

Analysis of the penalties at the World Cups

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1 Introduction

Penalty shootouts haven't been around that long. The first penalty shootout was held for the first time in 1982 at the World Cup in Spain, with West Germany beating France in the semifinals. It is one of those things in football that some people love and others detest. They can be very nerve-wracking for the spectators but especially for the professional players and goalkeepers.

The central objective of this paper is to leverage data to resolve queries pertaining to the influence of various factors on the execution of penalty shots. Specifically, this study seeks to discern which elements—attributable to either the player or the goalkeeper—may impact the outcome of penalty taking. Figure 1 presents the Critical Success Factors along with their associated key performance indicators, which have been identified by the authors of this study as potentially influential. These factors will be scrutinized within the confines of this academic investigation. For the purpose of this analysis, data was collected on all penalties executed during the World Cup tournaments between 1982 and 2022, with a singular focus on the penalty shootout phase.

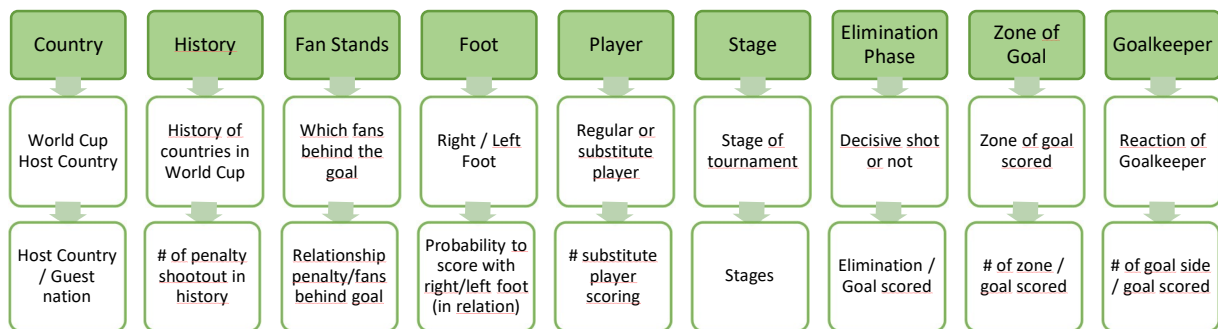


Figure 1: Critical Success Factors

2 Data Description

The dataset contains information about penalty shootout kicks taken during the World Cup matches from 1982 to 2022. Each row represents a single kick and includes the following information:

- Game_id: A unique identifier for the game in which the kick was taken.
- Team: The team taking the kick.
- Goal_Zone: The location within the goal that the kick was aimed at, with values ranging from 1 to 9.
- Goal_Side: The side of the goal that the kick was aimed at (L = left, R = right, C = center).
- Goal_Level: The vertical level of the goal that the kick was aimed at (top, middle, down).
- Foot: The kicking foot (L = left, R = right).
- Keeper: The side of the goal that the goalkeeper jumped to (L = left, R = right, C = center).
- OnTarget: A binary variable indicating whether the kick was on target (1) or not (0).
- Goal: A binary variable indicating whether the kick resulted in a goal (1) or not (0).
- Penalty_Number: The number of the kick in the penalty shootout.
- Elimination: A binary variable indicating whether the penalty was a matchball (1) or not (0).
- Fan_Tribune: The country of the fan who stands behind the goalkeeper during the penalty shootout.
- Regular_Substitution: A binary variable indicating whether the player taking the kick was a regular player (0) or a substitution (1).
- Year: The year in which the game took place.

- Stage: The stage of the tournament in which the game took place.
- Score: The score of the game before the penalty shootout.
- Country: The country in which the game took place.
- Country_Code: The ISO code for the country in which the game took place.
- Winner: The team that won the game.

The dataset at hand offers a robust platform for exploring the elements that contribute to the successful execution of penalty shootout kicks in international football matches. Potential variables that could be of interest encompass the targeted location and side of the goal, the foot employed for the kick, and the position of the goalkeeper. Furthermore, the dataset affords an array of information pertaining to the player and team participating in each kick. It also provides valuable details concerning the year, stage, and geographical location of the match. These myriad facets coalesce to offer a comprehensive understanding of the dynamics involved in successful penalty shootouts.

3 Analysis of Critical Success Factors

In this section, we will undertake an in-depth examination of the multitude of factors influencing the success rates of penalty kicks. The constituents under scrutiny encompass aspects such as the Country, Historical performance, Fan Tribune, preferred Foot, the Player, Tournament Stages, Zones of the goal, and the Goalkeeper. Penalty shootouts serve as a critical component in football tournaments, and hence, scrutinizing these significant success factors can facilitate comprehension of the underlying patterns and insights dictating shootout outcomes. Through a detailed inspection of these factors, we aspire to enhance our understanding of the distinguishing attributes that segregate successful penalty kickers from those who fail to achieve their intended targets. This analysis can be particularly useful for players, coaches, and fans alike in gaining an insight into the various elements that make up a successful penalty shootout performance.

3.1 Country

The table delineates a comprehensive summary of the performance exhibited by host and guest nations during the penalty shootout (PSO) phase of the Football World Cup. The information is partitioned into four distinct categories for each set of nations:

- 1) The aggregate count of attempted shots during the PSO,
- 2) The tally of successful goals secured during the PSO,
- 3) The frequency with which a goalkeeper from the adversary team successfully retained the ball, and
- 4) The incidence of players from the respective group failing to find the target.

This structured data presentation enables a detailed comparative analysis of the PSO performances between host and guest nations.

Host Nations	
number of scores from during PSO	36
number of goals scored in PSO	27

number of times goalkeeper from guest nation held ball	7
number of times player from host nation missed goal	2

Guest Nations	
number of scores from during PSO	284
number of goals scored in PSO	194
number of times goalkeeper held ball	64
number of times player missed goal	26

The following bar chart visualizes the data above.

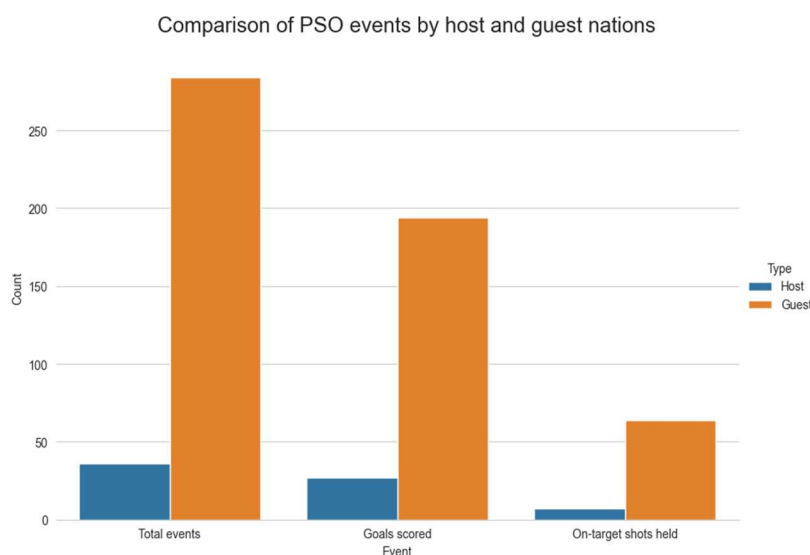


Figure 2: Comparison PSO

The analysis reveals that there is no significant difference in the performance of host nations and guest nations in penalty shootouts in a proportional perspective. Our findings suggest that a home advantage is not significant enough to have a material impact on the results of the penalty shootout.

3.2 History

Over the years, many teams have participated in penalty shootouts during international competitions like the World Cup. Some teams have had more success than others, and some teams have participated more frequently.

In this analysis, we will focus on the number of participations in penalty shootouts of different teams. We will look at which teams have participated the most and which teams have participated the least. We will also examine the success rate of these teams in penalty shootouts. By looking at the number of participations, we can get an idea of how often a team has been in high-pressure situations like a penalty shootout. This can tell us a lot about the performance of a national soccer team during penalty shootouts across all tournaments.

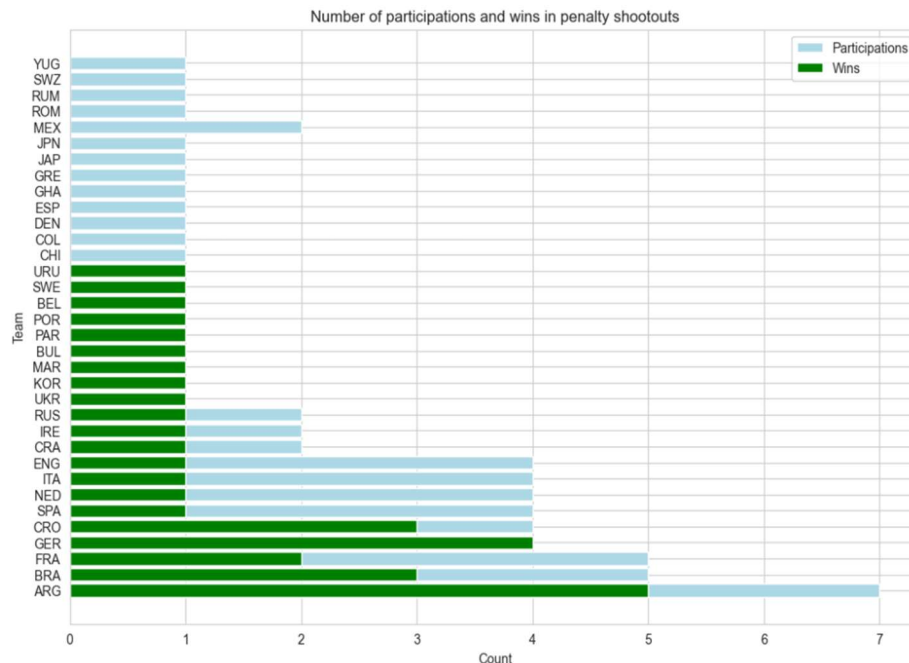


Figure 3: Number of participations and wins

Most teams have only participated in a penalty shootout once throughout all World Cups. Only countries such as Argentina, Brazil, France, Germany, Spain, Holland, Italy, England, Costa Rica, Ireland, and Russia have participated in penalty shootouts more than once. It is noticeable that some of these countries have achieved particularly good results. The leader in this regard is Germany, which has won every penalty shootout it has participated in out of four. It is also apparent that Argentina has participated in penalty shootouts by far the most and has won most of them. Croatia is also one of the teams that usually wins penalty shootouts. Other countries such as England, Italy, Holland, and Spain tend to lose penalty shootouts.

3.3 Fan Stands

In this section we investigate the effect of home fans on the tribune behind the goalkeeper during penalty shootouts in the soccer World Cup. Specifically, we will look at how the presence of home fans affects the performance of the goalkeeper and the success rate of penalty takers. By understanding the impact of fans on the outcome of penalty shootouts, we can gain insights into the psychology of soccer players and how external factors can affect their performance. The data used for this analysis was extracted from video recordings of the respective penalty shootouts. However, it is not always clear which fans are located in the stands behind the goalkeeper. Therefore, only data from games in which the identity of the fans behind the tribune could be clearly identified were used.

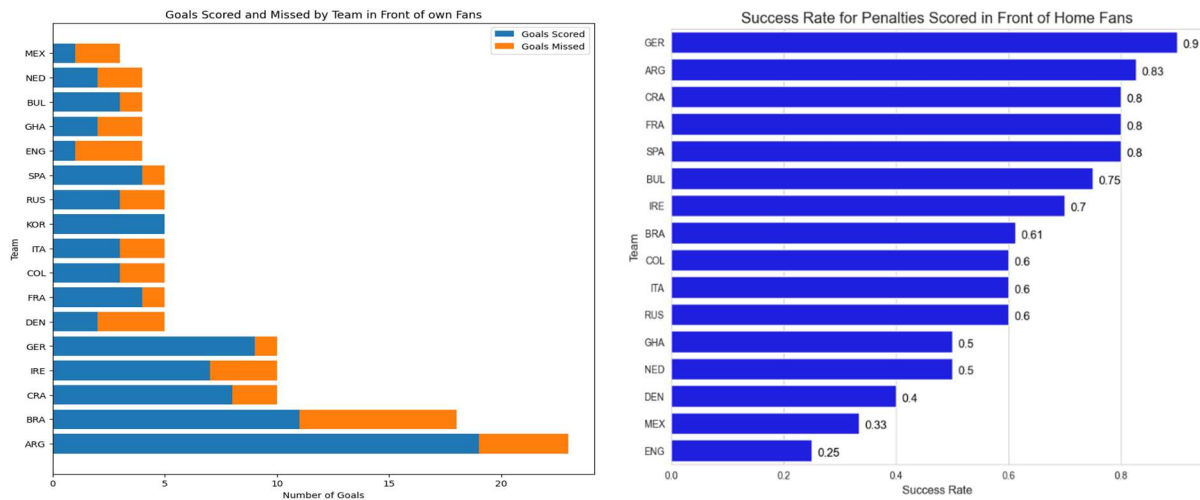


Figure 4: Charts of fan stands

The left chart displays the ratio between scored and missed penalties. It shows that Germany performs the best in front of their home fans, while England performs the worst in front of their home fans. Team South Korea shows the best performance on the chart. We decided to disregard this data point due to the circumstances surrounding it. It occurred during a penalty shootout in the South Korean World Cup, where the stadium was predominantly filled with home team supporters, and it was the only instance in which they participated. If we now consider the success rate in the right graph, it turns out that the teams can be divided into three groups. The top group performs above average in front of their own fans, including teams such as Germany, Argentina, Costa Rica, France, Spain, and Bulgaria. The second group performs in the midfield, where it is not clear whether the factor of fans is decisive. The third group shows the teams that perform significantly worse in front of their own fans.

3.4 Foot

One of the factors that can affect the success of penalty kicks is the foot used to take the shot. Some players may have a preference for a specific foot, which could influence the accuracy of their shots. The analysis of the World Cup penalty kick dataset allows us to explore the relationship between the foot used and the success rate of penalty kicks in the World Cup. In this analysis, we focus on the shots on target that did result in a goal during the penalty shootout. We calculate the proportion of shots for each foot.

The results of this analysis can provide valuable insights into the importance of the foot used in penalty kicks and can be used to inform the training of soccer players and coaches.

Total shots by foot:

Foot	
L	64
R	256

Total goals by foot:

Foot	
L	44
R	177

Goal percentage by foot:

Foot	
L	0.687500
R	0.691406

The table above displays the number of shots on target with the left and right foot in the left-hand column. The middle column shows the number of goals scored with each foot, and the right-hand column shows the percentage of goals scored with each foot. It can be observed that the difference between the percentages is negligible, with only 0.003% between them. Therefore, it can be concluded that the foot used to take the penalty does not significantly impact the outcome.

Right Foot:

Foot	
Shots:	256
Misses	23

Miss Percentage: 8.98%

Left Foot:

Foot	
Shots:	64
Misses	5

Miss Percentage: 7.81%

Looking at the ratio between total shots on target and missed shots, the situation appears quite different. Nearly 9% of shots missed when taken with the right foot, while 7.81% of shots missed when taken with the left foot. It seems that shots taken with the left foot tend to hit the target more accurately.

3.5 Player

Another factor that was analyzed is whether there is a difference in performance between regular starters and substitute players.

Probability of Scoring a Goal

Regular_Substitution	
0 (substitute players)	0.681818
1 (regular players)	0.693780

Number of Scored Goals

Regular_Substitution		
0 (substitute players)	35	75
1 (regular players)	64	145

The table shows the frequency and proportion of regular players vs. substitute players in relation to the outcome of the penalty shootout. The left table displays the proportions of regular players and substitute players. We can see that the proportion of regular substitution for regular players is slightly higher at 0.693780 compared to the substitute players at 0.681818.

The right table shows the contingency table for the relationship between regular substitution and outcome. The values in the cells represent the frequency of observations that fall into each category.

3.6 Stages

In this analysis, we will explore the relationship between the stage of the tournament and the probability of scoring a penalty in World Cup games. We will examine if there is a significant difference in the probability of scoring a penalty between different stages of the tournament. We will use data from previous World Cup tournaments and conduct a statistical analysis to determine whether there is a correlation between the stage of the tournament and the success rate of penalties. We will also create a visualization to display the results of the analysis in an easy-to-understand format. Overall, this analysis will provide valuable insights into the importance of the stage of the tournament in the outcome of penalty shootouts in the World Cup.

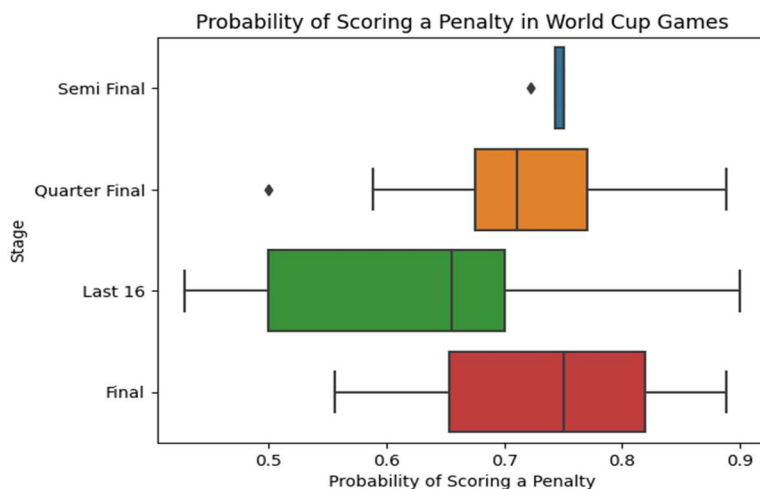


Figure 5: Stages of World Cup

Based on the analysis of the probability of scoring a penalty in the soccer world cup based on the stage of the tournament, it can be concluded that the performance of teams in penalty shootouts varies depending on the stage of the tournament. The boxplot visualization shows that the stage of "Last 16" has the lowest probability of scoring a penalty, as well as the highest variance in performance. This suggests that less experienced teams are participating at this stage level. On the other hand, the semi-finals and finals have a higher probability of scoring penalties, with the semi-finals showing the lowest variance and the highest median probability of approximately 0.74. The quarter-finals also have a relatively low variance and a median probability of approximately 0.7. The box plot also shows that during the final the variance increases again suggesting that the teams may face more pressure and difficulty scoring penalties at this stage of the tournament. Overall, the results suggest that teams may face different challenges and perform differently during penalty shootouts depending on the stage of the tournament.

3.7 Elimination Phase

Not only can the different stages of the tournament affect the outcome, but also in the elimination round. To be more precise, during the decisive shot, which determines the winning team. At first glance, the two charts, see figure 6, appear relatively similar. It can be seen, however, that in the decisive shot, slightly more attempts are made outside the goal. As mentioned in the previous chapter, the pressure from the players during the final stage would confirm this once again. Whether there is any substance to this cannot be determined, as the data on the elimination phase are significantly smaller.

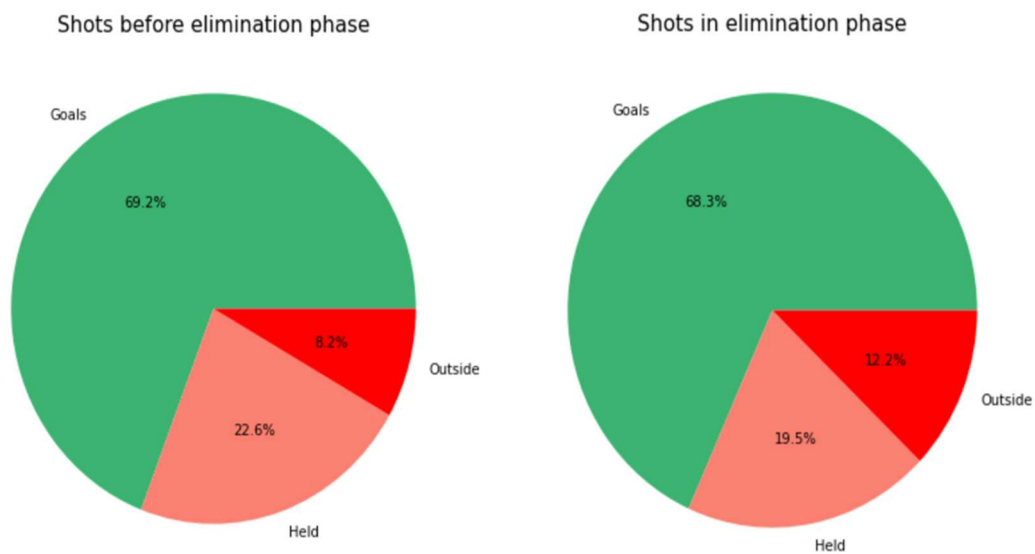


Figure 6: Pie Chart of penalty attempts

3.8 Zones of the goal

A further area of interest is in which corner of the net successful goals are scored. For this, a heat map was created, see figure 7, showing where goals were scored in percentages. About one in five successful penalties is shot in the lower third of the left corner. One could expect that players have more control of the shot there. It seems that kicks on the upper third of the goal have a higher likelihood of landing outside the goal. At the center of the goal, there is a much greater risk that the goalkeeper may catch the ball. On the whole, the chances of a goal being scored are greater if a player chooses to focus at the bottom or in the middle of the goal level, as well as towards either side of the net.

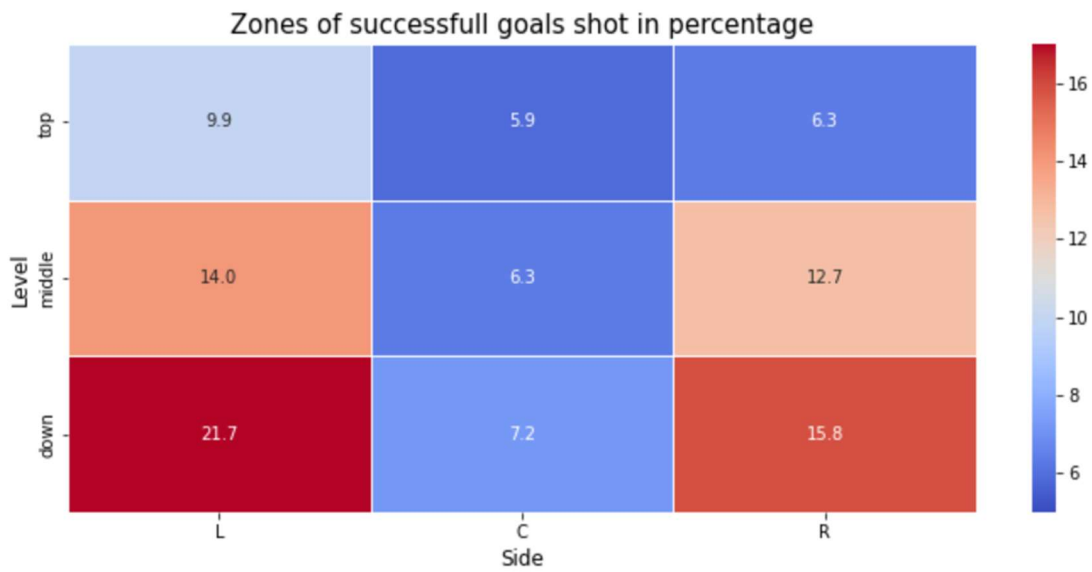


Figure 7: Zones of successful goals

A follow-up question is whether the pattern of successful shots changes during the decisive shot. Looking at the graph 8, there are some visible changes. At the bottom right, the probability of scoring a goal increases, whereas the chance declines in the middle right and left. For a better insight into the reason for the differences, the behavior of the goalkeeper will also be analyzed in the next subchapter.

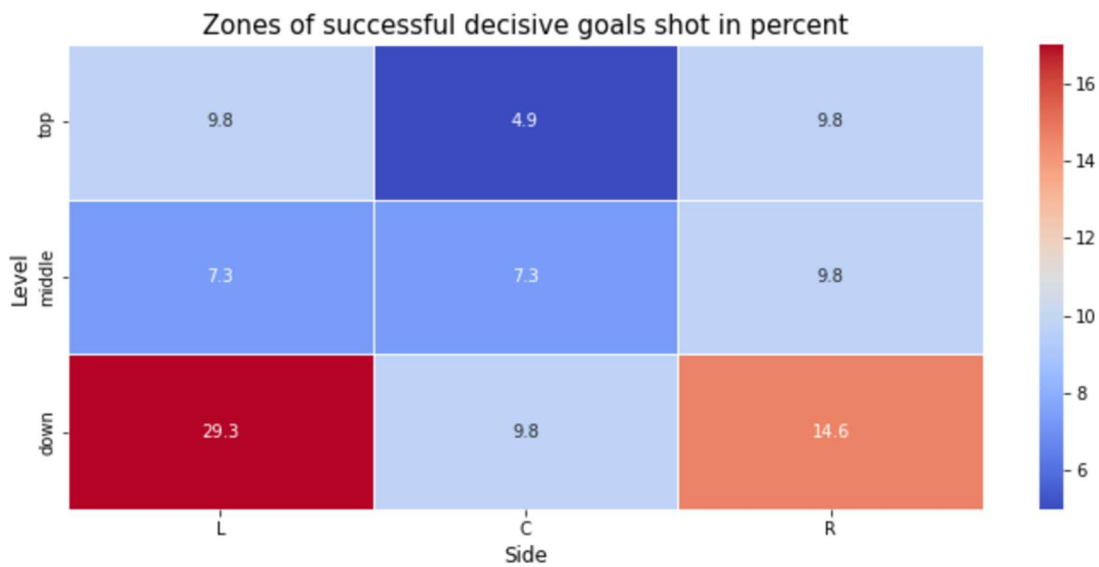


Figure 8: Zones of successful decisive goals

3.9 Goalkeeper

In this section our focus is on how the goalkeeper performs in a normal penalty situation as well as during the decisive shot.



Figure 9: Side of goalkeeper

First, it is determined on which side the goalkeeper frequently leaps and effectively defends the goal. 26% of all goals shot, in which the keeper moves to the left, were caught. However, only every 6th to 7th attempt, where the keeper remains in the middle of the net, gets caught. Here one could perceive somewhat of a contradiction to the previous chapter, as fewer goals are scored in the center of the goal. However, in this chart x, there could be different explanations, e.g. when the goalkeeper remains in the center while the player kicks to one side

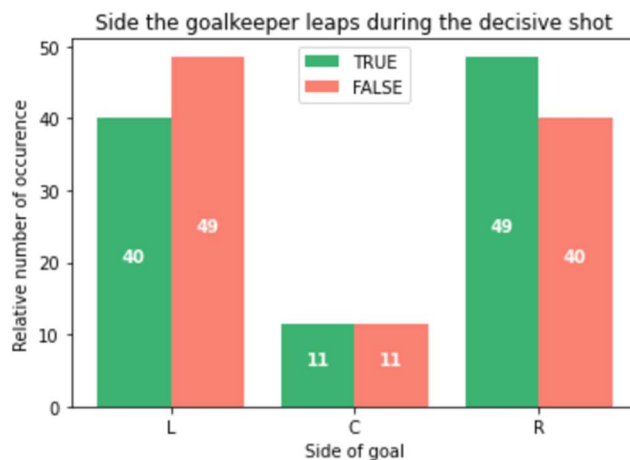


Figure 10: Side of Goalkeeper in elimination phase

What is also of interest is to see whether goalkeepers react in the same way when the decisive shot is taken, or if pressure causes them to react differently. This graph reveals a difference of about 9% on the left and right sides between the two situations. This would likely explain how, in the previous chapter, more goals were scored on the lower left during the elimination phase, as the goalkeeper jumps fewer to the left according to this graph.

Goal_Side		C	C	L	L	R	R
	Foot	L	R	L	R	L	R
Keeper	C	0	8	3	10	2	14
	L	9	20	9	78	8	27

	R	8	21	9	40	15	37
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Chi-square test results:

p-value: 0.009626464541964993

The table shows the contingency table and chi-square test results for the relationship between the goalkeeper's position and the side and foot used to score a penalty. The contingency table shows the number of penalties scored by using the left (L) or right (R) foot and targeting the center (C), left (L), or right (R) side of the goal, and the number of penalties scored against the goalkeeper in each category.

The chi-square test is a statistical test used to determine whether there is a significant association between two categorical variables, in this case, the goalkeeper's position and the side and foot used to score a penalty. The results of the chi-square test show that the p-value is 0.0096. This p-value is less than the standard significance level of 0.05, indicating that there is a significant relationship between the goalkeeper's position and the side and foot used to score a penalty. Therefore, the goalkeeper's position might influence the side and foot used by the penalty taker to score a goal, and vice versa.

4 Conclusion

The different factors we examined in this paper revealed, to a greater or lesser extent, that they do have some effect on the scoring of penalties, both on the player's side and on the goalkeeper's side. However, given that for some subjects the sample size was rather small, the interpretations of the graphs were only based on assumptions. A deeper investigation is needed to understand the reasons for the outcomes and to be able to provide factual insights. This would require collecting more data on penalty shootouts from various championships and other tournaments, as well as considering several more factors. Yet, this would exceed the scope of this paper. On the whole, it's interesting to learn that numerous aspects can determine a successful shot, beyond talent or luck, thus allowing teams to take a targeted approach.