Capturing complex human behaviors in representative sports contexts with a single camera

Ricardo Duarte¹, Duarte Araújo¹, Orlando Fernandes², Cristina Fonseca¹, Vanda Correia¹, Vítor Gazimba², Bruno Travassos¹,³, Pedro Esteves¹, Luís Vilar¹, José Lopes¹

¹Faculty of Human Kinetics, Technical University of Lisbon, Lisbon, Portugal,
²School of Science and Technology, University of Évora, Évora, Portugal,
³Faculty of Social and Human Sciences, University of Beira Interior, Covilhã, Portugal

Correspondence to R. F. L. Duarte, Faculdade de Motricidade Humana, Estrada da Costa, 1495-688 Cruz Quebrada, Portugal
E-mail: rduarte@fmh.utl.pt

Key words: TACTO device; direct linear transformation; representative sports contexts; complex behavior.

Summary. Background and objective. In the last years, several motion analysis methods have been developed without considering representative contexts for sports performance. The purpose of this paper was to explain and underscore a straightforward method to measure human behavior in these contexts.

Material and methods. Procedures combining manual video tracking (with TACTO device) and bidimensional reconstruction (through direct linear transformation) using a single camera were used in order to capture kinematic data required to compute collective variable(s) and control parameter(s). These procedures were applied to a 1vs1 association football task as an illustrative subphase of team sports and will be presented in a tutorial fashion.

Results. Preliminary analysis of distance and velocity data identified a collective variable (difference between the distance of the attacker and the defender to a target defensive area) and two nested control parameters (interpersonal distance and relative velocity).

Conclusions. Findings demonstrated that the complementary use of TACTO software and direct linear transformation permit to capture and reconstruct complex human actions in their context in a low dimensional space (information reduction).

Introduction

In the last years, theoretical and experimental evidence from sports performance literature have emphasized the need for a complex systems approach to sports behaviors (1–4). In fact, athletes perform in a complex environment within which they exchange energy, matter, and information (5). This mutuality between the performer and his/her surrounding is the basis for the study of behavioral dynamics in sports contexts (6, 7). Accordingly, the dynamics of the environment-athlete system should be captured by context-dependent variables (8). For example, Passos and colleagues (4) demonstrated how the angle formed between the defender-attacker vector and an imaginary horizontal line parallel to the try line captured the dynamics of attacker-defender interactions in youth rugby union. These types of variables that synthesize several degrees of freedom and describe the dynamics of the sport system subphase are called collective variables (or order parameters) (9, 10). The collective variables (i.e., the system state of order) may change qualitatively by the continuous scaling of other type of variables known as control parameters (9, 10) (for an example in sailing see (11)). At critical values, these parameters may abruptly change the state of the system (9, 10). For instance, Passos and colleagues (12) showed how specific values of interpersonal distance and relative velocity (i.e., the control parameters) influenced the dynamics of the attacker-defender interactions in rugby union near the try line, prompting qualitative changes in the previously mentioned angle (i.e., the order parameter).

One way to capture the collective dynamics of team sports at the level of individual-environment system is by means of players’ kinematic data collection (13). In this sense, the selection of procedures to capture and reconstruct players’ movement in their context of action comprises one of the most important issues for studying collective behavior in team sports. In the last years, several motion analysis methods have been developed, as well as different mathematical procedures used to reconstruct players’ spatial coordinates (14). Moreover, when analyzing movement with video-system analysis, a critical issue is the transformation of the virtual world data (i.e., what is seen on the computer screen) into real world data (i.e., what occurs in the

Medicina (Kaunas) 2010; 46(6):408-14
real frame of reference), minimizing the error (15). To adequately deal with this problem, the direct linear transformation (DLT) method has been one of the algorithms mostly used for camera calibration and reconstruction (16).

In this methodological paper, we will present procedures that joint manual video tracking and bidimensional reconstruction (2D–DLT), using a single camera. These procedures will allow the capturing of the kinematic data required to compute candidate order and control parameters to study complex behavior in team sports.

Material and methods
For illustrating the conceptual and motion analysis procedures used in this line of research, the 1vs1 football subphase was selected. This task was previously used by Duarte and colleagues (17) to investigate the interpersonal dynamics among youth football players. A detailed description of the representative task design, data collection, image treatment, camera calibration and 2D-reconstruction, signal filtering, reliability analysis, and data computation is presented.

Representative task design. With the purpose of generalizing performers' behavior from the research context (the experimental setting) to the performance context (the football game) (18, 19), we created an in situ experimental task. The designed task allowed performers to explore available informational variables and use them to achieve specific mutually exclusive goals (see Fig. 1).

Data collection. The first step for motion analysis procedures consisted in recording performers' behavior using a regular digital video camera. In the study of 1vs1 football subphase taken as a task vehicle, a fixed digital camera was set in an elevated plane (4 meters of height) using a tripod placed on the bleachers of a football stadium. In order to capture the movement of all players participating in each trial, the video camera formed approximately 45 degrees with the longitudinal dimension of the task (see Fig. 1). The \((x, y)\) coordinates of several noncollinear control points' candidates were also taken for subsequent calibration procedures (see camera calibration and 2D-reconstruction subsection). Video recorded images of every trial were transferred to digital support, coded, and saved as * .avi format.

Image treatment. For image treatment, we used the TACTO 8.0 software (15) originally created by Fernandes in Microsoft Visual Basic 6.0 programming language. This device has been continuously improved since its original version. It was created to collect and analyze the physical performance of football players (20). TACTO has been adapted to different goals in several studies, ranging from the measurement of the physical performance (20, 21) to measuring players’ behavioral patterns in many sports (6, 22) or to the codification of certain action categories (21).

TACTO screen is illustrated in Fig. 2. The procedures for digitization consisted in following the selected working point with a mouse cursor. For this study, the working point selected was the middle point between the feet of each player, as this point somehow represents the projection of the player’s center of gravity on the ground. The film was played in slow motion (1/2 normal velocity), and virtual coordinates were obtained at 25 Hz. The desktop resolution was 1280×800 pixels, and the device window did not move during the procedures.

Camera calibration and 2D-reconstruction. In the study of Duarte and colleagues (17), the authors utilized a planar analysis using the 2D–DLT method (16, 23) for calibration and object-plane reconstruction. This two-dimensional method uses the same DLT algorithms employed in tri-dimensional analysis, but considers the \( z \)-coordinates always equal to zero. The DLT method directly relates an object point located in the object space/plane and the corresponding image point on the image plane (see Fig. 3).

Object \( O \) is mapped directly to the projected image \( I \). The projection plane is called image plane, while point \( N \) is the new node or projection center. Hence, the object point \( (O) \), the image point \( (I) \), and the projection center \( (N) \) are collinear. This is the so-called collinearity condition, the basis of the DLT method. Two reference frames are defined in Fig. 3: object–space reference frame (the XYZ-system) and
Successive rearrangements of equations (1) and (2) resulted in 11 DLT parameters that reflect the relationships between the object-space/plane reference frame and the image-plane reference frame. In the current study, due to the utilization of planar analysis, DLT parameters were reduced to 8 (for mathematical details see (25)).

To study the 1vs1 football subphase, several non-collinear control points were tested. The use of 6 points was sufficient for accurate camera calibration and 2D-reconstruction procedures. Fig. 4 shows control point location, as well as the bidimensional reference frame for this task. In order to ensure the proper calculation of kinematic variables, zero-zero
coordinates (0, 0) were assigned with 2 m of safety margin (see Fig. 4).

Table displays the real coordinates \((x, y)\) measured in the field and the virtual coordinates obtained from TACTO software.

These coordinates (i.e., the virtual and the real coordinates) were the starting point to calculate the DLT parameters used in calibration and reconstruction procedures. MATLAB files were then created with 2D-DLT algorithms to create the DLT parameters. These parameters were firstly used for camera calibration and afterward for image reconstruction.

Filtering. Some data fluctuations may be due to lack of accuracy in digitization and calibration processes. Failure to treat these errors properly results in amplified and noisy velocity and acceleration data (16). However, due to the inherent variability of human movement data, it is difficult to distinguish it from instrumentation noise. In order to deal adequately with instrumentation error, a Butterworth low-pass filter was used (26). The original data set was compared with different cut-off frequencies. Fig. 5 concerns an illustration of this comparison made between a 3-Hz and 6-Hz filtering cut-off frequency on the \(x\) coordinates of an attacker displacement, in the 1vs1 football subphase. The percentage of variance accounted for VAF, computed as the normalized error between the original and filtered signal, was used to assess the adequate cut-off frequency (27). Results demonstrated less variation using a 6-Hz than 3-Hz cut-off frequency. This similarity between unfiltered and filtered data was taken as a criterion to use the cut-off frequency of 6 Hz for all trials (26).

Reliability analysis. To obtain data with minimal error, we developed a digitization training program during 7 consecutive days. On the first day, the tracking operator (i.e., the observer) completed 5 trials for two times as a pretest. In the next five days, the operator made 30 trials per day (15 trials \(\times\) 2 times). On the seventh day, he completed the same pretest protocol as posttest measures.

For the reliability measurements between trials in pretest and posttest, we used Pearson correlation coefficients and variation accounted for VAF (27). Results showed high \(R\) values for both pretest and posttest (pretest, \(R=0.997\pm0.004\) for \(x\) component and \(R=0.875\pm0.173\) for \(y\) component; posttest, \(R=0.996\pm0.003\) for \(x\) component and \(R=0.894\pm0.178\) for \(y\) component). VAF results also demonstrated high percentage of reliability for \(x\) and \(y\) component of the two players both in pretest and posttest (VAF always >99.99%).

Data computation. After the correct implementation of the aforementioned procedures, the kinematic variables that capture the collective behavior of the system under analysis were calculated. The running distance of any moving object in a \(t\) (time) interval was calculated as the sum of partial displacements.

| Table. Real (m) and virtual (pixels) coordinates of the control points measured |
|-----------------------------|-----|-----|-----|-----|-----|-----|
| Control point               | 1   | 2   | 3   | 4   | 5   | 6   |
| Real X-coordinate           | 2   | 2   | 10  | 11  | 9   | 2.9 |
| Real Y-coordinate           | 12  | 2   | 7   | 3   | 27  | 28.2|
| Virtual X-coordinate        | 461 | 597 | 642 | 726 | 420 | 325 |
| Virtual Y-coordinate        | 339 | 327 | 356 | 362 | 366 | 354 |

Fig. 4. Control points and zero-zero coordinates identification

Fig. 5. Effect of filtering on the \(x\) coordinates of player displacements
between each frame. By computing the derivative of the positions in each frame, instantaneous velocity data along time were obtained. Specifically created MATLAB files (MATLAB 2008a, MathWorks™) were used to compute these time series of kinematic variables. At a dyadic system level, as the one studied, the literature suggests the calculated kinematic variables as potential order and control parameters (for details see (4, 6, 12)).

Results and discussion

A graphical example of kinematic variables such as the distance to the defensive line and the velocity data of both players, in a random selected trial, are presented in Fig. 6.

The moment of phase transition (Fig. 6, dashed vertical lines) was related to the difference between the velocities of each player. Thus, the relative velocity (i.e., the difference between the velocity of the attacker and the velocity of the defender) was tested as a potential control parameter of this dyadic system. Left panel of Fig. 8 displays the relative velocity time series. This variable seems to be related to the phase transitions. This may indicate that the qualitative change of the collective variable was influenced by the increase in the velocity difference between both players. As demonstrated previously (17), a closed examination showed that high relative velocity values promoted phase transitions only when interpersonal distance displayed low values (right panel of Fig. 8). In fact, the organizational state of the 1vs1 association football subphase only jumped to another order state due to the nested influence of the two control parameters (i.e., relative velocity and interpersonal distance).

Conclusions

The presented time-motion analysis procedures revealed consistency to reconstruct the players’ movement in the performance context, with intraobserver reliability. As demonstrated in this paper, the combination between TACTO device and DLT method provides real kinematic data with minimal error, allowing identifying relevant order and control parameters. Conceptualized as complex systems, the internal and external constraints on players’ behaviors can be studied by analyzing the qualitative changes of the order parameter along time (10). As suggested by Passos and colleagues, the rate of change of the order parameter (i.e., its first derivative) seems to be a relevant way to understand this phenomenon.

The presented method captured and contributed to the understanding of the inherent complexity of team ball sport behaviors. The used time-motion analysis procedures can be carried out using a single camera. As a major limitation, manual tracking of each object, one by one, is very time consuming. However, the ongoing improvement of the TACTO device toward more automatic tracking procedures will overcome this limitation. It is worth outlining that these procedures captured the complexity of human movement systems, as the example provided at a team sports dyadic level. Using the concepts of order and control parameters applied to kinematic data, it is possible to study the collective behavior of the teams at different levels of analysis (3).

Acknowledgments

The first author was supported by a doctoral grant of the Portuguese Foundation for Science and Technology (SFRH/BD/43994/2008).
Fig. 7. Left panel: collective variable of the 1vs1 association football sub-phase and the phase transition between the two different qualitative states of order. Right panel: collective variable rate of change (first derivative)

Fig. 8. Example of the complementarities of relative velocity (left panel) and interpersonal distance (right panel) acting as control parameters of the 1vs1 football subphase

Kompleksinės žmogaus elgesenos stebėsena su viena kamera reprezentatyviuose sporto kontekstuose

Ricardo Duarte¹, Duarte Araújo¹, Orlando Fernandes², Cristina Fonseca¹, Vanda Correia¹, Vítor Gazimba², Bruno Travassos¹, ³, Pedro Esteves¹, Luís Vilar¹, José Lopes¹

¹Lisabonos technikos universiteto Žmogaus kinetikos fakultetas, Portugalija, ²Evoros universiteto Mokslo ir technologijos mokykla, Portugalija, ³Beira Interior universiteto Socialinių ir žmogaus moksly fakultetas, Koviljanas, Portugalija

Raktažodžiai: TACTO įrenginys, tiesinė transformacija, reprezentatyvus sportinis kontekstas, kompleksinė elgesena.

Santrauka. Paskutiniais metais sukurta keletas judėjimo analizės metodų neatsižvelgus į reprezentatyvų sportinį kontekstą. Šio darbo tikslas – paaškinti ir pabrėžti tiesioginį metodą matuojant žmogaus elgesną šiame kontekste.

Tirtiųjų kontingentas ir tyrimo metodai. Rankiniai vaizdo stebėjimo (su TACTO įrenginiu), dvimatė rekonstrukcija (naudojant tiesinę transformaciją) ir viena kamera buvo naudojama siekiant fiksuoti kinematinius duomenis bei apskaičiuoti kolektyvinius kintamuosius ir kontrolinius parametrus. Šios procedūros taikytos 1:1 futbolo uždavinyje kaip grupinio sporto substazės ilustracija ir autorių bus patelkiama kaip mokomoji priemonė.

Medicina (Kaunas) 2010; 46(6)
Rezultatai. Pirminė nuotolių ir greičių duomenų analizė parodė kolektyvinius kintamuosius (nuotolis tarp atakuojančio asmens ir gynejo gynybos zonoje) ir du susiję kontroliniai parametrai (tarpasmeninis nuotolis bei saintykinis greitis).

Išsudins. Tyrimas parodė, jog papildomos TACTO programinės įrangos ir tiesioginės transformacijos panaudojimas sudaro sąlygas fiksuoti ir atstatyti kompleksinius žmogaus veiksmus supančioje jį aplinkoje žemesnės dimensijos erdvėje (informacijos redukcija).

References
1. Davids K, Araújo D, Shuttleworth R. Applications of dynamical systems theory to football. In: Reilly T, Cabri J, Araújo D, editors. Science and Football V: The Proceedings of the 5th World Congress on Science and Football. Oxon: Routledge; 2005. p. 547-60.
2. McGarry T. Applied and theoretical perspectives of performance analysis in sport: scientific issues and challenges. Int J Perform Anal Sport 2009;9:128-40.
3. McGarry T, Anderson D, Wallace S, Hughes M, Franks L. Sport competition as a dynamical self-organizing system. J Sport Sci 2002;15:171-81.
4. Passos P, Araújo D, Davids K, Gouveia L, Serpa S, Milho J, Fonseca S. Interpersonal pattern dynamics and adaptive behavior in multiagent neurobiological systems: conceptual model and data. J Motor Behav 2009;41:445-59.
5. Beek PJ, Peper CE, Stegeman DF. Dynamical models of movement coordination. Hum Movement Sci 1995;14:573-608.
6. Araújo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. Psych Sport Exerc 2006;7:653-76.
7. Renshaw I, Davids K, Shuttleworth R, Chow JY. Insights from Ecological Psychology and Dynamical Systems. Theory can underpin a philosophy of coaching. Int J Sport Psychol 2009;40:580-602.
8. Kelso JAS, Engstrom DA. The complementary nature. Cambridge: MIT Press; 2006.
9. Kelso JAS. Dynamic patterns: the self-organization of brain and behavior. Cambridge: MIT Press: 1995.
10. Kelso JAS. Coordination dynamics. In: Meyers RA, editor. Encyclopedia of complexity and system science. Heidelberg: Springer; 2009. p. 1557-64.
11. Araújo D, Davids K, Rocha L, Serpa S, Fernandes, O. Decision making in sport as phase transitions. Int J Comp Sci Sport 2003;2:87-8.
12. Passos P, Araújo D, Davids K, Gouveia L, Milho J, Serpa S. Information-governing dynamics of attacker-defender interactions in youth rugby union. J Sport Sci 2008;26:1421-9.
13. Passos P, Araújo D, Davids K, Gouveia L, Serpa S. Interpersonal dynamics in sport: the role of artificial neural networks and 3-D analysis. Behav Res Methods Instrum 2006;38:683-91.
14. Carling C, Bloomfield J, Nelson L, Reilly T. The role of motion analysis in elite soccer: contemporary performance measurement techniques and work-rate data. Sports Med 2008;38:839-62.
15. Fernandes O, Folgado H, Duarte R, Malta P. Validation of the tool for applied and contextual time-series observation. Int J Sport Psychol (in press).
16. Kwon YH. Measurement for deriving kinematic parameters: numerical methods. In: Hong Y, Bartlett R, editors. Handbook of biomechanics and human movement science. Oxon: Abingdon; 2008. p. 156-81.
17. Duarte R, Araújo D, Gazinda V, Fernandes O, Folgado H, Marmeleira J, et al. The ecological dynamics of 1v1 sub-phases in association football. Open Sports Sci 2010;3:16-8.
18. Brunswik E. Perception and the representative design of psychological experiments. Berkeley and Los Angeles: The University of California Press; 1956.
19. Hammond KR, Bateman RA. Reply to comments: the need for representativeness persists. Int J Sport Psychol 2009;40:182-9.
20. Fernandes O, Caixinha P. A new method of time-motion analysis for soccer training and competition. In: Reilly T, Cabri J, Araújo D, editors. Book of abstracts of the V World Congress of Science and Football; 2003: Lisbon, Portugal: Faculty of Human Kinetics. 2003. p. 11-5.
21. Fernandes O, Caixinha P, Malta P. Techno-tactics and running distance analysis by camera. J Sports Sci Med 2007;6(Suppl 10):204.
22. Duarte R, Ferreira R, Folgado H, Fernandes O. Interpersonal dynamics in team sports: the role of TACTO and its applications. Int J Sport Psychol (in press).
23. Abdel-Aziz YI, Karara HM. Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. In: Proceedings of the symposium on close-range photogrammetry. Falls Church, VA: American Society of Photogrammetry; 1975. p. 420-76.
24. Marzan GT, Karara HM. A computer program for direct linear transformation solution of the collinearity condition, and some applications of it. In: Proceedings of Symposium on Close-Range Photogrammetric Systems. Falls Church, VA: American Society of Photogrammetry; 1975. p. 420-76.
25. Kwon YH. DLT method (web site on the Internet). Korea: VISOL, Inc.; (updated 2003 March 3; cited 2010 July 1). Available from: URL: http://www.kwon3d.com/theory/dlt/dlt.html
26. Winter DA. Biomechanics and motor control of human movement. 3rd ed. New York: John Wiley & Sons; 2005.
27. Moorhouse KM, Granata KP. Role of reflex dynamics in spinal stability: intrinsic muscle stiffness alone is insufficient for stability. J Biomech 2007;40:1058-65.