensity bursts of power alternated with rest<sup>1-2</sup> with players competing in distinct positions that each require specific activity, technical, and tactical demands. Offensive and defensive linemen, the Big group, frequently engage in short, explosive collisions such as blocking and tackling over a few steps, requiring rapid force production from a stationary or slow-moving start.<sup>3,4</sup> Skill positions, including wide receivers, cornerbacks, and running backs, the Skill group, perform repeated sprinting, cutting, and high-velocity ball-carrying or coverage maneuvers, often over distances of 10–40 m.<sup>3,4</sup> Hybrid positions such as tight ends and linebackers, the Big–skill group combine demands of both groups, alternating between sprinting and high-force collisions during a single play.<sup>3,4</sup> These repeated on-field tasks impose distinct biomechanical demands, particularly on the lower limbs, where the generation and absorption of mechanical work and power at the ankle, knee, and hip drive successful performance during sprinting, acceleration, and deceleration.

During running, mechanical work is required to rotate limb segments, restore energy lost during early ground contact, and propel the body forward. Joint power represents the rate at which mechanical work is accomplished at a specific joint, providing an estimate of muscle activity.<sup>6,7</sup> Positive joint power is generated primarily by concentric muscle contractions, with potential strain energy released, whereas negative joint power arises from eccentric contractions, storing strain energy and absorbing mechanical energy during running. The ankle contributes most substantially to positive joint power ( $\geq 60\%$  of total limb power), followed by the knee ( $\sim 25\%$ ) and hip ( $\sim 15\%$ ).<sup>7-10</sup> In contrast, negative power is predominantly absorbed at the knee and ankle during the braking phase, with the hip contributing minimally.<sup>8,11</sup>

Given the distinct movement demands of Big, Big-skill, and Skill players, it is plausible that repeated exposure to position-specific tasks could influence how each limb contributes to mechanical power during high-speed running. Although human gait is generally symmetric, minor interlimb differences are common, and lateral biases may influence the joint power produced during high-speed running.<sup>12</sup> Asymmetries in external leg power (tested during a countermovement jump) have been documented in American football players.<sup>13-16</sup> However, only one of the studies examined symmetry during running,<sup>16</sup> and the authors reported symmetry in ground reaction forces and not joint power allocations. Examining right-left symmetry of joint power contributions at the ankle, knee, and hip may provide insight into whether positional demands promote biomechanical specialization or impose asymmetric loading that could affect performance or injury susceptibility.<sup>17</sup> Therefore, the purpose of this study was to determine whether joint power contribution symmetry exists between limbs during high-speed running in American football players across position groups, Big, Big-skill, and Skill. Since Big players perform more blocking and tackling and do less change of direction running on the field, we hypothesized that Big would be more symmetrical than Big-skill and Skill. A secondary purpose was to determine differences in symmetry between the ankle, knee, and hip, regardless of position group. We hypothesized that the ankle would have the lowest asymmetry given its greater contribution to total joint power.

## Methods

### Participants

A convenience sample of 68 adult American football players was recruited from a group enrolled in a specialized training camp at a local performance center for the 2024 and 2025 NFL drafts. Players represented the three position categories of Big (e.g., offensive and defensive linemen), Big-skill (e.g., tight ends, linebackers), and Skill (e.g., wide receivers, defensive backs). See Table 1 for group demographics. All participants had just completed their collegiate football season, were active players training 5-6x per week, and were cleared by licensed medical staff to participate in the study.

**Table 1.** Means and standard deviations of participant demographics for each American football position group.

Demographic	Big (n=18)	Big-skill (n=24)	Skill (n=26)
Age (yrs)	23.0 $\pm$ 1.0	22.9 $\pm$ 1.0	23.0 $\pm$ 1.5
Height (cm)	192.4 $\pm$ 4.9	190.5 $\pm$ 5.0	182.9 $\pm$ 5.5
Body Mass (kg)	133.7 $\pm$ 12.0	110.9 $\pm$ 10.7	88.8 $\pm$ 5.8

Data are presented as the mean  $\pm$  SD.

### Protocol

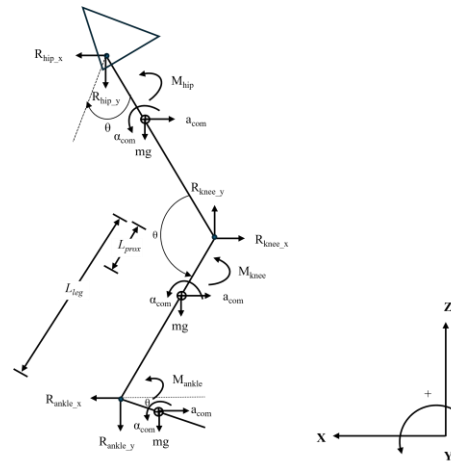
Participants reported to the Sports Performance and Gait Laboratory in groups of three at a designated time over 2 1/2 days at the start of training camp, within 1 month of finishing their university competitive season. They wore compression shorts and their own running shoes. After explaining the study and obtaining written informed consent, anthropometric measures were collected using the Vicon Nexus Plug-in Gait lower-body model (Vicon, Centennial, CO, USA) according to its specifications. These were used to estimate segment masses and moments of inertia necessary for inverse dynamics.

Following anthropometrics, participants completed a standardized 25-minute warm-up led by a single coach consisting of dynamic stretching, muscle readiness, and reactivity exercises. Then, sixteen 14 mm retroreflective markers were placed bilaterally on the participant's pelvis and lower limbs according to the specifications of Vicon's Plug-in Gait lower body model, and a local calibration was performed with the participant in anatomical position. The running trial took place on an instrumented split-belt treadmill (Bertec Corporation, Columbus, OH, USA) with participants running on one side with zero incline. They began by walking on the treadmill at 1.0 m/s for 2-3 minutes. Speed was

increased by 1 m/s in 1-second increments, with 3-second pauses at jogging (~3.5 m/s) and fast jogging (~5.0 m/s) speeds to facilitate comfort. When the participant reached the preferred maximum speed (the treadmill's maximum speed was 6.5 m/s), they ran for 1 to 2 seconds before a 5-s recording was taken. This capture time was selected to mimic the run durations most observed at the NFL combine, 36.6 m (40 yd). Mean running speed was 6.4 m/s. Only one running trial was collected.

### Data Processing

We compared the joint power absorbed (negative) and generated (positive), including the percent distribution from the hip, knee, and ankle to total limb power, between weeks one and six of training camp. Power was derived from kinematic and kinetic data using inverse dynamics with rigid body assumptions. Marker coordinates were labelled and gap filled, and joint angles were calculated using Vicon Nexus software (ver. 2.17). Since participants ran on one side of the split-belt treadmill, gait cycles were visually inspected to identify left and right ground contact and foot-off events in the software based on vertical ground reaction forces. This allowed for synchronization of the GRF with the motion capture data. Marker trajectories and ground reaction forces were filtered with a low-pass third-order Butterworth filter with a cutoff frequency of 10 Hz and 50 Hz, respectively. Figure 1 depicts the free-body diagram of the lower limb.



**Figure 1.** Free-body diagram of the lower limb. Reproduced from Mokha et al.<sup>7</sup>, with permission.

Joint moments ( $M_{joint}$ ) were computed in Vicon Nexus using the Newton-Euler approach of inverse dynamics. See equations 1 and 2 where equation 2 is specific to the knee.

$$(1) \quad M_{joint} = I_{com} \cdot \alpha_{com}$$

$$(2) \quad M_{knee} = I_{com} \cdot \alpha_{com} - R_{ankle\_y} \cdot L_{leg} \cos(\theta) + R_{ankle\_x} \cdot L_{leg} \sin(\theta) + mg \cdot L_{prox} \cos(\theta) - M_{ankle}$$

where  $M_{knee}$  and  $M_{ankle}$  are the moments at the knee and ankle, respectively.  $I_{com}$  is the moment of inertia about the segment's center of mass,  $\alpha_{com}$  is the angular acceleration about the segment's center of mass,  $a_{com}$  is the linear acceleration of the segment's center of mass,  $m$  and  $g$  represent mass of the segment and gravity, respectively and  $R_{ankle\_x}$  and  $R_{ankle\_y}$  are the x- and y-components of the ankle's reaction force.  $\theta$  is the joint angle,  $L_{leg}$  is the length of the lower leg segment, and  $L_{prox}$  is the length of the proximal portion of the segment. Joint powers for each joint ( $P_{joint}$ ) were the three degrees of freedom rotational powers between adjacent segments during ground contact and were calculated in equation 3. Although the computational powers reflect contributions from all three planes, high-speed running is predominantly a sagittal plane activity, and the resulting peak positive and negative joint powers represent sagittal plane muscle activity.

$$(3) \quad P_{joint} = M_{joint} \omega_{joint}$$

where  $\omega_{joint}$  is the joint's angular velocity. Data were then post-processed in a custom MATLAB® program (MathWorks, Natick, MA, USA) where ground contact was defined as the period of foot-ground contact with the treadmill when the vGRF exceeded 20 N. The timing of negative and positive power was defined by identifying the

point of zero crossing in the power curve, the transition from negative to positive power production. Values were normalized to body mass (W/kg).

### Statistical Analysis

To obtain the relative contribution (%) of each  $P_{joint}$  to the total limb power ( $P_{total}$ ), we divided each  $P_{joint}$  by  $P_{total}$ , where  $P_{total}$  was the sum of the hip, knee, and ankle. Finally, the Asymmetry Index (A)<sup>18,19</sup> in equation 4 was used to determine the interlimb percent difference in  $P_{joint}$  contribution.

$$(4) \text{ AI (\%)} = |\text{left} - \text{right}| / [(\text{left} + \text{right})/2] \times 100\%$$

A value of 0% for the Asymmetry Index indicates complete symmetry, and 100% indicates complete asymmetry.

The relative contributions data were tested for normality using the Shapiro-Wilk test. Several variables, especially  $P_{joint}$  at the hip and knee, violated the assumption of normality. Therefore, nonparametric Kruskal-Wallis tests were employed to analyze group differences in AI and joint differences in AI. Follow-up Mann-Whitney U tests with Bonferroni correction to adjust for multiple comparisons (adjusted  $\alpha = 0.017$ ) were used as necessary. Effect sizes ( $\eta^2$ ) were calculated and interpreted with values of .01, .06, and .14 representing small, medium, and large effects, respectively.<sup>20</sup> All statistical methods were conducted using SPSS (ver. 29.0.1).

### Results

The means, standard deviations, and 95% confidence intervals for positive and negative bilateral power percent contributions are presented for Big, Big-skill, and Skill position groups in Tables 2 and 3, respectively.

**Table 2.** Percent contribution of bilateral ankle, knee, and hip positive power across player position groups.

Joint	Limb	Big	Big-skill	Skill
Ankle	Left	65.2 ± 7.5 (61.4, 68.9)	64.0 ± 9.8 (59.8, 68.1)	67.0 ± 7.8 (63.8, 70.1)
	Right	65.3 ± 9.6 (60.5, 70.1)	63.2 ± 9.3 (59.3, 67.1)	69.4 ± 6.5 (66.7, 72.0)
Knee	Left	12.0 ± 4.6 (9.7, 14.3)	11.5 ± 4.8 (9.4, 13.5)	10.9 ± 5.4 (8.8, 13.1)
	Right	11.3 ± 5.4 (8.7, 14.0)	11.6 ± 4.5 (9.7, 13.6)	8.4 ± 3.1 (7.2, 9.7)
Hip	Left	22.9 ± 6.6 (19.6, 26.2)	24.6 ± 8.7 (20.9, 28.3)	22.1 ± 7.3 (19.1, 25.0)
	Right	23.4 ± 8.0 (19.4, 27.4)	25.2 ± 9.5 (21.1, 29.2)	22.2 ± 6.2 (19.7, 24.7)

Data are presented as a percentage of total limb power and displayed as the mean ± SD.

**Table 3.** Percent contribution of bilateral ankle, knee, and hip negative power across player position groups.

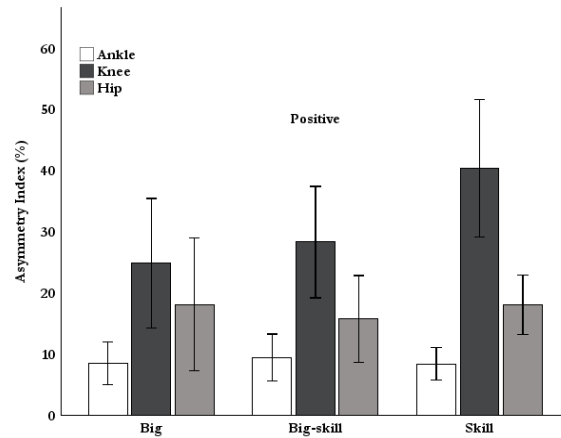
Joint	Limb	Big	Big-skill	Skill
Ankle	Left	39.2 ± 12.6 (32.9, 45.4)	49.6 ± 9.8 (45.4, 53.8)	54.9 ± 8.2 (51.6, 58.3)
	Right	41.7 ± 12.5 (35.5, 47.9)	49.5 ± 8.8 (45.8, 53.3)	58.3 ± 8.3 (54.9, 61.6)
Knee	Left	35.8 ± 14.6 (28.6, 43.1)	25.9 ± 9.2 (22.0, 29.8)	24.9 ± 5.9 (22.5, 27.3)
	Right	31.7 ± 14.9 (24.3, 39.1)	23.0 ± 7.6 (19.8, 26.2)	23.3 ± 6.5 (20.7, 25.9)
Hip	Left	25.0 ± 5.3 (22.4, 27.6)	24.5 ± 7.2 (21.5, 27.5)	20.1 ± 5.3 (18.0, 22.3)
	Right	26.6 ± 6.1 (23.5, 29.6)	27.5 ± 10.8 (22.9, 32.0)	18.4 ± 5.1 (16.4, 20.5)

Data are presented as a percentage of total limb power and displayed as the mean ± SD.

*Asymmetry Index Differences for Big, Big-skill, and Skill Groups*

*Positive Joint Power*

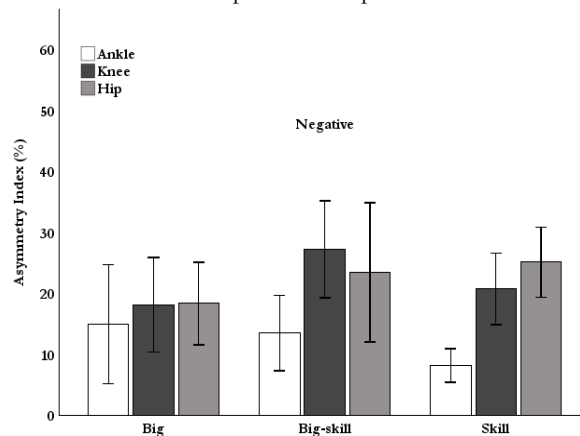
Figure 2 depicts the AI for positive joint power. No significant differences were observed for AI in positive joint power contribution across the ankle ( $F(2,65) = 0.14, p = .868, \eta^2 = .004$ ), knee ( $F(2,65) = 2.59, p = .082, \eta^2 = .074$ ), or hip ( $F(2,65) = 0.17, p = .846, \eta^2 = .005$ ) between player position groups. Effect sizes were trivial for the ankle and hip, with < 1% of the variance in AI at these joints. However, the knee AI for power generation showed a moderate effect size, indicating that approximately 7% of the variance in the knee AI may be attributable to player position, although not statistically significant.



**Figure 2.** Positive joint power AI by position group.

*Negative Joint Power*

Similarly, no significant differences were observed for asymmetry in negative joint power contribution across the ankle ( $F(2,65) = 1.54, p = .222, \eta^2 = .045$ ), knee ( $F(2,65) = 1.76, p = .181, \eta^2 = .051$ ), or hip ( $F(2,65) = 0.71, p = .496, \eta^2 = .021$ ) between player groups. See Figure 3. Effect sizes were small for the ankle, knee, and hip, indicating that the player group accounted for only ~2–5% of the variance in power absorption AI.

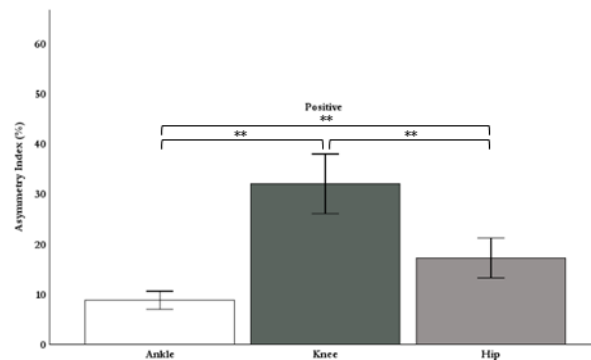


**Figure 3.** Negative joint power AI by position group.

*Asymmetry Index Differences for Ankle, Knee, and Hip Joints*

*Positive Joint Power*

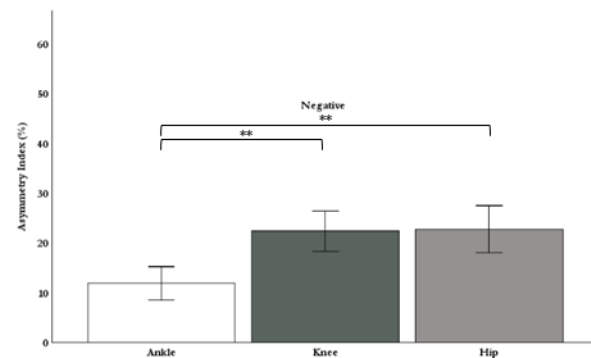
The comparison of AI for positive ankle, knee, and hip power yielded a significant difference ( $F(2,134) = 33.4, p < 0.001, \eta^2 = 0.332$ ), with a large effect size, indicating that the proportion of symmetry to total limb power differed across joints. Post-hoc pairwise comparisons with a Bonferroni correction ( $\alpha = .017$ ) showed that knee AI ( $31.9 \pm 24.5\%$ ) was significantly greater than both the ankle ( $9.6 \pm 6.9\%, p < 0.001$ ) and the hip contributions ( $18.1 \pm 28.9\%, p < 0.001$ ). The ankle was significantly lower than the hip ( $p < 0.001$ ). These findings suggest that asymmetry was greatest at the knee, followed by the hip and then the ankle. See Figure 4.



**Figure 4.** Positive joint power AI by joint.

#### Negative Joint Power

The comparison of negative ankle, knee, and hip AI yielded a significant difference ( $F(2,134) = 15.693, p < 0.001, \eta^2 = 0.19$ ) with a large effect size, indicating that symmetry in the proportion to total limb power differed across joints. Post-hoc pairwise comparisons with a Bonferroni correction ( $\alpha = .017$ ) revealed that knee AI ( $22.4 \pm 16.6\%$ ) was significantly greater than the ankle ( $11.9 \pm 14.1\%$ ,  $p < 0.001$ ) but not the hip ( $22.8 \pm 19.5\%$ ,  $p = 0.835$ ). The AI was significantly greater in the hip than the ankle ( $p < 0.001$ ). These findings suggest that the ankle had the least asymmetry, while the knee and hip were similar. See Figure 5.



**Figure 5.** Negative joint power AI by joint.

#### Discussion

The primary purpose of this investigation was to determine if interlimb differences in the contribution of ankle, knee, and hip power to total leg power differed between American football position groups. We hypothesized that Big would be more symmetrical than Big-skill and Skill. We reject our hypothesis. There was no significant influence of position group on interlimb asymmetry of power generated (positive) or absorbed (negative). Across all position groups, the absence of significant differences in AI values suggests that high-speed running elicits a strongly symmetric biomechanical strategy in American football players, regardless of position specialization. Big, Big-skill, and Skill athletes differ substantially in anthropometrics and on-field duties.<sup>1-4,16</sup> However, high-speed linear running is a universal component of training and competition, and the task constraints (i.e., unilateral stance, rapid limb cycling, sagittal-plane propulsion) are shared across positions. Linemen routinely accelerate from near-static starts into short sprints during screen plays or pursuit, Big-skill players transition between covering space and engaging in collisions, and Skill players perform frequent maximal sprints across the field. These repeated exposures likely reinforce similar interlimb control strategies, promoting similar symmetrical joint power allocation at the ankle, knee, and hip during high-speed running. Assessing interlimb asymmetries is common practice in clinical settings to determine return to play and/or identify injury risk with less than 10% and greater than 15%, respectively, suggested as thresholds.<sup>21,22</sup> Given the exploratory nature of this study (first of its kind) and the variability, it is difficult to contextualize our findings relevant to injury management.

The secondary purpose of this study was to determine if there were symmetry differences in power contribution between the joints. We hypothesized that the ankle would have the lowest asymmetry. We accept this hypothesis since the ankle exhibited the lowest AI values for both positive and negative power, indicating highly symmetrical function. The lower AI values may reflect mechanical symmetry that is structurally necessary for stability from initial contact to midstance (power absorption) and for propulsion from midstance to toe-off (power generation).<sup>23</sup> The ankle also has less range of motion than the hip and knee and operates in a constrained, spring-like manner, leaving less room for interlimb variability. This may reduce the ankle's capacity for joint power asymmetry. In contrast, the knee showed significantly greater AI in power generation than both the ankle and hip. There was also greater variability, especially for Skill players. Skill players, such as wide receivers and defensive backs, possess superior agility and speed as compared to Big-skill and Big players. They are often engaged in unanticipated changes in direction and unilateral jumps to receive or break up a pass. These field requirements may have influenced their results. Further, laterality, foot strike patterns, and prior injuries may have influenced positive knee power-allocation symmetry but were not assessed in the current study. Hip angular velocity, a component of power, has been shown to directly influence ground reaction forces and linear speed.<sup>24</sup> While the mean AI for positive hip contribution was not as large as the knee's, it was greater than the ankle's, and may indicate a training target if this cohort were required to demonstrate linear speed for selection, such as at an NFL combine or pro day.

The hip and knee have dual roles in braking and shock absorption during early stance, thereby slowing the runner's forward momentum.<sup>23</sup> However, research is limited in examining the symmetry of this negative power production during the gait cycle. Hashizume and colleagues<sup>11</sup> examined negative work asymmetry during running by male non-athletes at a lower speed (3.0 m/s). They showed negative work AI values in the hip ( $18.9 \pm 11.7\%$ ), knee ( $13.6 \pm 10.4\%$ ), and ankle ( $11.8 \pm 8.5\%$ ), which align with the current study of American football players running at a higher speed (6.4 m/s). It should be noted that at the time of data collection, all participants had just finished their regular competitive season. Thus, pre-season or earlier-season assessments may yield different AI values.

Several limitations should be considered when interpreting these findings. First, data were collected during a single session within one month of the competitive season for many of the participants, limiting the ability to determine whether asymmetry magnitudes fluctuate across different phases of training or competition. Second, only one high-speed running trial was analyzed per subject, and although a standardized protocol was enforced and at least eight steps per limb were recorded, reliance on a single trial may reduce reliability and increase within-subject variability. Third, individual factors such as limb dominance, prior injury history, and laterality were not assessed. Thus, their influence on joint power allocation could not be addressed. Fourth, the task examined only steady linear high-speed running on a treadmill; asymmetries during acceleration, deceleration, or contact-based movements in the field may differ and provide coaches with more useful information.

Despite limitations, the findings of this study provide useful insights for strength and conditioning coaches and sports medicine professionals working with American football players. Although joint power asymmetry magnitudes ranged widely (8.8–32%), the absence of position-group differences suggests that these asymmetries are a general characteristic of high-speed running rather than a product of positional demands. For practitioners, this indicates that observed asymmetry during sprinting should not automatically be attributed to position-specific loading patterns. Instead, practitioners may consider using these values as a reference for what is typical in highly trained American football athletes. Because the knee and hip exhibited the greatest asymmetry, targeted monitoring of these joints may be more meaningful than at the ankle, which was consistently the most symmetrical. The knee and hip may tolerate greater variability and be, therefore, more sensitive to overload or compensation, but this is speculative without longitudinal monitoring. Additionally, these asymmetries can serve as a baseline for future monitoring to determine whether greater asymmetry is associated with a higher incidence of injury.

## Conclusions

Most applied monitoring in American football, particularly in arenas such as the NFL Combine, relies on global performance outputs like 40-yard dash and 3-cone drill times. Little is assessed that provides insight into how joint biomechanics contribute to those outputs. By quantifying interlimb symmetry in ankle, knee, and hip power contributions during high-speed running, this study provides a mechanistic understanding of running biomechanics, which, with further study, could aid in identifying meaningful monitoring targets and establishing normative reference values. The results of this study also support that linear running is a universal motor task in American football across the positions. In conclusion, American football players demonstrate interlimb asymmetry between 8.8 - 32% in joint power contributions during high-speed running, but symmetry magnitude does not appear to be influenced by position.

Further, the ankle is the most symmetrical in power allocation for both generation (positive) and absorption (negative). Future studies may implement longitudinal monitoring, document lower-extremity injuries, and/or include other football-specific tasks in joint power asymmetry assessment.

### Acknowledgements

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### Conflict of Interest

The authors declare no conflicts of interest.

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