

## Article

# Goal-Direction Patterns in Amputee Football: Associations with Goalkeeper Missing-Arm Side and Shot Characteristics

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## Abstract

**Background and Aim:** Goalkeeper performance relies on bilateral upper-limb function. In amputee football, unilateral upper-limb absence asymmetrically reduces the defendable area, creating a task-specific biomechanical constraint. This study aimed to examine goal-direction patterns relative to the goalkeeper's missing-arm side and their associations with shot characteristics. **Methods:** We analyzed 474 goals from 115 matches (35 teams) in the 2021 European Championship and 2022 World Cup. Video recordings were coded by three analysts (Cohen's Kappa = 0.94). Logistic regression with cluster-robust standard errors was applied to 431 goals, accounting for within-match tactical clustering. The outcome was shot direction toward the goalkeeper's missing-arm side. **Results:** Approximately 52.9% of goals targeted the missing-arm side. Shot zone was the strongest predictor: center shots (OR = 0.39, 95% CI: 0.21–0.76, FDR-adjusted  $p = 0.012$ ) and opposite-side shots (OR = 0.18, 95% CI: 0.08–0.40, FDR-adjusted  $p = 0.001$ ) showed 61% and 82% reduced likelihood, respectively, compared to same-side shots. High shots were twice as likely as low shots to target the missing-arm side (OR = 2.06, 95% CI: 1.32–3.21, FDR-adjusted  $p = 0.009$ ). These may be consistent with trajectory-dependent differences in the challenges faced by goalkeepers with anatomical asymmetry. **Conclusions:** Shot zone and height were associated with goal-direction patterns relative to the goalkeeper's missing-arm side. Because only scored goals were analyzed, these findings do not establish greater scoring vulnerability on the missing-arm side or deliberate tactical exploitation of anatomical asymmetry.



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**Keywords:** amputee football; goalkeeper; analysis; anatomical asymmetry

## 1. Introduction

Football is a sport in which offensive and defensive players compete dynamically and continuously within a specific playing field according to specific rules [1]. Scoring a goal represents the pinnacle of football. Indeed, the winner is determined by the number of goals scored. However, many confounding factors are involved in scoring goals [2]. These confounding factors include the striker's abilities, the goalkeeper's positioning, anticipatory movements, and cognitive cues provided by anatomical constraints (dominant foot, dominant side, etc.), as well as angle, distance, and defensive pressure [3,4]. These factors must

be managed concurrently. A significant body of literature exists on the directional ecology of shooting in football [5]. In particular, it has been noted that athletes exhibit systematic asymmetries in penalty kicks [6]. For example, right-footed shooters systematically aim toward the goalkeeper's right (near post), whereas left-footed shooters exhibit more variable behavior. Goalkeepers display diving asymmetries linked to lateral dominance [6,7]. Dives toward the preferred side are characterized by superior kinematics, whereas dives toward the opposite side result in suboptimal patterns [8,9]. This is consistent with affordance-based decision-making [10]. Understanding the interaction between these constraints is of central importance for performance analysis and adaptive sports biomechanics. However, we cannot generalize all these findings to adapted amputee football.

In amputee football, there are different biomechanical and spatial conditions for players and goalkeepers compared to standard football [11]. The field dimensions are 45% smaller than those of standard football fields [11]. The 60 × 40 m playing field in amputee football presents players with different positioning, acceleration, and shooting angles compared to standard football. Additionally, field players have a single-leg amputation and move using forearm crutches [12]. This fundamentally differs from the two-legged movement dynamics of standard football in terms of stability, acceleration, and the distribution of body weight. In contrast, goalkeepers compete using only one arm [13]. In particular, the goalkeeper's use of a single arm to defend the goal creates a permanent asymmetrical geometry in the shot-saving area. While a standard goalkeeper has a reach of approximately 3.5–4.0 m in the horizontal plane using both hands [14], a one-armed goalkeeper may need to compensate for the reduced reach on the side of the missing arm through unilateral shoulder rotation and trunk tilting. This may affect goalkeeper lateral stability and upper-body reaction capacity. Additionally, the altered distribution of body mass and the need for compensatory movements may influence postural control and potentially the risk of losing balance during rapid lateral movement [7]. These structural and functional differences suggest that goalkeeper–shot interaction models developed for standard football may not be directly applicable to amputee football.

The current literature on amputee football falls far short of systematically addressing these conditions. The vast majority of existing studies have focused on athletes' physical and physiological characteristics (height, body weight, BMI, strength, reaction time, and sprint performance), the physiological effects of training loads (HRV, HRmax, distance covered, and intensity-based running durations), and seasonal variations [15–19]. The study most closely related to ours is the 2022 FIFA World Cup goal analysis study. Parameters such as the minute in which goals were scored, goal type, inside/outside the penalty area, whether the goal was scored from the right or left side of the field, the number of passes preceding the goal, and the type of attack (counterattack, organized attack, individual) were examined [20]. However, this study did not perform spatial classification analyses, such as the goalkeeper side, division into goal zones, or division of the half-field into zones [20]. Consequently, to our knowledge, no previous study has systematically described goal-direction patterns relative to the goalkeeper's missing-arm side in amputee football. In this context, the present study systematically examines associations between goal direction relative to the goalkeeper's missing-arm side and spatial and height-related shot characteristics in amputee football. This gap hinders both the deepening of theoretical understanding and the evidence-based development of training and tactical applications of this sport.

Therefore, the primary objective of this study was to examine goal-direction patterns relative to the goalkeeper's missing-arm side in relation to shooting zone and shot height among scored goals. Our main hypothesis was that goal direction would differ according to the shooter's lateral position relative to the goalkeeper. Our other hypothesis was

that high shots would be more frequently directed toward the goalkeeper's missing arm-side than low shots among scored goals. Given that only scored goals were analyzed, the study describes directional patterns among successful shots rather than estimating side-specific scoring probabilities or establishing deliberate tactical exploitation of anatomical asymmetry.

## 2. Materials and Methods

### 2.1. Study Design and Sample

In this study, an observational, cross-sectional design was adopted using a video-based notational analysis method to examine directional goal-scoring patterns in amputee football [21,22]. Data were collected from official international tournament matches at the 2021 Amputee Football European Championship (Istanbul, Turkey; 12–19 September 2021) and the 2022 Amputee Football World Cup (Istanbul, Turkey; 30 September–9 October 2022). The analysis focused on goals scored in matches involving male players; female players participating in the 2022 World Cup were not included in the analysis.

A total of 474 goals were analyzed in 115 matches. Fourteen national teams participated in the European Championship, and 38 matches were played (18 group stage matches, 4 quarterfinals, 2 semifinals, 1 final, and 13 placement matches). Twenty-four national teams participated in the World Cup, and 80 matches were played in total. (36 group stage matches, 8 Round of 16 matches, 4 quarterfinals, 2 semifinals, 1 final, and 29 placement matches). However, one match in the European Championship was excluded from the analysis because video footage was not available on an official broadcast platform (Belgium 0–7 Russia), and two matches in the World Cup were excluded because no goals were scored (0–0). As a result, 78 World Cup matches and 37 European Championship matches ( $n = 115$  matches) were included in the final dataset. All matches were accessed via full-match official broadcast recordings uploaded to YouTube.

### 2.2. Data Collection Method

This study examined the goals scored in the 2022 Amputee Football World Cup and the 2021 European Championship. Each goal was coded using the categorical variables described above. The data were collected between 25 July 2026, and 15 August 2026, by three different researchers during these time intervals.

*Tournament and match outcomes:* Goals were classified according to the tournaments in which they were scored (2022 Amputee Football World Cup or 2021 European Championship). The outcome of the match for the team that scored a goal was categorized as a win, loss, or draw. Goals scored in matches that ended in a draw after regular time and went into extra time (e.g., quarterfinals, semifinals, and finals) were classified as “winner” or “loser” based on the final outcome. For example, in a match that ended 4–2, the four goals scored by the winning team were coded as “winner,” while the two goals scored by the losing team were coded as “loser.” In matches that ended in a draw with goals scored, all goals were marked as “draw.”

*Goal Type:* Goals were classified into four categories based on how they were scored: (a) penalty kick: goals scored during regular time or in penalty shootouts following a tie; (b) direct free kick: goals scored directly from a free kick; (c) own goal: goals scored into one's own net due to a goalkeeper's error or after deflecting off a teammate; and (d) open-play shot: goals scored while the ball is in play and the game is in progress [20].

*Shot Location and Field Zones:* The positions from which shots were taken were categorized into two groups: inside the penalty area (within the penalty area or on the penalty line) and outside the penalty area. The amputee football field measures  $60 \times 40$  m, which is approximately 57% the size of a standard football field ( $105 \times 68$  m). The penalty area was

defined as an  $8 \times 10$  m rectangle and did not represent a proportional reduction compared to the standard football penalty area ( $16.5 \times 40.3$  m). Therefore, spatial classifications have been adapted to the unique field geometry and research objectives of amputee football games. The field was divided into nine zones ( $3 \times 3$  grid; zones 1–9) representing different shooting areas. This segmentation has been operationalized based on the reduced field dimensions of amputee football, drawing from various field segmentation approaches used in the existing football performance analysis literature (e.g., different applications such as dividing into six or two zones) [3,22–24]. The penalty spot was located in Zone 2 of the field segmentation (Figure 1A).

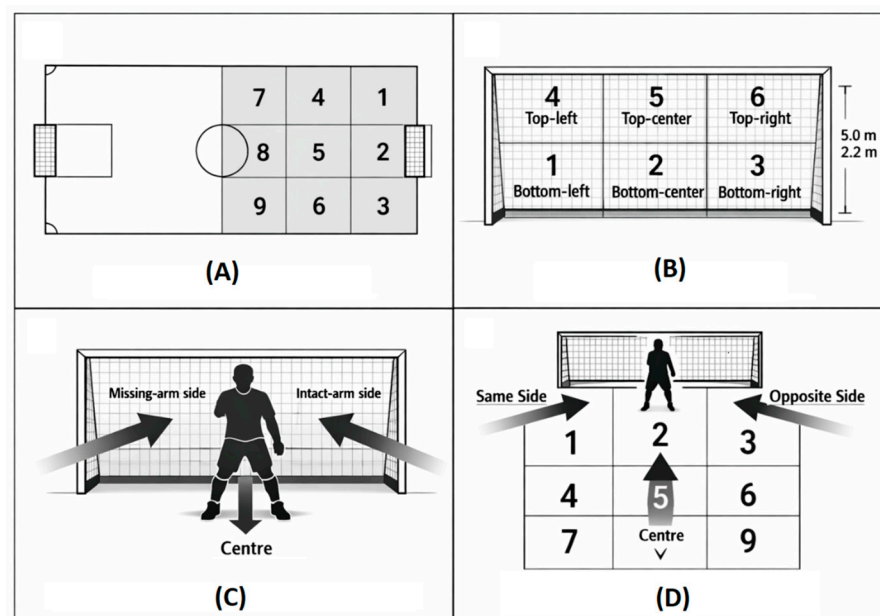


**Figure 1.** (A) Spatial segmentation of the playing field into nine zones. (B) Division of the goal into six zones. (C) Goalkeeper’s missing arm versus intact arm side with functional division of the goalmouth. (D) Categorization of shooting zone: same side, opposite side, and center.

*Goalkeeper Side and Shooting Zone:* The direction from which the ball enters the goal is classified into four categories based on the goalkeeper’s anatomical position. These are as follows: (a) armless side, the side of the goal corresponding to the goalkeeper’s missing limb; (b) arm side, the side of the goal corresponding to the goalkeeper’s intact limb; (c) empty net, goals scored when the goalkeeper has left the goal; and (d) own goal, goals scored into the goalkeeper’s own net due to a goalkeeper error or after deflecting off a teammate (Figure 1C). The goalkeeper’s “missing arm side” was determined at the start of the match and remained fixed throughout the entire match. For example, for a goalkeeper missing his right arm, the right side is always coded as the “armless side,” while the left side is coded as the “armed side.” For a goalkeeper missing his left arm, this assignment is reversed. Even when the goalkeeper was in motion at the moment of the shot, coding consistency was ensured by using the anatomical position of the missing limb as a reference. The shooter’s lateral position relative to the goalkeeper was evaluated in three categories (Figure 1D). These are: (a) same side: shots taken from the side of the field corresponding to the goalkeeper’s armless side (e.g., zones 1, 4, and 7 for goalkeepers missing their right arm; zones 3, 6, and 9 for goalkeepers missing their left arm); (b) opposite side: shots taken from the side of the field corresponding to the goalkeeper’s arm side; and (c) center: shots taken directly toward the goal (zones 2, 5, and 8).

*Shot Height:* The height at which the ball enters the goal was classified by dividing the goal into a  $2 \times 3$  grid (Figure 1B). These are the lower row (zones 1–3) and the upper row (zones 4–6).

*Adaptation of Field and Goal Zoning:* Because the dimensions of the amputee football field and goals are smaller than those of standard football, spatial zoning has been proportionally adapted from the existing performance analysis literature. The playing field was divided into nine zones (a  $3 \times 3$  grid), zones 1–9 represent different shooting areas, and zone 2 included the penalty spot. This division allows for the classification of shooting positions and examination of whether goals are directed toward the goalkeeper’s missing-arm side based on the field position. The goal area was divided into six zones using a  $2 \times 3$  grid; the bottom row (zones 1–3) and the top row (zones 4–6) were used to distinguish shot height in positional analyses [24]. The missing-arm and arm sides of the goalkeeper were coded based on the goalkeeper’s predetermined anatomical configuration, which remained fixed throughout the match (Figure 1C). This classification was used to operationalize the “missing-arm side” and “arm side” variables.

*Video Coding Protocol:* All goals were coded by three independent analysts using full match recordings uploaded to the official competition website and YouTube. The videos were viewed at 720p or 1080p resolution; the playback speed was reduced (slow motion), and the pause/resume functions were used as needed to enhance coding accuracy. The coders rewatched each goal situation as many times as necessary to accurately complete their analyses. While some coders made their decisions in a single viewing, others reexamined the situation by rewinding to 2–3 times. As the goalkeeper’s position at the moment of the goal was clearly visible in all videos, there were no situations that were too ambiguous to code. After independent coding, the coded records were compared to identify discrepancies. The small number of discrepant entries was re-examined, and some differences were found to result from data-entry errors. The corresponding goal situations were reviewed again by the analysts, and a consensus decision was reached for each discrepancy. A single consensus dataset was then compiled and used for all subsequent analyses.

*Inter-Rater Reliability:* To ensure the objectivity of the directional coding, inter-rater reliability was assessed using Cohen’s Kappa coefficient ( $\kappa$ ) [25]. Three independent analysts coded a randomly selected 10% of all goal observations ( $n = 43$ ). The analysis yielded a value of  $\kappa = 0.94$ , indicating high agreement among the coders. This high level of consistency demonstrates that the classification of goal directions is robust and minimizes the risk of subjective bias in the data-coding process.

### 2.3. Data Analysis

Frequency and percentage values were calculated for all categorical variables to examine the distribution of goals across tournaments, match outcomes, goal types and spatial variables. In directional analyses, empty net goals and own goals (total  $n = 43$ ; 9.1%) were excluded due to invalid goalkeeper-side variables, and comparisons between the non-goalpost side and the goalpost side were conducted based on  $n = 431$  goals.

Logistic regression analysis with cluster-robust standard errors was applied to examine the association between the predictors and the odds of a goal being scored on the goalkeeper’s missing-arm side. The dependent variable was dichotomously coded as whether the goal was scored on the non-goal side (1) or the goal side (0). The independent variables included the area from which the shot was taken (Center, opposite side; reference: same side), shot height (high; reference: low), goal type (free kick, open-play shot; reference: penalty kick), shot location (outside the penalty area; reference: inside the penalty area), match period (second half, first half of extra time, second half of extra

time, penalty shootout; reference: first half), and tournament (European Championship; reference: World Cup).

To evaluate the hierarchical structure of the data, the intraclass correlation coefficient (ICC) was calculated using an empty (null) multilevel logistic regression model. A multilevel logistic regression model with a random intercept at the match level was also fitted; however, the model encountered a boundary singularity. Therefore, the final fixed-effect estimates were obtained from a logistic regression model with cluster-robust (sandwich) standard errors clustered by match to account for within-match dependence [26,27].

The model was estimated using the simultaneous entry method (all predictors entered in a single step). Model fit was assessed using McFadden's pseudo- $R^2$ , and multicollinearity was controlled using variance inflation factors (VIF) ( $VIF < 5$ ). The assumptions of logistic regression (logit linearity and effective observations based on Cook's distance) were examined. The assumption of linearity between the model predictors and logit transformation was satisfied. Odds ratios (OR) and 95% confidence intervals (CI) were calculated for significant predictors. The effect sizes were interpreted in terms of clinical significance. The Benjamini–Hochberg false discovery rate (FDR) method was applied for multiple comparison corrections [28]. As 13 coefficients (12 independent variable coefficients + 1 intercept) were tested in the model, FDR correction was applied across all coefficients. This approach was chosen to control the expected proportion of false discoveries among the rejected hypotheses [28].

Since the primary analyses were conducted using logistic regression with cluster-robust standard errors, the sample size was considered sufficient [29]. A post hoc power analysis was performed for logistic regression [30,31]. This is because power estimation in models using cluster-robust standard errors requires simulation-based approaches and cannot be directly applied to the current software environment [26,27]. This was considered a limitation in assessing the adequacy of the sample size. However, because the sample included all goals scored in the two international tournaments ( $N = 474$ ), selection bias was eliminated.

### 3. Results

A total of 474 goals scored during the 2021 European Championship and the 2022 World Cup were included in the descriptive analysis. After excluding empty-net goals and own goals, 431 goals were included in the directional analyses. The descriptive distribution of goals and the effect sizes across selected goal categories are presented in Table 1.

**Table 1.** Effect Size Summary Across Goal Categories.

| Category         | <i>n</i> | % Missing-Arm | Cohen's <i>h</i> * | Interpretation   |
|------------------|----------|---------------|--------------------|------------------|
| All Goals        | 431      | 52.9          | 0.058              | Negligible       |
| Penalty          | 71       | 62.0          | 0.242              | Small            |
| High Zone        | 135      | 63.0          | 0.262              | Small            |
| Same Side        | 65       | 67.7          | 0.362              | Small–Medium     |
| Same Side + High | 20       | 70.0          | 0.412              | Medium           |
| Opposite Side    | 50       | 28.0          | −0.456             | Medium (inverse) |

\* Cohen's *h* thresholds: 0.20 = small, 0.50 = medium, 0.80 = large.

Of the goals scored, 315 (66.5%) were scored in the Amputee Football World Cup and 159 (33.5%) in the Amputee Football European Championships (Table 2). Based on the match results, 393 goals (82.9%) were scored by the winning teams, 75 goals (15.8%) by the losing teams, and 6 goals (1.3%) by the teams that tied.

**Table 2.** Distribution of goals scored in the Amputee Football World Cup and European Championships by category.

|                 | Variable                               | <i>n</i> | %    |
|-----------------|----------------------------------------|----------|------|
| Tournament      | Amputee Football World Cup             | 315      | 66.5 |
|                 | Amputee Football European Championship | 159      | 33.5 |
| Team            | Win                                    | 393      | 82.9 |
|                 | Lose                                   | 75       | 15.8 |
|                 | Draw                                   | 6        | 1.3  |
| Goal Type       | Penalty                                | 72       | 15.2 |
|                 | Free Kick                              | 35       | 7.4  |
|                 | Own Goal                               | 15       | 3.2  |
|                 | Open Play Shot                         | 352      | 74.3 |
| Shot Location   | Inside Box                             | 232      | 48.9 |
|                 | Outside Box                            | 242      | 51.1 |
| Goalkeeper Side | Missing-Arm Side                       | 228      | 48.1 |
|                 | Arm Side                               | 203      | 42.8 |
|                 | Empty Net                              | 32       | 6.8  |
|                 | Own Goal                               | 11       | 2.3  |
| Shot Height     | Low (1–2–3)                            | 296      | 68.7 |
|                 | High (4–5–6)                           | 135      | 31.3 |
| Shooting Zone   | Same Side (GK missing arm side)        | 65       | 15.1 |
|                 | Center                                 | 316      | 73.3 |
|                 | Opposite Side (GK arm side)            | 50       | 11.6 |

When goal types were examined, 352 goals (74.3%) were recorded as open-play shots, 72 goals (15.2%) as penalties, 35 goals (7.4%) as free kicks, and 15 goals (3.2%) as own goals. Regarding the shot location variable, 232 shots (48.9%) were taken from inside the penalty area, and 242 shots (51.1%) were taken from outside the penalty area.

From the goalkeeper's perspective, 228 goals (48.1%) were directed at the goalkeeper's missing-arm side, 203 goals (42.8%) at the arm side, 32 goals (6.8%) at the empty net, and 11 goals (2.3%) were own goals. Regarding shot height, 296 shots (68.7%) were taken at a low height (goal zones 1–2–3) and 135 shots (31.3%) at a high height (goal zones 4–5–6). In terms of shooting side, 316 shots (73.3%) were taken from the Center (facing the goal directly), 65 shots (15.1%) from the goalkeeper's missing-arm side, and 50 shots (11.6%) from the goalkeeper's arm side.

The dataset comprised 474 goals scored across 115 matches ( $M = 4.19$  goals per match,  $SD = 2.31$ ) from 35 teams participating in two major international tournaments (World Cup:  $n = 315$ , 66.5%; European Championship:  $n = 159$ , 33.5%). To evaluate the hierarchical structure of the data, we first fitted a null multilevel logistic model to estimate the intraclass correlation coefficient (ICC). The between-match variance component was  $\tau^2 = 0.098$ , corresponding to an ICC of 0.28–0.39 depending on the formula used. These estimates suggested potential within match dependence, which was considered when selecting the final analytical approach.

We initially fitted a random-intercept multilevel logistic regression model with match-level random effects. However, the model exhibited boundary singularity, with the estimated random-effect variance converging to zero. Because this model did not provide a stable estimate of between-match variance, we used logistic regression with match-clustered robust (sandwich) standard errors to account for within-match dependence [26,27]. The singularity of the random-intercept model limits the interpretation of between-match vari-

ability and does not establish that the observed associations reflect universal mechanisms or are generalizable across matches and tournaments.

Table 3 presents the results of the logistic regression model with match-clustered robust standard errors for goal direction among scored goals. After applying the Benjamini–Hochberg false discovery rate (FDR) correction to all 13 tested coefficients, three predictors remained significant. The shooting side was the strongest predictor: compared with same side shots, center shots had lower odds of being directed toward the goalkeeper’s missing arm side (OR = 0.39, 95% CI [0.21, 0.76],  $p_{\text{FDR}} = 0.012$ ), as did opposite side shots (OR = 0.18, 95% CI [0.08, 0.40],  $p_{\text{FDR}} = 0.001$ ). Additionally, high shots had higher odds than low shots being directed toward the missing-arm side (OR = 2.06, 95% CI [1.32, 3.21],  $p_{\text{FDR}} = 0.009$ ). No other predictors, including goal type, shot location, match period, and tournament, remained significant after correction for multiple comparisons.

**Table 3.** Logistic Regression Predicting Goals on Missing-Arm Side ( $n = 431$  goals, 115 matches).

| Predictor                        | b      | SE    | OR   | 95% CI    | $p$    | $p_{\text{FDR}}$ |
|----------------------------------|--------|-------|------|-----------|--------|------------------|
| Intercept                        | 1.175  | 0.504 | 3.24 | 1.21–8.69 | 0.014  | 0.047            |
| Shooting Zone (ref.: Same Side)  |        |       |      |           |        |                  |
| Center                           | −0.931 | 0.331 | 0.39 | 0.21–0.76 | 0.003  | 0.012 *          |
| Opposite Side                    | −1.746 | 0.425 | 0.18 | 0.08–0.40 | <0.001 | 0.001 ***        |
| Shot Height (ref.: Low)          |        |       |      |           |        |                  |
| High                             | 0.723  | 0.227 | 2.06 | 1.32–3.21 | 0.001  | 0.009 **         |
| Goal Type (ref.: Penalty)        |        |       |      |           |        |                  |
| Free Kick                        | −0.931 | 0.582 | 0.39 | 0.13–1.24 | 0.110  | 0.287            |
| Open Play                        | −0.261 | 0.404 | 0.77 | 0.35–1.70 | 0.477  | 0.731            |
| Shot Location (ref.: Inside Box) |        |       |      |           |        |                  |
| Outside Box                      | −0.354 | 0.266 | 0.70 | 0.42–1.18 | 0.176  | 0.382            |
| Match Period (ref.: 1st Half)    |        |       |      |           |        |                  |
| 2nd Half                         | 0.111  | 0.216 | 1.12 | 0.73–1.71 | 0.574  | 0.746            |
| ET 1st                           | −0.071 | 0.784 | 0.93 | 0.20–4.33 | 0.919  | 0.919            |
| ET 2nd                           | −0.917 | 0.913 | 0.40 | 0.07–2.39 | 0.305  | 0.566            |
| Penalties                        | −0.079 | 0.511 | 0.92 | 0.34–2.52 | 0.871  | 0.919            |
| Tournament (ref.: World Cup)     |        |       |      |           |        |                  |
| European Championship            | 0.033  | 0.213 | 1.03 | 0.68–1.57 | 0.869  | 0.919            |

SE = cluster-robust (sandwich) standard errors adjusted for 115 matches. OR = odds ratio; CI = confidence interval; FDR = false discovery rate (Benjamini–Hochberg adjusted). \*  $p_{\text{FDR}} < 0.05$ , \*\*  $p_{\text{FDR}} < 0.01$ , \*\*\*  $p_{\text{FDR}} < 0.001$ . McFadden R-squared = 0.065.

Model fit was assessed using McFadden’s pseudo- $R^2$ , which was 0.065. Multicollinearity was assessed using variance inflation factors (VIF), all values were below the conventional threshold of 5 (range 1.03–2.41) indicating no evidence of problematic multicollinearity.

To assess the robustness of the main findings, sensitivity analyses were conducted under six alternative coding and sample-restriction approaches (Table 4). Unlike Figure 2, which presents the estimates from the main model, Table 4 compares the odds ratios for the key predictors across alternative scenarios. Across these analyses, the associations for center and opposite-side shots remained below 1, whereas the association for high shots remained above 1. Estimates were broadly similar in the alternative coding and open-play analyses, but varied more in the tournament-specific analyses, particularly for the European Championship. Overall, the sensitivity analyses support the directional consistency of the main associations, while indicating some variation across tournaments.

**Table 4.** Sensitivity Analysis: Odds Ratios Across Scenarios.

| Scenario                   | <i>n</i> | Center OR | Opposite OR | High OR |
|----------------------------|----------|-----------|-------------|---------|
| Main model (Full sample)   | 431      | 0.39      | 0.18        | 2.06    |
| Empty net = Missing-Arm    | 463      | 0.41      | 0.22        | 1.83    |
| Empty net = Arm-Side       | 463      | 0.38      | 0.16        | 2.16    |
| Open Play only             | 315      | 0.37      | 0.21        | 2.07    |
| World Cup only             | 272      | 0.47      | 0.30        | 1.59    |
| European Championship only | 159      | 0.28      | 0.06        | 3.75    |

OR = odds ratio. Empty net goals were recoded as either “missing-arm side” or “arm-side” in the respective sensitivity scenarios. “Open Play only” excludes set pieces (penalties, free kicks) and own goals.

**Figure 2.** Predictors of Goals on the Goalkeeper’s Missing-Arm Side: Odds Ratios from Logistic Regression.

Figure 2 summarizes the odds ratios and 95% confidence intervals from the logistic regression model with cluster-robust standard errors. After FDR adjustment, shooting zone and shot height were significantly associated with goal direction. Center and opposite-side shots had lower odds, whereas high shots had higher odds of being directed toward the goalkeeper’s missing-arm side. These findings describe goal-direction patterns among scored goals and do not establish differences in scoring probability or goalkeeper vulnerability.

Table 4 compares the odds ratios for the key predictors across these scenarios to show whether the main associations remained consistent.

Figure 3 Forest plot of FDR-adjusted significant predictors of goals scored on the opposite side ( $n = 431$  goals, 115 matches). Odds ratios and 95% confidence intervals are displayed on a logarithmic scale. The dashed vertical line indicates the null value (OR = 1). Goals scored from the center and the opposite shooting side were associated with lower odds of being scored on the opposite arm side, whereas a high shot height was associated with higher odds (Figure 3).

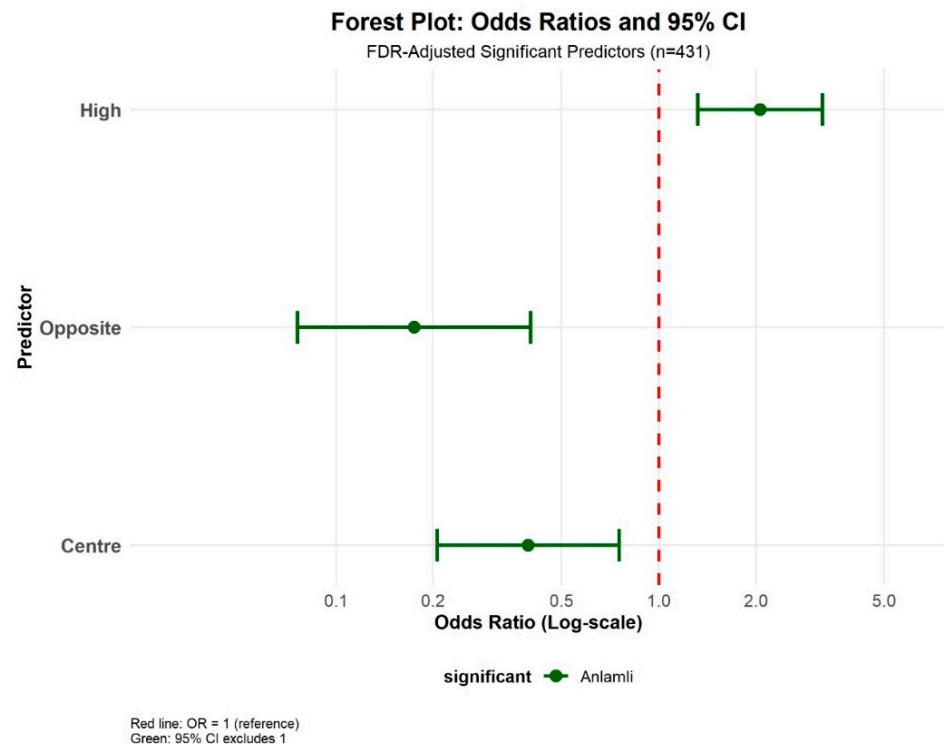


**Figure 3.** Forest Plot of FDR-Adjusted Significant Predictors.

The main finding of this study is that the region from which the shot is taken is the strongest predictor of direction of goals toward the goalkeeper's missing-arm side in amputee football. Compared with same-side shots, center shots were associated with 61% lower odds ( $OR = 0.39$ ) and opposite-side shots with 82% lower odds ( $OR = 0.18$ ) of being directed to the missing-arm side. Furthermore, high shots were associated with approximately two-fold higher odds ( $OR = 2.06$ ) than low shots. This finding highlights the restrictive effect of the shooter's field position on shot direction preference. The association between shooting zone and goal direction may partly reflect the geometric relationship between the shooter's position and the available shooting angles. Although shooting zones were classified relative to the goalkeeper's missing-arm side, the present analysis cannot establish that the observed associations are attributable to goalkeeper anatomy independently of shooting geometry. However, because the dataset included only successful shots, these findings describe goal-direction patterns rather than attackers' shot-selection decisions or scoring probabilities. Consequently, neither deliberate tactical exploitation of the goalkeeper's anatomical asymmetry nor greater vulnerability on the missing-arm side can be established from the available data. Addressing these questions would require data on all shot attempts, including unsuccessful attempts and saves, with shot direction and scoring outcome analyzed separately.

In the existing literature on amputee football, one research examined parameters such as the minute, goal type, and attack type of goals scored at the 2022 World Cup but did not assess the relationship between the goalkeeper's anatomical asymmetry and the direction of the goal [20]. That study reported 294 goals across 80 matches (3.67 goals per match), whereas the present study included 474 goals across 115 matches (4.19 goals per match). These descriptive figures provide context but should not be interpreted as a direct comparison because the tournament coverage differed. In this context, the present study provides systematic description of associations between goal direction relative to the goalkeeper's missing-arm side and spatial and height-related shot characteristics in amputee football.

In standard football, the angle and position of a shot shape the goalkeeper–shot interaction [10,32]. In amputee football, however, these spatial constraints, combined with the asymmetric saving geometry of the one-armed goalkeeper, may be relevant to goal-direction patterns. While the strategic effects of set-piece strategies and positional differences on direction have been reported in standard football, the narrower field in amputee football, along with the goalkeeper’s limited range of motion and functional capacity, as well as differences in game mechanics, may reduce these strategic differences [11]. The insignificance of the tournament variable indicates that no statistically significant difference between tournaments was detected in this sample; however, it does not establish the generalizability of the findings across competitions [33].

The higher odds of high shots being directed toward the goalkeeper’s missing-arm side may suggest that shot height is relevant to goal-direction patterns in amputee football. Previous research in standard football has examined goalkeeper reach and diving kinematics [8,14]. However, whether these biomechanical factors explain the present findings in amputee football remains uncertain, as goalkeeper kinematics, reach, and save outcomes were not measured. However, because goalkeeper kinematics, reach, and save outcomes were not measured, the present findings cannot establish whether these biomechanical factors explain the observed goal-direction patterns. Similarly, the goal-only dataset does not allow us to determine whether low shots are saved more frequently than high shots or whether specific compensatory mechanisms are less effective against high shots. This interpretation should therefore be considered a potential explanation that requires direct testing in future studies. Research in standard football has also examined how shot trajectory and ball position relate to goalkeeper performance, although it did not specifically investigate goal direction relative to anatomical asymmetry [34].

Notably, goal type did not emerge as a significant independent predictor. Although a proportion of penalty goals was directed toward the missing-arm side, this descriptive pattern does not establish systematic targeting behavior or deliberate exploitation of anatomical asymmetry. In standard football, right-footed players tend to shoot to the goalkeeper’s right during penalty kicks [6], and goalkeepers exhibit diving asymmetries linked to lateral dominance [8]. In amputee football, the goalkeeper’s use of one arm creates an asymmetric defensive configuration; however, the present data cannot establish how this configuration influences penalty-taking decisions. During video review, some goalkeepers appeared to position themselves slightly closer to their missing-arm side during penalty kicks. This observation was not systematically coded or tested and should therefore be regarded as anecdotal rather than as evidence of a deliberate positioning strategy. Although goalkeepers in standard football may exhibit lateral preferences [35], further research is needed to determine whether similar positioning strategies occur in amputee football.

A moderate effect size was calculated for the combination of the “Same Side” and “High” categories (Cohen’s  $h = 0.412$ ). This finding suggests a potentially meaningful difference in the distribution of goal directions across these categories. However, because the dataset included only scored goals, this effect size cannot be interpreted as an increase in the probability of scoring or as evidence that this combination is more successful in actual shot attempts. According to Cohen’s conventional benchmarks, this value represents a moderate effect size [36], although it should be interpreted cautiously because differences in scoring success could not be assessed. Therefore, in accordance with the principle of parsimony, the focus was first placed on the main effects [37]. Consequently, only exploratory inferences can be made regarding combinatorial effects, and targeted analyses are required to validate these interactions [38].

Although the ICC 0.28–0.39 and  $\tau^2 = 0.098$  obtained from the null model in the dataset indicate potential between-match differences, the variance converged to zero in

the multilevel model with a random intercept [39]. This paradox may be related to the low event density (an average of 3.9 goals per match), the fact that strong fixed effects (particularly the shooting zone and shot height) may account for some of between-match variance, and the risk of model over-parameterization [30]. This should be interpreted cautiously rather than as a technical error. However, it does not demonstrate that goal-level predictors explain most of the variance or that no additional match-level variance exists. Therefore, it does not establish universal mechanisms or confirm the generalizability of the findings across matches and tournaments. Due to singularity, the final logistic regression model used cluster-robust (sandwich) standard errors. This approach accounts for clustered dependence and helps preserve statistical inference [26,27]. These modelling decisions and the remaining uncertainty should be considered when interpreting the results.

The explanatory power of the model was limited (McFadden  $R^2 = 0.065$ ). While this low value is a common occurrence in observational data, it indicates the presence of important variables not included in the model that could influence the direction of the shot. Factors that are inaccessible via video-based coding but could be theoretically significant include shot speed, shot angle, the goalkeeper's center-of-gravity position at the moment of the shot, the intensity of pressure from defensive players, and the goalkeeper's reaction time [40].

These findings may inform future research on tactical and training approaches in amputee football. However, the present study does not establish whether directing high shots toward the goalkeeper's missing-arm side provides a tactical advantage or whether specific compensatory strategies improve save performance. Future studies incorporating all shot attempts, goalkeeper movement, and save outcomes are needed to evaluate these possibilities.

First, the dataset included only scored goals and did not include unsuccessful shots, shots saved by goalkeepers, or other unsuccessful attempts. Therefore, the study could describe goal-direction patterns but could not estimate side-specific scoring probabilities, establish whether the missing-arm side was more vulnerable, or determine whether attackers deliberately exploited this anatomical asymmetry. Our study had some limitations. Since this study has an observational and cross-sectional design, the relationships between variables cannot be interpreted as causal [41]. Video-based coding does not include fine-scale technical variables, such as shot speed, shot distance and angle, goalkeeper reaction time and starting position or defensive pressure. Information on shooter footedness and broader attack patterns was also unavailable, limiting our ability to account for these factors. This shortcoming limits the model's explanatory power and mechanistic interpretations [40]. Including these variables in the model could enhance its explanatory ability. However, it was not possible to measure these parameters in the current study. Therefore, while the current findings provide the strongest evidence within the existing data structure, they require additional data collection protocols to develop a more comprehensive model. The data focused on the 2021–2022 season, national team matches, and male players. Excluding empty net goals and own goals resulted in a loss of 9.1% of the total data [42]. The interaction terms were not statistically modeled. Therefore, only exploratory inferences can be made regarding the combinatorial effects [38]. Finally, the singularity encountered in the multilevel model and the use of cluster-robust standard errors in the final logistic regression model are technical decisions that may influence the interpretation of the results. These decisions were reported transparently and were supported by sensitivity analyses [26,27]. Individual goalkeeper identifiers were not available in the dataset; therefore, goalkeeper-level random effects could not be estimated, and residual dependence associated with individual goalkeepers across matches cannot be ruled out. In addition, individual differences in goalkeepers' training backgrounds, physical condition, and visual

reaction abilities were not directly assessed and therefore could not be accounted for in the analyses.

Our findings indicate that the observed goal-direction patterns may be consistent with potential biomechanical constraints associated with goalkeeper asymmetry. However, these mechanisms were not directly measured in the present study. Therefore, in future studies, a kinematic analysis of the goalkeeper's tendency to shift their center of mass toward the side of the missing limb during the shot would be valuable for elucidating the biomechanical mechanisms underlying defensive strategies. In the current model, the significance of the "shooting side  $\times$  shot height" interaction term was borderline; testing this interaction using penalized regression methods (e.g., LASSO or ridge) would allow for an objective assessment of the added value of interaction terms while keeping the risk of overfitting under control.

In the medium term, incorporating longitudinal data structures and eye-tracking measurements of the goalkeeper's perception could reveal the dynamics of decision-making processes over time. In the long term, external validation studies should be conducted using data obtained from different leagues, age groups, and sexes through multicenter designs including women's amputee football competitions such as the 2024 World Cup, where applicable data are available. Furthermore, exploring complex nonlinear relationships using machine learning methods, such as decision trees, random forests, or gradient boosting beyond traditional logistic regression, could enhance the generalizability of the current findings.

#### 4. Conclusions

In conclusion, in amputee football, goal direction relative to the goalkeeper's missing-arm side was associated with shooting zone and shot height among scored goals. These findings describe goal-direction patterns and should not be interpreted as evidence of greater scoring vulnerability on the missing-arm side. The lack of statistically significant associations with other included variables indicates that no statistically significant independent associations with goal direction were detected for these variables in the fitted model. Future studies should examine all shot attempts, including unsuccessful shots and saves, to better understand these patterns.

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## Abbreviations

The following abbreviations are used in this manuscript:

|       |                                    |
|-------|------------------------------------|
| HRmax | Heart Rate Maksimum                |
| HRV   | Heart Rate Variability             |
| ICC   | Intraclass correlation coefficient |

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