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Taking the goalkeeper's side in association football penalty kicks

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Abstract

Approximately 70% of penalty kicks in men's professional football are scored, hence being decisive in increasing the chances of winning, since matches have only 2.5 goals on average. This study assesses the improving chances for the goalkeeper to save penalty kicks, using actual shot speeds in computer simulation and considering actual and experimental data. Simulated kicks were directed at the goal divided in nine areas. The goalkeeper's movement was chosen to start at five different times before, at and after the instant of the kicker's impact on the ball. Chances of saving were analysed through logistic regression taking into account area of the goal, ball speed and moment of goalkeeper's reaction. Saves were found to depend essentially on the beginning of the goalkeeper's motion according to the area. In the central areas of the goal, saves were statiscally independent of ball speed and time of reaction. The goal region further away from the centre, where real shots are frequently saved, presented highest dispersion. This suggests that saves depend mainly on the goalkeeper's reaction time but also on the ball speed. Finally, chances are low (but not inexistent) near the posts.

Keywords: Association football, penalty kick, goalkeeper, computer simulations.

1. Introduction

One of the most dramatic and often decisive instances of association football is the penalty kick. This is also the easiest aspect of the game to study; the kicker shoots a stationary ball located 12 yards (~11 m) from the goal, against only the goalkeeper, who must remain on the goal line until the ball is kicked (FIFA 2012). The importance of optimal performance of both rival players during the penalty kick is paramount, especially since the introduction of the penalty shoot-out in major competitions to determine which team progresses after a drawn match (McMorris and Hauxwell, 1997; Lover and Blatter, 1998; McGarry and Franks, 2000).

Since the ball reaches the goal from the penalty landmark in 0.2 – 0.3 s (Chiappori *et al*., 2002; Palacios-Huerta, 2003) or 0.5 – 0.6 s (Kuhn, 1988), a widespread conception is that the goalkeeper cannot intercept the ball trajectory if he does not choose the direction to move before the ball is put into motion. Hence, most goalkeepers decide beforehand to jump to one of two sides, right or left in 95 % of instances (Kuhn, 1988; Bar-Eli *et al.,* 2007). The penalty kick then becomes the outcome of a random game with shoot direction and goalkeeper motion are essentially independent (Jordet *et al*., 2007). Consequently, the goalkeeper is clearly at a disadvantage, which explains the fact that *approximately 70 % % of penalty kicks in men's professional football are scored* (Kuhn, 1988; Morya et al., 2005; Jordet *et al*., 2007; Wright and O'Donoghue, in press). However, penalty takers, despite being elite professional players, have been found to aim only low proportions of penalties to the areas determined the most difficult for a goalkeeper to save (Bar-Eli and Azar, 2009; Wright and O'Donoghue, in press). It is then an important issue whether the goalkeepers can save more penalties than they actually do, about 18% of those aimed at the goal area (Bar-Eli *et al*., 2007).

We analyse here the chances of intercepting the ball trajectory using two approaches. First, through an observational study, goal regions, ball speed and moment of reaction of the goalkeeper in regard to the ball were assessed. Then, computer simulations were performed, considering a wide range of realistic ball speeds taken, different areas of the goal, and actual reaction times of the goalkeeper. During simulations we also considered the possibility of anticipation, defined as the minimum time prior to the kick for the goalkeeper's initial movement, assuming the hypothesis that in this period a change in the kicker's swing could jeopardise the speed and accuracy of the shot (Osman *et al*., 1986; Band and Van Boxtel, 1999; Morya *et al*., 2001, 2003; Van Der Kamp, 2006).

2. Methods

2.1. Observational studies

Prior to simulations we analysed penalty kicks footage of definitions in international leagues, Copa América, World Cups and Eurocup, to obtain direction of the shots, motion velocities of the goalkeeper during the penalty kicks and ball speed.

Moreover, we made more controlled observations of 50 penalty kick shot in controlled conditions by players of the reserve team of Club Atlético Peñarol in May 2010. Those kicks were filmed and subsequently analysed to corroborate the values of the variables just mentioned as obtained from videos.

2.2. Simulations

To determine the chances of saving the penalty kicks the odds of intercepting the trajectory of a randomly directed ball with the goalkeeper in a static, random position within the limits of the goal are analysed. The area covered by an average, 1.83 m tall goalkeeper was taken as ~2 m^2, and the goal area available to score is 17.86 m^2. If every conceivable ball trajectory is equiprobable, the ratio of the goalkeeper and goal areas gives a rough estimate of this probability.

In our simulations, the goalkeeper will intercept the trajectory if the ball hits any part of his body, which may lead to a certain overestimation of the successful savings. On the other hand, this must have been compensated by the fact that the finer correction movements of the distal segments are not taken into account in our model, which in turn may have led to an underestimation of the successful savings. Since the objective of this study is to assess the chances of intercepting a ball aimed at a given area of the goal, it was further assumed that the goalkeeper was able to correctly choose the intended direction of the kick, i.e., if the goalkeeper chooses one side to jump and the kicker chooses the opposite side, the chances of saving is 0 (Bar-Eli *et al.*, 2007), so this would not be informative. Hence, only one side of the goal was analysed. Following Bar-Eli and Friedman (1988), the goal was divided in central, medial and lateral areas (Figure 1). Regarding the height at which the ball is directed each area was further divided in three: low, medium and high (Savelsbergh *et al.*, 2002; Bar-Eli *et al.*, 2007).

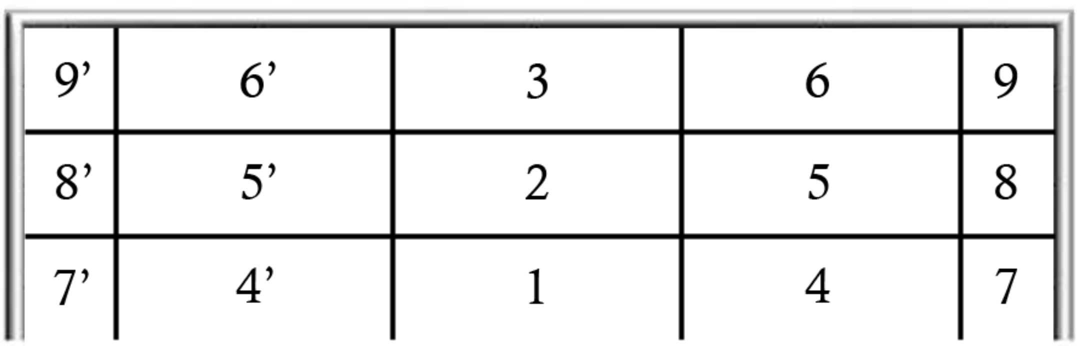

Figure 1. Analysed locations in the goal**.** The 15 areas in which the goal was subdivided. Three central areas (1 to 3), six medial areas (4 to 6 and 4’ to 6’) and six lateral areas (7 to 9 and 7’ to 9’). Each central and medial areas are 2 m long and 0.81 m high, lateral areas are 0.66 m long and 0.81m high. It is assumed for the simulations that the goalkeeper’s movements are equally performed in both directions, no matter what side has been chosen. Therefore, only the areas from the centre to the right (1 to 9) were considered.

The software 3D Studio Max v. 9.0 (Autodesk, 2007) was used for the simulations. The goalkeeper was built using Biped System, which provides great flexibility for the animations. A generalized goalkeeper of 1.83 m height was chosen and his motion was performed according to the laws of the International Football Association Board (and Blatter, 1998). The average goalkeeper velocity was also chosen according to realistic speeds observed in high competition matches and corroborated in our field observations. These simulations were carried out considering optimal body postures according to the goal area they were directed at, since it is not possible to cover all points in one type of motion (Figure 2). For the central areas (1, 2 and 3), the goalkeeper only moves vertically according to the height of the shot (low, medium or high). For the medial low and lateral low areas (4 and 7) the goalkeeper moves laterally and downwards. For the medium height areas (5 and 8), the movement is mainly lateral. For the medial and lateral high areas (6 and 9), the goalkeeper performs a lateral movement followed by a dive.

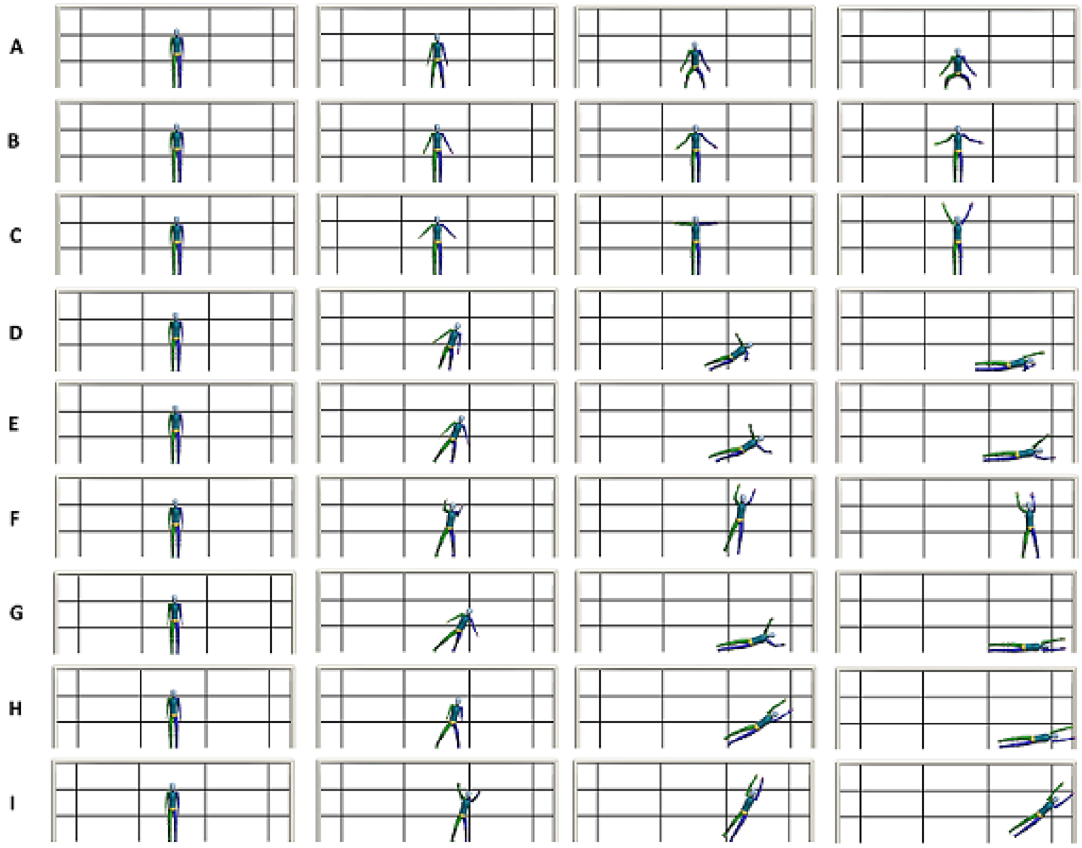

Figure 2: Body postures of the goalkeeper that were assume through simulations to intercept the kicks aimed at the different areas in the goal. The figure shows a series of four images for the different movements performed to reach the different areas. **A**, movement for kicks aimed at area 1. **B**, movement for kicks aimed at area 2. **C**, movement for kicks aimed at area 3. **D**, movement for kicks aimed at area 4. **E**, movement for kicks aimed at area 5. **F**, movement for kicks aimed at area 6. **G**, movement for kicks aimed at area 7. **H**, movement for kicks aimed at area 8. **I**, movement for kicks aimed at area 9.

The balls were simulated using Particle System, a procedural animation tool that enables animate large groups of objects (particles) by setting several parameters such as start time, velocity and amount of objects. The particle emitter was located in the penalty mark and the particles were aimed at a target in the goal line, while the kicker was not simulated. For the central and medial areas 500 particles were used in each simulation and only 165 for the smaller lateral areas to keep the same ball density.

To calculate the saved balls, 13 deflectors (space warps that act as a barrier to particles) were linked to the bones of the Biped, 3 in each arm, 3 in each leg and 1 in the torso. The particles that bounce after colliding with deflectors are considered saves.

Five different activation times were established for the beginning of the goalkeeper motion: 250 and 150 ms before kicker's impact on the ball, the instant of impact, and 150 and 250 ms after impact. Morya *et al*. (2001, 2003) shows that, if the goalkeeper begins to move between 102 ms and 250 ms before the kick, the kicker correctly identifies which side the goalkeeper will choose in only 50% of the cases. Consequently, the kicker is not likely to determine the side at which the goalkeeper will dive if the latter starts to move later than 250 ms prior to the kick.

Chances of saving were analysed for the area of the goal at which the shot was aimed, ball speed and moment of goalkeeper's reaction. Those variables were considered independently to determine whether each of them is predictive of the saving probability. Then, a logistic regression was performed with the following multivariate model:

$$\text{Log } P/(1-P) = \text{K} + \alpha^{*} \text{ ball speed } + \beta^{*} \text{ goal area } + \gamma^{*} \text{ time of reaction}$$

where P is the probability of saving.

For each variable, the category that included the most difficult situation for saving was chosen as reference; number 9 among goal areas, the fastest among the speeds and +250 ms as the goalkeeper's time of reaction. For the remaining cases, the oddsratio (OR) was calculated.

3. Results

3.1. Observational studies

Based on information of penalty kicks (both from videos and direct field observations), the goalkeeper speed was assumed as 3.3 m s^{-1}.

Also, the values of ball speeds allowed us to assume values of 20, 20.8 and 23 m s^{-1} for the simulations, which is congruent with the figure given in the literature (Kuhn, 1988; Bar-Eli *et al*., 2007).

Table 1 shows the result of the simulations, the amount of kicks aimed at those regions that were scored and the total kicks. in the last editions of the three most important championships (2010 World Cup in South Africa, 2011 Copa América in Argentina and UEFA Euro 2012 in Poland and Ukraine).

The penalty kicks analysed in the practice of C.A. Peñarol showed the same trend, 84.2 % of shots were aimed at areas 1 to 6.

Table 1. Percentage of saves in the 9 areas considered in this study independently of ball speed and beginning of the goalkeeper's motion. Championships studied were 2010 World Cup in South Africa, 2011 Copa América in Argentina and UEFA Euro 2012 in Poland and Ukraine.

Area	Percentage of saves in our simulation	Percentage of saves in high competition championships	Percentage of shots in high competition championships
1	26.8	0	5.5
2	27.4	0	2.7
3	13.7	0	5.5
4	26.8	19.4	33.3
5	1.4	0	15.2
6	9.2	0	11.1
7	15.9	0	16.6
8	6.5	0	5.5
9	2.7	0	4.1
All areas	14.5	19.4	

3.2. Simulations

The static situation analysis showed that the probability of intercepting the ball as a function of the area that a motionless goalkeeper is able to cover is 11%. This value is lower than the observed in real situations of blocked penalty kicks (Kropp and Trapp, 1999).

A total of 52425 simulations were analysed. As can be seen in Figure 3 the percentage of saves depends essentially on the beginning of the goalkeeper's motion according to the area. The general average can be seen in Table 1. The values found in some areas deserve special attention: all the three central areas show low dispersion; 1 and 2 with a percentage of saves between 24 % and 30 %, while area 3 has a lower proportion of interceptions, between only 11 % and 16 %.

Among the medial areas, more varied results are obtained. Particularly, area 4 shows a great dispersion, from 7%, at tardy reaction (+250 ms) and high ball speed, to 38%, at not so prompt reaction (-150 ms) and intermediate ball speed. Notice that, in general, tardy reactions imply less saves (< 20%) and the percentage grows as reactions are prompter, with the exception of more saves done at -150 ms than at -250 ms at the same ball speed. Area 5 shows a remarkably low proportion of saves taking into account that is an area relatively close to the initial position of the goalkeeper.

Finally, areas 6 to 9 show unsurprisingly lower save percentages, less than 20 % for all ball speeds and reaction times. Our simulations showed that there are areas where the probability of intercepting the ball is very low even if the goalkeeper correctly chooses which side to jump at (points 8 and 9 for any kick velocity and goalkeeper reaction time). However, the possibility of saving kicks aimed at area 7 does exist, provided an optimal combination of reaction time and ball speed are warranted.

The separate analysis of the variables was performed for determining whether each one of them is predictive of the probability of saving and it yielded that speed is not. The approximate values of saving probability in each goal area and with each reaction time is given as oddratios (see M&M) in Table 2. If, for instance, the shot is aimed at area 1, it is 13 times more likely to be saved than if it goes to area 9. Also, and again by a way of example, if the goalkeeper start to moves 150 ms before the ball is impacted, the save is 1.7 more likely than if he starts 250 ms afterwards.

Table 2. Results of the univariate logistic regression for the goal areas, taking area 9 as the reference, and for the start time of goalkeeper's movement, taking the latest time (+ 250 ms) as the reference.

Area	B	σ	Exp (B)
Goal area 1	2.574	.000	13.123
Goal area 2	2.608	.000	13.573
Goal area 3	1.740	.000	5.696
Goal area 4	2.574	.000	13.123
Goal area 5	-.635	.000	.530
Goal area 6	1.296	.000	3.653
Goal area 7	1.915	.000	6.784
Goal area 8	.917	.000	2.501
Start time of goalkeeper movement	B	σ	Exp (B)
- 150 ms	.531	.000	1.701
0 ms	.520	.000	1.683
+ 150 ms	.564	.000	1.757
+ 250 ms	.296	.000	1.345

The statistical model used here does not show a perfect fit but, in general, allows quantifying the differences (lower part of Figure 3). The worst fit was that of the rather heterogeneous area 4. It is also remarkable that area 3 showed a worse fit than area 7. The goal areas, if the goalkeeper choses the most adequate movement, can be ordered the probability of saving decreases as: 1, 2, 4, 7, 3, 6, 8, 5, 9.

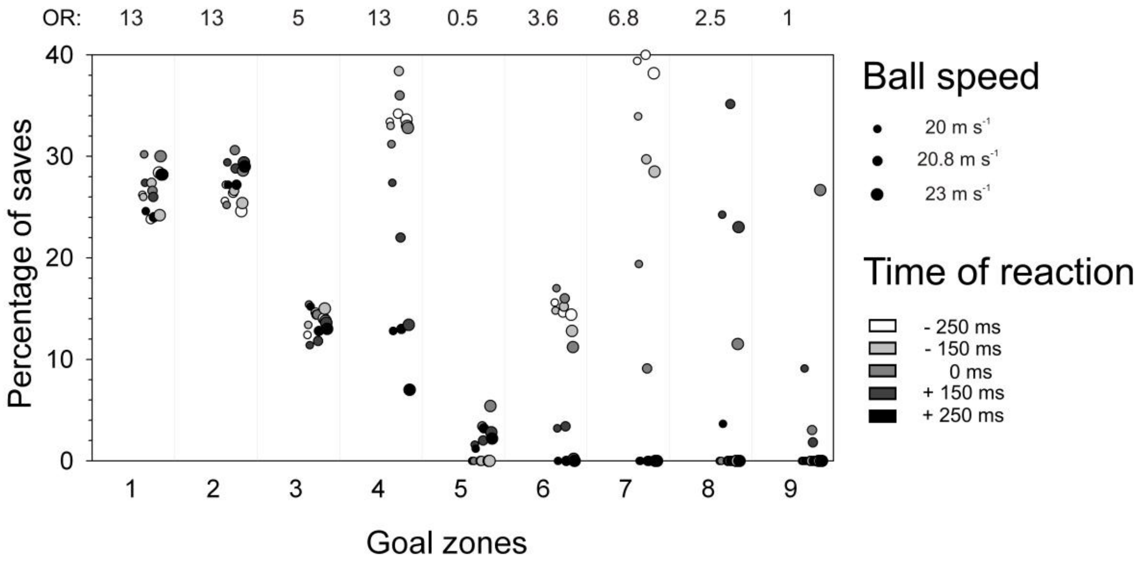

Figure 3. Graph showing the results of our simulation. Darker symbols represent later responses by the goalkeeper, while larger symbols imply higher ball speeds. The appropriate statistics OR for each area is given at the top of the Figure.

4. Discussion

According to the results obtained by comparing the goal area and that of the goalkeepers, and taking into account movements of distal segments of the body (ie, forearms and hands), penalty kicks seem to be blocked in a proportion that does not differ too much from random. Also, the outcome of the shots (i.e., 70 % successfully turned into goals) is a clear indicator that in an actual penalty kick there are elements that determine an advantage of the kicker in this play.

The results of simulations obtained here tend to contradict a widespread belief in the soccer community that the outcome of shoot-outs from the penalty mark is like gambling. Quite on the contrary, the outcomes of penalty kicks follow a logical pattern involving factors that can be influenced by psychological variables enhanced by systematic practice and preparation (Jordet *et al*., 2007).

Analogously, our analysis, although involving a different approach from the just mentioned, also showed that it is possible to improve the odds of intercepting the ball by training. In this study, it was intended to determine whether the goalkeeper can increase his chances of saving penalty kicks, assuming he can correctly assess the side (and area) of the goal the shot will be directed at.

Incidentally, our results differ from those of actual penalties in high competition matches and shoot-outs (Table 1). It can be observed that in the three last of the most important championships (2010 World Cup in South Africa, 2011 Copa América in Argentina and UEFA Euro 2012 in Poland and Ukraine) only those penalties aimed at area 4 have a substantial percentage of saves, and as much as nearly 50% . This is interpreted as due to our assumption that the goalkeeper in our simulation must be able to identify whether the shot will be directed a) at his right or his left, and b) also at which particular area of the goal. Finally, we assumed that the goalkeeper will be able of making the optimal movement to make the save.

The area at which most of the shots are aimed is between about 1 m from the goal centre and 0.64 m from the goal-post (areas 1 to 6 in our study, Fig. 1). In the penalty kicks taken during the 1986 World Cup (both during the matches and the shoot-outs), 50% of penalty kicks were aimed at this area of the goal (Bar-Eli *et al*., 2007). Also, our own observations of the three aforementioned high competition matches are congruent with this: from a total of 72 shots not missing the goal, 53 of them, or 73.6 % were aimed at those areas (Table1). Moreover, the penalty kicks analysed in the practice of C.A. Peñarol shows the same trend, 84.2 % of shots were aimed at areas 1 to 6. The average percentage in our simulations of saves in penaty kicks directed to areas 1 to 6 (17.5%) is close to those in real matches (19.6% in our observations and 18%, as said in Kuhn, 1988). However, a closer look shows some aspect that could improve the goalkeeper's performance.

As said above, in the high competition matches observed, many of the shots saved (19.6 % of the total shots) were all directed at area 4. In the penalty kicks at C.A. Peñarol, the percentage of total shots aimed at area 4 and saved was 15.8 % (the remaining saved shots, 10.5 % of the total, were aimed at area 5). An increase of this proportion is seen when these percentages are compared with the shots saved in our simulations for area 4 (26.4 %). Besides, this is the value for the average of all reaction times and ball velocities. If we take the independent values this percentage could be as high as 38 % for intermediate ball speed and -150 ms of reaction time.

As expressed in the Results section, taking into account the potential movements by the goalkeeper, the most favourable to block a shot aimed at areas 1 to 3 are movements A, B and C (Fig. 2). It is interesting to point out that, despite that motion would improve so much the blocking chances of penalty kicks of most frequent direction, it is not the most frequently selected motion by the goalkeepers, which may be explained by apparent inaction yielding a heavy psychological burden (Bar-Eli *et al*., 2007). Another remarkable aspect is the low dispersion of the outcome of saved shots aimed at the central areas of the goal. This reflects that, when a penalty is kicked at the centre of the goal, the probability of save it does not vary significantly with ball speed and does not depend too much either on the time of reaction, which means that those areas are not safe for shots unless the goalkeeper starts to move too early. From the three central areas, number 3 is the most difficult for the goalkeeper but, in compensation, the risk of a missing is higher. Since the probability distribution of the observed direction in 286 penalty kicks in top leagues and championships world wide shows that they cluster near the goal centre, the optimal strategy for goalkeepers is to stay in his original position (Kuhn, 1988).

The second stripe of the goal, i.e. the medial areas 4, 5 and 6, was that in which most surprising results were found. Area 4 presents the highest dispersion, which suggests that the probability of a save depends on the moment in which the goalkeeper starts to move and on the ball speed. Among those two variables, it is the time of reaction that explains most of the observed variation: as the goalkeeper starts to move earlier, his chances of success increase. However, at medium speed the simulations show that the optimal time for the goalkeeper's starting to move is 150 ms before the ball is impacted by the kicker. This means that, if applied to a realistic situation, when the ball is directed to that area and the goalkeeper moves too early, his body passes through the interception point sooner that the ball. As discussed for areas 1 to 3, to make a save in area 4, the goalkeeper must not anticipate too much. Thus, it can be said that there is a large proportion of the goal area in which the chances of saving increase if the goalkeeper does not move randomly. In the area 5, which could be considered more likely for the goalkeeper to save the kick than other, more distant areas (for example, area 7), simulations show the lowest percentage of saves (Table 2 and figure 3). This is remarkable, since a fast (hence less accurate) shot aimed at that area would not imply a high risk of missing the goal. It could be stated that this is the kicker's safest choice.

Finally, the most distal part of the goal, that comprised by the areas 7 to 9, show very low percentage of saved penalty kicks, but our results are not congruent with the received knowledge among coaches, reporters and other agents that area 7, i.e. on the ground close to the goal-post, is the optimal point at which to kick a penalty (Table 2 and figure 3). Precisely, a research developed in the Liverpool John Moores University (BBC sport website; see also Leela and Comissiong, 2009) of a purported 'perfect' penalty kick, according to which a ball placed high to the corner at 26 m s^{-1} will not be stopped by the goalkeeper even if he anticipates and would hence have a 100% strike rate.

Interestingly, this proposal seems not to have been heeded by kickers. In a study based on top men's professional leagues worldwide (such as England, Spain, France, Italy, Germany, Brazil and Argentina), and European, South American and World Championships less than 10% of the kicks were directed at the upper lateral areas defined as one-ninth of the goal area (Bar-Eli and Azar, 2009). Even assuming equiprobability of kicks directed at that area, our area 9, is chosen by the kicker only once every 40 penalty kicks.

Moreover, not even kickers of English teams that may have been familiar with the proposal seem to have heeded it after it was broadcasted; in two 2009 European summer Cups played after that, and in whose finals there were shoot-outs (i.e., Audi Cup final between Manchester United and Bayern Munich, and Community Shield between again Manchester United and Chelsea), or in the South Africa World Cup qualifying games played by the English National team in which penalties were kicked. In those matches, none of the kicks were targeted at the spot considered unreachable by the goalkeeper. This could be explained by the psychological stress of the kicker, who is likely to feel his chances of shooting too high or too wide (or both) increase as the ball is kicked near the high corner of the goal and as the speed of the ball is higher (Andersen and Dörge, 2009). In this context, with kickers reluctant to target the ball to close to the posts or the crossbar, the possibility of intercepting the ball trajectory could increase if the goalkeeper manages to get cues beforehand about the intended direction of the kick.

This can be done by observing the behaviour of the kicker as he approaches the ball and then deciding which side to jump at just before the kick. If this decision is taken after the point of no return (Osman *et al*., 1986; Logan, 1994; Band and Van Boxtel, 1999), when the kicker cannot change their motor action, a good decision could increase the chance of interception in many shoots. Thus, the decisions of the kicker and goalkeeper with regard to their actions turns the penalty kick into an interesting problem that can be considered analogous to the escalation or arms race in evolution (Dawkins and Krebs, 1979; Vermeij, 1987).

As said above, the chances of intercepting the ball clearly decrease if the goalkeeper moves after the impact, since only kicks aimed at the goal centre (areas 1, 2 and 3, Fig. 1) can be blocked if the goalkeeper moves at t = 0.250 s. According to our simulations, the chance of interception is nearly nil when the goalkeeper starts to move at t = +0.250, and slightly higher if he moves at t = -0.250 s compared with t = 0 s. However, anticipation could result in a greater proportion of erroneous guesses as to the direction of the shot.

The open loop strategy (Fudenberg and Levine, 1988), in which the kicker selects one side of the goal to shoot at while ignoring any actions taken by the goalkeeper (Kuhn, 1988), was preferred by 78% of kickers. Therefore, since the intercept chances at t=-150 s, t=0 or t=-150 s are almost equally good (Table 2) for most analysed areas, it will be advisable for the goalkeeper to use anticipation moving at the kick time, having assessed the situation after the point of no return of the kicker. This could invert the actual state of the arms race in the penalty kick, at least until the kickers modify their strategy accordingly.

Based on this, and according to several works in which it has been shown the benefits of sport-specific training for enhancing perceptual anticipation (Abernethy *et al*., 1999; Williams and Ward, 2003; Savelsbergh *et al*., 2002, 2005), we suggest that perceptual training related to the skill of anticipating the side (and precise area) of the goal the shot will be directed at may be essential for enhancing goalkeeper performance.

5. Conclusions and Perspectives

Saves in penalty kicks depend mainly on the goalkeeper’s reaction time but also on the ball speed. Chances are low near the posts, but not impossible. Specific training strategies can improve the goalkeeper’s performance. Future studies should be undertaken to include other elements involved in the chance of interception by the goalkeeper (for example, the rather usual goalkeeper technique of stepping forward, not considered here), as well as to determine the signals that goalkeepers could use to predict ball direction.

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