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Performance analysis in field hockey goalkeeping during penalty corners: a case study

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ABSTRACT

BACKGROUND: The purpose of this study is to investigate the kinematics of field hockey goalkeeping during penalty corners, in order to provide the first model of performance from a physical standpoint during this particular and important phase of goalkeeping that goes from the injection of the ball (the push-in) up to the shot on goal during a penalty corner. In particular, the focus was on the preparation phase before the actual saves.

METHODS: Four goalkeepers playing at the international level (age: 22±2.45 years; height: 1.85±0.09 m; body weight: 79.25±8.42 kg; BMI: 23.06±0.69 kg/m^2; role experience 11.5±1.91 years; international caps: 30.00±15.25) participated in the study. A complete video footage was recorded using two high-speed video cameras, using 210 fps sampling rates.

RESULTS: The goalkeepers covered 1.48±0.32 m, using 3.23±0.43 steps, from the goal line in about 1.33±0.21 s. The estimated mean acceleration was 0.93±0.54 m/s^2. Differences in these parameters were found among the goalkeepers (one-way ANOVA; $P<0.05$, ES as partial $\eta^2>0.14$), also demonstrating a different technical efficiency in relation to the task to be performed.

CONCLUSIONS: The results of this case study confirm that the principal aim of the goalkeepers during the preparation phase of defending penalty corners is to arrive in the best position of readiness within the available time frame of about 1.5 s. They ran out from the goal line about 1.5 m, not reaching an ideal better distance (≈4 m), for tactical reasons, concerning the possible interventions of other attackers arriving close to the posts, to enlarge the goalmouth.

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International field hockey is a fast and complex team sport, and the variety of skills displayed can bemuse even the most knowledgeable spectator.[1] The goalkeeper (GK) is a vital member of any hockey team.[1-3] His/her ability to perform the specific skills required to play this role is reckoned as crucial by the vast majority of the world top coaches. The penalty corner (PC) is a particular set pieces situation [4, 5] lasting about 2 seconds when concluded with a direct shot on goal [6-8] in which a relevant part of the total amount of the goals of this sport discipline are scored.[9] PC are awarded against defenders for deliberately playing the ball over their back line, a foul between the 23 m line and the circle or an unintentional foul inside the circle. The stroke is taken from the goal line. Teams drills to get the ball as quickly as possible from the corner taker to a teammate on the edge of the shooting circle, who either traps it or plays it to another to slam home before the advancing defense blocks it.

Top coaches and other insiders,[1, 3, 10, 11] have determined the relevance and importance of the goalkeeper's

performance from a defensive standpoint. The moments preceding the shot on goal, particularly the skill of the GK to reach a balanced position of readiness (POR) out of the goal line — "attacking the ball" — along that bisecting line connecting the ball and the center of the goal, is critical.[1] The aim is to narrow the angle of the goalmouth [3] for the opposing striker and thus reducing the odds of making a goal.

The concept of goalmouth needs to be precisely defined in this context. From a geometrical point of view, this is the goal width according to the Regulation (3.66 m). That width, together with the height of the goal (2.13 m) represent the total size — about 7.80 m^2 — which the goalkeeper must defend, while standing exactly on the goal line. It is widely known that the goalkeeper's positioning along the line joining the ball to the center of the goal (bisecting the angle formed by the ball and the two posts) "narrows" the apparent size of the goal to the striker ready to shoot. In other terms the goalkeeper could manage differently his/her possible side movements to save the shot, in relation to his/her positioning along this bisecting line: the closer to the ball, the lesser side movements will be required in order to cover the goalmouth.[1] From the physical point of view this is the ability to combine an initial acceleration with a controlled deceleration, to be performed exactly at the time before the shooting, usually when the ball is trapped by the "stopper player".[3] Although field hockey increases in popularity and diffusion throughout the world, as per other team sports (*i.e.* soccer, handball, ice hockey, etc.) very little is known about some of the physical parameters regarding the performance of goalkeepers.[12] To our knowledge and to date, no scientific papers have been published on field hockey goalkeeping during PC, thus the aim of this case study is to report on the preliminary research we conducted. The purpose here is to provide the first model of performance from a physical standpoint during this particular and important phase of goalkeeping that goes from the injection of the ball (the push-in) up to the shot on goal during a PC.

Materials asnd methods

Methods

In this descriptive study, we considered four goalkeepers playing at the international level. According to the experimental design above reported, our analysis addresses the stage of "positioning" before reaching the POR.

This position is described by some authors [1-3] as one that provides the alignment of some landmarks on the lateral plane: head over knees over ankles (acronym HOKOA), while the body weight is equally distributed on both feet and they are parallel to each other. According to many top coaches [3] this position should be reached immediately before the shooting, namely when the stopper player traps the ball after the push-in.

For this purpose, high-speed video footages were produced, digitized and then analyzed to study the kinematics concerning this crucial phase of preparation, while performing some PC) routines.

Before starting the measurement trials, the goalkeepers have performed a general warm-up routine, which included a number of PC, performed by the specialist's strikers using the drag flick technique.[7, 8] Each participant striker was then instructed to perform, using his own stick, twelve drag-flicks as the one performed during a real PC, although in this study a complete defensive unit was not provided.

A complete video footage of the performances was recorded, by the means of two video cameras (Casio Exilim EX-FH20) set at right angles to each other and recording with sampling rates of 210 fps. Through the analysis of the transverse view, performed frame by frame — and corresponding to a time of 4 ms each frame — the kinematic parameters of time, distance and acceleration have been calculated. Through the analysis of the longitudinal view of these performances the deviation from the bisecting line (as indicator of the centrality in relation to the goal) when the goalkeepers were approaching the end POR was studied. The video data was then processed using the DartFish software v.6.5.

For the video analysis of the variables considered appropriate for this study, we have defined as the relevant period of time of the goalkeeper's performance during PC as follows:

1. the push-in or the injection of the ball from the goal line (t_1) (Figure 1);
2. the time at which the goalkeeper ends his longitudinal approach towards the point from which the shot will be performed (t_2), usually when the ball is trapped [3] by the stopper player (Figure 2). To define this time we considered in our slow motion video analysis the alignment of the two feet in a parallel position, (transverse view) after the three or four strides taken to advance;
3. the subjects have different body types and techni-

Figure 1.—Field hockey penalty corner: the push-in (t_1).

Figure 2.—Field hockey penalty corner: trapping the ball before shooting (t_2).

cal strategies (number of steps, initial acceleration, etc.) that were considered to determine the possible influence on the behavior of the goalkeepers in their technical choice.

Since two high-speed cameras were used, the elapsed time between t_1 and t_2 was computed using a conversion table between the times provided by the DartFish stopwatch (which cannot operate on the actual recording time rate, *i.e*. 210 fps) and the real values corresponding to a time rate of 210 fps.

Reliability study

Two expert observers took the repeated measures reported in this study. The intraclass correlation coefficients (ICC) for mean measures are provided as indices of the consistency of the measurements taken over time (Table I).

Subjects

Four goalkeepers (N.=4) of the Italian senior national men's field hockey team participated in this study (age: 22±2.45 years; height: 1.85±0.09 m; weight: 79.25±8.42 kg; BMI: 23.06±0.69 kg/m²; role experience 11.5±1.91 years; international caps: 30.00±15.25). All these goalkeepers play in the Italian (*Serie A1*; N.=2), Spanish (*Division de Honor A*; N.=1) and German (*Bundesliga*; N.=1) top leagues, respectively. In their career, they have also all been part of the Italian national youth teams (Under-16, -18 and -21).

TABLE I.—*Intraclass Correlation Coefficient (ICC) for each considered performance parameters in this study.*

Parameter	ICC (mean)	95% CI	P
Time spent to reach POR (s)	0.726	0.109-0.980	0.018
Space covered (m)	0.988	0.955-0.999	0.000
Mean acceleration (m/s²)	0.832	0.423-0.988	0.002

POR: position of readiness.

TABLE II.—*Individual anthropometrics and biographical data.*

	GK 1	GK 2	GK 3	GK 4
Age (years)	23	20	25	20
Weight (kg)	89.00	77.00	69.00	82.00
Height (m)	1.96	1.85	1.75	1.85
BMI (kg/m²)	23.18	22.51	22.55	23.98
Role experience (years)	12	10	14	10
International caps (N.)	33	22	50	15

GK: goalkeeper; BMI: Body Mass Index.

In order to present the individual characteristics of each goalkeeper involved in this study, we report some anthropometrics and biographical data in Table II.

They provided a written informed consent, after familiarization and explanation of the benefit and risks involved in the procedures of this study. They were informed that they were free to withdraw from the study at any time without penalty. The Institutional Research Board (the Ethical Committee of the School of Sports and Exercise Science, in the Faculty of Medicine and Surgery of the University of Rome "Tor Vergata") approved our research protocol and provided clearance for the procedures before the commencement of this study. All procedures were carried out in accordance with the Declaration of Helsinki of the World Medical Association as regards of the conduct of clinical research.

Procedures and instrumentation

The data collection process was completed during the first training stage of the National Senior Field Hockey Men's Team, held at the "Giulio Onesti" Olympic Training Center of Rome, on March 6th-10th, 2014.

The penalty corners were performed considering the normal routines adopted by this team, that is involving seven attacking players. All the participating players were of international level. No defensive unit was involved during this study.

The playing field was built with artificial turf by Polytan and it was wet as necessary in accordance with the manufacturer's instructions. This pitch is approved for international field hockey events. The weather during data collection was ranging from mild to slightly rainy, with a mean temperature of 16 °C. The kinematic parameters were recorded with a video system consisting of two high-speed cameras (Casio Exilim EX-FH 20) sampling at 210 fps, mounted on two tripods and positioned as follows:

— camera "1" (longitudinal view): at 5 m from the top of the shooting circle and at right angle to the centre of the goal, on the bisecting line;

— camera "2" (transverse view): 10 m from the left post of the goal and 0.5 m from the goal line.

We requested each goalkeeper to make at least 12 saves on as many penalty corners, performed by the specialist PC strikers (indicated as A, B, C, or D; N.=4;_____).

In order to compensate the possible influence of the effect of learning in goalkeepers during the performance of the tests being studied, we have planned the sequence of tests using a Latin square as indicated in Table III.

Forty-eight PCs were performed, filmed and analyzed. After the video-analysis procedures, forty-three PCs (N_{pc}=43) were considered valid for the purposes of this study. Five PCs were considered not valid for technical errors that occurred in the phase of trapping the ball.

TABLE III.—*Latin square protocol adopted in this testing procedure.*

A (GK 1)	B (GK 2)	C (GK 3)	D (GK 4)
A (GK 2)	B (GK 3)	C (GK 4)	D (GK 1)
A (GK 3)	B (GK 4)	C (GK 1)	D (GK 2)
A (GK 4)	B (GK 1)	C (GK 2)	D (GK 3)

GK: goalkeeper; A, B, C, D: specialist penalty corner strikers.

To analyze the collected data, the DartFish software v.6.5 for video analysis has been used. To verify our hypothesis we analyzed the following variables:

— the maximum distance covered by the goalkeeper from the goal line to reach the POR;

— the time taken to reach this position, calculated from the moment of the injection of the ball to the attainment of this position by the goalkeeper;

— the number of steps taken;

— the mean acceleration, calculated by dividing the distance covered by the square of the time taken to reach the POR.

Statistical analysis

Data are presented as mean and standard deviation (mean±SD) and 95% confidence intervals (95% CI). The assumption of normality was assessed using the Shapiro-Wilk test. The ICC for mean measures are provided as indices of relative reliability of the observations. To identify the differences in the parameters we considered (time spent, distance covered, acceleration reached) among the goalkeepers participating in the study the one-way ANOVA was used.

Effect size (ES) in ANOVA was computed as partial η^2, to assess meaningfulness of differences, with partial $\eta^2<0.01$, $0.01<$partial $\eta^2<0.06$, $0.06<$partial $\eta^2<0.14$ and partial $\eta^2>0.14$, as trivial, small, moderate, and large ES, respectively.

The value of statistical significance was accepted with $P\leq0.05$. The corresponding P values are provided for each analysis. SPSS v.20.0 for Windows (IBM Corp., Armonk, NY, USA) was used to analyze and process the collected data.

Results

In order to present the individual characteristics of each goalkeeper involved in this study, we report the considered parameters values recorded (mean±SD) during the performances (Table IV).

The one-way ANOVA has been carried out to determine whether there were significant differences among each investigated group of saves performed by the four goalkeepers, considering these parameters: the time of performance to reach the POR, the space covered during this phase and the mean accelerations reached.

TABLE IV.—*Considered performance parameters in this study, for each goalkeeper.*

Parameter	GK 1	GK 2	GK 3	GK 4	Mean±SD
Time spent to reach POR (s)	1.29±0.16 (0.05; 1.19-1.40)	1.24±0.22 (0.07; 1.08-1.40)	1.28±0.22 (0.07; 1.12-1.44)	1.48±0.15 (0.05; 1.38-1.58)	1.33±0.21
Space covered (m)	1.16±0.04 (0.01; 1.13-1.18)	1.98±0.14 (0.04; 1.88-2.08)	1.39±0.14 (0.04; 1.29-1.49)	1.44±0.14 (0.04; 1.34-1.53)	1.48±0.32
Mean acceleration (m/s^2)	0.73±0.21 (0.06; 0.59-0.86)	1.48±0.86 (0.27; 0.87-2.09)	0.90±0.24 (0.07; 0.73-1.06)	0.68±0.19 (0.04; 0.56-0.81)	0.93±0.54
Steps taken (N.)	3.00±0.00	4.00±0.00	3.00±0.00	3.00±0.00	3.23±0.43

Values are reported as mean ± SD and (standard error; 95% CI).
GK: goalkeeper; POR: position of readiness.

The time of performance showed significant differences among the investigated groups of saves (ANOVA: $F_{(3,42)}$=3.351; P=0.029; partial η^2=0.205; power=0.716). Subsequent *post-hoc* tests, performed with the Bonferroni correction of significance level, confirmed that there were statistically significant differences among GK4 and the other three goalkeepers (P<0.05).

The space covered during this phase showed highly significant differences among the investigated groups of saves (ANOVA: $F_{(3,42)}$=87.895; P<0.0001; partial η^2=0.871; power=1.000). Subsequent *post-hoc* tests, performed with the Bonferroni correction of significance level, confirmed that there were statistically significant differences among all GKs (P<0.05).

The mean accelerations, recorded during this phase of preparation, showed highly significant differences among the investigated groups of saves (ANOVA: $F_{(3,4)}$=6.925; P=0.001; partial η^2=0.348; power=0.966). Subsequent *post-hoc* tests, performed with the Bonferroni correction of significance level, confirmed that there were statistically significant differences among GKs (P<0.05).

Through video analysis procedures, we studied the individual efficiency of goalkeepers in relation to the shots actually directed at the goal. The outcomes are reported in table V. The differences found, although interesting, are not significant under a statistical standpoint (Kruskal-Wallis test, P>0.05).

Discussion

This is the first case study to our knowledge that describes some physical parameters of the field hockey goalkeepers' performance, during PCs, focusing on those actions undertaken immediately before the shot on goal. Currently there are no scientific papers available to provide a sufficient insight of this particular aspect, hence our decision to initiate this field of research, to be considered as a pilot study for further researches, but nevertheless able to provide some useful information for those who want to better understand some of the physical aspects required to play at the highest level in this important role.

In our study we considered the actions that the goalkeeper makes in the moments just before the shot on goal, during a PC — namely when the opposing stopper player traps the ball — in order to perform the necessary save.

According to Whitaker [3] there are three main methods of saving PCs under the rules as they stand: standing, going down to save and charging, indoor style. Of these, the latter is the least used. It is useful to emphasize that to date there are no other publications that have addressed this issue in depth. In his book Whitaker suggested: "*The distance goalkeeper moves off his line will vary depending on the size of the goalkeeper and his reaction time. Generally, a shorter goalkeeper will need to move further off his line than a taller goalkeeper, in order to narrow the angle […] The goalkeeper must be in a position of readiness before the shot from the top of the circle […] The goalkeeper must advance quickly from the line of about 4-5 m, coming to rest with the weight on the outside of the right foot, and inside of the left.*"

In our study the technical recommendations of Whitaker still seem to be valid to the present day, with the exception of the distance traveled by the goalkeeper off his line, during the preparation phase before the shot (4-5 m *vs*. 1.5 m we observed).

This phase, which we have circumscribed in the time frame that goes from the push-in of the ball [5] to the moment in which the POR is reached, usually when the

TABLE V.—*Estimated values of the apparent dimension of the goalmouth with regard to the distance of the goalkeeper from the goal line.*

Distance of GK from goal line, moving along the bisecting line (m)	Apparent reduction of goalmouth size in relation to distance from goal line (m)
0.0	3.66
0.5	3.47
1.0	3.35
1.5	3.22
2.0	3.10
2.5	2.98
3.0	2.85
3.5	2.73
4.0	2.61

These calculations were performed considering the point of shooting placed exactly on the line bisecting the goal, on the top of the circle (distance from the goal line = 14.62 m). The values were calculated using the Law of Sines.

opposing stopper player traps the ball, lasts less than 2 s (1.33±0.21 s).

In this short period of time the main tactical aim of the goalkeeper is to advance from the goal line to meet the ball, thus narrowing the angles of the goalmouth, and at the same time to achieve the POR (HOKOA) that allows the GK to maintain the biomechanical efficiency required to perform the subsequent save.[3]

This phase implies the ability of the goalkeeper to move accelerating frontally (mean acceleration 0.93± 0.54 m/s^2) and then stop when the opponent striker is ready to the shot on goal, reaching that optimal POR, that is:

— geometrically advantageous under the tactical point of view — *i.e*. narrowing the angles of the goalmouth — moving along the bisecting line (mean distance from the goal line =1.48±0.32 m) (Table V);

— biomechanically correct to allow the best technical execution of the save, according to the "HOKOA" principle.[1, 3]

We made some speculations about the efficiency of the different goalkeeping strategies adopted and the final outcomes of the shots. Despite the reduced sample size and the lack of statistical significance, nevertheless we underline the greater efficiency of goalkeeper 2, who was able to save about 71% of the shots directed at the goal, in comparison with the other goalkeepers who averaged about 50% in their saves (Table VI). We should note that goalkeeper 2 reached the highest initial acceleration (1.48±0.86 m/s^2 compared to a mean of 0.93±0.54 m/s^2), covered the farthest distance

TABLE VI.—*Individual efficiency of goalkeepers in relation to the shots actually directed at the goal.*

Parameter	GK 1	GK 2	GK 3	GK 4
Shot saved	50.0%	71.4%	44.4%	55.6%
Shot not saved (goal)	50.0%	28.6%	55.6%	44.6%
Totals	100.0%	100.0%	100.0%	100.0%

Kruskal-Wallis test: P=0.756.
GK: goalkeeper.

(1.98±0.14 m compared to a mean of 1.48±0.32 m) in a shorter period of time (1.24±0.22 s compared to a mean of 1.33±0.21 s) and took 4 steps instead of the 3 taken by the other goalkeepers.

In the reasoning followed so far, we should consider also the component of cognitive load (the tactical choice) that the goalkeeper must also endure during this crucial set pieces gameplay.[11]

In particular it should be underlined that the possible choice of advancement along the bisecting line is performed also in relation to the possible participation of the attacking opponents, off the ball, who are arriving quickly to the sides of the goal, to widen the goalmouth, in search of possible deviations.

Limitations of the study

With this case study, we decided to highlight the factors of similarity among the participants than any differences, with the aim of providing the coaches some coaching points to be practically applied during specific training sessions.

The most obvious limitation of this study is the number of goalkeepers who participated (N.=4). So all the evidences shown in our research should be treated with extreme caution and can only be used as initial reference for possible comparisons with athletes of the same gender, age and specific sporting experience.

Lack of generalizability is a common trait in quanti-qualitative studies, conducted on small samples. However, we want to emphasize the importance of such a research when the total lack of published studies do not allow any speculation based on scientific evidence. Of course we do hope that this first study will stimulate other researches, with adequate sample sizes, able to define the correct performance models in this discipline, with particular reference to the gender and the level of qualification (*i.e*. elites *vs*. sub elite).

Conclusions

Many top coaches in the world underlined the relevance of the PCs as situations in which many goals in field hockey are scored. The importance of the goalkeeper from the defensive point of view is considered crucial.

In our study we investigated the performances of four goalkeepers playing at the international level, that have different physical characteristics and showing different results ($P<0.05$; partial $\eta^2>0.14$) in the different physical parameters that we considered: the distance covered, the time spent and the mean acceleration reached during the preparation phase of a save performed during a penalty corner. These differences highlight the different individual interpretation of the role, which must take into account the different body sizes considered,[3] different gaming experience and possible interactions with those other players involved in the defensive unit, during the PCs.[11]

Nevertheless, the considerations that can be made in relation to this first study can be summarized as follows:

1. all four goalkeepers have chosen to get out from the goal line about one meter and a half (1.48±0.32 m; 95% CI: 1.38-1.57 m), narrowing the goalmouth of about 50 cm, corresponding to a mean reduction of ≈12-14%. To do so, they used a mean of 3.23 steps (mode 3);

2. this movement is not the maximum conceivable in order to reduce the size of the goalmouth, in the mean available time (1.33±0.21 s; 95% CI: 1.26-1.39 s): if the goalkeepers had wanted to accelerate more (*e.g*. about 2 m/s^2) they could easily achieve a reduction of the goalmouth by about one meter (about 30%), comfortably reaching about the 4 meters from the goal line;

3. the choice of a "low acceleration" (0.93±0.54 m/s^2; 95% CI: 0.76-1.10 m/s^2) must be regarded as a:

— the best possible choice in order to maintain a controlled and balanced displacement, during this preparation phase, that represents also the phase of the anticipatory study about the intentions of shooting of the striker;[13-16]

— a tactical choice by the goalkeeper, concerned about the possible attacks by the opposing players on the sides of the goal.[11]

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