Sports Biomechanics
June 2011; 10(2): 125–134

Early visual cues associated with a directional place kick in soccer

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(Received 2 November 2010; accepted 2 February 2011)

Abstract
The purpose of this paper was to establish postural cues in kicking that may be of use to goalkeepers. Eight male soccer players (age 20.5 ± 1.1 yrs; height 1.78 ± 0.053 m; mass 75.18 ± 9.66 kg) performed three types of kick: a low side-foot kick to the left hand corner of the goal, a low side-foot kick straight ahead, and a low instep kick straight ahead. Kicks were recorded by an optoelectronic motion analysis system at 240 Hz. At kicking foot take-off (about 200 ms before ball contact) the variables which were significantly different and could act as cues were support foot progression angle, pelvis rotation, and kicking hip and ankle flexion. The support foot progression angle was considered to be the most valuable of these variables as its angle coincided with the direction of ball projection. The other variables were less clear in their interpretation and so less valuable for a goalkeeper to use for decision making. Cues appearing after support foot contact were thought unlikely to be of value to a goalkeeper in their decision making. These include kicking leg knee flexion angle, and support leg shank and thigh angles.

Keywords: *Biomechanics, penalty kick, decision making*

Introduction

The penalty kick in soccer is a major set piece which offers the opportunity to score goals and with penalty shoot-outs common in major tournaments, to win games. Two types of strategy used by goalkeepers have been suggested by Khun (1988). These were an 'early strategy' and 'late strategy'. In the former, the goalkeeper dived before the ball was hit while in the latter the goalkeeper dived at contact or after the ball was hit. In European club matches Khun (1988) reported that 77% of dives were early while only 23% were late. However, the late strategy dives were more successful with a 60% chance of success compared to only 8% success for the early strategy. A trend for the preferred use of the late strategy was suggested by Morya et al. (2005) based on evidence from club matches and from the 2002 World Cup where around 40% of the dives were late. Although the success rate of these dives was less (around 36%) than that reported by Khun (1988) they were more successful than the early dives which still had a low success rate of around 11%. Thus, the late strategy would seem to be a beneficial strategy for goalkeepers to use. When using a late strategy, the

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ISSN 1476-3141 print/ISSN 1752-6116 online © 2011 Taylor & Francis
DOI: 10.1080/14763141.2011.569565

goalkeeper must look for early visual cues from the kicker's actions before ball contact in order to help decision making.

When taking a penalty two types of kick are commonly used depending on the desired outcome of the kick. The instep kick is used when a faster ball speed is required while the side-foot kick is used where more precision is required. In a typical penalty kick, the player may decide to kick the ball powerfully or kick the ball more accurately. Sixteen out of the 17 penalty kicks in the 2006 World Cup Tournament were taken using the side-foot technique, indicating the importance of accurate placement over ball speed. The side-foot kick, and its comparison with the instep kick, has been the subject of recent biomechanical study (Levanon & Dapena, 1998; Nunome et al., 2002). The ball speed is higher for the instep kick than the side kick (Levanon & Dapena, 1998; Nunome et al., 2002). Generally for a side-foot kick which is kicked straight ahead, players tended to orientate the pelvis towards the kicking leg side and to externally rotate the kicking leg and foot in order to orientate the side of the foot to the intended direction of ball travel. These changes in the orientation of segments as the kick unfolds could provide postural cues for the goalkeeper to decide on the likely direction the ball will take.

The ability of goalkeepers to use early postural cues is rather important in sports where the ball velocity dictates the decisions that must be made in advance of the action (Savelsbergh et al., 2002). If the goalkeeper could employ an anticipatory method of where the ball is likely to be kicked, there would be a greater chance that the penalty kick could be saved. Only one study has made a suggestion for a cue for goalkeepers in order to increase their chances. Using notational analysis methods, Franks and Harvey (1997) studied all penalty kicks in World Cup competitions from 1982–1994 and concluded that the placement of the support foot 200–250 ms before ball contact was the earliest reliable predictor of where the shot was likely to result. Although gaze behaviour has been the subject of recent investigation (Dicks et al., 2010a), no study has investigated this possibility, or indeed the existence and timing of other postural cues that may be available to goalkeepers. Therefore, the purpose of this paper is to establish the postural and timing differences that occur between kicks of different types and directions in order to establish whether these differences may be of use to goalkeepers as early visual cues.

Method

Participants

Eight male soccer players (age 20.5 ± 1.1 yrs; height 1.78 ± 0.053 m; mass 75.18 ± 9.66 kg) volunteered to participate in this study. Each gave their informed consent following approval from the Institution's Ethics Committee. All participants were skilled at kicking and played in top amateur or semi-professional clubs. All were injury free, right footed and kicked the ball with the right foot. Retro-reflective markers (25 or 14 mm diameter) were placed on the participant's lower limbs. Marker clusters, each made up of four markers attached to a rigid thermoplastic shell, were firmly taped on the right and left shank and thigh. Separate markers were attached to the pelvis (left and right anterior superior iliac spine, and sacrum half way between the posterior superior iliac spines) and to each foot (left and right lateral and medial malleolus, heel and fifth metatarsal head). Before data collection, eight calibration markers were added at the left and right greater trochanter (2), iliac crest (2) and left and right medial (2) and lateral (2) knee epicondyle. These markers were removed before kicking commenced. Four markers were placed on the ball to record ball speed.

Data collection

All kicks were made in an indoor environment with a soccer ball of standard size and pressure kicked into a goal mouth with net and simulated the penalty kick. Due to laboratory constraints, the goal mouth was smaller than standard size but located closer to the kicker such that kicks made to the corner of the goal were at the same angle as would be required in a full size configuration. Because of these limitations it was only possible to perform kicks straight ahead and to the kicker's left side. Participants were given an opportunity to warm-up and practice maximal instep kicks before data recording began. Participants were asked to perform three types of kick: a low side-foot kick to the left hand corner of the goal (Side Angled), a low side-foot kick straight ahead (Side Ahead), and a low instep kick straight ahead (Instep Ahead). The instep kicks were performed last in order to avoid the effects of fatigue (Apriantono et al., 2006). Participants were allowed to rest between sets, but also between kicks if required. A wood target (0.5 m x 0.5 m) was located in the goalmouth to assist participants' aim. Although accuracy was not recorded, pilot work established that this sized target could be hit with a minimum of 80% of the kicks. Participants were asked to approach the ball with an angled approach using two steps, using the same approach angle and distance for all kick types. The ball was placed so that the support foot landed on a force platform (Kistler, model 9287B, Winterthur, Switzerland) with force data sampled at 960 Hz. The 3D position of each marker was simultaneously recorded at 240 Hz using an eight camera opto-electronic motion capture system (Proreflex, Qualysis, Gothenburg, Sweden). A total of 10 successful trials were collected and analysed for each of the three conditions.

Data analysis

The 3D motion data were tracked (QTM, Qualysis, Gothenburg, Sweden) and exported to a 3D motion analysis package that computed joint kinematics and kinetics (Visual3D, C-Motion, Rockville, USA). A 15 Hz fourth-order Butterworth low pass filter was used to smooth all displacement data. A 40 Hz fourth-order Butterworth low pass filter was used to smooth force data. The laboratory and segment local coordinate systems were defined as illustrated in Figure 1. The local coordinate system was defined at the proximal joint centre for each segment. For the foot, the proximal joint centre was located mid-way between the medial and lateral malleolus markers and its distal joint centre was located 0.05 m from the fifth metatarsal towards the middle of the foot in the plane of the three markers defining the foot (medial and lateral malleolus, and fifth metatarsal). For the shank, the proximal joint centre was located mid-way between the medial and lateral knee markers, while the distal joint centre was at the ankle as defined for the foot. For the thigh, the proximal joint centre was located at a distance of 0.1 m from the hip marker towards the middle of the thigh in the plane of the three markers defining the thigh (medial and lateral knee, and hip). The distal joint centre was at the knee as defined for the shank. For the pelvis, the proximal joint centre was located mid-way between the iliac crest markers and the distal joint centre was located mid way between the thigh proximal joint centres. For all segments the positive Z (int/ext rotation) axis was defined in the direction of distal to proximal joint centres. The positive Y (ab/adduction) was defined as perpendicular to the Z axis and the plane of the segment (as determined by the three or four markers defining the segment), while the X (flexion-extension) axis was defined as the vector cross product of Y and Z.

Variables chosen to represent the kick were the progression angle of the support foot during foot contact in the X-Y plane relative to the laboratory Y axis; flexion-extension (X axis) rotations of the kicking (right) hip, knee and ankle joints; ab-adduction rotations (Y axis

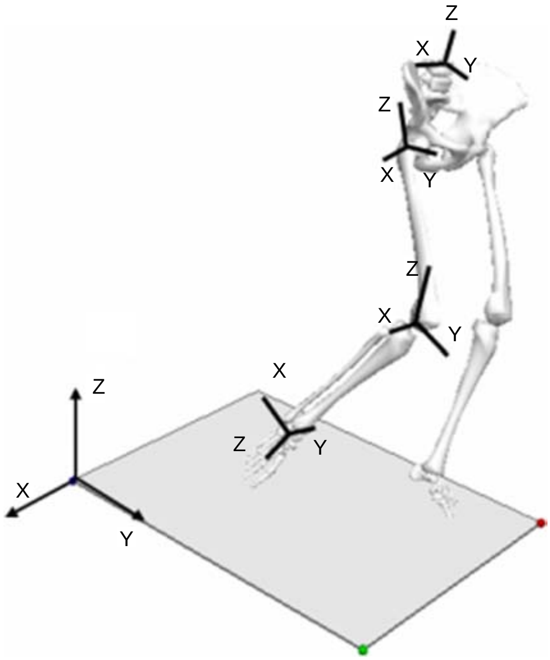

Figure 1. Laboratory and segment coordinate systems (see text for further details).

rotations) of the thigh and shank; internal-external rotations (Z axis) of the pelvis, all relative to the laboratory. Joint angles were obtained from an X-Y-Z Cardan rotation sequence (Lees et al., 2010). In addition the timing of the phases, as described below, was recorded.

Data reduction

Each trial was defined by the instances of kicking defined by Nunome et al. (2002) as kicking (right) foot take-off (KFTO), support (left) foot touch-down (SFTD), maximum hip extension (MHE), minimum knee flexion (MKF), and ball contact (CONTACT) determined from kinematic or force platform data as appropriate. The period from KFTO–CONTACT was termed the event duration. The period KFTO–MHE was termed the back swing phase; the period MHE–MKF the leg cocking phase; and the period MKF–CONTACT the leg acceleration phase. For graphical presentations, the event duration was normalised to 101 points and a mean produced by averaging across trials and participants.

Statistical analysis

A One-Way, repeated measures ANOVA was performed on selected variables to test differences between the three conditions of Instep Ahead, Side Ahead, and Side Angled. Post-hoc analysis was performed using pair-wise comparisons with the alpha level adjusted for the number of comparisons. A level of significance of $p < 0.05$ was used.

Results

Ball speed was recorded as given in Table I and was significantly different in each condition. Due to the requirements of accuracy and the production of a low trajectory, the ball speeds were lower than commonly reported in the literature. A speed-accuracy trade off has been demonstrated for lofted instep kicks by Lees and Nolan (2002) and the speeds reported here for the instep kick are similar to their study.

The event duration (KFTO–CONTACT) was shorter for the instep kick than both of the side-foot kick conditions (Table I) but not significantly. The leg cocking phase was shorter for the Instep Ahead condition while the leg acceleration phase was longest for the Side Angled condition. The leg cocking phase was the longest of the three phases (Instep Ahead = 47.2%, Side Ahead = 56.8%, Side Angled = 49.3% of event duration).

The support foot progression angle is presented in Figure 2. After a small adjustment as the foot settled onto the ground, the orientation of the foot remained constant with the Side Ahead kick orientated closer to the ahead direction while the Side Angled kick was orientated further away (i.e. abducted). The mean (±*SD*) stabilised progression angles were Instep Ahead = 6.4±8.9°, Side Ahead = 1.9±11.2° and Side Angled = 19.9±9.9° and were significantly different ($F_{(2,14)} = 93.6$, $p < 0.05$) with a post-hoc analysis revealing that there were significant differences between Instep Ahead and Side Angled, and Side Ahead and Side Angled.

The orientation (retraction-protraction) of the pelvis around its Z axis is presented in Figure 3. The pelvis was retracted on the kicking side for all kick types, but was retracted further for the Side Ahead kick. While the pelvis protracted through the movement in both the Instep Ahead and Side Angled kicks, it retracted for the Side Ahead kick to externally rotate the kicking leg. At SFTD mean orientation angles were Instep Ahead = -13.3°, Side Ahead = -22.7° and Side Angled = -9.6°. The Side Ahead kick was significantly different from Instep Ahead and Side Angled kicks ($F_{(2,14)} = 37.1$, $p < 0.05$). At CONTACT mean orientation angles were Instep Ahead = -3.8°, Side Ahead = -28.0° and Side Angled = -5.7°. The Side Ahead kick was significantly different from Instep Ahead and Side Angled kicks ($F_{(1.34,7.940)} = 66.7$, $p < 0.05$).

The orientation of the kicking leg hip, knee and ankle joints are given in Figures 4–6 respectively. The hip was more extended throughout the kick in the instep kick compared to the side kicks. At KFTO the mean extension angles were Instep Ahead = 11.8°, Side Ahead = 5.8° and Side Angled = 3.0°. The Instep Ahead kick was significantly different from the Side Angled and Side Ahead kicks ($F_{(2,14)} = 4.760$, $p < 0.05$). The knee showed little difference between kick types during the early part of the movement but did show a

Table I. Ball speed, phase and event durations, and phase duration as a percentage of event duration ($M \pm SD$).

	Ball speed[a] (m/s)	Backswing[d] (ms)	Leg cocking[b] (ms)	Leg acceleration[c] (ms)	Event duration[d] (ms)
Instep ahead	17.5±2.2	55.5±28.3	97.3±19.4	53.0±7.7	205.8±38.9
		27.0%	47.3%	25.7%	
Side ahead	14.5±1.4	40.6±24.5	123.0±15.8	53.0±5.9	216.6±31.1
		18.7%	56.8%	24.5%	
Side angled	14.1±1.7	47.9±31.0	107.1±30.2	62.1±8.6	217.1±34.1
		22.1%	49.3%	28.6%	
Mean phase%		22.6	51.1	26.3	

Note: The event duration is the sum of the three phase durations.; [a] Instep ahead > Side ahead > Side angled, $p < 0.023$; [b] Instep ahead < Side ahead, $p < 0.001$; [c] Side ahead < Side angle, $p = 0.004$; [d] no significant differences.

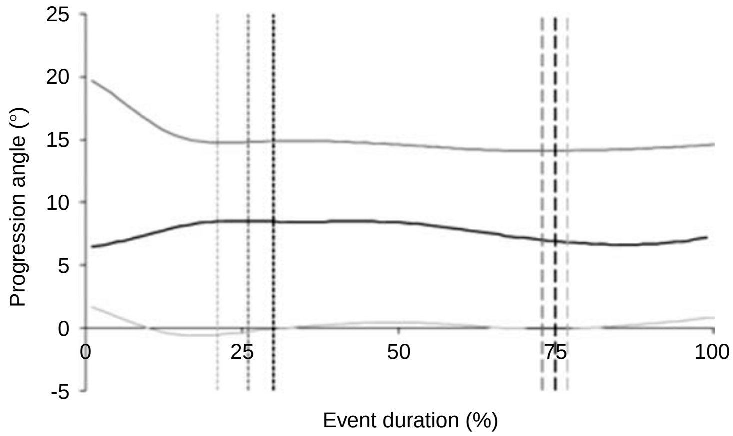

Figure 2. Mean progression angle of the support foot in the X-Y plane relative to the Y axis. Positive values indicate foot abduction. The event duration is from kicking foot take-off (KFTO) to ball contact. The dashed vertical lines indicate maximum hip flexion (~25%) and minimum knee flexion (~75%). (Black – Instep Ahead; Dark Gray – Side Angled; Light Gray – Side Ahead).

greater knee flexion for the instep kick and was more extended at ball contact, but this was not significant. The ankle was in a less flexed position in the instep kick than the side kicks and this difference remained throughout the kick. At RFTO the mean flexion angles were Instep Ahead $= 42.3°$, Side Ahead $= 70.4°$ and Side Angled $= 60.2°$. The Instep Ahead kick was significantly different from the Side Angled and Side Ahead kicks ($F_{(2,14)} = 24.504$, $p < 0.05$).

The shank and thigh were abducted at KFTO (Figure 7 and 8) but these were not significantly different. Shank and thigh abduction increased in the Instep Ahead and Side Angled but remained unchanged for the Side Ahead kick as the kick progressed.

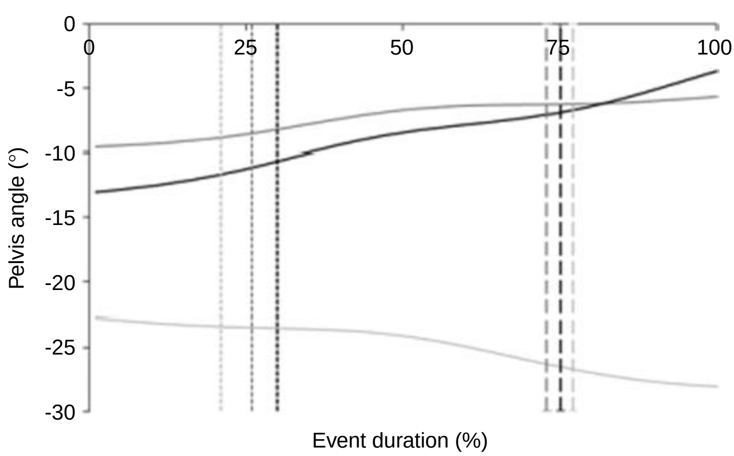

Figure 3. Mean pelvis rotation in the X-Y plane relative to the Y axis. Negative angle represents pelvis retraction on the kicking leg side.

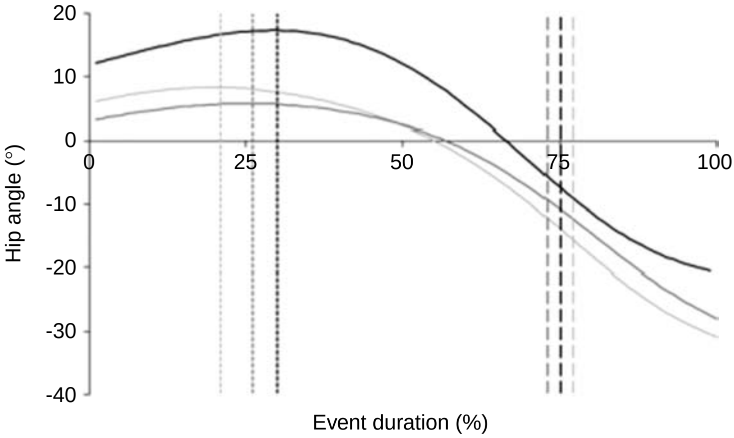

Figure 4. Mean flexion-extension (X axis) angles for the kicking leg hip. Positive values indicate hip extension.

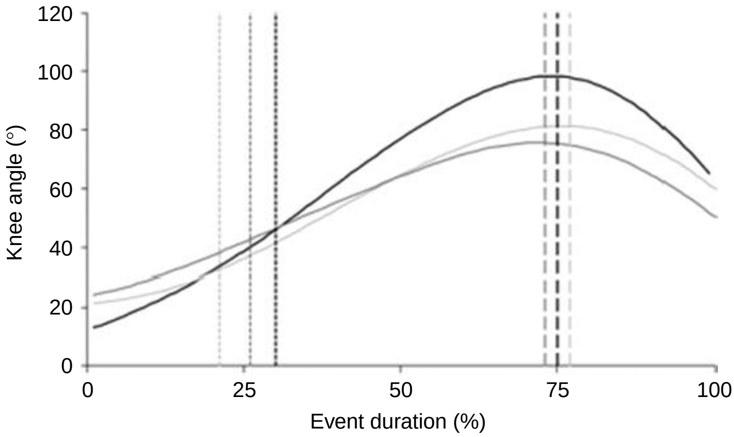

Figure 5. Mean flexion-extension (X axis) angles for the kicking leg knee. Positive values indicate knee flexion.

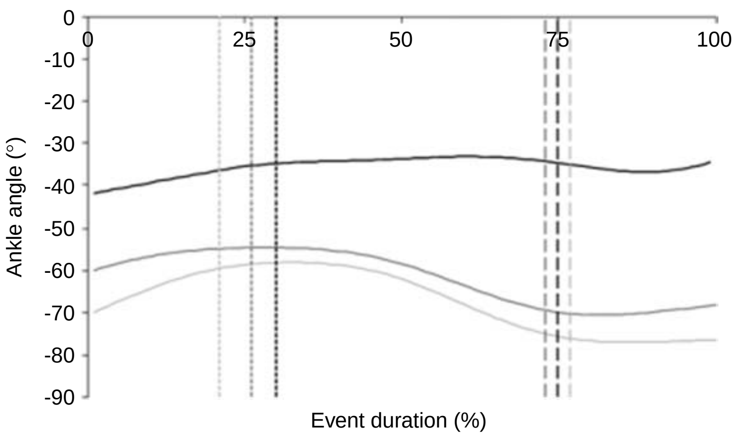

Figure 6. Mean flexion-extension angles for the kicking leg ankle. Negative values indicate ankle flexion.

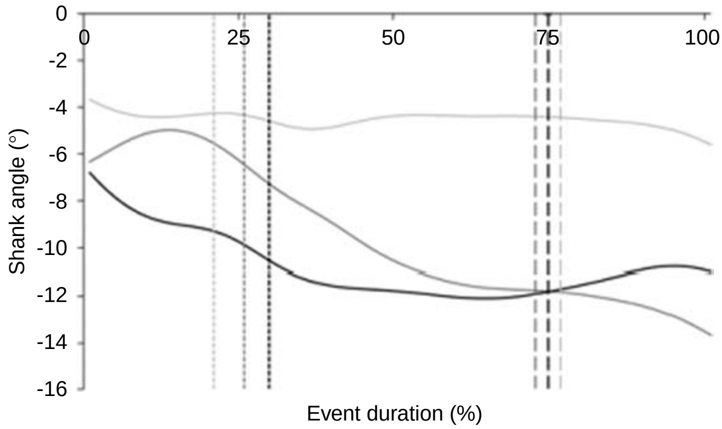

Figure 7. Mean shank abduction angle for the support leg relative to the Z axis. Negative values indicate abduction relative to the knee joint.

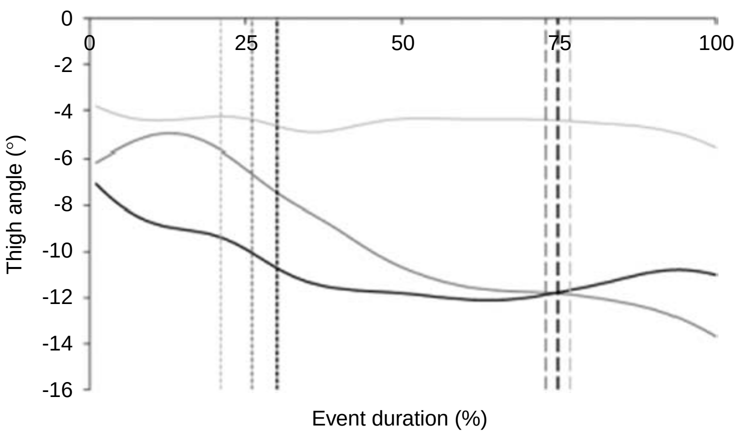

Figure 8. Mean thigh abduction angle for the support leg relative to the Z axis. Negative values indicate abduction relative to the hip joint.

Discussion

Goalkeepers may use a predetermined strategy based on knowledge of the opponent or visual cues at the start of the run up to determine dive direction but this study is concerned with whether there is any information in the later stages of the kick just before ball contact that goalkeepers can utilise. Biomechanical research (Levanon & Dapena, 1998; Nunome et al., 2002) has shown that kick type and direction are determined by actions occurring after the kicking foot has left the ground (KFTO) so this provides a window for the action to be modified and for this modification to be detected by the goalkeeper.

At KFTO differences were evident in posture which might be useful cues to the goalkeeper. One is the progression angle of the support foot which is clearly defined at support foot contact but an indication of its future position is given at KFTO. The angled kick is associated with a greater progression angle of the support foot. Thus, it appears that the support foot is orientated in the direction of ball travel. We were not able to investigate an angled kick to the kicker's right side due to restrictions in laboratory space but we would expect for such a kick the foot would be angled in that direction, i.e. the progression angle would be negative. A second variable which demonstrates differences in posture at KFTO is pelvis rotation, but for this variable the differences are less clearly related to kick type and direction. The pelvis is most markedly different for the Side Ahead kick. It appears that orientation of the kicking foot to produce a Side Ahead kick requires not only a support foot orientated in the direction of ball travel but additional pelvis rotation. A side foot kick to the kicker's right side is likely to require further support foot orientation and pelvis rotation in that direction. For this type of kick these two cues would be complimentary. For a Side Angled kick to the players left, the pelvis was not rotated as much and so is not distinguishable from the Instep Ahead kick.

Two further variables are worth noting which show consistent differences throughout the event duration. These are the flexion-extension rotations of the kicking leg hip and ankle. These angles differ between the instep kick and the side foot kicks with the larger hip angle reflecting the greater speed of an instep kick. This is also indicated by the length of the penultimate stride as stride length is greater in faster kicks (Lees & Nolan, 2002). Thus, if the goalkeeper can decide on the type of kick (instep or side foot) early then the keeper may be able to interpret more accurately the pelvis rotation angle noted above. The time to process these several possibilities though is very limited. It is unlikely that the goalkeeper will be able to detect ankle flexion of the kicking foot during its support phase (i.e. before KFTO) due to the perspective and distance.

Dicks et al. (2010b) reported that the best goalkeeper in their study made his first movement from ~ 50 ms before ball contact. This is in contrast to the suggestions of Khun (1988) and Morya et al. (2005) who suggest that goalkeepers may begin their movement after ball contact. This difference may have something to do with the level of goalkeeper expertise. Nevertheless, it is reasonable to consider that a goalkeeper needs to begin moving at or around ball contact for a save to be made. It is not known what duration is required for goalkeepers to make a decision and react, but this has to be made before ball contact. Franks and Harvey (1997) suggested a duration of 200–250 ms is necessary which is approximately the duration from KFTO to ball contact. Thus, the goalkeeper would need to be observing visual cues around 200–250 ms before ball contact to stand any chance of being able to make a movement in the correct direction.

The event duration (from KFTO to CONTACT) in this study ranged from 205–217 ms, thus the goalkeeper must be looking at events at the early part of this window. The KFTO was used in this study to define the start of the action as it was not thought that actions before this could reliably influence the direction of the kick. As noted above, the direction of the ball is determined by the orientation of the kicking foot and pelvis which takes place as the support foot comes into contact with the ground. Based on the timings above, cues appearing after support foot contact are unlikely to be of value to a goalkeeper in their decision making. These include kicking leg knee flexion angle, kicking leg acceleration (around 50–60 ms before ball contact) and support leg shank and thigh angles.

Cues may be available before KFTO. Noted above is the stride prior to kicking foot support. Related to this are the approach distance, angle and speed used by a kicker as well as upper body motions. We have not looked at these parts of the approach but they would be useful for further study. Further, we have not considered whether these cues are in fact visible to the goalkeeper although the greater success of the 'late strategy' would imply that their decision making process is aided in some way by what they see (Savelsbergh et al., 2002).

It is possible for the kicker to camouflage the kick by sending false postural cues. It is not known whether this is possible during the appropriate time periods as indicated above but this would also be worthy of future study.

Conclusion

For goalkeepers to use a 'late strategy' where they move at or after ball contact they must use visual cues and make a decision on which way to dive during the period of support of the kicking foot prior to ball contact. Of the cues investigated in this study, the best one is the orientation of the support foot as it is brought through and before it is planted on the ground. In general terms the orientation of the support foot indicates the direction of the ball, so a foot orientated to the kicker's left indicates a ball travelling to the kicker's left while a more forward orientation indicates a ball travelling straight ahead. Other cues are available such as the rotation of the pelvis and extension of the hip but these are more ambiguous with regard to interpretation. Other cues are available but occur too late for the goalkeeper to use.

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