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Video-Analysis of player's kinematics in running out of boundaries in association football fields.

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Abstract

The risk of injury following a player's impact with objects in sport facilities is a growing problem, as shown by serious accidents that happen when players have head impacts with obstacles and barriers installed around the play area. At present, no experimental data are available about the kinematics of football (soccer) players during a running-out of playing areas scenario. Experimental tests on a sample of 14 skilled football players, aged between 17 and 19 years, were conducted to investigate athletic performances in common gaming actions of running, considered potentially-damaging when they occur near the boundary lines of the regular pitch. In the current research, a player's motion was captured with a high-frequency camera and kinematic data were video-analysed. The experimental trials resulted in kinematic data plots, characterised by a decelerating trend of the speed versus the distance covered by the players during the required movements. A section at the starting point and three sections at consecutive distances (a total amount of four sections in correspondence of 0 m and consecutive 1.5 m, 2.5 m, 3.5 m on the lane covered by players) of the decelerating trends of data were analysed. Findings of this pilot study should be useful for the improvements of passive safety in sports fields, allowing the correlation of the potential impact energy of players with the installation distances of protective devices.

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Keywords: Video-Analysis, Kinematics, Association Football, Running-out, Passive Safety, Sports Equipment and Facilities

1. Introduction

The issues associated with passive safety in sports present a serious problem. Concerning the design of football field facilities, especially at the amateur level, it is necessary to ensure the highest degree of player safety during activities. In particular, the most dangerous event to be avoided is the accidental collision of the player's head against any obstacles and barriers installed outside the playing field, as shown by many deadly accidents [1],[2].

The causes of these accidents are often due to a "human error", but the consequences like injuries or fatalities are mainly referred to as a lack of safety requirements in sport regulations. In fact, from the point of view of risk prevention, current football requirements [3],[4] are based only on minimum distances of dangerous equipment from the boundary lines of the playing pitch, not taking into account the physical behaviors of players during their performances. Thus, from the point of view of injury protection, they do not prescribe specific actions (*e.g.*, by covering sport facilities with high energy-absorption materials) in attenuating the potentials correlated to accidental impacts of the player head against external sport equipment. Furthermore, international standards [5] in shock-absorption behavior of sports equipment, require not to exceed, in a low-velocity impact test, a limit value of impact parameters (acceleration and Head Injury Criterion, i.e. HIC) corresponding to a threshold of

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survivability. However, these values are not correlated to the particular impact kinematics of the discipline under consideration and are not adequately characterized by a coherent evaluation procedure as suggested by many authors in scientific studies [6] on protective polymer-based foam installed in a sports area.

In this paper, a pilot study was conducted on a group of 14 football players to highlight kinematic data during in-vivo sessions of running-out of the playing area and at certain distances from the pitch boundaries. This study aims to expand the knowledge on athletic performances of football players with particular reference to the amount of kinetic energy that has to be carefully taken into account as a risk when a typical gaming action occurs in the direction of unprotected sports equipment.

2. Methods

Experimental tests were conducted by video-analysis of player movements in real-game actions that are considered potentially damaging when they occur near the boundary lines of the regulation field [7]. The testing sample was composed of 14 skilled players, aged between 17 and 19 years (maximum performance referring to the age) and affiliated with a semi-professional club attending the Italian National Amateur League. An anthropometric description of the sample is shown in Table 1. A written informed consent was obtained from each of the participants after familiarization and explanation of the benefit and risks involved in the procedures adopted. The study was approved by the Ethical Committee of the School of Sports and Exercise Science - University of Rome "Tor Vergata" - Faculty of Medicine and Surgery. All tests were carried out in accordance with the Declaration of Helsinki of the World Medical Association (WMA) with regards to the conduct of clinical researches.

Table 1. Anthropometric data for the sample under study

Player N.	Height (cm)	Weight (Kg)	Body Mass Index, BMI (Kg/m^2)	Age (Years)
1	186.2	75.2	21.7	17.2
	180.0	69.5	21.5	17.5
3	165.5	58.4	21.3	17.8
4	168.6	60.5	21.3	17.3
5	161.3	55.8	21.4	18.0
6	165.9	58.3	21.2	17.6
7	173.4	65.7	21.9	17.5
8	164.7	60.1	22.2	18.1
9	181.2	73.8	22.5	19.2
10	185.1	76.0	22.2	17.8
11	176.0	70.5	22.8	19.6
12	173.2	65.3	21.8	17.9
13	172.0	67.1	22.7	18.2
14	167.5	63.3	22.6	17.8

Specifications of the spot area adopted for reproducing the real condition of testing are given in Fig. 1. In particular, this area corresponds to a portion of the football field (natural turf in dry conditions) placed out of the pitch coming up to the side line, as defined by a border of 16 training cones with each longitudinal length leaving free the transversal ones. Each cone was positioned at a uniform distance of 0.25 m from the others on the two longitudinal lines whereas a distance of 2.5 m was imposed between cones on transversal lines. This design scheme resulted in a total testing length of 4.0 m for the athletic performance lane. Two special cones were positioned in correspondence of the side line of the field, each characterized by a vertical beam of 1.0-m length. Four lines of interest for this study DØ, D1.5, D2.5 and D3.5 are also shown in Fig. 1 to represent distances from the sideline of 0 m, 1.5 m, 2.5 m and 3.5 m, respectively.

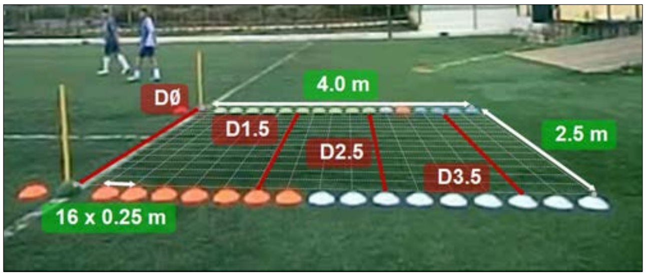

Fig. 1. Graphical representation of the experimental testing area on the football field

Each player was instructed to execute the movement pattern of running without the ball [8], by producing his maximum efforts through a protocol as follows:

- The player begins to run at approximately the middle of the football field, following the direction orthogonal to the sideline, reaching his maximum speed in correspondence of the same line (graphically identified with DØ line in Fig. 1).
- The player starts to slow his running action in correspondence of DØ with the final purpose to stop himself by reducing the speed in the following available few meters of the lane (passing through D1.5, D2.5, D3.5 lines), as quickly as possible.

A video-analysis technique was adopted and in-vivo kinematic data were revealed using a digital high-frequency camera, model type Casio XZ, operating at 240 Hz, with fixed lens (no angular displacement; focus and shutter manually set). The spot area was marked by physical objects fixed on the field (cones in Fig. 1) useful to obtain the actual conversion factors required for the calculation of the spatial coordinates. In particular, the horizontal dimension was calibrated through uniform distances between cones (0.25 m), and the vertical one was identified by the height of the beams (each length, 1.0 m) installed in correspondence of the sideline. To minimize parallax errors, the camera was attached on a tripod of 1.7 m of height, then it was located at a distance of 3.45 m from the nearest longitudinal line and at a distance of 2.0 m from the sideline of the field. Finally, it was oriented to be perpendicular to the subject's sagittal plane [9],[10]. The player's athletic performance was monitored trough a tracking procedure of markers placed in correspondence with the *repere* points selected for this study and, in particular, in correspondence of the center of the player's head.

The captured video dataset was analysed through SimiMotion® 2D/3D software (Unterschleissheim, Germany) to investigate speed variations of *repere* points with respect to distances from the sideline covered by the players during the required performances. In particular, each frame was analysed offline to obtain coordinates of reference points in dependence of the graphical matrix of the PC screen, for a period of time required to complete a single player's movement tracking. For measurement consistency, all videos were elaborated by the same operator. Finally, real coordinates were obtained in a two-dimensional x-y space via the previous calibration phase of the spot area. Temporal functions of x and y coordinates were filtered using a Butterworth low-pass filter of second order with a cut-off frequency of 8 Hz. To obtain the speed variations with respect to the covered distances, the spatial coordinates were processed within an algorithm of numerical derivation based on quintic-spline functions.

An example of the performed test is shown in Fig. 2, where the player's running-out is captured in four different frames and in correspondence of four different distances DØ, D1.5, D2.5, D3.5 of interest for this study.

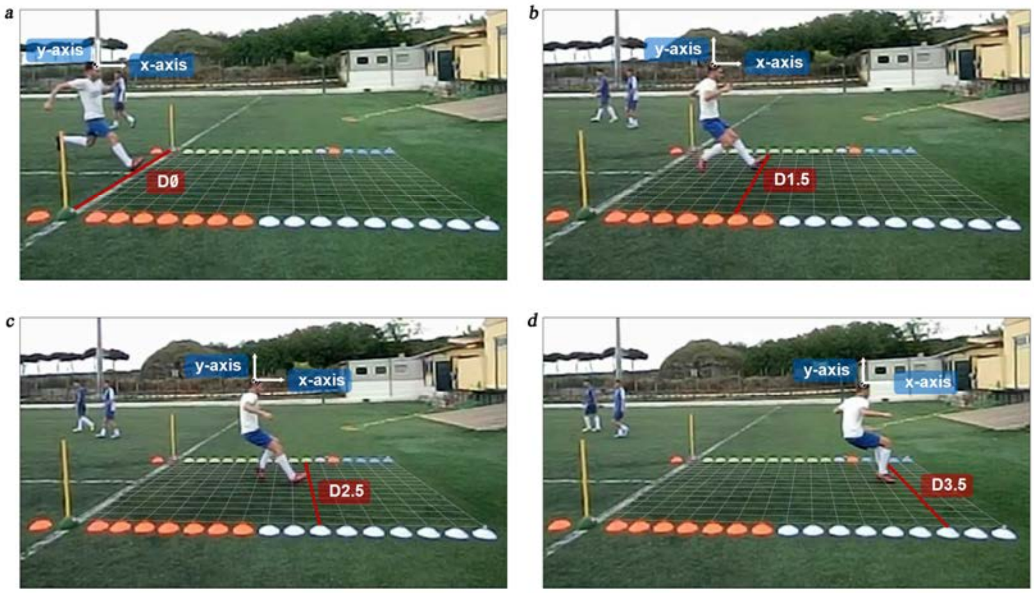

Fig. 2. Position reached by the player during the athletic performance at a distance from the side line of (a) 0 m, (b) 1.5 m, (c) 2.5 m, and (d) 3.5 m.

3. Results

The video-analysis allowed obtaining a kinematic data plot of the athletic performance per each player. A typical kinematic data plot in terms of the speed registered (absolute value of x-component of velocity) with respect to the position assumed during the running-out is shown in Fig. 3 (dashed line) for the player N. 7: in particular, he reached the maximum speed in correspondence of the sideline (DØ), then he decreased the amount of kinetic energy along greater distances from the sideline (D1.5, D2.5) until the minimum registered speed at the end of the available lane (D3.5). The kinematic data plots showed a non-linear trend (that needs to be further investigated) that justified the choice in analysing only a few sections of the same plots.

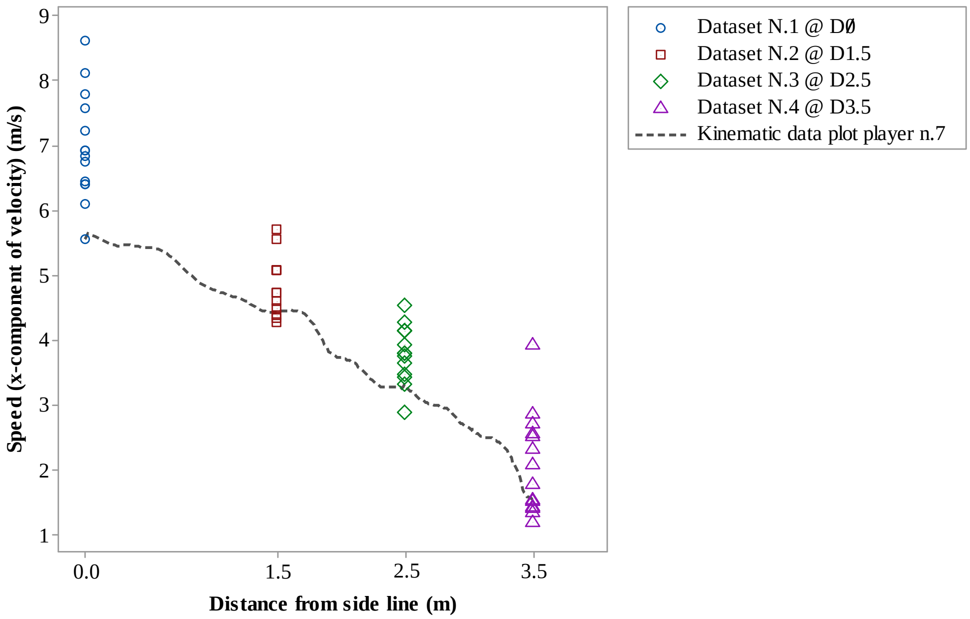

Fig. 3. Graphical representation of datasets in terms of speed values (x-component of velocity) and an example of a kinematic data plot for player n.7

Thus, four datasets (in Fig. 3, dataset N.1, 2, 3, and 4) composed by 14 speeds each (in Fig. 3, 14 x-components of velocity per dataset) were selected within the overlay plots and, in particular, were extracted in correspondence of four consecutive sections, whose distances from the sideline coincided with DØ, D1.5, D2.5 and D3.5. A complete sheet with all dataset values is given in Table 2 by identifying with $s_{Ø}$, $s_{1.5}$, $s_{2.5}$, $s_{3.5}$ the variable in terms of speed (absolute value of x-component of velocity), in correspondence of the previous cited distances DØ, D1.5, D2.5, D3.5, respectively.

Table 2. Datasets of player's speeds (x-component of velocity) in correspondence of each distance

	Dataset N.1	Dataset N.2	Dataset N.3	Dataset N.4
Player No.	$s_{Ø}$ (m/s)	$s_{1.5}$ (m/s)	$s_{2.5}$ (m/s)	$s_{3.5}$ (m/s)
1	8.1	4.7	4.1	2.6
2	7.8	5.1	3.8	1.5
3	6.9	4.4	3.3	2.5
4	8.6	5.1	4.3	2.9
5	6.8	4.7	3.4	1.8
6	6.1	5.1	3.9	1.2
7	5.6	5.1	3.8	1.5
8	7.6	5.6	4.5	3.9
9	6.5	5.7	3.5	1.4
10	7.2	4.5	4.1	2.1
11	6.8	5.1	3.8	1.4
12	6.4	4.3	3.6	2.3
13	6.9	4.6	4.1	2.7
14	6.4	4.3	2.9	1.4

The *Kolmogorov-Smirnov (K-S)* test was applied to each dataset to verify the Null hypothesis of Normal distribution. To this end, the *K-S* statistic D_n was calculated for each dataset and reported in Table 3 together with means, standard deviations and sample size N=14.

Table 3. *K-S* statistics, means and standard deviations for datasets N.1, 2, 3, 4.

	Dataset N.1	Dataset N.2	Dataset N.3	Dataset N.4
N	14	14	14	14
D_n	0.161	0.179	0.133	0.188
Mean	7.0	4.9	3.8	2.1
St. Dev.	0.83	0.44	0.44	0.77

The Null hypothesis for *K-S* test (not to reject the Normal distribution) is verified if the statistics D_n are less than the critical value of 0.343 for the sample size of N=14 at a significance level of α=0.05. The statistics scores, shown in Table 3, confirmed the acceptance of the null hypothesis and the distributions of speeds for each distance can be considered normal. Normal probability plots for each distance DØ, D1.5, D2.5, D3.5 are shown in Fig. 4.

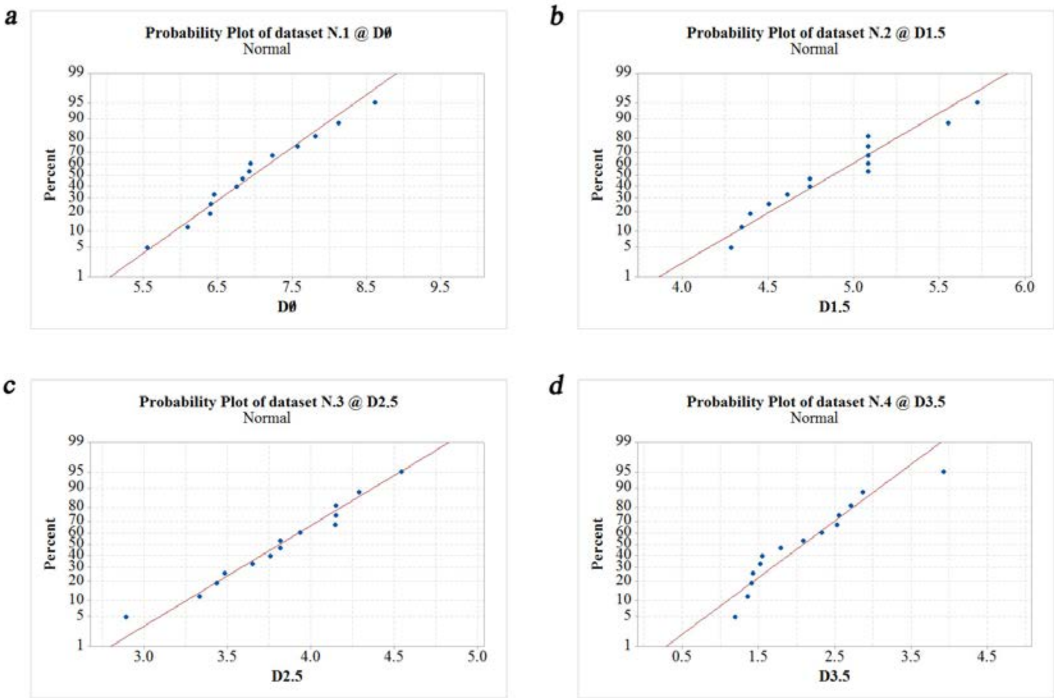

Fig. 4. Normal Probability plots for dataset (a) N.1 at DØ, (b) N.2 at D1.5, (c) N.3 at D2.5, (d) N.4 at D3.5

Finally, on the basis of cumulative density functions for normal distributions, it was possible to calculate percentile scores of speeds, as shown in Table 4. In this table, each row contains speed values below which we can assume to find the corresponding percentage of all-player-speeds population (90% for the first row, 95% for the second row, 99% for the third row, 99.9% for the fourth row, 99.99% for the fifth row, 99.999% for the sixth row).

Table 4. Percentile scores of speeds in correspondence of distances DØ, D1.5, D2.5, D3.5 (Dataset N.1, 2, 3 and 4, respectively).

Percentile	Dataset N.1	Dataset N.2	Dataset N.3	Dataset N.4
	$s_Ø$ (m/s)	$s_{1.5}$ (m/s)	$s_{2.5}$ (m/s)	$s_{3.5}$ (m/s)
90.000%	8.0	5.4	4.4	3.1
95.000%	8.3	5.6	4.5	3.4
99.000%	8.9	5.9	4.8	3.9
99.900%	9.5	6.2	5.2	4.5
99.990%	10.1	6.5	5.4	5.0
99.999%	10.5	6.8	5.7	5.4

4. Discussion

The results of the pilot study lead to the following remarks in terms of kinematics: in accordance with the procedure adopted for the study. Each player complied with a running-out performance characterized by a decelerating behavior, as confirmed by the decreasing trend of speed with the respect to distances covered along the lane. Thus, the datasets reported in Table 2 and statistically summarized in Table 3 allowed to highlight the different performance skills of the players involved in the study. In particular, the greater standard deviations in correspondence of the starting and ending lines (DØ, D3.5) than the middle ones (D1.5, D2.5) confirmed the variability in the highest acceleration supplied until the sideline (maximum speed value of Player N. 4 equal to 8.6 m/s compared to the average of 7.0 m/s at DØ line) and in the lowest deceleration supplied until the end line (maximum speed value of Player N. 8 equal to 3.9 m/s compared to the average one of 2.1 m/s at D3.5 line). In contrast, speed values registered at the middle lines D1.5 and D2.5 showed lower scatter as demonstrated by the lower standard deviation of 0.44 (as compared to 0.83 and 0.77), common for both lines. Finally, considerable speeds, as registered during the experimental program, confirmed the high performances reached by all players (with particular reference to their ages) and, in particular, they resulted to be representative of the 99th percentile of player population (percentile scores calculated in Table 4).

As shown in the Results section, players were unable to stop running within a distance of 3.5 m from the boundary line, rather they still have a considerable amount of kinetic energy up to this distance. With particular reference to the 99th percentile of the player population, the best condition from a player passive-safety point of view was represented by the lowest speed of 3.9 m/s at D3.5 line: the installation of a concrete wall at this distance (a solution widely adopted in amateur fields) would cause severe injuries in the case of a head impact. In fact, the speed value that exceeds the threshold of human survivability (in terms of maximum acceleration and HIC during a potential impact) is equal to 1.7 m/s for concrete materials [11] and results to be lower than the lowest speed reached by players during the running-out performances.

5. Conclusions

This study has highlighted that unprotected obstacles on the sidelines of football pitches represent a risk for human health for the case of head impacts. In particular, the protection of unsafe obstacles at the boundaries of football fields is highly recommended to be introduced to minimize potential risks of brain injury to sports participants. Thus, the knowledge of player kinematics in running-out of the pitch could allow a safer and efficient design of high absorption protective devices to be adopted in covering sports facilities (obstacles or barriers) of the fields.

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