Analyzing the Relationship Between Run Up Steps, Shot Placement, and Penalty Kick Success

Group 3

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1 Introduction to the data

1.1 Previous Works

Penalty kicks in soccer have long been studied within sports analytics because of their decisive influence on match outcomes and their unique blend of biomechanics, strategy, and psychological pressure. Across professional competitions, penalty success rates typically fall between 75% and 80% (according to the studies referenced in this section), but researchers have shown that this success is shaped by many factors whether that be technical or perceptual.

One core line of research focuses on shot placement and the tradeoff between speed and accuracy. In a recent experimental study, Sørensen et al. [2024] demonstrated that when players were instructed to prioritize accuracy, they produced more controlled shots but with reduced velocity, whereas emphasizing power encouraged higher-risk placements toward the upper corners of the goal. This highlights the classic speed versus accuracy dilemma in penalty kicking, where choosing between precision and force directly influences scoring probability.

Another major research theme concerns goalkeeper anticipation and timing. Zheng et al. [2021] found that goalkeepers often initiate their dive based on cues from the kicker's non-kicking leg, frequently committing to a direction before the shot is taken. This creates an interaction where even small changes in the kicker's body orientation can influence goalkeeper decisions. Complementing this, Noël et al. [2021] reported that the dynamic interplay between goalkeeper and penalty taker significantly affects outcomes, emphasizing that penalty kicks are not isolated technical events but strategic duels shaped by timing, deception, and adjustments.

More recent work explores penalty kicks through data-driven and computational lenses. Bransen et al. [2025] introduced an AI-based optimization framework for goalkeeper decision-making, using large annotated datasets to simulate optimal dive strategies under uncertainty. Their results show that penalty success often depends on probabilistic interactions between kicker behavior and goalkeeper policy, reinforcing the strategic complexity of the event.

Although this body of research covers many technical and psychological aspects of penalty kicks, it focuses almost entirely on what happens at the moment of the shot rather than how the kicker approaches the ball. Prior work has documented the advantages of placing the ball in the upper corners [Bar-Eli et al., 2007], differences between left footed and right footed shooters [Palacios-Huerta, 2003], typical patterns in goalkeeper anticipation, and how pressure influences the balance between speed and accuracy [Jordet, 2009]. Yet even studies that rely on large penalty kick databases do not report any measure of the kicker's run up.

This omission creates a clear gap in the literature. Coaches, players, and commentators frequently describe certain kickers as using long approaches, short approaches, hesitation steps, or distinctive personal rhythms, suggesting that approach style is widely recognized as meaningful. However, no existing empirical work has examined whether the number of steps taken in the run up relates to scoring success or to the region of the goal where the ball is placed. As a result, run up length remains an aspect of penalty taking that is frequently discussed but not scientifically studied.

1.2 Our goal

The research gap identified above motivates the central goals of our project. Since existing work does not incorporate information about the kicker's approach to the ball, our study examines whether a simple observable element of the run up, the number of steps taken before the shot, has any measurable relationship with penalty kick outcomes.

To investigate this question, we constructed a dataset that includes run up steps along with standard variables such as shot placement, footedness, goalkeeper movement, and basic match information. By combining publicly available player statistics with our own video-based coding of each penalty event, we create a framework that allows us to study aspects of penalty taking that traditional datasets cannot capture.

With this dataset, our project focuses on two main objectives. The first is to determine whether the number of approach steps affects the final result of the penalty, including whether the attempt is scored, saved, or missed. The second objective is to examine whether step count influences where the ball is placed within the goal. Because our data includes precise shot quadrants, we can assess whether players with different approach lengths tend to favor particular regions of the goal or exhibit different placement patterns.

Together, these goals allow us to explore an element of penalty kicking that is widely discussed but has never been evaluated empirically. By analyzing run up steps, we aim to provide new insight into how approach style may relate to both scoring success and shot direction.

1.3 Our Data

We collected our dataset on November 17th, 2025, using information from Transfermarkt and YouTube. On TransferMarkt, we identified kickers who had scored and failed to score at least five penalties for each outcome. We also identified goalkeepers who had both conceded and stopped five penalties for each outcome. For each relevant player, we recorded the following information: kicker's name, keeper's name, kicker's position, kicker's PK conversion rate, goalkeeper's PK stop rate, goalkeeper's height (in meters), date of each match, and match spread at the time of the penalty. After gathering this data, we located the specific match and penalty event on YouTube. By watching these events, we recorded the penalty shot quadrant (1–6, 7 if missed), the dive quadrant of the goalkeeper (1–6), the kicker's shooting foot, penalty result (Goal, Saved, or Missed), and the number of steps the kicker took before shooting. From Transfermarkt, we identified 15 kickers and 15 goalkeepers who met the following criteria:

- each kicker had scored at least five penalties and failed at least five penalties;
- each goalkeeper had saved at least five penalties and conceded at least five penalties.

For each selected kicker and goalkeeper, we collected ten penalties (five successful and five unsuccessful), and the opponents involved in these penalties differ across observations. For each penalty, we recorded:

- kicker's name (Kicker);
- kicker's position (Kicker Role);
- kicker's percentage of penalty kicks scored (Kicker Ability);
- goalkeeper's name (Goalkeeper);
- goalkeeper's percentage of penalty kicks saved (Goalkeeper Ability);
- goalkeeper's height (in meters) (Goalkeeper height);
- date of each match (Date);
- match spread at the time of the penalty (Spread), defined as the difference between the kicker's team score and the goalkeeper's team score before the penalty:

$$\text{Spread} = \text{Score}_{\text{kicker team}} - \text{Score}_{\text{goalkeeper team}}$$

After gathering this information, we located each specific match and penalty event on YouTube. By watching the footage, we recorded:

- penalty shot quadrant (Ball position): a value from 1 to 6, or 7 if missed;
- goalkeeper dive quadrant (Goalkeeper position): a value from 1 to 6;
- kicker's shooting foot (Foot): left or right;
- penalty result (Result): goal, saved, or miss;
- number of run-up steps (Steps).

Quadrants were defined as follows:

- 1 = high left;
- 2 = high center;
- 3 = high right;
- 4 = low left;
- 5 = low center;
- 6 = low right;
- 7 = missed attempt (ball off-target, such as wide or over the crossbar).

Quadrants 1–7 apply to the shot direction, while only quadrants 1–6 apply to the goalkeeper's dive direction.
In total, our dataset contains 300 observations, each representing a single penalty kick.

Table 1 shows a sample of 10 observations from our dataset

Table 1: Sample of 10 observations from the penalty-kick dataset (some names of the variables have been shortened for space reasons).

Date	Kicker	Kicker role	Foot	K. ability	Ball pos.	Goalkeeper	GK ability	GK height (m)	Steps	GK pos.	Result	Spread
23/8/15	D. Villa	Centre Forward	R	84.95	6	D. Ricketts	8.70	1.93	3	4	goal	-4
16/1/22	R. García	Attacking Midfield	R	79.00	5	T. Courtois	17.00	2.00	4	5	save	-2
10/9/19	A. Griezmann	Second Striker	L	64.10	2	J. Antoni	15.79	1.81	2	2	save	1
24/6/24	L. Modrić	Central Midfield	R	81.00	4	G. Donnarumma	25.00	1.96	5	4	save	0
29/10/23	C. Palmer	Attacking Midfield	L	95.00	3	A. Becker	22.00	1.93	7	6	goal	-2
28/05/23	A. Mitrović	Centre Forward	R	73.00	5	D. De Gea	18.00	1.92	11	5	save	-1
17/02/24	A. Pinamonti	Centre Forward	R	83.00	4	M. Carnesecchi	33.00	1.91	5	4	save	-1
08/08/14	Z. Ibrahimović	Centre Forward	R	83.65	6	J. Placide	15.38	1.81	4	6	save	1
13/10/18	V. Junior	Left Winger	R	64.00	7	L. Ureta	11.00	1.79	12	6	miss	0
14/09/25	M. Salah	Right Winger	L	83.00	3	M. Dúbravka	14.00	1.91	9	4	goal	0

2 Summary of the data

Ball position

Cat.	Count	%
6	99	33.0
4	95	31.7
5	32	10.7
7	21	7.0
1	19	6.3
3	18	6.0
2	16	5.3

Goalkeeper position

Cat.	Count	%
4	127	42.3
6	109	36.3
5	47	15.7
1	7	2.3
2	5	1.7
3	5	1.7

Kicker role

Category	Count	%
Centre Forward	129	43.0
Left Winger	49	16.3
Right Winger	39	13.0
Attacking Midfield	28	9.3
Central Midfield	20	6.7
Second Striker	14	4.7
Defensive Midfield	11	3.7
Forward	3	1.0
Centre Back	2	0.7
Left Back	2	0.7
Right Back	2	0.7
Winger	1	0.3

Footedness

Foot	Count	%
R	227	75.7
L	73	24.3

Table 2: Summary of categorical variables: ball position, goalkeeper position, kicker role and footedness with counts and frequency of the observations.

Variable	Min	Max	Mean	SD	Median
Goalkeeper ability	0.00	50.00	19.39	6.54	19.00
Goalkeeper height (m)	1.79	2.01	1.91	0.04	1.91
Kicker ability	0.00	100.00	78.62	13.83	81.00
Spread	-4.00	5.00	-0.04	1.31	0.00
Steps	1.00	18.00	5.94	2.73	5.00

Table 3: Summary of the 5 numeric statistics we kept track of in our dataset. We calculated the minimum, maximum, mean, standard deviation and median for each of the statistics.

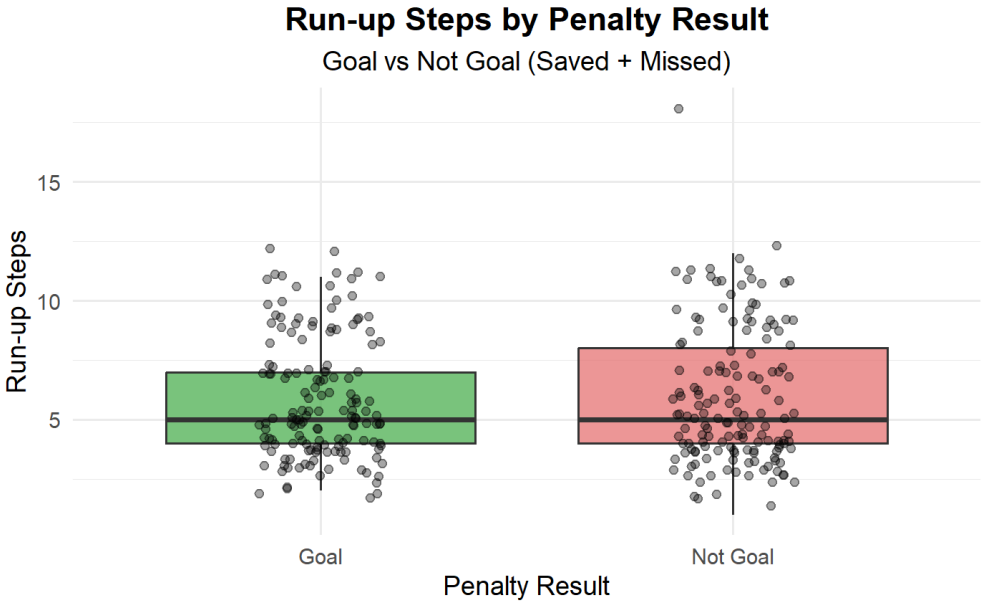

Figure 1: Boxplots with overlaid individual observations comparing the number of run-up steps between successful penalties (goals) and unsuccessful attempts (saved or missed).

To evaluate whether kickers change ball placement when altering their approach, we created a step routine classification based on the distribution of step counts in our sample. Let S denote the sample

of step counts across all attempts, and let $Q_{0.25}$ and $Q_{0.75}$ be the 25th and 75th percentiles of this sample. We define the "Normal" step range as the range between $Q_{0.25}$ and $Q_{0.75}$ which is 4 to 8 steps. Additionally, we classified a "Shortened" routine as attempts less than 4 steps and a "Lengthened" routine as attempts greater than 8 steps.

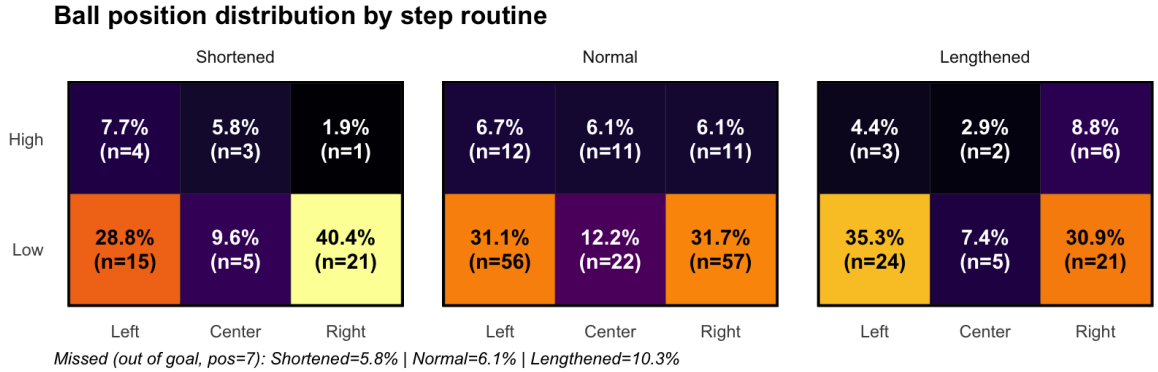

Figure 2: distribution of ball position (1–6) between each step routine category (Shortened, Normal, Lengthened). Within each panel, each tile displays the percent relative frequency and count of attempts landing in that zone. Across all three routines, kicks were concentrated in the low-left and low-right zones, while high placements were rare. The comments at the bottom report the rate of Missed (out of goal, pos=7) attempts for each routine, with relative frequency.

3 Insights from the Data

3.1 Steps vs Penalty Outcome

Based on Figure 1, we aimed to investigate whether the number of steps a kicker takes during the run-up is correlated with scoring success. From a coaching perspective, the underlying question is practical: do longer or shorter approaches meaningfully affect a kicker's likelihood of converting a penalty? Because run-up steps are a discrete variable and the penalty outcome (Goal vs Not Goal) is binary, our first step was to assess whether the distribution of run-up steps met the assumptions required for standard parametric tests. Shapiro–Wilk tests applied separately to the Goal and Not Goal groups indicated strong evidence of non-normality (Goal: $p = 2.495 \times 10^{-7}$; Not Goal: $p = 3.86 \times 10^{-8}$), meaning a two-sample t-test would not be appropriate. We therefore used the Wilcoxon Rank-Sum test to compare the distributions of run-up steps across the two outcomes. This test yielded a $W = 11416$ with a $p = 0.8244$, indicating that we fail to reject the null hypothesis that the two groups have the same central tendencies. In other words, there is no statistical support for the idea that run-up length affects scoring probability.

When examining the variables shown in Figure 1 for any practical coaching signals, no such pattern emerged: the full range of run-up lengths appears in both successful and unsuccessful penalties, and neither carries a reliably higher failure rate. Overall, our analysis suggests that run-up length should be treated as a stylistic component rather than a performance lever. For coaches, this means focusing training time on factors with demonstrated impact, such as ball placement, shot power, or reading goalkeeper tendencies, rather than attempting to manipulate a kicker's step routine for performance gains. If a kicker prefers a particular run-up length, the data provide no reason to intervene unless it is directly causing technical inconsistency in their mechanics.

3.2 Steps vs Ball Position

Using Figure 2 as motivation, we evaluated whether step routine and ball position are independent. From a coaching standpoint, the key question behind Figure 2 is simple: when a kicker changes from a normal run-up, does placement or accuracy change in a real way? We first applied a chi-square test

of independence to the full ball-placement distribution (positions 1–7) across the three step routines because both variables are categorical (step routine: Shortened/Normal/Lengthened; ball position: 1–7), and the chi-square test is designed to assess whether two categorical variables are associated. This test produced:

$$\chi^2(12) = 7.89,\ p = 0.79,$$

so we fail to reject the null hypothesis of independence. Specifically, we did not find enough evidence to say step routine changes the overall placement distribution. However, we noticed a potentially meaningful coaching signal in miss (pos. 7) rates of Figure 2: off-target misses (ball position 7) were 10.3% for Lengthened attempts compared to 6.1% for Normal and 5.8% for Shortened. To focus specifically on this accuracy outcome, we created a binary variable M where M = 1 if the attempt was missed out of goal and M = 0 otherwise, and then tested whether the proportion of M = 1 differed by step routine (again using a chi-square / difference-in-proportions framework). That follow-up test indicated that the apparent difference in off-target rate was not statistically significant in our sample:

$$\chi^2(2) = 1.47,\ p = 0.48.$$

Overall, these results suggest that deviating from the normal step range does not reliably change ball placement or miss-rate. A coach should treat step-routine changes as a player preference rather than a performance tool. Conclusively, training time is likely better spent improving repeatable mechanics and decision-making (where to aim) rather than encouraging players to shorten or lengthen steps to gain an edge. If a player insists on changing routines, the only actionable guidance this paper can give a coach is to monitor out of goal shots and default back to the normal step routine when misses increase.

3.3 Critiques

- One limitation of our work is the reliance on Transfermarkt data, which includes only in-game penalties. Because shoot-outs are excluded, the dataset does not capture extreme pressure scenarios, meaning that our conclusions apply only to regular-play penalties and not to high-stakes situations like tournament eliminations.

- Another issue concerns the way run-up steps were measured. Since steps were counted manually from video, the process may introduce observer error, especially in cases where the camera angle makes the early part of the approach difficult to see or when players use small hesitation steps that are hard to categorize. Related to this, our analysis uses only the number of steps, but not their length, speed, or angle, so we capture only a small part of the run-up mechanics.

- A further limitation is that missed shots are all coded as "position 7," which groups every type of off-target attempt into a single category. This prevents us from analyzing where players tend to miss (for example, wide left, wide right, or over the bar), and it reduces our ability to understand directional error patterns.

- Another limitation is that, even though we collected a fairly wide range of variables, only a portion of them ended up playing a meaningful role in the analysis. Several measures were included in the dataset but were ultimately not incorporated into the statistical models or comparisons, which means that some potentially informative relationships may have gone unexplored. The stratification we attempted did not contribute as much as expected.

- Finally, our dataset is mostly made up of elite male players and top-level goalkeepers. This means the results may not apply as well to other groups, such as women's leagues, youth players, or lower-division football.

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