Professor Stephen Hawking's World Cup Study for Paddy Power

This study was commissioned by Paddy Power for the 2014 World Cup. It answers the following two questions.

1. **What conditions suit England in a World Cup?**
2. **How do you take the perfect penalty in a World Cup penalty shootout?**

Introduction

The England football team are playing in the 2014 World Cup finals in Brazil, which is the ninth finals they will have participated in since their winning year, 1966. To find the conditions that suit England in a World Cup we have analysed the 45 matches that England have played since 1966. To work out how to take the perfect penalty, we have analysed the 204 penalties taken in the 22 World Cup final penalty shootouts.

The results of the study are two general logistic model equations linking the probability of England winning a match, and the probability of a player scoring a penalty, respectively, to the explanatory variables. Among the variables analysed, those that had an effect on the probability of England winning a match were found to be the stadium temperature, the stadium altitude, distance from London, the nationality of the referee and opposing nation, the colour of shirt worn and team formation. The variables in our study that were found to affect the probability of a player scoring a penalty during a shootout were the player's position, the length of run-up, where on the boot the ball was kicked from, the player's hair type and where the ball was aimed. In terms of saving penalties it was found that how the goalkeeper moved when the ball was kicked impacted the probability of saving the penalty.

The next sections will, firstly, describe the exploratory analysis, whereby the effect of each factor on winning a match was analysed in isolation, and secondly explain the final selected model.

The probability of England winning a match

It is widely accepted in the field, that a key factor of achieving World Cup champion status is winning matches. In this study, we quantify the conditions under which England are most likely to win a match. As summarised in Table 1, the impact of diverse collection of conditions were analysed. Considering the complex nature of the game, the quantification of factors ranging from environmental and physiological to political, psychological and sartorial was found to be necessary.

Table 1. Factors considered affecting the probability of England winning a match

Environmental Factors	Distance from home Temperature on game day Stadium Altitude Kick-off time
Physiological and Psychological Factors	Colour of shirt worn Player Age Age of the captain
Political Factors	Continent of opponent Nationality of referee
Tactical Factors	Team Formation

Exploratory Analysis

Prior to building a multivariate model to quantify England's probability of winning a match, we looked at individual effects of each factor under investigation.

Environmental Factors

Distance from home

The distance that a team travels from its mother country to the championship location is correlated with many factors that can affect its performance. Jetlag, lower supporter numbers, host nation advantage and the stress of different cultural norms can all take their toll on the sensitivities of a professional football player. Hill et al (1993) noted that 'after travel, there was disruption of mood state and a reduction in dynamic strength' and 'mood state, anaerobic power and capacity, and dynamic strength were affected by rapid transmeridianal travel, and even highly trained athletes suffered from jet lag' . To quantify the impact, if any, of travel we examined the relationship between the distance from a team's national capital to the stadium and the expected binomial probability of winning the match was quantified using a generalised linear model with a logistic link. This particular exploratory analysis is based on data from all 604 World Cup final matches between all teams from 1966 to 2010. The graph in Figure 1 suggests a trend that further distances travelled may lower the probability of a team winning a match. Whilst the impact of distance travelled is shown to be significant it should be noted that any impact could be dissipated or diluted by team behaviour. Reilly et al. (2007) is concluded that the impact of jetlag could be mitigated somewhat by 'social activity and fitting in with local time can facilitate… the restoration of normal circadian rhythms'.

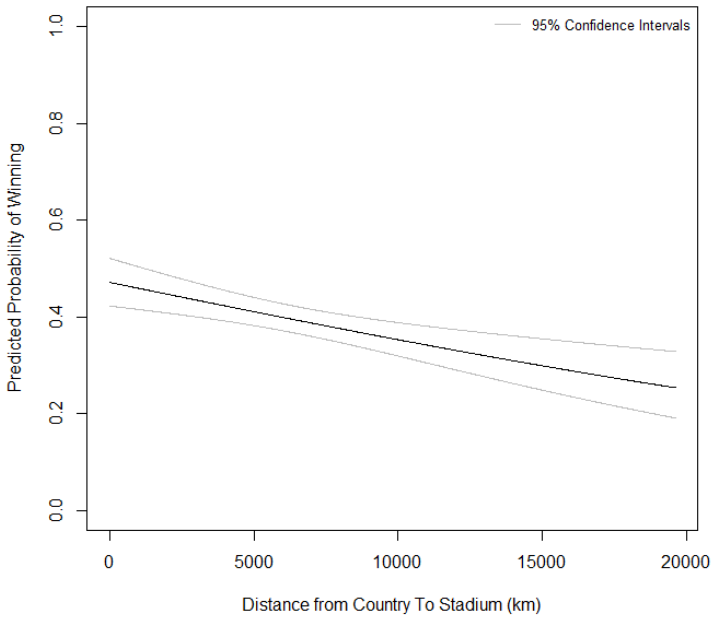

Figure 1: Impact of distance from home capital to stadium (all countries)

In particular the data show that England are 22% more likely to win when playing a short haul (< 800km) match relative to playing a long haul game; 67% of short haul matches were won, compared to 45% when longer distance travel was required.

Temperature on game day

For England, in particular, it was found that the temperature plays a nontrivial role in their chances of success. Over their World Cup campaigns from 1966 to present, it was found that higher temperatures decrease their chances of winning significantly. The temperate climes of London have been ideal playing conditions for the English team. Figure 2 displays the effect of temperature on the binomial probability of winning as modelled using a logistic link function. From past data there is a strong indication that colder temperatures lead to a higher probability of victory for England.

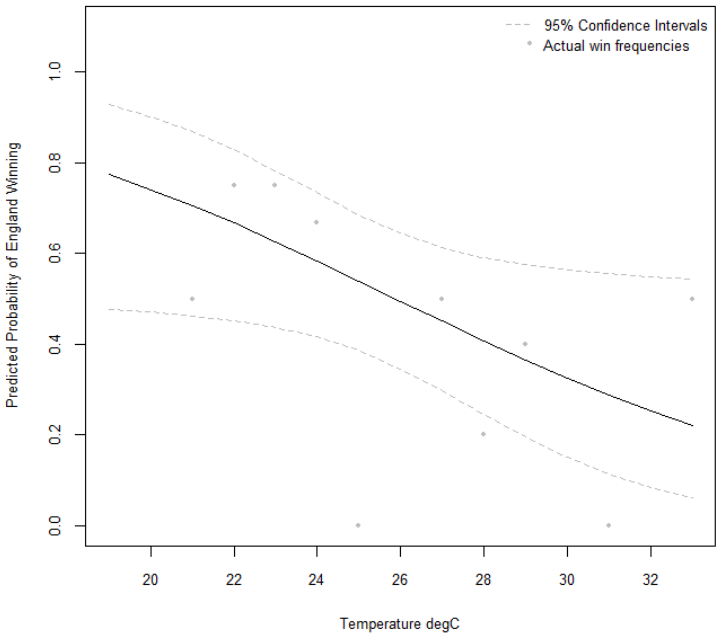

Figure 2: Impact of day of match temperature

Stadium Altitude

The next environmental factor considered was the altitude at which the match was played. Do other teams endure the impact of reduced oxygen levels beyond England's abilities? A potential effect is illustrated in Figure 3, suggesting that higher altitudes may dampen England's chances of success. With over 59% of matches won at low altitude, compared to 31% at altitudes over 500m above sea level, England have been twice as likely to win in lower altitude stadia.

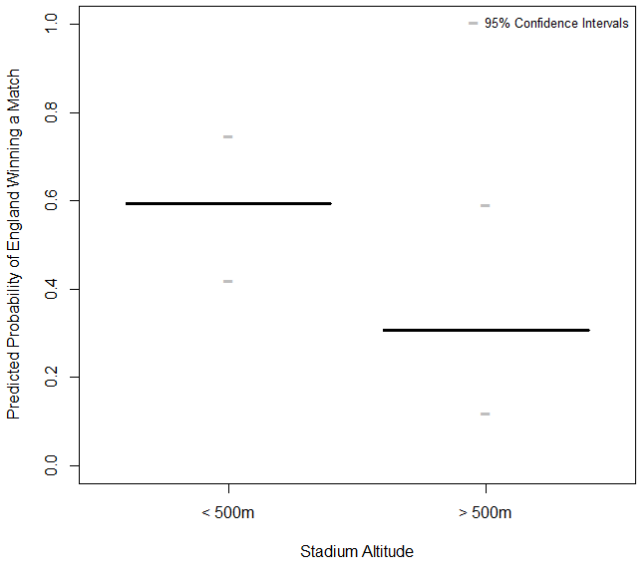

Figure 3: Effect of Altitude on England performance

Kick-off time

The kick-off times for World Cup matches can vary substantially. England have played 11 'Early' matches, kicking off before 16:00 local time, 12 'Late Afternoon' matches starting between 16:00 and 18:00 hours and 22 'Evening' matches kicking off at or after 18:00 hours. Past data shows that England tend to win more matches during the early or late afternoon, and evening matches tend to have lower level of success for them, as shown in Figure 4. The evening matches played by England were on or east of the Greenwich Meridian Line.

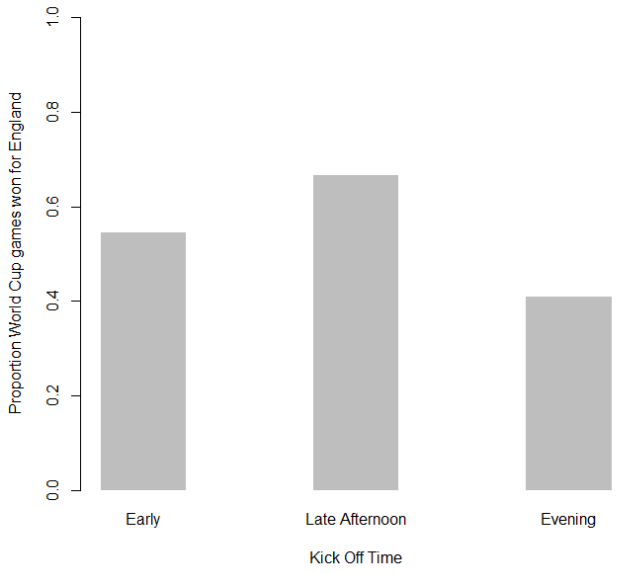

Figure 4: Game time (local) effect on England's chances

Physiological and Psychological Factors

Colour of shirt worn

The England team doesn't tend to deviate greatly from the wearing of their iconic white shirts, but blue and red shirts have made a number of appearances. As Greenlees et al (2013) found evidence to suggest that the colour of a goalkeeper's can affect the probability of scoring a goal, it was considered prudent to assess if this theory extended to the impact of playing in coloured shirts on England's potential success. To increase the data set, European Cup matches were also included. Out of the seventy World Cup and European Cup matches played by England since 1966, a total of 57 were in white shirts with varying success. As shown in Figure 5, England tend to be more successful when wearing blue or red shirts winning 20% more often in this choice of kit.

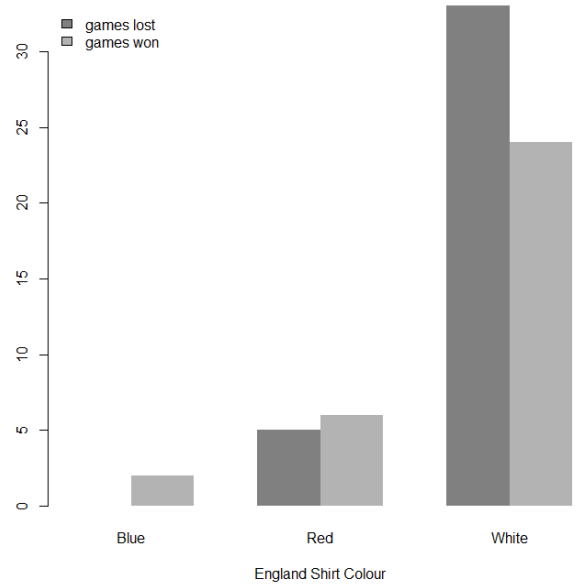

Figure 5: Effect of Home and Away kits (European League & World Cup)

Player Age

Squad selection for a World Cup team can pose difficulty for international football managers as many of the candidate players will have scarce experience at World Cup level on which to assess their form. As age has a major impact on peak athletic performance and match experience, it was taken into account in our study. However, no evidence was found to suggest that the average age of the team as an impact on the probability of England winning a game. Furthermore, the effect of individual player ages on performance for each player position was evaluated but no evidence was found to suggest that age makes a difference within the age range of the past World Cup squads.

Age of the captain

The proportion of World Cup matches won for the various England captains' ages was calculated where more than one match was captained. The results are displayed in Figure 6. The data is too sparse in comparison to the variation in captain ages, to conclude any significant relationship.

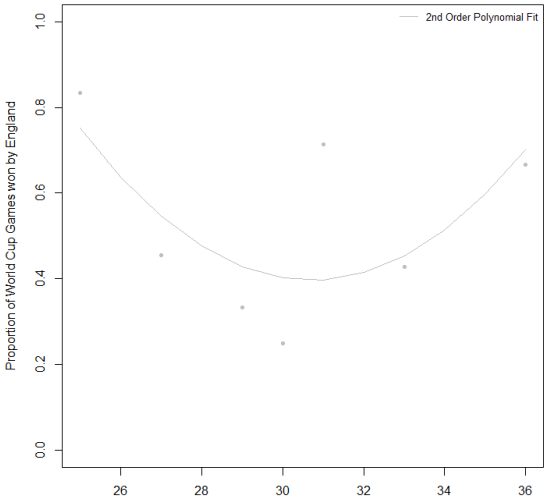

Figure 6: Leading the team – the effect of the Captain's age

Political Factors

Continent of opponent

As illustrated in Figure 7, England have performed relatively better against Eastern European teams (86% success rate) and relatively worse against Western European teams (33% success rate) in comparison to opposing African and American teams. Some further study would be required to study causality for this factor to examine whether such effects are explained to the strength of the comprising teams in these continents.

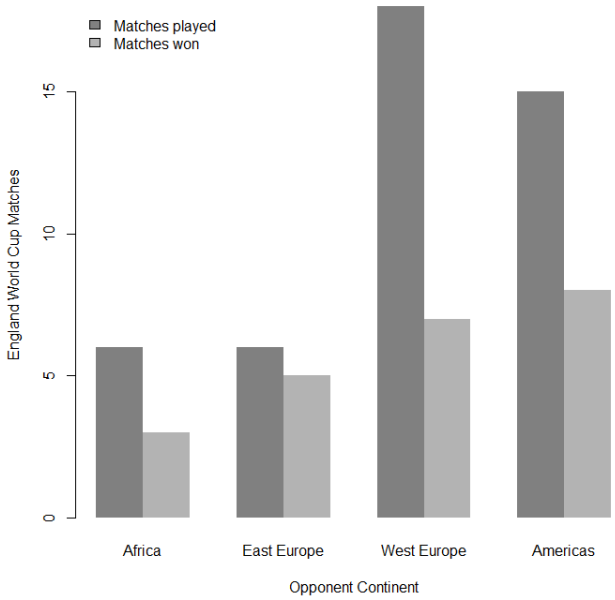

Figure 7: Continent of opponent

Nationality of referee

Hlasny & Kolaric (2013) concluded that the geographical distance between a referee's home town and the stadiums of the respective teams have a significant impact on the disciplinary cautions issued during a match. Dawson & Dobson (2010) found that 'nationality is… important influence on the decision making of referees. In considering principal-agent relationships, account needs to be taken not only of how agents (referees) decide under social pressure but also of how national identity shapes agents' decision making'. In order to account for any evidence of referee bias against the team affecting the final result, the differences between the empirical probabilities of winning matches for the continent of the referee were explored. As shown in Figure 8, England tends to fare better under the watch of a European referee with 63% of matches won. In contrast, their rate of winning, at 33%, is lower than average when refereed by an official from the Americas.

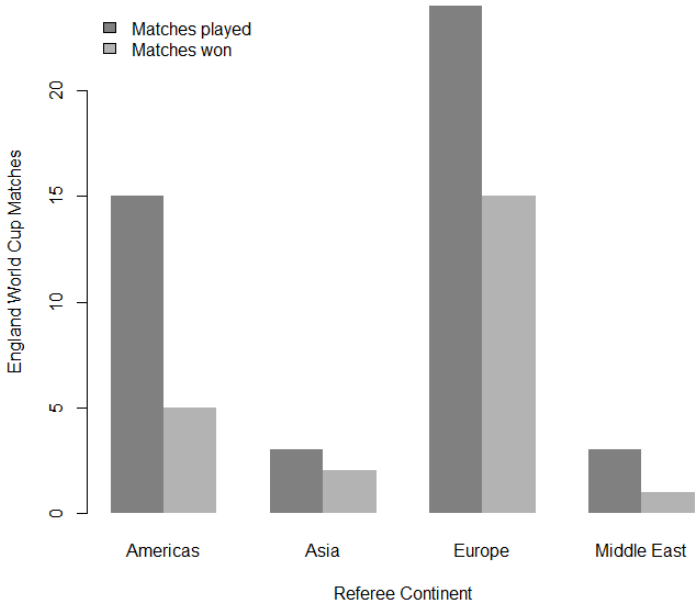

Figure 8: Continent of referee

Team Formation

The English team haven't varied their team formation to any great extent over their World Cup final campaigns. Out of 45 matches played, 25 have been played in the classic 4-4-2 formation and 12 in 4-3-3 formation. Empirically, the 4-3-3 formation has been more successful (58% of matches won in 4-3-3 compared to 48% in 4-2-2).

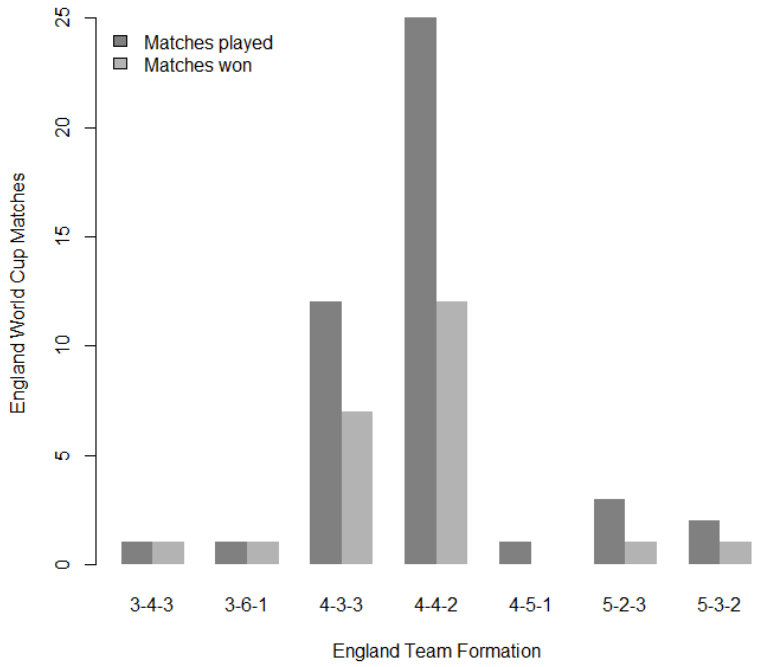

Figure 9: Analysis of formation

Explanatory Model

A multivariate model was built in order to quantify the effects of each factor with all other factors taken in to account and to assess their statistical significance. The data were modelled in the form of a general logistic equation, to link the expected probability of winning with the variables of interest.

The final model is represented by the following equation[1]:

$$\frac{\hat{\pi}}{1-\hat{\pi}} = X_0 \left(\frac{e^{0.34\gamma+0.3\eta\theta+0.08\beta_1}}{e^{0.18T+0.04\log(\alpha)+0.23\beta_2+0.11\beta_3+0.28\delta+0.3\epsilon}} \right) \qquad (1)$$

where:
$\hat{\pi}$ is the expected probability of England winning a match, and therefore, $\frac{1-\hat{\pi}}{\hat{\pi}}$ represents the fractional odds for an England win

X_0 is a known variable
T is the stadium city temperature difference from $25°C$
α is the distance from London to the stadium in kilometres
$\beta_1 = 1$ if England's opponent is from Eastern Europe, 0 otherwise
$\beta_2 = 1$ if England's opponent is from Western Europe, 0 otherwise
$\beta_3 = 1$ if England's opponent is from the Americas, 0 otherwise
$\gamma = 1$ if the referee is from Europe, 0 otherwise
$\delta = 1$ if the stadium is at an altitude > 500 m, 0 otherwise
$\epsilon = 1$ if kick-off is at or after 18:00 hours local time, 0 otherwise
$\eta = 1$ if the squad are in 4-3-3 formation, 0 otherwise
$\theta = 1$ if the squad are wearing a blue or red shirt, 0 otherwise

According to the model, an increase of 1° is expected to reduce England's chances of winning to 84% ($e^{-0.18}$) of what they would have been otherwise, all else equal. A 5° increase is expected to reduce their chances by 59%, or to 41% ($e^{5*(-0.18)}$) of their chances, otherwise. Later starts are not generally positive on the probability of winning, with earlier match expected to improve chances by a third ($e^{0.3}$ ~ 1.34). 4-3-3 formation only works well when the team dons an away strip.

As an explanatory model, this formula is considered effective in quantifying how varying factors affected the outcome of past World Cup matches for the England team.

[1] See Appendix 1

The probability of scoring in a penalty shootout

Since 1978, when penalty shootouts were introduced to the World Cup finals, 18.6% of knock-out stage matches have been decided by penalty kicks. England have a very poor record in this respect, having lost all three World Cup final penalty shootouts in which they participated. This section of the study focuses on evaluating the optimum tactics for scoring in a World Cup penalty shootout.

Exploratory Analysis

The data set analysed comprised of all 204 penalties taken during World Cup finals. Player level factors and tactical factors were analysed with respect to the probability of scoring, as summarised in Table 2.

Table 2. Factors considered affecting the probability of scoring in a penalty shootout

Player Factors	Position
	Hair type
	Age of player
Tactical Factors	Where to aim
	Length of run-up
	Kicking foot
	Position of ball on boot
Goalkeeper Factors	Goalkeeper movement

Player Factors

Position of player

In total, 49 penalties have been taken by defenders, 93 by midfield players and 62 by forwards. As expected, forwards tend to score more penalties (81%) than midfielders and defenders. However, with a scoring rate of 65%, defenders have a similar record to midfield players (67%).

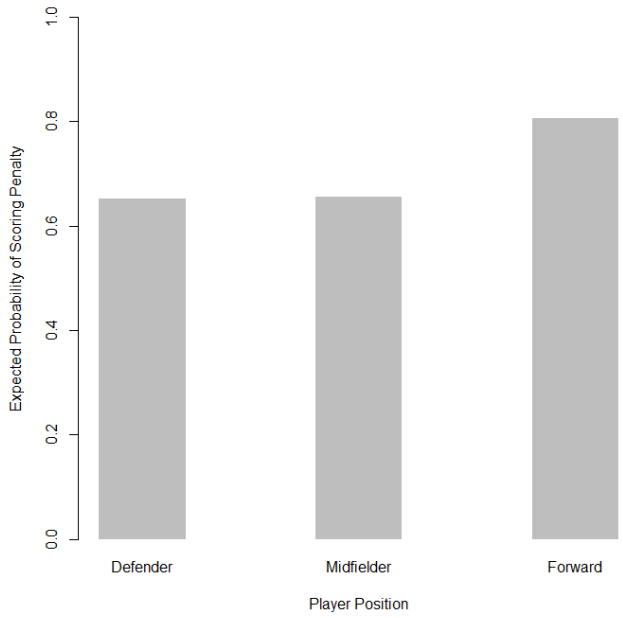

Figure 10: Backs against forwards - Who should take penalties?

Age of player

No distinct relationship between the player age and the probability of scoring is evident. Figure 11 shows the proportion of penalties scored for all players within each age group. Age groups with only one penalty taken were omitted.

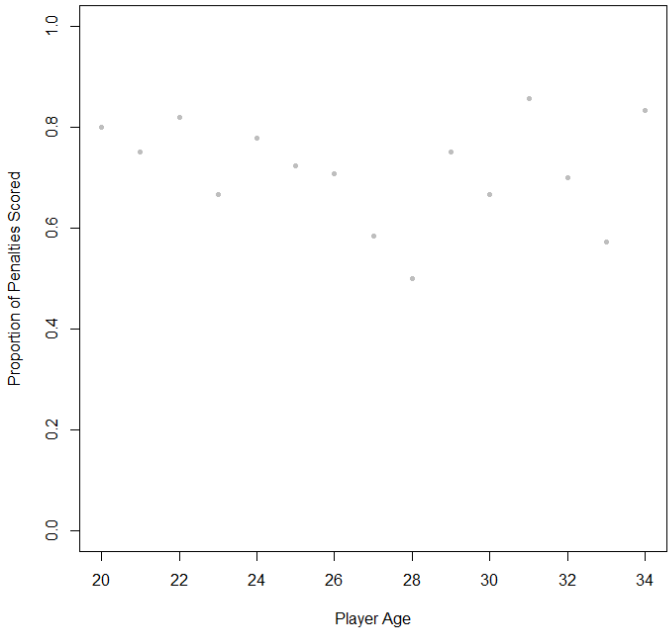

Figure 11: Old heads – does age impact success rate?

Hair colour of player

As shown in Figure 12, although most penalty takers have brown or very dark hair, fair haired and bald players tend to have a higher success rate. The fair-haired cohort consists of both blonde and ginger players and they have enjoyed a success rate of 84%. Bald players have scored 71% of their attempts and the remaining players scored 69% of their attempts. Hair colour could be high correlated with the team nation, however, and hence the team's penalty taking strength. Furthermore, whether the hair colour was natural or dyed was not taken into account, therefore there is no evidence to suggest or dismiss that tactical hairdressing would result in a higher penalty success rate. This remains an area for further study.

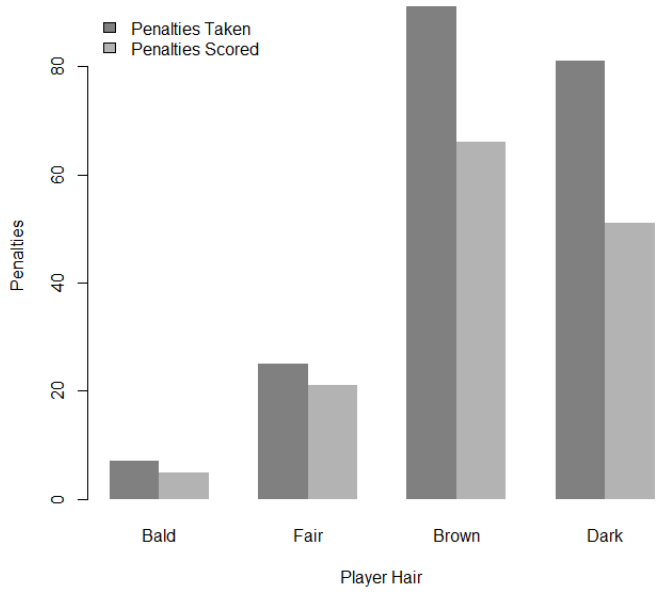

Figure 12: Examination of impact of hair colour

Tactical Factors

Where to aim the penalty

Data on where each penalty was aimed in terms of height (bottom, middle or top) and direction (left, centre or right) was collected and analysed. Figure 13 displays the expected binomial probability of success for a penalty based on where it was aimed. It can be seen that the top right and top left have the highest expected probability of success, with centre bottom having the lowest. In the past, 84% of penalties aimed in a top corner were scored. Where the penalty is aimed could be correlated with the ability of the player to score penalties (and place the ball out of the goalkeeper's reach).

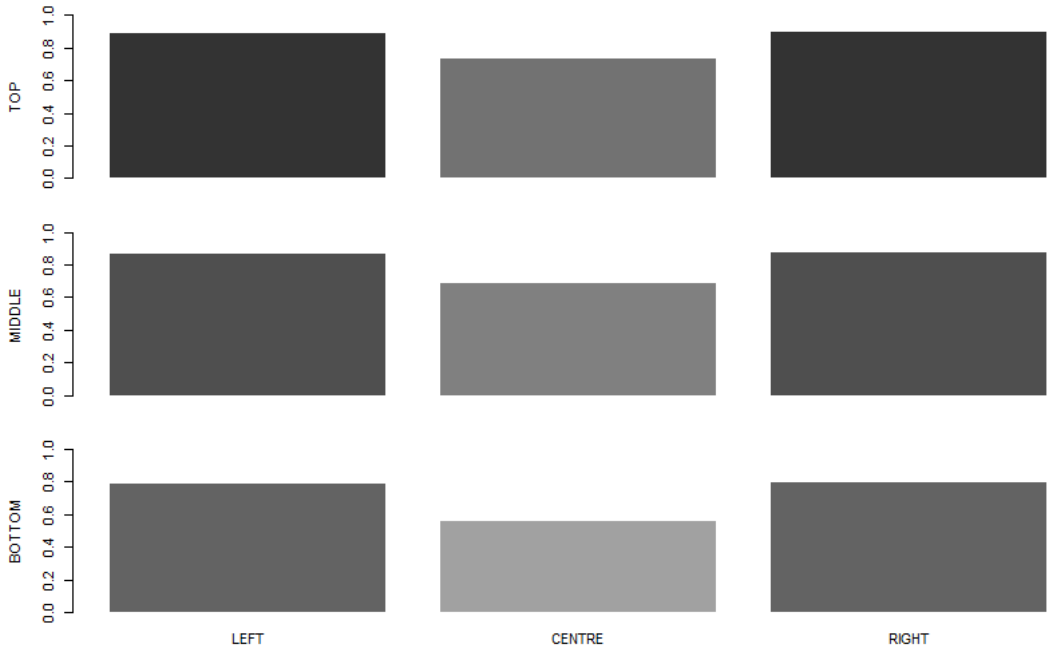

Figure 13: Where to aim? Expected binomial probabilities for each area of the goal

Kicking Foot

A total of 38 penalties were taken with the left foot and the remaining 166 on the right foot. There was no significant difference found between the success rates.

Length of run-up

The distance between the placed ball and where the player started running before kicking was divided into 'short' and 'long' groups, whereby the 'short' group represents approximately between one and three steps. Out of 26 penalties taken with what we considered to be a short run-up only 58% resulted in scores. 87% of the other 178 penalties taken were successful.

Boot position

Players are faced with a choice between for kicking the ball with the side of their boot to control the direction of the ball or for kicking with the front of the boot to increase the velocity. The majority of World Cup penalties were taken from the side of the boot, 161 out of the 204. As illustrated in Figure 14, it was found that kicking the ball with the side of the foot tended to be a more successful with a success rate of 74% compared to 64%.

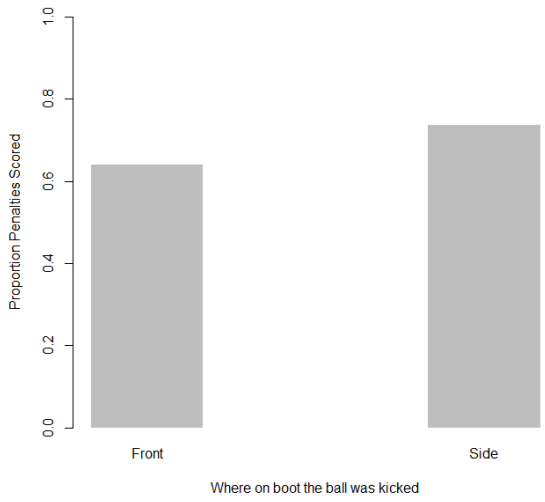

Figure 14: Impact of blasting or placing the kick

Goalkeeper tactics

Goalkeeper movement

Here, the movement of the goalkeeper before or at the moment the ball was kicked was studied to gauge the effect of distraction on the player on their probability of scoring. Whether the keeper swayed from side to side or moved forward during the player's run-up was under consideration. It was found that when the goalkeeper moved from side to side, the empirical probability of scoring was lowered, as shown in Figure 15.

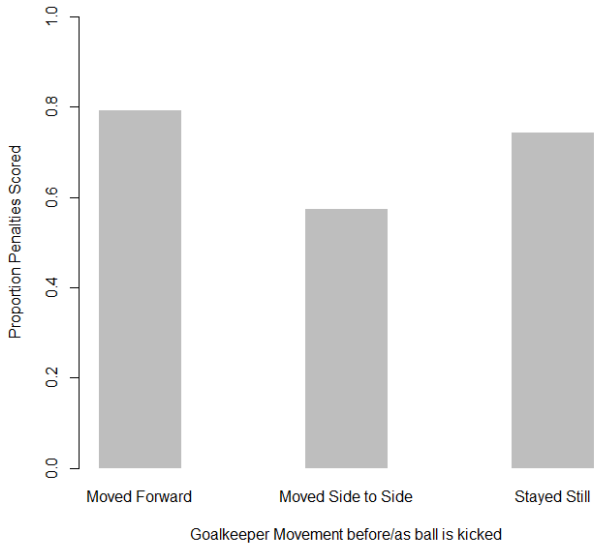

Figure 15: Impact of goalie mobility

For goalies – although moving about the place might give them something to do while they wait for the penalty to be taken – it is also the optimal axis of activity – actually

beating moving forwards in terms of probability of saving the penalty. Goalkeepers managed to save (or create a miss) 43% of penalties when they moved side to side, while only 25% were averted otherwise.

Penalty Model

Similarly to the previous section, the data were modelled by generalised logistic regression, with a binary response for the penalty scored, in order to estimate the expected binomial probability of the penalty score.

The final model is represented by the following equation[2]:

$$\frac{\hat{\pi}}{1-\hat{\pi}} = X_0 \left(\frac{e^{0.7\alpha_1 + 1.13\beta_1 + 1.09\beta_2 + 0.9\delta + 0.3\theta_1 + 0.3\epsilon}}{e^{0.06\alpha_2 + 0.9\eta + 0.7\theta_2}} \right) \qquad (2)$$

where:
$\hat{\pi}$ is the expected probability of the penalty being scored, and therefore, $\frac{1-\hat{\pi}}{\hat{\pi}}$ represents the fractional odds for a score

X_0 is a known variable
$\alpha_1 = 1$ if the player's position is forward
$\alpha_2 = 1$ if the player's position is defender
$\beta_1 = 1$ if player aims penalty left
$\beta_2 = 1$ if player aims penalty right
$\delta = 1$ if player's hair colour is fair (or ginger)
$\theta_1 = 1$ if player aims at upper $\frac{1}{3}$ of goal
$\theta_2 = 1$ if player aims at lower $\frac{1}{3}$ of goal
$\epsilon = 1$ if player directs the ball using the side of foot
$\eta = 1$ if player does not take any run up before striking the ball

We can see that the horizontal direction in which the ball is aimed has the effect of greatest magnitude. For instance, aiming the ball to the left is expected to increase the chances of scoring by a factor of $e^{1.13}$ (approximately by 3), compared to a ball aimed in the centre. It should be taken into account that this may depend on the player's ability to aim the ball away from the centre accurately. The model suggests that players with fair hair tend have higher chances of scoring compared to bald or dark haired colleagues. A short run-up to taking the penalty is expected to decrease the chances of scoring by a factor of $e^{-0.9}$ to approximately 41% of their chances with a tangible run-up, all else equal. Aiming high also tends to increase the expected probability of a player scoring, and those who can stroke the ball into the net using their side foot have an increased expected probability of scoring.

[2] See Appendix 1

References

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Appendix 1

The following shows how equations (1) and (2) were derived from the general logistic form:

$$\begin{aligned}
\log\left(\frac{\hat{\pi}}{1-\hat{\pi}}\right) &= \beta_0 + x_1\beta_1 + x_2\beta_2 + x_3\beta_3 \\
\frac{\hat{\pi}}{1-\hat{\pi}} &= e^{\beta_0 + x_1\beta_1 + x_2\beta_2 + x_3\beta_3} \\
&= e^{\beta_0} e^{x_1\beta_1} e^{x_2\beta_2} e^{x_3\beta_3} \\
&= X_0\left(e^{x_1\beta_1} e^{x_2\beta_2} e^{x_3\beta_3}\right) \\
&= X_0\left(\frac{e^{x_1\beta_1} e^{x_2\beta_2}}{e^{-x_3\beta_3}}\right)
\end{aligned}$$