ISSN 1750-9823 (print)
International Journal of Sports Science and Engineering
Vol. 03 (2009) No. 02, pp. 093-102

Analysis of the Keeper-Dependent Strategy in the Soccer Penalty Kick

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(*Received May 8, 2009, accepted June 5, 2009*)

Abstract. The penalty kick plays a decisive role in the outcome of many Association Football (soccer) matches, and it is important for the kicker to choose the best strategy to score. This paper looked at the keeper-dependent strategy in which the kicker reacts to the goalkeeper's movement, and determined the amount of time needed before foot-ball contact for a player to successfully adjust their kicking direction. Field tests were conducted with 8 participants using lights to simulate the time and direction of a keeper's dive. A second experiment involving 6 participants determined simple, choice and discriminative reaction times for leg movements. It was found that the critical time needed to react and shoot the ball to the opposite side of the keeper was approximately 0.3 seconds. For three different strategies, involving different initial shooting directions, chance performance was found when stimuli were presented 300-400 ms before contact and full success rate was achieved when more than 500 ms were available. There were no significant differences between the strategies with regard to success. A large part of the pre-contact time was needed for reacting to the stimulus, and the time in which the adjustment could be made was approximately 135 ms.

Keywords: soccer, penalty kick, response, reaction times, motor control

1. Introduction

International In the 2006 FIFA World Cup, 49 penalty kicks were taken: 33 were scored, 9 saved, and 7 missed [1]. Many of the top players in the world failed to score from 12 yards, some of the great teams were knocked out on penalties and the final itself was decided on penalties. A player taking a penalty in competition must be clear on which strategy will give the greatest chance of scoring. For an average-paced shot, 32 m·s-1, it takes just 344 ms for the ball to reach the goal-line [2]. Therefore goalkeepers mostly dive prior to the player making contact with the ball to create a greater chance of saving the shot. Some players use a strategy in which they aim to take advantage of this by watching the keeper's movement and adjust their kicking motion to shoot into the empty side of the goal.

Taking a penalty kick in a shoot-out is a discrete motor skill in which there is a recognisable beginning and end. It is, however, a complex movement which requires a high-level "motor" aspect. The two general control strategies for taking a penalty, presented by Kuhn [3], are closed and open loop control, referring to the control process for responding to, and ignoring, the goalkeeper's movements, respectively. This study, however, uses the more descriptive terms of keeper-dependent (closed loop) and keep-independent (open loop) [4].

This study concentrates on the keeper-dependent strategy in which the motor system considers visual feedback from the keeper to ensure that the set condition is met [5]; a goal is scored. The strategy accounts for the changing environment (the keeper) and success depends heavily on the extent to which the individual can adapt their motor behaviour to that changing environment. The difficulty in performing a complex skill with closed-loop control is that the performer must process both task-intrinsic and environmental-dependent feedback. The nervous system has a limited attention capacity [6] and the processing of additional feedback is likely to affect the accuracy of the task.

Morya et al. [6] carried out computer simulated tests on the keeper-dependent strategy. Dots represented movement of the goalkeeper, ball and kicker, and shot direction was determined by the inclination of a lever

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upon the kicker reaching the ball. They concluded that perfect performance was achieved when the goalkeeper's movement occurred 400 ms before contact, and that "chance" performance occurred if this time was reduced to 150 ms. Since these tests involved no kicking of a ball, field investigations were required to validate their findings. Van Der Kamp [4] considered a more realistic penalty situation with the use of lights to represent the goalkeeper's movement. He found that a player needs the keeper to move at least 400 ms before contact to allow enough time to react and shoot successfully to the opposite side. He also recorded shot accuracy between the keeper-dependent and keeper-independent strategies and found that, even in trials which didn't require a change in shot direction, accuracy decreased when a player was anticipating a change in direction. Much is still unknown about the response required in changing shot direction and no previous study has evaluated the advantage of this change being from left to right against vice versa.

Previous studies have shown that right-footed players are more accurate shooting to the left, and vice versa for left footed players, thus giving rise to the terms natural side and unnatural side for the more and less accurate sides respectively [7,8]. It is therefore proposed that a player will be capable of successfully adjusting, from shooting towards the unnatural side to shooting towards the natural side, in less time than vice versa.

The total time to change shooting direction is composed of information gathering and processing stages, the pre-motor component of the movement and the adjustment time. In order to better understand the response process it is helpful to know each of these component times. In this experimental set up only reaction time (RT) to the stimulus and adjustment time to redirect the kicking action were involved. This limits the ecological validity of the study somewhat as in a game situation players rely heavily on anticipation and picking up cues from the opposition player [9]. However, as only the RT and adjustment times are involved, and each can be determined, some further insight into the limitations of the penalty takers actions can be determined, which could have implications on training technique. To allow such distinctions to be made, RTs for the initiation of leg movement must be found, ensuring that no movement time is included. Three types of RT will be explored as the different aspects of simple, choice and discriminative RTs may apply more appropriately to the different strategies.

Since some players use the keeper-dependent strategy (Kuhn [3] reported approximately one quarter, although recent competitions suggest this value is debatable), the aims of this study were: to assess the effectiveness of the keeper-dependent strategy; investigate different variations of the strategy (with or without a predetermined shot side and changing from natural or unnatural side); and to explore reaction times involved in this strategy.

2. Methods

2.1. Penalty kick tests

Eight male participants aged 19-24 took part and had given informed consent in accordance with the university's ethical advisory committee procedures. All participants played competitive university football and all had experience taking penalties. Participants were given general instructions at the beginning of the session, and specific instructions before each condition. They were instructed that as they approached ball contact they must keep their head up and react to the lights. For all trials participants were instructed to kick the ball with a similar pace that they would use if taking a penalty kick in competition. Ball speeds were measured for random trials of each participant, by digitizing the first 10 video frames (9.82 ms) of free flight after foot contact.

A full-size mock up of a goal was constructed with target areas and two LED light arrays positioned at the centre (Figure 1). Each array consisted of 4 red LEDS, 5 lumens, 30 degree field of view, spaced 1 cm apart in a vertical line. The light arrays were positioned in the centre of the goal approximately 1 m above the ground and 1 m apart, corresponding to the area at which a kicker looks for visual cues as to which way the goalkeeper is diving [10]. The stimulus lights were manually triggered at various times before foot-ball contact based on the judgment of a practiced researcher who was able to judge the speed of the run up to gain an appropriate range of times to ball contact. The time between light activation and ball contact was measured using a digital high speed video camera (Phantom v4.0, Vision Research, New Jersey, US) triggered simultaneously with the lights. The camera frame rate was set at 1018 Hz. The goal and penalty spot dimensions were consistent with FIFA regulations, and footballs used were of official mass and circumference [11]. For the keeper-dependent trials, the two light arrays were used as stimuli to represent the direction of a keeper's dive.

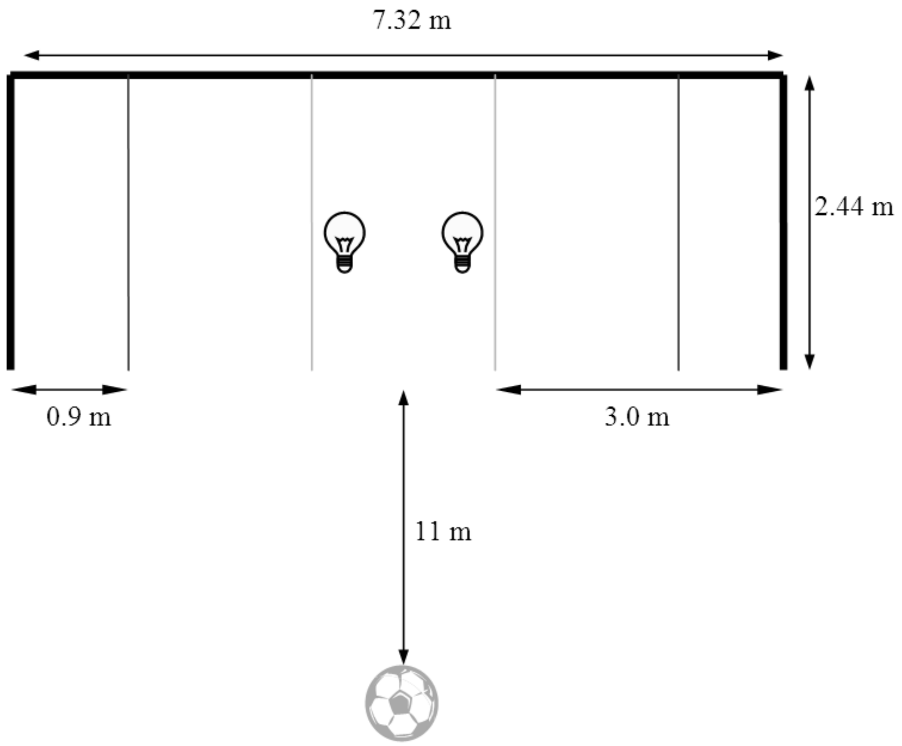

Fig. 1: Schematic of target areas and measurements.

Participants were first asked to take 10 shots, 5 to each side, to test for accuracy and were required to aim for the target area within 0.9 m of the post. This target size was determined from preliminary tests as a size for which the participants were likely to achieve around 50% success rate.

Participants were required to take 12 shots with no predetermined side. In these trials, if a light appeared participants were required to react and aim to the opposite side of the light (within 3 m of the post), and if no light appeared the participant should shoot into the middle of the goal. Participants also took 12 shots with the right side of the goal as the predetermined side and 12 shots with the left side as the predetermined side. If the light on the predetermined side was activated participants were expected to adjust and aim to the opposite side of the goal (within 3 m of the post for a successful shot). If no light appeared or the light on the non-predetermined side appeared, a shot was deemed successful if the ball passed within 0.9 m of the post in the predetermined side of the goal. See Table 1 for outline of trials and accuracy requirements. A change in shot direction was required in half of the trials. The order of no predetermined side, left predetermined and right predetermined side was varied systematically between participants.

Predetermined side	Number of trials	Light activation Yes/No	Light activation Side	Shot aim	Accuracy conditions
None	12	Y	Left	Right	within 3.0m of post
		Y	Right	Left	within 3.0m of post
		N	*-*	*Middle*	*within 0.66m of centre*
Left	12	Y	Left	Right	within 3.0m of post
		Y	*Right*	*Left*	*within 0.9m of post*
		N	*-*	*Left*	*within 0.9m of post*
Right	12	*Y*	*Left*	*Right*	*within 0.9m of post*
		Y	Right	Left	within 3.0m of post
		N	*-*	*Right*	*within 0.9m of post*

Table 1: Criteria of keeper-dependent trials in detail. Trials in italics were used to encourage the participant to be aiming towards the predetermined side and were included at random. Trials not in italics required a change in shot direction away from the predetermined side.

For analysis, trials which required a direction adjustment were grouped into eight bins of stimulus pre-contact times for each strategy and each bin contained 7 $\pm$ 2 shots. The success rate for each bin was calculated and plotted against pre-contact time. A logistic function, $P(x) = 100/(1+e^{-(x-c)/\tau})$, was fit to the data for each strategy, using the Nelder-Mead simplex method (MATLAB fminsearch function) [12]. The function was solved by minimising the root mean square (RMS) difference between the sample data and the logistic function by varying the parameters c (midpoint) and τ (steepness). Logistic regression with dummy variables for side was used to test for significance between conditions.

2.2. Reaction time tests

All Investigations of leg reaction times were carried out using six participants, four of which took part in the penalty kick trials, and an extra two for increased statistical power. All participants were male and physically fit, with ages ranging from 22 to 34 years, for whom there is minimal variation in reaction time [13]. A Kistler Force platform sampling at 2000 Hz (type 9281B11, Kistler Instruments AG, Winterthur, Switzerland) was used to obtain simple, choice and discriminative RTs for whole leg movement from the change in ground reaction forces. Participants were given 3 practice trials before performing 10 recorded trials, for each condition. The beginning of the fore-period was signalled by the word “ready” and the fore-period was randomly varied between one and five seconds. A lights set-up, identical to that of the kicking trials, was used to provide the stimuli, and was synchronized with the force platform. Preliminary tests showed that using a ‘standing foot lift’ or ‘press’ technique gave lower and more consistent measures of movement onset and thus RT (Table 2). Out of these two techniques the foot lift was considered to be a more appropriate action to how a kick would be adjusted and was thus used to determine RT. In this technique, the participant stood upright on the force plate, with each foot directly above a force transducer, and then lifted the whole of the appropriate foot in response to the stimulus. Movement initiation was determined by visual inspection of the vertical and horizontal force traces. Maximum error in determining RT was 5 ms. At the initiation of movement a distinct countermovement was noted for each trial. The onset of a physical response was considered as the beginning of the countermovement.

Test technique	Simple RT (ms)		Choice RT (ms)		Discriminative RT (ms)	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
seated foot raise	150	12.2	190	43.0	201	40.9
standing foot press	118	20.7	160	37.6	141	24.3
standing foot lift	121	17.7	140	17.2	183	53.6
sideways step	134	22.2	163	16.9	186	55.0
forward step	129	16.4	142	30.2	154	48.3

Table 2: Preliminary reaction time tests: Average reaction times from two participants comparing different techniques for measurement.

For the simple RTs there was one light and participants responded by lifting their predetermined leg. For the choice RTs there were two lights and two possible responses; participants lifted the leg which was opposite to the side the light appeared. For discriminative RTs there were two lights but only one required a response which is equivalent to having a predetermined side in a keeper-dependent penalty. If the light appeared to the predetermined side, the participant made a movement to the opposing side. If no light appeared or the other light appeared the participant stayed still. The order of light activation was random.

3. Results

3.1. Penalty kick tests

In the accuracy tests, participants varied from 3 out of 10 successful to 8 out of 10 successful and the tests failed to support the hypothesis that accuracy is greater shooting towards the natural side (Z = -0.162, p = 0.872). Accuracy decreased slightly for the shots in the keeper-dependent trials where no change in direction was required presumably due to the attention given to the lights. Participants were at all times eager to achieve a successful shot which included attempting to be accurate in aiming for the 0.9 m wide area on the predetermined side when a change in shot direction was not required. For the keeper-dependent trials, ball speed varied between participants (18-24 m/s). Success rates for each strategy had an agreeable fit with the logistic function (Figure 2) with RMS differences of 4.9%, 5.8% and 8.0% for no predetermined, unnatural and natural side predetermined respectively.

The strategy which required the least time for changing shot direction was that with no predetermined side, for which chance performance (50% success rate) was found to be at 325 ms before ball contact. The 50% success rate has been widely accepted as a determinant for the critical time needed [4,6]. Perfect performance (100% success rate) was achieved when players had longer than 500 ms to react.

Although the critical time needed was shorter for the no predetermined side condition (Figure 2), and the logistic function fit shows a steeper gradient through the 50% success level (0.817 %/ms compared to 0.379 %/ms for unnatural side predetermined and 0.343 %/ms for natural side predetermined), the difference between the no predetermined side strategy and the predetermined side strategies as a whole was not significant ($p > 0.1$). The results suggest that a greater success rate at the longer time periods is achievable with the no predetermined side condition but this study has insufficient evidence to support that claim.

There was little difference between the time needed in adjusting from the unnatural side to the natural side and vice versa. Chance performance occurred for a slightly shorter time period when the unnatural side was predetermined (348 ms) compared to the natural side (362 ms) but there was also no significant difference between these conditions. See Figure 3 for a closer comparison.

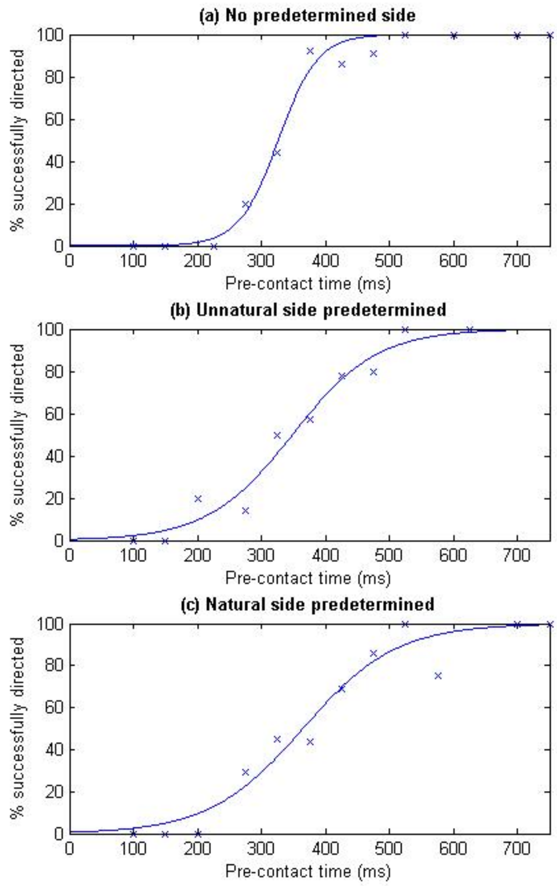

Fig. 2: Percentage of shots successfully redirected in the three keeper-dependent strategies. Solid line in each case is the best-fit logistic function.

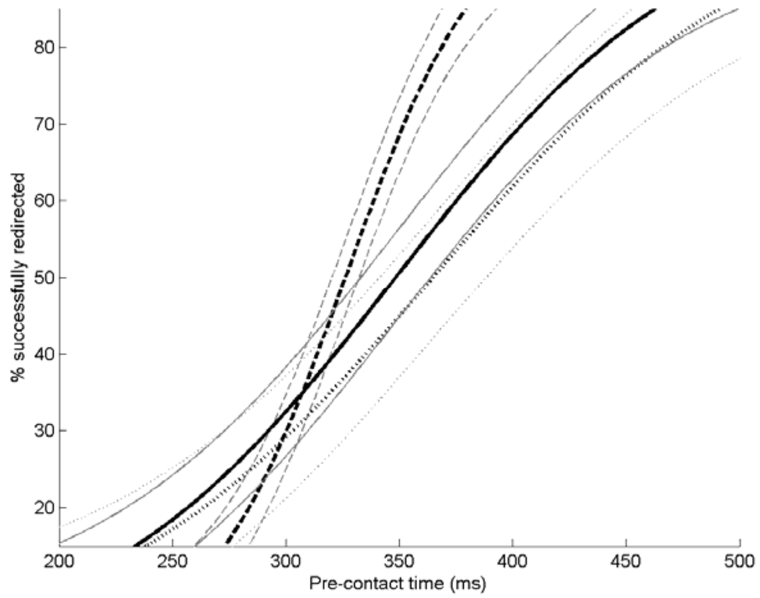

Fig. 3: Logistic functions (black lines) of the three strategies shown around 50% success rate. Grey lines represent +/- 1 RMS error. Dashed lines, no predetermined side; solid lines, unnatural side predetermined; dotted lines, natural side predetermined.

3.2. Reaction time tests

There was a significant variation of RT results between participants (ANOVA, F=2.670, p=0.024). Mean RTs were 134 ms, 163 ms and 179 ms for simple, choice and discriminative, respectively (Table 3). As expected, simple RTs were significantly shorter than choice (paired t-test, t=3.59, df=5, p=0.016) and discriminative (paired t-test, t=4.59, df=5, p=0.006). Discriminative RTs were longer than choice RTs for all but one participant, although the mean difference was not significant (paired t-test, t=1.94, df=5, p=0.111). No more than two incorrect movements were made by any of the participants in the choice or the discriminative RT trials.

Participant	Simple RT (ms)	Choice RT (ms)	Discriminative RT (ms)
1	136.1	140.7	180.0
2	114.4	147.8	192.7
3	134.0	142.9	148.5
4	140.2	167.6	170.9
5	138.2	181.7	174.1
6	138.7	194.5	208.6
Mean	**133.6**	**162.5**	**179.1**

Table 3: Mean reaction times measured from force platform.

4. Discussion

The results of chance performance around 350 ms and perfect performance in the region of 500-600 ms, fall between the values of two previously published papers. Morya *et al.* [6] found perfect performance above 400 ms and chance performance at 150 ms. In their experiment, instead of having to redirect the kicking of a ball, participants chose direction of shot by inclining a vertical lever to the left or the right. Where an adjustment in kicking action is required, a greater response time is to be expected. Van Der Kamp [4] found that when 600 ms were available, only 75% of the kicks were successfully redirected. Despite similar criteria for a successfully redirected shot, participants in their study attempted to redirect their shot at a particular target (0.6 x 0.6 m). Van Der Kamp's more challenging task may have caused the larger estimation in response time required.

Although less time was needed on average for chance success in the strategy with no predetermined side, no strategy was significantly more or less successful than any other strategy. The drawback of having no predetermined side is that if the goalkeeper does not move until less than 325 ms before contact, or does not move to one side or the other at all, the kicker would find it difficult to shoot anywhere else other than near the centre of the goal. This time is assuming that the goalkeeper gives no cues in advance of his movement, if he is going to make one, which is unlikely as the goalkeeper is allowed to move on the line. The use of anticipation and cues are vital for success in saving penalties and would also be vital when employing a keeper-dependent strategy. However, anticipation still relies on taking in information and performing an action based upon it. Whether the kicker relies on a key piece of information that acts as a single decision making factor, or builds up a steady bank of smaller data pieces until a threshold, or tipping point arises, is not known in the penalty taking situation. Whichever strategy is used there comes a point when the last piece of external information can be incorporated into the final kicking action. Given that some decision making process will be involved in determining if or how the last piece of information is used, it is unlikely that the utilisation of the last piece of information will occur with a delay much less than the simple or the choice RT. Furthermore if the kicking action is a ballistic action once it starts it is unlikely to undergo any major adjustments as there will be a refractory period where a new action cannot be initiated even though new information can be processed. This can lead to the feeling of knowing that you are doing the wrong thing but you cannot stop yourself from doing it.

The force plate RTs were shorter than other general studies of RTs have indicated. Simple RTs in response to visual stimuli are generally agreed to be around 190 ms based mainly on computer tests [14,15]. Such tests account not only for the reaction time but also movement time and processing time of the computer [16]. The use of force sensors has been shown to give lower reaction times than methods that rely on detecting a finite amount of motion [17].

Other literature shows that visual feedback can be utilised in just 135 ms [18]. Paulignan *et al.* [19] concluded that if a target changes position then vision of the perturbations could be used in as little as 100 ms, although corrective accelerations towards the new target did not begin until 180 ms. These values fit well with the processing times of 134, 163 and 179 ms found in this study (here approximated as RT). McLeod [20] found that alterations in shot choice (reaction and adjustment) for cricket batsman could not be made less than 200 ms before contact which is slightly shorter than the minimum time in which a shot was redirected in the present study (249 ms) and could be accounted for by a difference in adjustment time. Based on a typical RT of 150-165 ms, for a kicker to react and redirect a shot in a total of 300 ms, the adjustment time would account for 135-150 ms. This is depicted in figure 4 and demonstrates that RT is a large part of the task of responding to a keeper's dive.

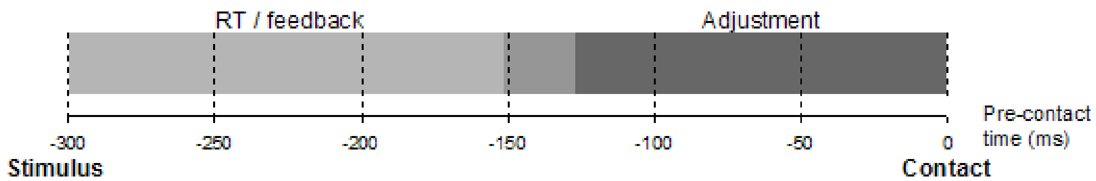

Fig. 4: Approximate time of feedback and adjustment in the last 300 ms before contact for a typical shot successfully redirected.

Savelsbergh *et al.* [21] found that successful expert goalkeepers moved at 230 ms before ball contact (time before ball contact will be denoted as -X ms) and the kickers making ground contact with their plant leg at -350 ms. In this study plant leg ground contact was at just over -200 ms, similar to the -200 to -250 ms found in Franks & Hanvey [22]. The -350 ms in Savelsbergh *et al.* [21] seems to be rather high and if the plant leg action is the main cue used by the keeper it could at least partly account for their high success rate in choosing the correct side to dive. Savelsbergh *et al.* had the successful expert goalkeepers choosing the correct side 90% of the time and the less expert groups, that moved at -360 ms and -480 ms, had 70% success rates. In the 2006 FIFA World Cup only 50% of the time that the keeper dived to a side were they successful in choosing the correct side.

Assuming the goalkeepers in Savelsbergh *et al.* [21] have the same processing time of 163 ms (choice RT) means the successful expert keepers were deciding on the side to move to just before plant foot ground contact. Franks & Harvey [22] had shown that in 80% of penalty kicks the plant foot points in the direction of the shot, indicating that using this obvious cue, as guide to which side to dive, would give a high success rate in the direction to dive. Using plant foot ground contact times of -200 to -250 ms means the goalkeepers would be deciding to move during the early swing phase of the plant foot of the kicker and would likely be less successful, as in the 2006 FIFA World Cup.

Given the time that the expert keepers move in relation to ball contact, the kicker will be unable to use the goalkeepers actual dive motion as the last piece of information he/she can use to determine shooting direction. However, he/she can use the dive motion of the poorer keepers and any cues that occur before -325 ms from any keeper. If the kicker keeps the time between plant foot contact and ball contact low the keeper will have to work from the early swing phase of the plant leg. The kicker can then also try to keep the plant leg swing phase as uniform as possible for any type of subsequent kicking action. This would reduce the keeper's ability to use any obvious plant leg cue to decide the correct side to dive to.

This study is also of use to goalkeepers, since if they dive no earlier than 325 ms before foot-ball contact, as the best goalkeepers do, they can be confident the kicker will be unlikely to have sufficient time to deliberately react and shoot the opposite way, assuming no advance cues of a dive direction were apparent. Figure 5 shows the position, a) 300 ms and b) 150 ms before contact, of two kickers on a typical paced run-up.

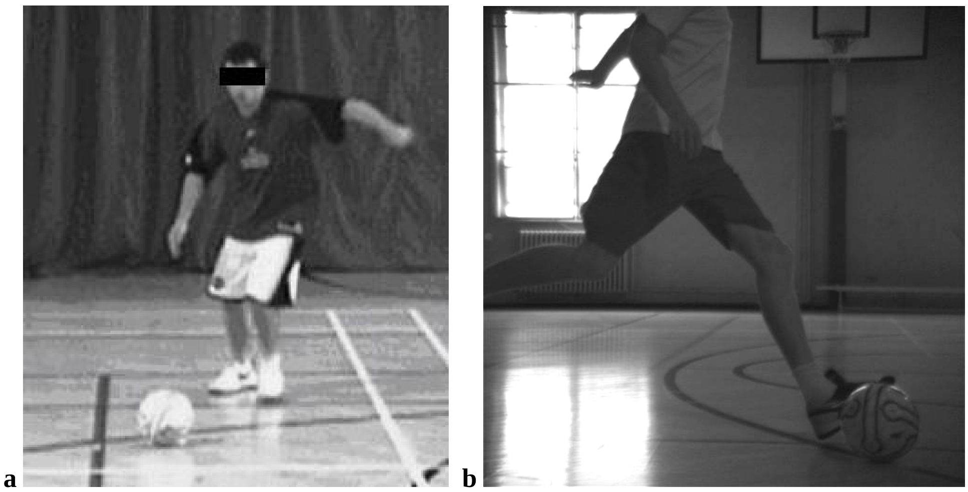

Fig. 5: Typical kicking position a) 300 ms (front-on view) and b) 150 ms (side-on view) before ball contact.

Within the confines of this experimental protocol some caution must be taken in applying these RTs too closely to the kicking situation. Firstly, there could be a small temporal anticipation advantage [23] in the kicking trials because the participant knows that, if the stimulus occurs, it will be within one second before contact, where as in the RT tests the anticipation period was four seconds. Secondly, discrepancy could arise because all the same participants could not be used in the RT tests as in the penalty kick trials. Finally it is worth noting that when kicking a ball a player must also pay some attention to the task-specific control of the generic kicking motion which could have a negative influence on RT [24].

It could be argued that having a predetermined side may reduce the time needed to react because only one possible response is required resulting in a discriminative RT rather than a choice RT being involved [25]. With no predetermined side the kicker has to react to either light, and then decide which light and hence which side. With a predetermined side the kicker only needs to focus on the light for their predetermined side. It may, however, be an oversimplification to consider shots with a predetermined side to be applicable to a discriminative RT, due to the fact that a motor program is already in action and the go/no-go delay (the reaction delay as a result of the decision whether to start a motor pattern or not) does not occur. When there is uncertainty over whether or not to react, it may be easier to cause an *adaptation* of an already active movement than to cause the *initiation* of a new movement.

5. Conclusion

It was found that at least 300 ms – 350 ms are needed to react to the keeper and successfully redirect a shot to the opposite side to the dive. There was no significant difference between the three strategies. The predetermined side strategies have the advantage that even if the kicker does not adjust, the shot may still be accurate enough to score despite the keeper diving the correct way, as they were able to place the shot within 0.9 m of the post. The keeper-dependent strategy can be reliable if the player learns the point after which he/she cannot successfully change shot direction (approximately 350 ms – 400 ms before contact) and what information may be available from the keeper up to this point in time.

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