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Original Article

A predictive model of penalty-kick direction based on body posture and kinematic indicators

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Abstract
Soccer is a popular sport with a global following; it is a national sport played by many players affiliated with sports clubs worldwide. Therefore, the current study aims to develop a model based on body posture and kinematic indicators for both goalkeepers and penalty kickers. A descriptive and analytical method was utilized to analyze the videos sourced from the official websites of the International Federation of Association (FIFA) and the Union of European Football Associations (UEFA) between 2020 and 2024. Accordingly, the researchers analyzed 142 penalty kicks and shootouts using Kinovea software. To meet the study's objectives, SPSS version 26 was used to calculate the study variables' values, including the direction of the supporting foot, the kicker's torso direction, and the kicker's head direction, all assessed at a 95% confidence level. The findings indicated that in 89.44% of penalty kicks, the supporting foot's direction and the ball's trajectory after kicking aligned, whereas 10.56% showed directional incompatibility. Similarly, compatibility between the kicker's torso direction and the ball's trajectory occurred in 49.29% of the analyzed penalties and penalty shootouts. Additionally, 33.80% of penalty kicks demonstrated directional compatibility between the kicker's head direction and the ball's trajectory. Based on these results, the predictive model developed emphasizes the supporting foot direction as the primary indicator, followed by the kicker's torso direction and then the kicker's head direction. Scientific studies should continue to be conducted to uncover additional indicators for improving goalkeepers' performance in saving penalty kicks and shootouts, while accounting for differences across samples, such as females and juniors.
Keywords: Analysis, Ball, Biomechanics, Kinovea, Soccer

Introduction

Soccer is a popular sport with a large global following; a national sport practiced by many players affiliated with sports clubs worldwide. This sport requires a variety of abilities and skills, such as agility, cardiovascular endurance, kicking, passing, and psychological attributes such as fighting spirit and mental strength. Penalty kicks are decisive factors in determining the outcomes of matches in tournaments worth millions of dollars. Successful execution is regarded as an essential technical skill for soccer players and also amplifies the sport's entertainment value. Frequently, these kicks become the pivotal element in settling major competitions (Csato, 2020). Per international football regulations, the kick is taken from 11 meters (12 yards) from the goal line, with no player except the kicker and opposing goalkeeper, who represents the sole obstacle to intercepting the penalty kick. The ball reaches the goal after approximately 500 to 600 milliseconds from the kicking point (Van der Kamp et al., 2018). Another study's by Smeeton et al. (2023) showed that the ball takes 80 milliseconds to cross the goal line after kicked.

A penalty kick is an action in a soccer match which only the kicker and the goalkeeper engage in confrontation (Almeida et al., 2016). Similarly, the strategy of mutual influence between players has been highlighted (Weigelt et al., 2012). In addition, penalty kicks or shootouts hold significant importance in determining the outcomes of soccer competitions (Makaruk et al., 2020). At the 2012 London Olympics, South Korea qualified after defeating the host nation, the United Kingdom, on a penalty kick. Consequently, Penalty kicks play a vital role in deciding the outcomes of competitions (Mu et al., 2013). Penalty kicks are often referred to as lucky kicks (Wood et al., 2015). In addition to luck, many other factors have influence on the probability of a successful penalty kick (Memmert et al., 2013). Studies indicate that 39% of knockout matches

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in the World Cup finals included penalty kicks or shootouts. Also, during penalty kicks, the kicker and goalkeeper must choose a specific strategy they believe will be successful, but which of these strategies is best? (Bar Eli & Azar, 2009; Weigelt et al., 2012).

Several factors contribute to successful kicking, including accuracy, power and the swing technique (Bar-Eli et al., 2007). Especially with penalty kicks, the probability of scoring a goal is 80%, and diversity in penalty kick performance has become an important factor for soccer players (Csato, 2020). Therefore, the body movement path of the kicker is a key factor in the successful execution of penalty kicks (Abdelkader et al., 2020). Upon reviewing the theoretical literature and studies related to the current research topic, by analyzing penalty kicks in professional matches researchers found that several models have been developed for the successful execution of penalty kicks in soccer (Bar-Eli et al., 2007). These models estimate the frequency with which shooters or goalkeepers will aim or dive towards the left, right, or center of the goal in order to optimize their chances of scoring or saving (Chiappori et al., 2002). Therefore, there are numerous factors influencing the intricate interplay between the kicker and the goalkeeper, which ultimately determines the probable trajectory of the kick (Hunter et al., 2018).

Studies have highlighted ongoing trends and advancements in goalkeeper performance, with precise data in sports science providing valuable insights into the demands placed on both individual players and team dynamics (Marco et al., 2022). To prevent the ball from crossing the goal line, goalkeepers strive to time their movements accurately and position themselves effectively on either side of the goal line, relying on visual cues from the kicker's body to anticipate the direction of the kick, or merely making a guess (Dicks et al., 2010; Savelsbergh et al., 2005). As a result, predicting the ball's direction improves significantly when more precise information is gathered from the kicker's body and when the goalkeeper delays their movement (Smeeton & Williams, 2012). Goalkeepers who move later have been shown better predictive ability for the trajectory of the kick (Hunter et al., 2018). On the other hand, while goalkeepers also tend to initiate and move before the ball is kicked, there is variation in their chosen timing of movement depending on the time of the kicking (Hunter et al., 2018). Goalkeeper skills play a significant role in intercepting kicks; with former Spanish national team coach Luis Enrique stating that the Spanish team lost the 2022 World Cup to Morocco due to the exceptional skills of Moroccan goalkeeper Yassine Bounou (Football by the Minute, 2022).

A kinematic analysis of a penalty kick indicates that the average time for the ball to enter the goal after being kicked is 0.5 seconds. In comparison, the average time for world-class goalkeepers to intercept a ball after it is kicked is 0.75 seconds (Hun, 2014). The combination of accuracy and speed is a key factor in the success of shots (Vieira et al., 2018). McGarry and Franks (2000) found that penalty kicks have a success rate of 85.2% during regular competitions and 75.6% in penalty shoot-outs. Almeida et al. (2016) further highlight that 15% of penalty kicks target the upper third of the goal, a placement that goalkeepers seldom manage to save. Brinkschulte et al. (2021) also indicate that 25% of penalty kicks taken in high-level professional matches are either saved by goalkeepers or missed entirely. Noel et al. (2021) suggested that goalkeepers prefer to delay their movement before the kicker's foot touches the ball.

Penalty-kick performance analysis in soccer is a key component of sports analysis (Patterson et al., 2020). The body orientation of the kicker is the primary factor in determining penalty success (Li et al., 2015). According to Abdel Fattah et al. (2023), 83.75% of penalties during the FIFA World Cup involved the support foot being aligned with the ball's trajectory. Moreover, 82.83% of kicks where the support foot matched the trajectory resulted in goals. Similarly, Piars and Vickers (2011) proposed that goalkeepers depend on visual cues from the penalty taker to predict the ball's direction before it is struck. Goalkeepers' ability to anticipate is influenced by the ball direction and their perception of the kicker's kinematic cues (Müller & Abdernethy, 2012).

Based on the previous presentation, the current study problem is the lack of research aimed at helping goalkeepers save penalty kicks. In addition, penalty kickers are working to develop their skills. Therefore, there is a pressing need for ongoing scientific research to keep pace with these developments. The current study aims to develop a predictive model that uses kinematic and body indicators for goalkeepers and kickers to improve goalkeepers' effectiveness and efficiency in intercepting penalties or shootouts. It should be noted that the components of the proposed predictive model are objective because they rely on movement and statistical analyses; in other words, they are realistic and derived from football competitions. The researchers expect that the study results will help goalkeepers by giving them more time to make decisions. It may also prompt coaches to focus more on training that improves goalkeepers' ability to react to and intercept penalty kicks.

Materials and Methods

This study employed a descriptive analytical approach to achieve its objectives. Penalty kick videos from the FIFA World Cup between 2020 and 2024 were sourced from the official website of the International Federation of Association Football (FIFA) at https://www.fifa.com/fifaplus/ar. Similarly, penalty kick videos from the 2020 to 2024 European Football Championship were retrieved from the official website of the Union of European Football Associations (UEFA) (https://www.uefa.com/). The researchers analyzed a total of 142 penalty kicks and shootouts using Kinovea software (version 0.9.5-x64.exe), available for download at https://www.kinovea.org/download.html. This software was employed to extract the study variables, primarily concentrating on:

1. Supporting foot direction: referring to the orientation of the supporting foot in relation to the goalkeeper, indicating its directional placement.
2. Contact time: This measures the interval from when the supporting foot lands on the ground to when the kicking foot strikes the ball, recorded in seconds.
3. Ball time: referring to the ball time taken to cross the line of goal after being kicked.
4. The kicker's head direction at the moment of kicking relative to the goalkeeper.
5. The kicker's torso's direction inclination at the moment of kicking relative to the goalkeeper (Figure 1).

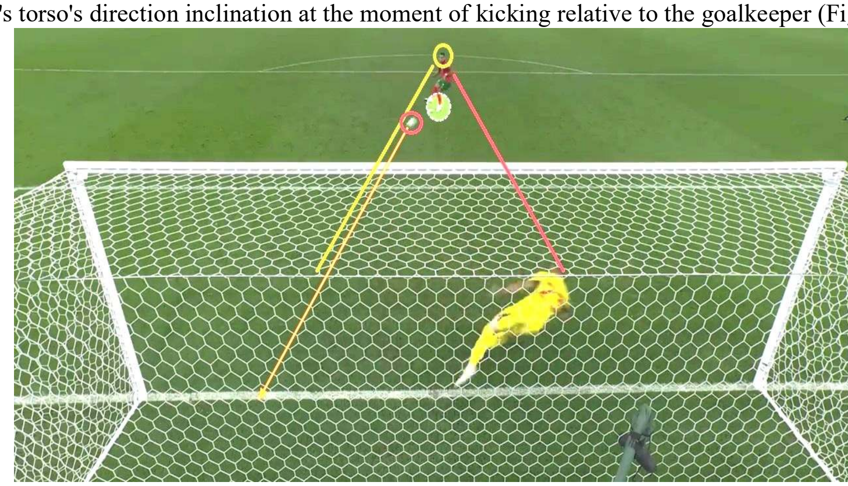

Figure 1. Demonstrates the study variables' relative to the goalkeeper

Data analysis

To fulfill the study's objectives, SPSS version 26 was utilized to calculate numerical values for the study variables through frequencies, percentages, and means, with a 95% confidence level (p-value = 0.05)

Results

The current study aims to provide a predictive model that relies on kinematic and body posture indicators for both goalkeepers and penalty kickers to increase the effectiveness and efficiency of goalkeepers in intercepting penalties or shootouts. The study emphasizes the analysis of factors during a kick, including the direction of the supporting foot; the time taken for the kicker to complete the movement after the supporting foot touches the ground, the orientation of the kicker's head at the moment of kicking, and the inclination of the kicker's torso at that precise instant. Table 1 highlights the alignment between ball direction and supporting foot direction. Table 2 presents the relationship between the kicker's head orientation at impact and the ball's trajectory. Table 3 outlines the correlation between the kicker's torso inclination during the kick and the resulting ball direction. Figure 2 provides a visualization of the predictive model, showing how compatibility levels between various body indicators of the kicker and the ball's trajectory contribute to its design

Table 1. Highlights the penalty kick determined by the direction of the supporting foot and the contact time variable's (n=142)

The number of kicks are compatible with the supporting foot's position		127	89.44%
The percentage % of successful attempts		112	88.19
The percentage % of unsuccessful attempts		15	11.81
The number of kicks are not compatible with the supporting foot's position		15	10.56%
The successful attempts percentage(%)		10	66.67
The unsuccessful attempts percentage (%)		5	33.33
Mean of the contact time/ s		0.10 ± 0.02	
Mean of the ball Time taken to reach the goal/ s		0.38 ± 0.08	
The kicks direction	Goalkeeper's right (n=80)	Successful	60 (42.26%)
		Unsuccessful	20 (14.09 %)
	Goalkeeper's left (n=44)	Successful	28 (19.72%)
		Unsuccessful	16 (11.26 %)
	Center of the goal(n=18)	Successful	16 (11.26 %)
		Unsuccessful	2 (1.41 %)
Goalkeeper movement before kicking the ball	Moved (n=114)	Successful	79 (55.64%)
		Unsuccessful	35 (24.64%)
	Didn't move(28)	Successful	25 (17.60%)
		Unsuccessful	3 (2.12%)

Table 2. Illustrates the compatibility between the kicker's head direction and ball direction (n= 142)

The number of kickers' head direction compatibility with the ball direction	48	33.80%
The percentage % of successful attempts	36	25.35%
The percentage % of unsuccessful attempts	12	8.45%
The number of kickers' head directions is not compatible with the ball direction	94	66.20%
The percentage % of successful attempts	68	47.88%
The percentage % of unsuccessful attempts	26	18.32%

Table 3. Illustrates the compatibility between the direction of the kicker's head and ball direction (n= 142)

The number of kickers' torso direction compatibility with the ball direction	70	49.29%
The successful attempts and percentage %	47	33.10 %
The unsuccessful attempts and percentage %	23	16.19 %
The number of kickers' torso direction is not compatible with the ball direction	72	50.71%
The successful attempts and percentage %	57	40.14 %
The unsuccessful attempts and percentage %	15	10.57

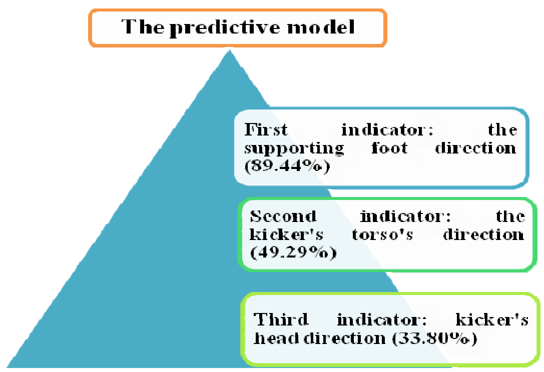

Figure 2 illustrates the components of the predictive model based on the compatibility level between the body posture indicators and the direction of ball after kicking.

Discussion

Analysis of 142 penalty kicks and penalty shootouts showed that 104 (73.23%) were successful and 38 (26.77%) were unsuccessful. These results are similar to studies that indicate an 80% probability of scoring a goal from a penalty kick (Csato, 2018). McGarry and Franks (2002) also indicated that the success rate of penalty kicks during competitions was 85.2% and 75.6% for shootouts. Brinkschulte et al. (2021) indicate that 25% of penalty kicks taken in international professional competitions are either saved by goalkeepers or missed entirely. By reviewing the mean time taken for a kicked ball to cross the goal line, the analyses showed that this time amounted to 0.38 ± 0.08 seconds. These values are close to those achieved in the Hun (2014) study, which indicated that the time taken for a kicked ball to cross the goal line was 0.50 seconds. Also, Vanderkamp et al.(2018) indicated that the a kicked ball took 0.50–0.60 seconds to cross the goal line. Meanwhile, another study showed that it took 0.75 seconds (Hun, 2014).

In another context, the current study showed that the mean contact time of the pivot foot with the ground until the kicker's foot touches the ball is 0.10 ± 0.02 seconds. It can be noted that these values, in addition to the time taken for the ball to cross the goal line after being kicked, are additional indicators that can help goalkeepers in intercepting the ball. Studies indicate that goalkeepers need to intercept the ball 0.75 seconds after being kicked (Hun, 2014). The researchers believe that the kicker's body posture indicators increase goalkeepers' efficiency in intercepting penalties and shootouts. On the other hand, our analyses showed that 56.35% were to the right of the goalkeepers, 30.98% to the left of the goalkeepers, and 12.67% to the center of the goal. Furthermore, 80% of goalkeepers rely on movement patterns before kicking the ball as an interception strategy, but this alone is ineffective. In this regard, Abdel Fattah et al. (2023) found that 36.25% of the balls' direction was to the goalkeeper's left, 55% to the goalkeeper's right, and 8.75% in the middle.

By reviewing our analysis results, we found that 69.29% of kicks in which goalkeepers moved before kicking resulted in goals, while only 30.71% of kicks were intercepted. Conversely, 19.72% of goalkeepers relied on a pre-kick immobility strategy as their penalty interception strategy. This approach is also considered ineffective, as the results of the current study confirmed that 89.28% of kicks in which goalkeepers did not move resulted in goals. In comparison, only 10.72% of kicks were intercepted. Based on these results, the researchers suggest that goalkeepers adopt a movement pattern based on the kicker's body indicators, in addition to other indicators such as the pivot foot and the direction of the kicker's head and torso. In this regard, Smeeton and Williams (2012) suggest that predicting the ball's direction becomes more effective when goalkeepers obtain more accurate information about the kicker's body and the delay in movement. While Hunter et al. (2018) showed that goalkeepers who move later have better predictive ability for the ball's trajectory; there was also variation among goalkeepers themselves in their choice of move depending on the kicking time.

In order to build a predictive model for ball direction in penalties and shootouts that includes several objective indicators, our analysis revealed that 89.44% of kicks had their direction aligned with the supporting foot's position and the ball's trajectory post-kick, while 10.56% of kicks showed no such alignment. This emphasizes the significant role of the supporting foot's direction. These findings align with the study by Abdel Fattah et al. (2023), which reported that 83.75% of penalty kicks in FIFA World Cups had the pivot foot perfectly aligned with the ball's trajectory. Additionally, the current study found that 33.80% of kicks showed no compatibility between the kicker's head direction and the ball's trajectory after kicking, whereas 66.20% demonstrated alignment between the two variables. The researchers believe that this indicator can be relied upon with the rest of the other indicators that make up the proposed predictive model.

Regarding the kicker's torso direction indicator, the results showed that 49.29% of the analyzed penalties and shootouts were compatible between the kicker's torso direction and the ball's trajectory after kicking. Therefore, these indicators can be relied upon together to improve the efficiency and effectiveness of goalkeepers in intercepting penalties and shootouts. In this context, Piars and Vickers (2011) suggested that goalkeepers rely on the visual cues of kickers to anticipate the direction of the ball before kicking it. Müller and Abdernethy (2012) also indicated that goalkeepers' ability to anticipate is influenced by the ball direction and their awareness of the body cues of penalty and kickers. Dick et al. (2010) suggested that goalkeepers can increase their effectiveness in intercepting the ball before it crosses the goal line by relying on visual indicators from the kicker's body to predict the ball's direction or make an effective guess.

Conclusions

The researchers confirm that sports analytics are invaluable for both goalkeepers and coaches, and contribute to enhancing goalkeepers' efficiency in competitive situations and the tactics used by kickers. The current study demonstrated that posture body, and kinematic indicators enhance goalkeepers' ability to accurately predict the ball's direction in penalties and shootouts by contributing to the low success rate of these situations. The results of our analyses showed that the proposed predictive model relies on the supporting foot direction indicator as the first indicator, 89.44%, the kicker's torso direction as the second, 49.29%, and the kicker's head direction as the third, 33.80%. Therefore, providing body posture and kinematic indicators for goalkeepers when facing kickers will improve their success rate in saving penalties. Researchers also emphasize the importance of exploiting the time the pivot foot touches the ground before kicking, and the time it takes the ball to reach the goal after kicking, as additional indicators that can be employed in strategies applied by goalkeepers to intercept penalties and shootouts.

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