ANALYSIS OF SPORT PERFORMANCE BY MEANS OF A DLT-2D BASED PHOTOGRAMMETRIC SYSTEM

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The aim of this study was to validate and apply a bi-dimensional photogrammetric video system to collective and cyclic sports. Twenty-one football matches were filmed using three video-cameras positioned at the main stand of the stadiums and computerized analysis of the films was performed using DLT (direct lineal transformation) based algorithms. This procedure was used during the FIFA under-17 World Championship Finland 2003 and the FIFA Confederations Cup 2005 to obtain a detailed kinematical analysis of high-standard official's physical and technical match-performance. In another study, the frequency and amplitude of cycle of 2 subjects swimming 400m at incremental progressive velocities were analysed with the same methodology.

KEY WORDS: 2D photogrammetry, football, referees, swimming

INTRODUCTION: Biomechanics normally analyse the sport technique using 3D photogrammetric systems based on the known Direct Linear Transformation Algorithm. This procedure has been probed to be very precise and easy to use. However, some researches are interested in movements produced on big spaces such as collective sports or displacement sports (running, swimming). In the case of collective sports, there have been several studies studying the position, velocities and distances covered by players and referees; in most of the cases, the procedures employed have been based on subjective observations; additionally, the statistical techniques used to validate the different methods have not been indicated or have not been appropriate. In other sports as swimming and running a lot of authors (Thompson, 2000) have recorded kinematics variables as the frequency and the amplitude of the cycle; still, not any information about the use of DLT-2D based photogrammetric systems was found in these studies.

Therefore, the purposes of this study were to:

(i) Validate a DLT-2D based photogrammetric video system
(ii) Apply this methodology to the analysis of sport performance of football referees and swimmers.

METHOD:

Data Collection. Study 1: Twenty-one matches from the FIFA under-17 World Championship 2003 (*n*=12) and the FIFA Confederations Cup 2005 (*n*=9) were filmed using three JVC GY-DV500E cameras positioned at the main stand of the stadiums. The cameras remained fixed during the whole match and were conveniently distributed, in such a way that the whole playing area was constantly covered. Before kick-off, the pitch was measured with a 50-m pre-calibrated measuring tape. For each camera, a six-point calibration system was used.

Computerized analysis of the frames was carried out with the software Photo 23D (Mallo & Navarro, 2004). The three films obtained (one from each camera) were synchronized and the projection of the centre of mass of the referee in the ground was digitized with the mouse in each frame at a frequency of one frame per second. The calibration system was also digitized and 2D-DLT-based algorithms (Abdel-Aziz & Karara, 1971) were used for transforming the screen displayed coordinates (in pixels) to real coordinates (in meters). These coordinates were smoothed using quintic spline functions with the Cross Generalized Validation procedure as a method for evaluating the adjusting factor. The obtained variables were the distances between the referee and the infringements (the specific point in space where the foul was committed), the total distances covered and the velocities.

To validate the present photogrammetric technique, several pilot studies were carried out. First, 40 markers were randomly distributed in a football ground, while the field was filmed from the main stand. The position of these markers was determined using a pre-calibrated 50-m measuring tape and later obtained through digitization of the frames. The root mean error (RMS) (Allard, Blanchi & Aïssaqui, 1995) in the reconstruction of the coordinates in the *x* and *y*-axis was 0.23 and 0.17 m, respectively. The RMS error when reconstructing the distance between two points was 1.98%.

Data Collection. Study 2: The subjects were 10 swimmers of national level. They swam 400m. crawl in 25m pool. Four velocities were established corresponding with the following times in 100m: 1' 45'', 1'35, 1' 35'' and 1' 25''. The subject changed the velocity each 100m. beginning for the slowest. A system to control the velocity of the swimmer was used; the device was composed of a cable set up on the bottom of the pool along the lane; a light moving along the cable helped the subject to get a constant velocity. A digital camera JVC GY-DV500E was positioned at the main stand of the pool. The camera remained fixed during the whole race. Twenty meters along the six lanes of the pool formed the recorded view field. A 50-m pre-calibrated tape was used for measuring a four-point calibration system.
The data processing was similar to that in the former study. The 2D coordinates of projection of the head of the subject were calculated at the beginning and the end of each of the swimming cycles. The final variables were the frequency and the amplitude of the cycle and the velocity.
To calculate the error of the amplitude, a known distance of 2.236m. was calculated along the 20 m of the lane. The root mean error (RMS) (Allard, Blanchi & Aïssaqui, 1995) in the reconstruction of the distance coordinates was 0.08m. (4.2%).

Data Analysis: Differences between two sets of data were determined using a paired test. When comparing more than two means of data, a one-way repeated measures analysis of variance (ANOVA) was performed. In the case of detecting any significant interaction, Newman-Keuls *post-hoc* tests were performed. Significance was set *a priori* at $P<0.05$ for all statistical tests.

RESULTS:

Study 1: The next day after the match, a report was presented to the Refereeing Department of FIFA. In this report all the incidents that had occurred during the match were analyzed and distance from the referee to the infringement (or from the assistant referee to an off-side situation) was calculated (Figure 1). The results were exposed to the referees in the diary technical de-briefing.

Figure 1: Technical analysis. Distance from infringements.

Two weeks after the end of the tournaments, the technical report was completed with the physical performance data from the officials. The selected performance parameters (computed throughout the match in 90-, 45-, 15- and 5-minute intervals) were:

(i) Total distance covered;
(ii) Time spent in different locomotive categories (standing still, walking, jogging, cruising and sprinting) (Figure 2);
(iii) High-intensity activities.

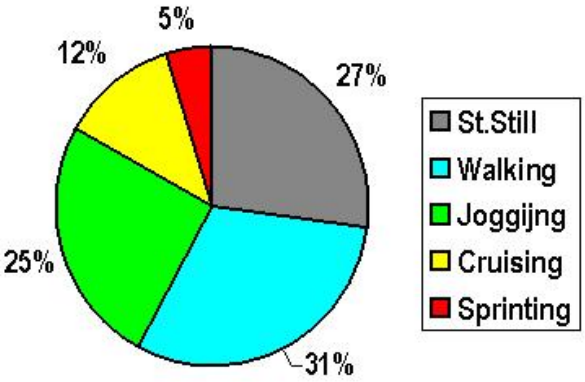

Figure 2: Time-motion analysis: Time spent (%) in different locomotive categories.

Study 2: The results presented here are part of a more complete research about the performance of swimmer in relation with the frequency and amplitude of cycle. In this occasion two levels of velocity (the lowest and the fastest) of two swimmers were analysed. A two factor ANOVA was carried out; factors were Subject (2) and velocities (2 repeated measurements).

Table 1: Frequency and amplitude in relation to velocity and subjects

SUBJECT	VELOC	Frequency Cycles/min	Amplitude m/cycle
1	1	23,361	2,308
	2	29,163	2,286
2	1	28,075	1,941
	2	31,503	2,089

DISCUSSION: The traditional methodologies applied to team and cyclic sports have used different observational and instrumental procedures to calculate the distances travelled and to estimate the velocities of the displacements of the sportsmen. In order to improve the validity of the results, the linear velocity of the displacements should be calculated directly. In the present study we developed and validated a bidimensional photogrammetric video system, and we applied it during an international-level tournament to determine the activity profile of high-standard football referees. In the study carried out with swimmers, we could observe that the frequency of subject 1 at low velocity (23.4 cycles/minute) was significantly lower than at high velocity (29.1 cycles/minute). However, the amplitude remained constant (2.4 m.). While the results of the frequency in subject 2 showed a similar behaviour, the amplitude increased ($p<0.05$) between the lowest (1.94 m.) and fastest (2.08 m.) velocity. That is, subject 1 increased the velocity by means of the frequency while subject 2 used both frequency and amplitude. Also, significant differences in the frequency were found between the two subjects at the lowest velocity (23.4 and 28.1 cycles/minute; $p>0.05$) and at the fastest (29.2 and 31.5 cycles/minute; $p>0.05$). It seems that each swimmer selects its own optimal frequency. There were significant differences in the amplitude between the subjects.

CONCLUSION: A 2D-DLT based photogrammetric procedure seems to be a useful tool in the analysis of the collective and cyclic sports. The precision of this procedure guarantees a

high validity in the results obtained. This method is especially appropriate to evaluate objectively the technical performance of football referees and swimmers. The set-up of the methodology is relatively easy, so the system is portable to different facilities without any interference with the movements of the athlete (external validity).

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Acknowledgement

This study was logistically and economically supported by the Refereeing Department of the Federation International de Football Association.