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A field simulation study of the effectiveness of penalty kick strategies in soccer: Late alterations of kick direction increase errors and reduce accuracy

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Abstract

This field experiment investigated the relative merits of approaching the penalty kick with either a keeper-independent or keeper-dependent strategy. In the keeper-independent strategy, the shooter selects a target location in advance and disregards the goalkeeper's actions during the run-up. In the keeper-dependent strategy, the shooter makes a decision resting on the anticipation of the goalkeeper's movements during the run-up. Ten intermediate-level soccer players shot at one of two visually specified targets to the right and left side of the goal. In the keeper-independent strategy condition, participants were told that the visually specified target would not change. In the keeper-dependent strategy condition, participants were told that in half of the trials the visually specified target would change side at different times before ball contact, indicating that the direction of the kick needed to be altered. The results showed that penalty-taking performance was apt to be less than perfect in the keeper-dependent strategy condition. A decrease in the time available to alter kick direction resulted in a higher risk of not only an incorrect but also inaccurate shot placement. It is concluded that anticipating the goalkeeper's movements may degrade penalty kick performance, mainly due to insufficient time to modify the kicking action.

Keywords: *Penalty kick, anticipation, action, perception, decision making*

Introduction

Penalty kicks are decisive events in soccer (or Association Football), especially after the penalty shoot-out was introduced to settle drawn cup ties during the World Cup and the UEFA European Championship tournaments (e.g. Grant, Reilly, Williams, & Borrie, 1998; Miller, 1996). Although both experts and pundits are often of the opinion that an overwhelming advantage belongs to the penalty taker, many (20 – 35%) penalty kicks are missed (Franks & Harvey, 1997; Kropp & Trapp, 1999; Kuhn, 1988; Morris & Burwitz, 1989). There are many factors that can affect penalty kick performance, not least the large amount of psychological stress placed on the performer. Mental rehearsal may diminish these adverse effects of psychological stress (e.g. Bar-Eli & Friedman, 1988), but a necessary prerequisite to increase the probability of successful performance is the implementation of the "best" penalty kick strategy.

Kuhn (1988; see also Miller, 1996) identified two ways a player can approach a penalty. Adopting the "keeper-independent" strategy, the penalty taker chooses the target location ahead of time and disregards any action of the goalkeeper during the run-up. The pre-established plan about the direction of the kick may be based on the penalty taker's kicking biases, knowledge of a particular goalkeeper's preferences, or the goalkeeper's place in the goal, but importantly the penalty taker makes no alterations to the plan once the run-up has begun. Alternatively, using the "keeper-dependent" strategy, the penalty taker chooses a temporary target location in advance, but leaves the final decision on the direction of ball placement until the last moment. During the run-up, the penalty taker tries to obtain information from the actions of the goalkeeper in an attempt to anticipate which side the goalkeeper will dive. Correct anticipation results in the penalty taker placing the ball to the opposite side. Kuhn (1988) suggested that around three-quarters of penalty takers use the keeper-dependent strategy, but he did not report whether the strategy is more successful than the keeper-independent strategy. (Kuhn referred to these

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strategies as "closed" and "open loop", respectively.) By anticipating the side that the goalkeeper will dive, the penalty kicker intends to decrease the probability that the goalkeeper can reach the ball and save the kick. It can be supported by the use of early advance information concealed in the goalkeeper's postures and movements, but may also be facilitated by knowledge about a particular goalkeeper's preferred side. The keeper-dependent strategy appears particularly advantageous when the goalkeeper commits himself early. It is perhaps for this reason that many players prefer the keeper-dependent strategy over the keeper-independent strategy.

Nevertheless, Morya, Ranvaud and Pinheiro (2003) recently suggested that trying to take into account the goalkeeper's actions might seriously impede the successful conversion of the penalty kick. Their study involved a coincidence timing task that aimed to simulate the penalty kick. A computer monitor displayed a goalmouth and three dots that represented the goalkeeper, ball and player. The dot representing the goalkeeper was located in the middle of the goalmouth. A second dot that represented the penalty taker moved towards the dot that represented the stationary ball. Participants were instructed to move a lever either to the right or to the left, corresponding to the two sides of the goal, at the exact time the "kicker" reached the "ball". The participants were required to use a keeper-dependent strategy – that is, the lever had to be moved to the opposite side of the lateral movement of the "goalkeeper". It was shown that, when the "goalkeeper's" movement was initiated 400 ms before the "penalty taker" reached the "ball", participants' performance (i.e. the proportion of trials that the "ball" was directed to the side opposite to where the "goalkeeper" dived) was almost 100% correct. However, performance decreased to chance levels when the "goalkeeper's" movement began 150 ms before "ball contact". Morya *et al.* claimed that anticipating the goalkeeper's movements thus may result in a weak shot. However, the constraints imposed on both action and perception in the computer-simulated penalty kick were vastly different from those during a "real-life" penalty kick. Therefore, as Morya *et al.* themselves recognized, before recommendations can be made about the desired penalty kick strategy, the findings need to be validated in field studies. The present paper aims to do just that.

The employment of a keeper-dependent strategy appears no guarantee that the ball is placed in the direction opposite to the goalkeeper's movement (Morya *et al.*, 2003). This is particularly evident when information about the goalkeeper's dive is detected shortly before ball contact, as there may remain insufficient time to alter the direction of the kick. A late decision may not only result in placing the ball to the same side as the goalkeeper, but might also result in a relatively inaccurate placement. The time available to alter the direction of the penalty kick, therefore, appears a critical factor for the success or failure of the keeper-dependent strategy. Morya *et al.* (2003) suggested that kickers will only approach perfect performance if the goalkeeper commits himself to one side more than 400 ms before ball contact, and will show chance performance when the goalkeeper moves less than 150 ms before ball contact. Executing a penalty kick, however, is a great deal more complex than tilting a lever. Essentially, a penalty kick corresponds to an instep kick of a stationary ball (cf. Grant *et al.*, 1998). It can be characterized as an angled approach to the ball consisting of at least one stride, with placement of the supporting foot at the side and slightly behind the ball. Concurrently, the kicking leg is swung backwards, and forward motion of the kicking leg is then initiated in a proximo-distal sequence of the thigh and lower leg. After that, the thigh begins to decelerate until it is essentially motionless at ball contact. Simultaneously, the lower leg vigorously extends about the knee to almost full extension at ball contact. As a result, the velocity of the kicking foot reaches maximum just before contact with the ball (Lees & Davids, 2002; Lees & Nolan, 1998). Precise details pertaining to the control of the direction of the ball with an instep kick are not available, as the biomechanical descriptions of the instep kick are restricted to ball speed and/or accuracy constraints (e.g. Lees & Nolan, 1998; Levanon & Dapena, 1998; Nunome, Asai, Ikegami, & Sakurai, 2002). An exception is the study by Franks and Harvey (1997), who sought to identify the sources of advance information than can be used by goalkeepers to stop a penalty kick. Based on an analysis of penalty kicks taken in World Cup tournaments (1982 – 1994), Franks and Harvey concluded that the placement of the non-kicking foot was the earliest reliable predictor of shot direction, approximately 200 – 250 ms before ball contact. This correlates well with the reported movement duration of the instep drive of about 250 ms (e.g. Lees & Nolan, 1998; Levanon & Dapena, 1998; Nunome *et al.*, 2002). Hence, redirecting the penalty kick requires the first adjustments of the kicking movement at least 200 – 250 ms before ball contact, and probably earlier. It must also be taken into account that the adjustments in the kicking movement do not follow instantaneously after the pick up of critical information specifying the alteration of direction. For whole-body actions, McLeod (1987) provided a 190 ms estimate of the visuo-motor interval, although others have reported smaller values (e.g. Caljouw, van der Kamp, & Savelsbergh, 2004). For soccer, Williams and Weigelt (2002) have recently suggested that the visuo-motor interval may be as small as 115 ms. One may speculate, given these constraints on action, that the decision to alter the direction of the shot ought to be made at least 300–500 ms before ball contact, to prevent the degradation of penalty kick performance. Delaying the decision may lead to either a failure to place the ball to the side of the goal opposite to the direction of the goal-keeper's dive (the very reason to employ a keeper-dependent strategy), or to a considerable decrement in the spatial accuracy and/or speed of the ball. Although these speculations match rather closely the critical time of 400 ms that Morya *et al.* (2003) reported, they need further substantiation before any firm conclusion can be drawn.

The keeper-dependent strategy may also be problematic as a penalty-taking method because of the constraints placed on perception (or visual attention) during the run-up. It is now generally accepted that when aiming at a far target, a gaze fixation on the target location precedes the aiming movement (e.g. Vickers, 1993, 1996). It is thought that these anticipatory gaze fixations function to gather useful information about the target location that is necessary to control an aiming movement accurately. Others have argued that a common mechanism underlies both the control of eye movements and aiming movements, suggesting that a gaze fixation on the target ensures accurate control of aiming movements (Land & Furneaux, 1997; Norman & Shallice, 1986). Highly skilled golfers and basketball players are reported to make greater use of information about target location, as indicated by lower frequencies and longer durations of gaze fixations before the initiation of the aiming movement, compared with their less skilled counterparts (Vickers, 1993, 1996). By analysing gaze fixations in various simulated dynamic soccer situations, Helsen and Pauwels (1993a, 1993b) concluded that experts used fewer gaze fixations to more appropriate future locations. Unfortunately, Helsen and Pauwels did not specifically report gaze fixations for the penalty kick; however, one might hypothesize that gaze fixation on a target location near the post might improve the accuracy of the penalty kick. By contrast, a penalty taker who is searching for predictive information about the goal-keeper's intention will fixate the goalkeeper instead of the target location. This may reduce the accuracy of the penalty kick, even if the direction of the penalty kick and thus the kicking action is not altered (i.e. independent of the constraints on action). The same holds true when gaze remains on the ball throughout the kicker's approach, as the participants were instructed to do in the simulation study of Morya *et al.* (2003). The keeper-independent strategy, however, neither curbs the spatial location of gaze fixations nor their timing. It permits an optimal pattern of gaze fixations for accurate aiming of the kick.

In the current study, field penalty-taking performance of intermediate-level soccer players was evaluated in situations that simulated keeper-independent and keeper-dependent strategies. The participants had to aim the ball at one of two targets located to the right and left side of the goal. The target side was always visually specified before the penalty taker started the run-up. In the keeper-independent strategy condition, the participants were told that the prescribed target would not change side. In contrast, in the keeper-dependent strategy condition, the participants were told that during half of the penalty kicks the prescribed target side would change at different times during the run-up. However, the participants were unaware whether during the run-up the prescribed target would actually change. It was hypothesized that, although the keeper-dependent strategy may be advantageous in selecting the side opposite to the goalkeeper's dive, making use of a keeper-dependent strategy would increase the risk for degraded penalty kick performance. This may be attributed to the constraints imposed on action and/or perception. It was anticipated that if constraints on action are decisive, then kicking performance in the keeper-dependent strategy condition, in which the target side *changes* during the run-up, would show a performance decrement relative to the performance in the keeper-independent strategy condition. The magnitude of this effect was expected to increase with a decrease in the time available to alter kick direction. In addition, the minimum time necessary to successfully redirect the kick was assessed. Furthermore, if constraints on perception influence penalty-taking performance, then it was expected that performance in the keeper-dependent strategy condition, in which the target side remains *unaltered* during the run-up, would be negatively affected relative to the performance in the keeper-independent strategy condition. Finally, a comparison of the two keeper-dependent strategy conditions (i.e. target side changes and remains unaltered) would provide an indication as to the relative importance of the two types of constraint.

Methods

Participants

Ten right-footed male participants (mean age = 22.8, $s = 2.7$ years) took part in the experiment. They were students from the Faculty of Human Movement Sciences and had played football in regional amateur leagues of the Dutch football association for, on average, 12 years ($s = 2.7$ years). The participants were therefore considered to be intermediate players. Moreover, four of the participants had regularly taken penalty kicks during competition. They all had normal or corrected-to-normal vision and gave their written consent before the experiment. The participants were treated in accordance with the guidelines of the local ethics review committee.

Apparatus

The participants took penalty kicks on a synthetic grass pitch. The size of the goal (7.32 × 2.44 m) and the distance of the penalty spot from the goal (11 m) were in accordance with FIFA (1997) laws. A "FIFA-approved" ball was used. An orange PVC canvas, which was attached around the goalposts and the crossbar, covered the whole goalmouth and the goalposts. On the PVC canvas white lines were painted that divided it into squares of 30 × 30 cm (Figure 1), with the exception of the two rows in the middle of the goal, the width of which measured 20 cm (i.e. the total width of the canvas measured 7.6 m and included the goalposts). Two target areas that consisted of four squares and measured 60 × 60 cm were marked with a black line. The centres of the target areas were positioned 120 cm above the ground, 120 cm beneath the crossbar, 135 cm from the inner side of each goalpost and 230 cm from the middle of the goal. Normally in competition a penalty taker would aim for the bottom or top corners of the goal, since these are the most difficult locations for the goalkeeper to reach in time. Targets at these locations, however, may have resulted in a relatively high proportion of kicks missing the goalmouth. Hence in the present experiment, to increase the number of shots from which a measure of accuracy could be obtained, the two target areas were positioned more towards the centre of the goal.

To indicate to the participant which of the two target areas to aim for, two identical white lights (100 W each) were placed next to each other, 20 cm above the ground, approximately in the position a goalkeeper would stand – that is, just before the goal line in the middle of the goal (Figure 1). An iron frame around the lights served as protection for the rare occasion the ball would hit the lights. Only one light was switched on at a time. The lights were manually operated by an experimenter who by pressing a button swapped the light that was lit. The experimenter stood at the border of the penalty box 2 m behind the ball (Figure 1). A continuous signal of the button press was amplified and fed into a computer (1000 Hz).

A digital video camera (25 Hz), used to record where the ball hit the canvas, was positioned 3 m behind and 1 m to the side of the ball. The video recordings were analysed off-line. A pin-head microphone was placed 50 cm to the right of the ball to register the impact of the foot against the ball. A second microphone was attached to the PVC canvas to register the impact of the ball with the canvas. The continuous signals of both microphones were amplified and fed into a computer (1000 Hz).

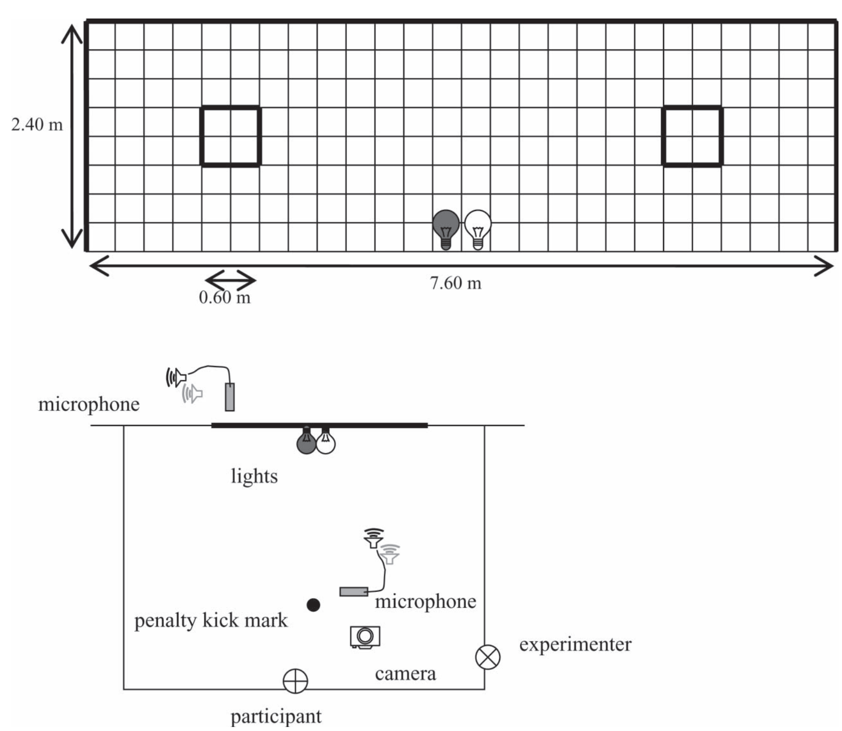

Figure 1. Schematic representation of the experimental set-up showing a front view of the goal with a PVC canvas in the goalmouth with the two target areas and the two lamps in front of it (upper panel), and a top view of the penalty box (lower panel).

A Labview software package was used to synchronize the signals of the experimenter's button press with the two signals of the microphones.

Experimental design

A repeated measurements design was used. Participants took three blocks of penalty kicks in a keeper-independent, a keeper-dependent-unaltered, and a keeper-dependent-changed condition. All participants started with 10 blocked keeper-independent trials, in which the target was indicated before the run-up began. Participants then shot 48 balls in the keeper-dependent strategy condition; half of the trials were keeper-dependent-unaltered trials and the other half were keeper-dependent-changed trials. In the dependent-unaltered condition, participants were told that the target could change during the run-up; however, it did not. In the dependent-changed condition, the target did alter, either early in the run-up, in the middle, or late in the run-up. The order of the trials of the keeper-dependent conditions was randomized. In all three conditions, an equal number of shots was directed to the right and left target areas.

Procedure

After giving their written consent, participants were instructed that the aim of the study was to compare kicking performance under several conditions. Participants then performed a 5 – 10 min warm-up that included penalty kicks using a different goal to that used in the experiment.

In the experiment, participants were instructed to shoot the ball, as accurately as possible, into the target area that was on the opposite side to the light that was switched on. Participants were required to start their run-up at least 3.5 m behind the ball and were asked to take the penalty as they would normally (e.g. with their preferred foot). No other instructions were given. To familiarize themselves with the experimental situation, participants were allowed to take a further three penalty kicks, during which one light was switched on and remained on during the run-up.

Participants then performed the ten trials within the keeper-independent condition. They were told that the prescribed target, indicated by the lights before the start of the run-up, would not change during the run-up. Following the keeper-independent condition, participants completed 48 trials in the keeper-dependent conditions. Participants were informed that during their run-up the prescribed target may or may not change. It was demonstrated that the target change was signalled by switching off the light that was lit at the start of the run-up and the concurrent switching on of the second light. The participants were told that such a switch would occur during half of the trials at different times before ball contact. The experimenter switched the lights off and on when participants were at one of three different distances from the ball: (i) *early* in the approach, when the participants were 2.4 m from the ball; (ii) in the *middle* of the approach at 1.6 m from the ball; and (iii) *late* in the approach at 0.8 m from the ball (a pilot study indicated that at approximately 0.8 m the instep kick begins – that is, the kicking foot contacts the ground for the last time before hitting the ball). A series of small flags were placed on the approach to the ball. Unknown to the participants, three of these flags indicated to the experimenter the distances of 2.4, 1.6 and 0.8 m from the ball. For each participant, the same experimenter operated the light switch.

Data analysis

Penalty-taking performance was assessed from the video recordings. First, the square at which the ball contacted the PVC canvas was determined. If the ball was shot wide of the posts or over the crossbar, it was categorized as a missed shot and excluded from further analysis. For the remaining shots, it was established whether the penalty kick was shot in the correct direction (the side opposite to the side of the lit light). Subsequently, the distance (cm) from the target was obtained by calculating the distance between the centre of the target area and the centre of the hit square. If the ball hit a line or a junction of two lines, the distance between the centre of the target area and the middle of the line or the junction, respectively, was calculated.

The ball flight time was determined by calculating the difference between the moment of foot to ball contact and the moment of ball to canvas impact as indicated by a sudden increase in the auditory signals of both microphones. Finally, the available time to modify the direction of the penalty kick was obtained by calculating the difference between the moment the experimenter pressed the button (the moment at which the lights changed) and the moment of foot–ball contact.

The effect of penalty-taking strategy on performance was assessed by submitting the means and intra-individual standard deviations for the percentage of missed shots, percentage of direction errors, the accuracy of the shots directed to the correct side, the ball flight time, and the ball flight times of the shots directed to the correct side to a three-way (keeper-independent vs. keeper-dependent-unaltered vs. keeper-dependent-changed) analysis of variance (ANOVA) with repeated measures. In the case that the sphericity assumption was violated (i.e. for

ε smaller than 1.0), the Huyn-Feldt adjustments of the P-values are reported (Schutz & Gessaroli, 1987). The *post-hoc* pairwise comparisons were conducted using the Bonferroni correction procedure in order to keep the Type I error rate to the 5% level, and Cohen's d was used as the measure of effect size. Following Cohen (1988), a d of 0.8 defined the minimum threshold for an effect size as large, and was considered to represent a meaningful difference between conditions.

To assess the effect of time of target change within the keeper-dependent-changed condition, the percentage of direction errors, the accuracy of the shots directed to the correct side, ball flight time, and the ball flight times of the shots directed to the correct side were examined by a three-way (early vs. middle vs. late) ANOVA with repeated measures. Furthermore, the percentage of correctly redirected shots as a function of available time to alter the direction of the kick was fitted to a logistic (S-shaped) curve model. This model was then used to determine the time before ball contact at which 50% of the shots were redirected to the correct side of the goal. Finally, the accuracy and ball flight time of the correct and incorrect shots were compared using paired t-tests.

Results

Effects of strategy

Approximately 10% of the balls went wide of the post or over the crossbar (Table I). Yet, for the percentage of missed shots, no significant differences were found across the conditions ($F_{2,18} = 0.58$). However, a three-way ANOVA showed that there was a clear effect of strategy on the percentage of direction errors ($F_{2,18} = 161$, $P < 0.0001$, Table I). *Post-hoc* pairwise comparisons indicated that considerably more shots were placed to the wrong side during the dependent-changed condition as compared to the independent ($P < 0.0001$, $d = 5.88$) and the dependent-unaltered conditions ($P < 0.0001$, $d = 5.12$). The difference between the independent and dependent-unaltered conditions failed to reach significance ($P = 0.04$, $\alpha = 0.019$), but the effect size was large ($d = 0.87$). These findings suggest that not only the need to change the direction of the shot leads to more direction errors, but also being on the look out for changes *might* affect the amount of direction errors.

Table I. Means (and average intra-individual standard deviations) for the dependent measures as a function of strategy.

	Independent	Dependent-unaltered	Dependent-changed
Missed shots (%)	9.3	7.2	10.6
Direction errors (%)	0	1.5	25.4
Accuracy of correct shots (cm)	88 ± 32	93 ± 44	98 ± 44
Ball flight time (ms)	549 ± 43	558 ± 35	560 ± 39
Ball flight time of correct shots (ms)	549 ± 43	556 ± 35	561 ± 40

Examination of the effect of strategy on the accuracy of the penalty kick was performed by comparing the distance from the target for the three conditions. To guard against inflating inaccuracy due to direction errors, only the shots to the *correct* side were included in the analysis. The three-way ANOVA did not reveal significant differences between conditions ($F_{2,18} = 1.97$; Table I). A similar three-way ANOVA on the average intra-individual standard deviations of the distance from the target of the shots indicated significant differences between conditions ($F_{2,18} = 6.13$, $P < 0.01$). As can be seen from Table I, the variability in accuracy during the independent strategy condition was lower than during both dependent strategy conditions (P's < 0.01, $d = 1.59$ and $d = 1.31$). Hence, paying attention to a contingent change of target appears to increase the variability in the accuracy of the shots independent of direction errors, even when the prescribed kicking direction did not change during the run-up.

Finally, three-way ANOVAs on the means and average intra-individual standard deviations of ball flight time did not reveal significant differences between strategy conditions ($F_{2,18} = 0.62$ and $F_{2,18} = 0.69$, respectively); nor were any found for the means and average intra-individual standard deviations of ball flight time for the correct shots only ($F_{2,18} = 0.63$ and $F_{2,18} = 0.65$, respectively; Table I).

Effects of the time of the target change

A three-way ANOVA showed that manually switching off and on the lamps at three different distances brought about the desired effects on the time available to alter the direction of the kick ($F_{2,18} = 383$, $P < 0.001$, all d's > 2.0; Table II). As a consequence of participants approaching the ball at different speeds, the average time available to alter the direction of the kick was variable among participants. Table II indicates that the percentage of direction errors increased when the time available to alter the direction of the kick decreased, which was confirmed by a significant three-way ANOVA ($F_{2,18} = 28.3$; $P < 0.0001$). *Post-hoc* pairwise comparisons indicated that the percentage of direction errors was larger when the change of target was signalled late as compared to early ($P < 0.0001$, $d = 3.48$) or during the middle of the run-up ($P < 0.001$,

Table II. Means (and average intra-individual standard deviations) for the dependent measures as a function of the time of target change.

	Early	Middle	Late
Time available to redirect the shot (ms)	948 ± 122	704 ± 101	396 ± 70
Direction errors (%)	3.3	12.8	57.9 ± 48.9
Accuracy of correct shots (cm)	90 ± 40	91 ± 36	134 ± 38
Ball flight time (ms)	555 ± 40	554 ± 28	562 ± 35
Ball flight time of correct shots (ms)	561 ± 31	558 ± 27	568 ± 29

$d = 2.66$). The difference between the early and middle conditions was not significant and the effect size was medium ($P = 0.08$, $d = 0.76$).

Using a least squares iterative fit procedure, the minimum time required for participants to alter kick direction was derived by curve fitting the percentage of shots that were redirected successfully for the times prior to ball contact at which the prescribed target changed, to a logistic (S-shaped) function of the form where y is the proportion of redirected kicks, x is the time available, c is the 50% point and k is a measure of the slope at this point:

$$y = \frac{1}{1 + e^{-k(c-x)}}$$

The time available at which 50% of the shots were successfully redirected can be regarded as the minimum time necessary to successfully alter the direction of the kick (for similar reasoning, see Oudejans, Michaels, Bakker, & Dolné, 1996; Peper, Bootsma, Mestre, & Bakker, 1994). To this end, the range of times available (x) was obtained by grouping all trials from all participants in the dependent-changed condition in intervals of 50 ms. The percentage of redirected shots for each 50 ms interval was then determined. These are plotted in Figure 2 together with the estimated logistic function ($r^2 = 0.89$, $c = 0.414$, $k = 5.83$). On average, the target change in the late condition occurred at 396 ms ($s = 70$ ms) before contact (Table II). Trials in which the target changed very close to ball contact (< 150 ms), when kickers will not be able to redirect their shot, were rare (i.e. only two trials). This might have contributed to the estimated logistic function never reaching zero. Further analyses, fitting alternative functions to the data, did produce comparable but slightly shorter times for the 50% point of redirected shots. These alternative analyses included an increase in the time intervals to 100 ms, resulting in a 50% point at 392 ms ($r^2 = 0.90$), and estimating linear and second-order polynomial functions, resulting in 50% points at 399 ms ($r^2 = 0.77$) and

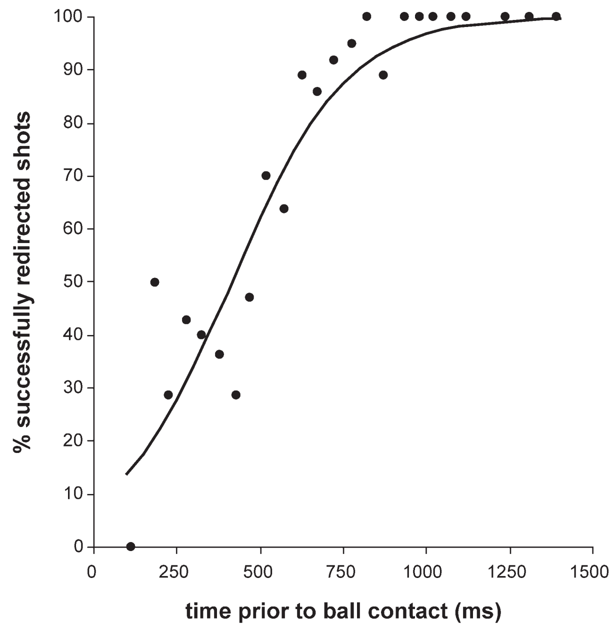

Figure 2. The logistic curve showing the percentage of redirected shots as a function of the time available before ball contact.

385 ms ($r^2 = 0.88$), respectively. To some extent, the 414 ms derived from the logistic curve fit might thus be a conservative estimate. Hence, the findings suggest that the *minimum* time required to successfully alter the direction of the kick is approximately 400 ms. However, even with approximately 600 ms available (at which 75% of the kicks were successfully redirected; Figure 2), kicking performance was still not perfect. The earliest unsuccessfully redirected shot occurred when the target change was signalled at 773 ms before the ball was hit, and the latest successful redirected kick was signalled at 174 ms before ball contact.

To examine the effect of time of target change on the accuracy of the shot, the distance from the target of only the successfully redirected shots was compared for the early, middle and late conditions (Table II). A three-way ANOVA showed that the accuracy of the successfully redirected shots was significantly reduced when there was less time available to alter kick direction ($F_{2,18} = 5.28$, $P < 0.05$). *Post-hoc* pairwise comparisons indicated a significant difference only between the late and middle conditions ($P = 0.016$, $d = 1.05$). The difference between the late and early conditions failed to reach significance, but the effect size was large ($P = 0.028$, $\alpha = 0.019$, $d = 1.08$). A similar three-way ANOVA on the standard deviation of the accuracy of the successfully redirected shots showed no significant effect of the time of target change ($F_{2,14} = 0.46$; for two participants, the standard deviation could not be calculated because they performed too few successfully redirected shots).

Finally, the accuracy of the successfully redirected shots was compared to the accuracy of the shots that were placed to the wrong side (i.e. shots that were not redirected, although a target change indicated a redirection). The accuracy of a shot placed to the wrong side was defined as the distance from the incorrect (original) target. A paired t-test showed that the shots placed to the wrong side (mean value = 83, $s = 41$ cm) were significantly more accurate than those that were successfully redirected (mean value = 98, $s = 44$ cm; $t_9 = 4.95$, $P < 0.01$), but the effect size was only medium ($d = 0.35$). Analysis of the standard deviations of the accuracy of shots showed no significant differences between the successfully redirected shots and the shots placed to the wrong side ($t_9 = 0.99$). In short, altering the direction of the kick late in the run-up leads to a significant decrement in the accuracy of that shot relative to the shots from which the direction erroneously remained unaltered (but thr effect size was not large). The accuracy of the shots to the wrong side was comparable to the accuracy of the shots in the keeper-independent and keeper-dependent-unaltered conditions (Table I). This *might* suggest that the reduction in accuracy of the successfully redirected shots is primarily due to the modification of the kicking action instead of being on the look out for target changes.

Three-way ANOVAs on the means and average intra-individual standard deviations of ball flight time did not indicate differences between time of target change conditions ($F_{2,18} = 0.47$ and $F_{2,18} = 0.96$, respectively). Furthermore, no significant differences were found for the means and average intra-individual standard deviations of ball flight time for the successfully redirected shots only ($F_{2,18} = 0.59$ and $F_{2,14} = 0.07$, respectively; Table II). In addition, the paired t-tests that compared the ball flight times of the successfully redirected shots (mean value = 41, $s = 17$ ms) and the shots placed to the wrong side (mean value = 29, $s = 10$ ms) failed to reach significance for both the means and the average intra-individual standard deviation ($t_9 = 0.67$ and $t_9 = 2.10$, $P = 0.06$, respectively). The latter had a large effect size ($d = 0.86$), which might suggest that variability of ball flight time was greater for the successfully redirected shots.

Discussion

A penalty taker can employ either a keeper-independent or a keeper-dependent strategy. By adopting the keeper-dependent strategy, the player decides on the target location before the start of the run-up and ignores the movements of the goalkeeper. The expert goalkeeper, in an effort to exert an advantage, extracts information from the penalty kicker's actions during the run-up and may as a result make an accurate judgement about which side the penalty kick is to be placed (Franks & Harvey, 1997; Savelsbergh, van der Kamp, Williams, & Ward, in press; Savelsbergh, Williams, van der Kamp, & Ward, 2002; Williams & Burwitz, 1993). Consequently, to ensure that the ball remains beyond the reach of the goalkeeper, the penalty taker who makes use of the keeper-independent strategy should place the ball relatively accurately (e.g. the bottom or top corners of the goal) and strike it with power. By contrast, if the player uses the keeper-dependent strategy and correctly anticipates the side the goalkeeper intends to dive, they can place the ball to the side opposite of the goalkeeper into the empty part of the goalmouth. If successful, the keeper-dependent strategy can raise some of the constraints on the spatial accuracy and speed of the shot. Hard data on this issue is lacking, but it might be deduced from the observation that in 70% of penalty kicks goalkeepers choose the wrong side that many penalty kickers anticipate the goalkeeper's intention and actions (Bootsma & Savelsbergh, 1988; see also Kuhn, 1988).

The results of the present study reveal caveats in approaching the penalty kick with a keeper-dependent strategy, the most important of which is the time remaining to alter the direction of the kick. Clearly, the nearer the kicker comes to ball contact, the higher the probability of placing the ball to the same side as the diving goalkeeper. Although one of the soccer players managed to successfully change the direction of one shot with only 173 ms available, overall the participants required at least 400 ms (see Figure 2, 50% point) to alter kick direction. Perfect penalty-kicking performance was still not reached if the players had 600 ms available (Figure 2, 75% point); indeed, one participant failed to redirect the ball 770 ms before ball contact. Moreover, even if the penalty taker was successful in redirecting the ball late in the run-up, this was at the expense of shot accuracy (i.e. the ball was hit an additional 50 cm away from the target centre; see Table II). Thus, the participants were not able to fully modify the kicking action shortly before they hit the ball. Redirecting the shot, however, did not significantly affect the ball speed, although it might have increased the trial-to-trial variability in ball speed relative to shots that were not altered in direction.

The general conclusion, that the penalty takers required a minimum amount of time to be able to redirect the penalty kick, is similar to that proposed by Morya *et al.* (2003) in their computer simulation study. However, the present, more ecologically valid on-field simulation study did not concur with the critical times reported by Morya and colleagues. The times found in the present study are almost twice as long, suggesting that the keeper-dependent strategy is less effective than first thought. The message to the penalty taker then would be not to try to redirect the shot in reaction to the goalkeeper's movements, as even a penalty that is successfully redirected late in the run-up may be less accurate than when the goalkeeper's actions arew not taken into account.

The applicability of the reported findings to "real-life" penalty taking should be viewed with caution. Unlike the movements of a goalkeeper, the switching off and on of the lights is an abrupt event that only simulated the goalkeeper's dive. Keller, Hennemann and Alegria (1979; see also Miller, 1996), for example, made the casual observation that before diving a goalkeeper sometimes makes preparatory movements with the side of the body opposite to the side of the final spring to the ball. It might turn out that the use of these sources of advance information may increase the time available to modify the direction of the penalty kick, and consequently lower the risk associated with the keeper-dependent strategy. On the other hand, lights switching off and on are unambiguous information sources, which, depending on the goalkeeper's proficiency in concealing (or fooling) their movement intentions, may be easier to detect than the goalkeeper's movement intention. Finally, it also remains unclear to what extent a moving goalkeeper (the current study simulated a stationary goalkeeper in the keeper-independent strategy condition) can entice the penalty taker into a change of strategy to a keeper-dependent strategy.

The relatively poorer quality of the penalty kicks in terms of shot placement (i.e. direction errors and the decrement in accuracy) associated with the keeper-dependent strategy could be due to constraints imposed upon action and/or perception. The decrement in performance was mainly observed for those kicks that actually required a change in shot placement. Hence, the main impeding factor of the keeper-dependent strategy appears to be the insufficient time to alter the kicking action. Future kinematic measurements must show what exactly the limiting parameters are that stand in the way of a successful change in the direction of the kick. A major issue in such analyses would be to establish whether these involve (re-)planning, control or both (e.g. Glover, 2004). In prehension, for instance, Paulignan, MacKenzie, Marteniuk and Jeannerod (1991) demonstrated a rapid adjustment of reach and grasp movements when target position was perturbed *after* the initiation of the movement. Although the total movement duration only increased by 100 ms, the corrections of the wrist trajectory were not completed until 250 – 300 ms after the perturbation. In contrast, changes in target location *before* movement onset have been found to result in much longer delays, such that movement time may increase by up to 300 ms (e.g. Soechting & Lacquaniti, 1983). The difference in the two studies is that with perturbations during the execution of the movement, "automatic" adjustments may arise from the on-line coupling between visual information about the new target location and kinaesthetic information generated by the movements themselves. Such on-line adjustments can even be observed if target displacement is not consciously perceived (Goodale, Pelisson, & Prablanc, 1986). In contrast, a location perturbation before the movement has started is likely to produce an entire re-planning of the movement that takes much more time than on-line adjustments (Paulignan *et al.*, 1991; Pisella *et al.*, 2000). Therefore, a more fine-graded experimental control over the exact time of change of target location (i.e. goalkeeper movement) accompanied by kinematics of the kicking action may provide insight into whether the observed decrement in the quality of the penalty kicks is due to insufficient time available to re-plan the kicking movements or caused by unfinished "automatic" control processes.

The current study remains equivocal *vis-à-vis* the constraints that are imposed on perception (or visual attention) during a keeper-dependent strategy. There was an indication of kicking performance being adversely affected by the keeper-dependent strategy relative to the keeper-independent strategy, even when the perceived goalkeeper's intention remained unchanged during the run-up (i.e. independent of changes in the penalty taker's action). The keeper-dependent-unaltered condition resulted in a slight, but *meaningful* increase in involuntary direction errors, and a higher variability in the accuracy of the shots compared with the keeper-independent condition. One interpretation would be that directing visual attention to the lights (i.e. "goalkeeper") incapacitated or prevented the gaze fixation at the target location. If a gaze fixation at the aimed target preceding the shot is compulsory, then this would increase the likelihood of an inaccurate shot placement (Vickers, 1993, 1996) or a shot to away from the desired target (Land & Furneaux, 1997). However, the accuracy of the erroneously unaltered shots during the dependent-changed condition, where the constraints on perception and action are like those for the dependent-unaltered condition, was not degraded. By contrast, the higher accuracy of the erroneously unaltered shots relative to the correctly redirected shots may suggest that the constraints on perception are of relatively minor importance. Clearly, an assessment of the spatial as well as temporal characteristics of the gaze fixation patterns during the penalty kick is needed to resolve these apparently contradictory observations (F.C. Bakker *et al.*, submitted). In a "real-life" penalty scenario, involuntary direction errors and/or a larger variability in penalty placement may enhance the probability of the goalkeeper saving the penalty or an outright miss.

What does the present study offer to the penalty taker? Scoring from the penalty spot is not as easy as it seems, particularly when it is going to decide the outcome of the match. The penalty taker faces up to a goalkeeper who seeks to bring about a loss of concentration on the part of the penalty taker. Similarly, the verbal and non-verbal behaviour from the opponents huddled around the penalty box, and sometimes the behaviour of team-mates, may also be causes for distraction. Additionally, there is the presence of spectator pressure from the crowd, not to mention the millions watching at home in the case of professional soccer. Distraction and high-pressure exposure may seriously hamper the shooting action. The current study does not directly help the penalty taker to overcome these adversities. However, paramount in dealing with distracting and pressure-packed situations is automaticity. Modern theories of skill acquisition and expert performance concur that it is not so much the attention being diverted, but conscious attempts to exert control over the action that lead to failure under pressure (Beilock & Carr, 2001; Masters, 1992, 2000; Willingham, 1998). Recent observations of experienced players' golf putting and football dribbling skills have hinted at the possibility that distracting conditions (i.e. secondary tasks) might even enhance instead of degrade performance (Beilock, Bertenthal, McCoy, & Carr, 2004; Beilock, Carr, MacMahon, & Starkes, 2002). Beilock and Carr (2004) suggested that elite performers should adopt self-distraction techniques in high-pressure situations, if the perceptual-motor skill is fully automated. Until empirical evidence has been reported on the effect of the keeper-independent and keeper-dependent strategies under psychological stress, generalizations to "real-life" penalty taking must be made with caution. Nevertheless, the current study does provide an indication of what strategy a penalty taker may or may not wish to implement and automate. In this respect, each penalty taker must weigh the benefits of the keeper-dependent strategy (i.e. a greater chance of successfully placing the ball to the opposite side of the goalkeeper's dive) against its drawbacks (i.e. the continual risk of erroneously placing the ball to the same side as the goalkeeper, a substantial reduction in the accuracy of ball placement). Yet, for the penalty taker it seems unwise to regard the penalty situation as a waiting game. The shorter before the strike the player decides to alter the direction of the kick, the more unlikely the penalty will be successful. Similarly, it appears unwise for goalkeepers to commit themselves to one or the other side earlier than 600 ms before the ball is hit. Waiting longer increases the chance of a weak shot and provides the opportunity to extract information from the shooter's action to which side to dive, a strategy which has shown to be prevalent for some of the more proficient penalty stoppers among goalkeepers (Savelsbergh *et al.*, 2002, in press).

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