Ballesta Castells, C.; García Romero, J.; Fernández García, J.C. y Alvero Cruz, J.R. (2015). Métodos actuales de análisis del partido de fútbol / Current methods of Soccer Match Analysis. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 15 (60) pp. 785-803. Http://cdeporte.rediris.es/revista/revista60/artmetodos632.htm

REVISIÓN / REVIEW

CURRENT METHODS OF SOCCER MATCH ANALYSIS

MÉTODOS ACTUALES DE ANÁLISIS DEL PARTIDO DE FÚTBOL

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FUNDING: this review is included in a research project funded by the Andalusian Centre for Sports Medicine (*Centro Andaluz de Medicina del Deporte*) of the Autonomous Regional Government of Andalusia, Department of Tourism, Trade and Sport, Official Gazette of the Autonomous Regional Government of Andalusia no 239. ORDER issued on 9 November 2006.

Código UNESCO / UNESCO code: 5899 Otras especialidades pedagógicas (Educación Física y Deporte) / Other pedagogical specialities (Physical Education and Sport).
Clasificación del Consejo de Europa / Council of Europe Classification: 4. Educación Física y deporte comparado / Physical education and compared sports

Recibido 1 de agosto de 2012 **Received** August 1, 2012
Aceptado 18 de noviembre de 2013 **Accepted** November 18, 2013

ABSTRACT

The increasing stringency of modern soccer calls for a reappraisal of the game's physical demands and of traditional planning models and training methods. With this aim in mind, a collection of 86 references has been reviewed to analyse, in

the light of the latest research, the benefits and limitations of modern systems for soccer player analysis during match-play. The results show that the use of computer-aided video analysis and GPS to code movement patterns provides great insight into players' physical workload, while observational design facilitates the assessment of technical and tactical behaviour both at the individual and at the team level. To conclude, we have nonetheless observed that the options commercially available on the market are based on a variety of different methods and that the technology is still at an early stage of development.

KEY WORDS: time-motion analysis, soccer, tracking system, GPS, observational design.

RESUMEN

Ha sido realizada una revisión de 86 artículos, con el objetivo de analizar a través de los estudios más recientes los beneficios y limitaciones de los nuevos sistemas para el análisis del futbolista durante el partido, debido a que las mayores exigencias en el rendimiento del fútbol moderno está obligando a replantearse cuáles son las demandas físicas, así como los modelos de planificación y los métodos de entrenamiento tradicionales. Los resultados muestran que el vídeo análisis asistido por ordenador para la codificación de los patrones de movimiento y la tecnología GPS se presentan como herramientas de gran utilidad para conocer mejor la carga física del jugador, mientras que el diseño observacional facilita la evaluación del comportamiento técnico-táctico del futbolista y el equipo. Como conclusión podemos decir que hemos observado sin embargo una metodología diferente entre las opciones comerciales disponibles y una tecnología ubicada todavía en una etapa inicial de desarrollo.

PALABRAS CLAVE: análisis tiempo-movimiento, fútbol, sistema de seguimiento, GPS, diseño observacional.

1. INTRODUCTION

Studying players' activity during match-play is an essential part of training plan design, as it enables fine-tuning means and procedures for optimum preparation and improved performance on the playing field. A wide array of techniques have been used for this purpose, ranging from real-time observation and note-taking to post-game computer-based video-analysis. Hand notation systems are practical and easy to implement, but their validity and reliability hinges on a number of factors, such as the number, skills and experience of the observers deployed and the location from which they observe the game (Barris and Button, 2008; De la Vega-Marcos, Del Valle-Díaz, Maldonado-Rico and Moreno-Hernández, 2008). Moreover, traditional motion analysis methods are labour-intensive and time-consuming in terms of data capture and review (Di Salvo, Collins, Mc Neill and Cardinale, 2006), which has confined them to

university-based research projects (Carling, Bloomfield, Nelsen and Reilly, 2008).

Some of these methods have been examined in a number of reference studies (e.g. Reilly, 2005; Stølen, Chamari, Castagna and Wisløff, 2005; Barris and Button, 2008; Carling et al., 2008), but the increasingly fast pace at which new technologies are adopted means frequent reviews are needed. Study papers focusing on player performance indicators during match-play include pieces concerned with the technical and tactical side of the game, while others focus on appraising physical and/or physiological effort, and on social and psychological aspects (Reina-Gómez and Hernández-Mendo, 2012).

This review article, which is the first of its kind written in Spanish, is based on extensive research of specialised literature. It aims to provide a compilation of the different methods currently used to analyse soccer players during match-play, focusing on physical and technical-and-tactical aspects. A critical appraisal of each method is performed, studying the degree to which it may be applied to control player performance.

2. MATERIAL AND METHODS

2.1. Documentary research strategy

This review draws from reference literature produced between 1974 and 2012, although due to recent advances in computer-based video-analysis technology, only 4.5% of the bibliography researched dates from before 2000. Our research strategy focused firstly on recent sources of information and progressed backwards in time. The following databases were researched:
- PubMed (htpp://www.ncbi.nlm.nih.gov/pubmed).
- Dialnet (htpp://www . dialnet.unirioja.es).
- Teseo (htpp://www.educacion.es/teseo/).
- SportsDiscus (htpp://www.search.ebscohost.com).

The following descriptors were used: time-motion analysis, motion analysis, computer-aided motion analysis, computerized time-motion analysis, computer-based tracking, vision-based motion analysis, automatic tracking system, GPS and observational design, each one combined with the words “soccer” or “fútbol” (the Spanish spelling of “football”) with the boolean operators “and” and “y” (the Spanish word for “and”). The Google search engine (Google Ltd., Mountain View, CA, USA) was also utilised to locate companies specialising in video-analysis, using the aforementioned descriptors in the same way.

2.2. Inclusion and exclusion criteria

The following inclusion criteria were applied to select the scientific papers used in this review: (1) studies focusing on GPS-, image- or computer-based technologies for athlete analysis, and/or scientific validation papers on such

technologies; (2) studies concerned with motion analysis that were produced before the introduction of current systems; (3) studies of athlete performance analysis based on current systems; (4) reviews and studies of supplementary and commercial information relating to the new technologies under analysis.

The exclusion criteria were the following: (1) studies based on unpublished data or data published in journals not having a clear scientific-technical approach; (2) studies of new technologies applied to sport having no relation to game analysis or to the instrumentation used for this purpose; (3) studies written in languages other than English or Spanish; (4) essays, opinion articles and the like that do not follow the scientific method.

3. RESULTS

The use of the descriptors specified above in the four databases searched (PubMed, Teseo, Dialnet and SportsDiscus) returned a total of 86 articles after filtering by the exclusion criteria, which were grouped into four categories, as shown in Table 1. The source distribution of the references included in the sample was: scientific journals (n = 70), textbooks (n = 4), conferences and congresses (n = 9) and doctoral theses (n = 3). On the basis of this literature, a list of current systems for recording and analysing soccer player performance during match-play was compiled (Table 2). Setterwall (2003) makes a distinction between, firstly, manual applications for editing and creating video from information collected during match-play, and secondly, applications that additionally feature automated analysis of such video footage, providing real-time physical and tactical data. A third group may be added to these two, comprising GPS-based systems.

The first group includes, without limitation: The Observer® XT (Noldus Information Technology, Leesburg, VA, USA), SportsCode® (Sportstec, Camarillo, CA, USA), Nac Sport® (New Assistant for Coach Sport S.L., Las Palmas de Gran Canaria, Spain), IPS Analyzer Pro® (Interplay-sports, Oslo, Norway) and Dartfish® (Dartfish Ltd, Freiburg, Switzerland). The second group includes: Feedback Football® (Feedback Sport, Christchurch, New Zealand), ProZone® (ProZone Sports Ltd, Leeds, UK), AMISCO Pro® (Sport Universal Process, Nice, France), TCoach® (TRACAB, Solna, Sweden), DVideo, University of Campinas, Brazil), ASPOGAMO (Intelligent Autonomous Systems Group, Munich, Germany), VIS TRACK® (Cairo Technologies AG, Munich, Germany), Venatrack® (Venatrack Ltd, Slough, UK) and Mediacoach (Mediapro I+D y LFP, Madrid, Spain). As for the GPS receivers used by professional teams, these include: SPI Elite® (GPSport Systems, Canberra, Australia), MinimaxX v2.0®, (Catapult, Scoresby, Australia) and RealTrackFútbol Pro® (C&M Comunicación y Multimedia, Almeria, Spain).

Table 1. Article categories based on inclusion criteria.

Category	References
Operation of current athlete analysis technology	Anguera (2004); Barbero-Álvarez, J., Coutts, Granda, Barbero-Álvarez, V. and Castagna (2010); Bloomfield,

	Jonsson, Polman and O'Donnoghue (2005); Borrie, Jonsson and Magnusson (2001); Borrie, Jonsson and Magnusson (2002); Castellano and Hernández-Mendo (2003); Castellano, Perea and Alday (2005); Castellano, Alday and Hernández-Mendo (2008a); Courtney (2002); Coutts and Duffield (2010); Dabanch, Gil, Pérez and Rodríguez (2002); De la Vega-Marcos et al. (2008); Di Salvo et al. (2006); Edgecomb and Norton (2006); Ekin, Tekalp and Mehrotra (2003); Figueroa, Leite and Barros (2006); Gedikli, Bandouch, Hoyningen-Huene, Kirchlechner and Beetz (2007); Jonsson (2004); Jonsson, Blanco-Villaseñor, Losada and Anguera (2004); Jonsson et al. (2006); Leoand, D'Orazio, Spagnolo and Distante (2005); Macleod, Morris, Nevill and Sunderland (2009); Noldus, Trienes, Hendriksen, Jansen, H. and Jansen, R.G. (2000); Ohashi, J., Miyagi, Nagahama, Ogushi and Ohashi, K. (2002); Perea (2008); Redwood-Brown, Cranton and Sunderland (2012); Ren, Orwell, Jones and Xu (2004); Ren, Orwell and Jones (2006); Schutz and Herren (2000) ; Shiokawa et al. (2003); Terrier, Ladetto, Merminod and Schutz (2001) ; Terrier and Schutz (2003); Townshend, Worringham and Stewart (2008); Wan, Yan, Yu and Xu (2003); Wang, Xu, Chng, Wah and Tian (2004); Xu, Orwell and Jones, (2004); Witte and Wilson (2004); Witte and Wilson (2005)
Traditional analysis of athlete performance	Bangsbo, Mohr and Krustrup (2006); Castagna, D'Ottavio and Abt (2003); Helgerud, Engen, Wislølff and Hoff (2001); Krustrup, Mohr, Ellingsgaard and Bangsbo (2005); Miyagi, Ohashi and Kitagawa (1999); Mohr, Krustrup and Bangsbo (2003); Van Gool, Van Gerven and Boutmans (1988)
Current analysis of soccer player performance	Ardá and Anguera (2000); Barbero-Álvarez and Castagna (2007); Barbero-Álvarez, J., Gómez, Barbero-Álvarez, V., Granda and Castagna (2008); Barros et al. (2007); Bloomfield, Polman and O'Donoghue (2004); Bloomfield, Polman and O'Donnoghue (2007a); Bradley et al. (2009a); Bradley et al. (2009b); Burgess, Naughton and Norton (2006); Carling (2010); Castellano, Perea and Hernández-Mendo (2008b); Castellano, Blanco-Villaseñor and Álvarez (2011); Di Salvo, Barón and Cardinale (2007); Di Salvo, Gregson, Atkinson, Tordoff and Drust (2009); Harley et al. (2010); Harley, Lovell, Barnes, Portas and Weston (2011); Hewitt, Withers and Lyons (2007); Pino, Martínez-Santos, Moreno and Padilla (2007); Plestina, Dujmic and Papic (2009);Rampinini, Coutts, Castagna, Sassi e Impellizzeri (2007); Rampinini, Impellizzeri, Castagna, Coutts and Wisl0ff (2009); Randers, Jensen and Krustrup (2007); Randers et al. (2010); Rupf, Thomas and Wells (2007); Silva, Sánchez-Bañuelos, Garganta and Anguera (2005); Vigne, Gaudino, Rogowski, Alloatti and Hautier (2010); Weston, Drust and Gregson (2011); Zubillaga (2006); Zubillaga, Gorospe, Hernández-Mendo and Blanco (2007)
Supplementary or commercial informaiton on new technologies	Barris and Button (2008); Bloomfield, Polman and O'Donoghue (2007b); Carling et al. (2008); Castellano, Masach and Zubillaga (1996); Duncan, Badland and Mummery (2009); Magnusson (1996); Magnusson (2000); Reilly (2005); Reina-Gómez and Hernández-Mendo (2012); Setterwall (2003); Stølen et al. (2005)

Table 2. Current systems used for soccer analysis.

Firm/Institution	System	Type	Website
Feedback Sport	Feedback Football®	AV	http://www.feedbacksport.com
Propone Holdings Ltd	ProZone®	AV	http://www.pzfootball.co.uk
Sport-Universal Process S.A.	AMISCO Pro®	AV	http://www.sport-universal.com
TRACAB	TCoach®	AV	http://www.tracab.com
University of Campinas	Dvideo	AV	
Intelligent Autonomous Sys.G	ASPOGAMO	AV	http://ias.cs.tum.edu/
Cairo Technologies AG.	VIS TRACK®	AV	http://www.cairos.com
Venatrack Ltd	Venatrack®	AV	http://www.venatrack.com
Mediapro I+D y LFP	Mediacoach	AV	http://www.lfp.es
Citech Holdings Pty Ltd	Biotrainer®	GPS	http://www.citechholdings.com
GPSports Systems	SPI Elite®	GPS	http://www.gpsports.com
C&M Comuniciación y Multi.	RealTrackFútbol®	GPS	http://www.realtrackfutbol.com
Noldus Information Tech.	Observer Pro®	MV	http://www.noldus.com
Sportstec	SportsCode®	MV	http://www.sportstec.com
NAC Sport S.L.	Nac Sport®	MV	http://www.nacsport.com
Dartfish Ltd	Dartfish®	MV	http://www.dartfish.com
Interplay-sports	IPS Analyzer Pro®	MV	http://www.interplay-sports.com

AV: automatic video; MV: manual video; GPS: global positioning system.

4. DISCUSSION

The first motion analysis studies, which were predicated on the premise that energy expenditure is based on total distance run, classified players' actions according to their speed. The main categories were walking, jogging, cruising (striding) and sprinting, with other additional movements such as backward running and several actions with the ball (Reilly, 2005). Other more recent papers (Mohr et al., 2003; Krustrup et al., 2005; Randers et al., 2007) have continued to calculate speed from the time it takes players to pass different reference markers on the playing field, while total distance covered is determined from the total time and the average distance for each speed category. Movement pattern coding, however, is computer-aided.

Hand notation is an earlier technique (Knowles and Brooke, 1974, and Whitehead, 1975, in Stølen et al., 2005) which involved noting down player movements on graph paper and then transferring them on to a scale plan of the

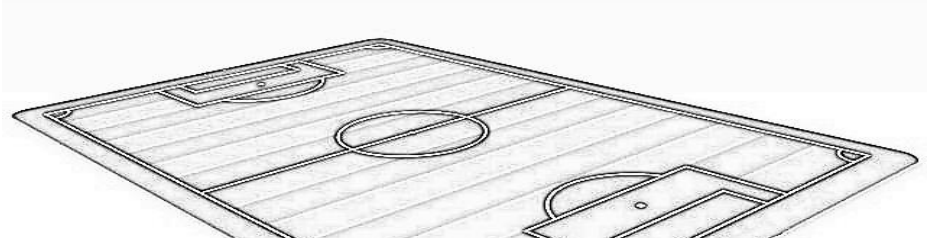
playing field using spatial estimation to calculate the distance covered by the player. In addition to the advantage of its non-invasiveness, this method enabled determining player performance during match-play, as it recorded not only total distance covered and approximate energy expenditure, but also motion type, intensity, duration and frequency. Trak Performance® (SportsTec Pty Ltd, Sydney, Australia) is a current system that calculates the total distance covered by a player with an error of less than 5% by using a mat and an electronic pen connected to a standard computer, with pre-markers placed on the playing field to calibrate the application (Burgess et al., 2006).

Other measurement instruments and resources used for data collection include film cameras (Van Gool et al., 1988), video cameras (Bangsbo et al., 1991; Helgerud et al., 2001; Castagna et al., 2003; Mohr et al., 2003; Shiokawa et al., 2003; Krustrup et al., 2005; Bangsbo et al., 2006; Bloomfield et al., 2007a; Randers et al., 2007), and trigonometry (Miyagi et al., 1999; Ohashi et al., 2002). Recent technical advancement has produced technologies that enable real-time, fast, reliable data collection and processing. As a result, computer-aided time-motion systems (computer-aided motion analysis, computerised time-motion analysis, computer-based tracking) and/or vision-based systems (vision-based motion analysis, automatic tracking systems) are increasingly preferred over traditional systems (Figure 1).

No common criteria are shared by the numerous studies based on traditional methodology, however, where movement classification and movement recording are concerned. Zubillaga (2006) supports Castellano et al. (1996) in arguing that the disparate results obtained by these studies are due to one or more of the following reasons: widely diversified profiles taking into account the sample size and characteristics; excessive subjectivity in determining intensity of motion; great variability in recording procedures and techniques, with low degrees of accuracy in descriptions of player positions in the team's playing system and no references to the strategic interaction context in which the match is played; and insufficient arguments to support the instrumentation's validity and reliability.

Figure 1. Current systems for soccer match analysis.
Seguimiento por GPS = GPS tracking
Seguimiento por ordenador = Computer tracking
Seguimiento por vídeo = Video tracking

Figura 1. Sistemas contemporáneos de análisis del partido de fútbol.



One of the current methods for analysing player motion during match-play uses GPS, a global navigation system that enables establishing the position of an object or a person by using a network of satellites that orbit the Earth with synchronised trajectories, covering its entire surface. Several references have examined the reliability of GPS when used in connection with physical exercise, including all its reception forms: "nondifferential GPS" (Witte and Wilson, 2004; Townshend et al., 2008; Macleod et al., 2009), "differential GPS" (Schutz and Herren, 2000; Terrier et al., 2001; Terrier and Schutz, 2003) and "WAAS-enabled GPS" (Witte and Wilson, 2005).

GPS systems combined with a heart rate monitor and an accelerometer are used to quantify training loads and the different types of motion and body movement in real time; in team sports (Edgecomb and Norton, 2006; Barbero-Álvarez and Castagna, 2007; Rupf et al., 2007; Macleod et al., 2009; Duncan et al., 2009; Barbero-Álvarez et al., 2010; Coutts and Duffield, 2010) and specifically in soccer (Hewitt et al., 2007; Pino et al., 2007; Barbero-Álvarez et al., 2008; Harley et al., 2010; Randers et al., 2010; Harley et al., 2011). Whereas the great advantage of this system is that it allows real-time measurement of each player's movements and their intensity, as well as ball trajectories, its disadvantage is that the equipment the player needs to wear is not permitted by FIFA (Fédération Internationale de Football Association) regulations. This precludes the performance of any studies using this method in official matches and restricts their use to training sessions and friendly games.

In parallel to the above, recent progress in the area of information and communication technology has produced significant advancement in the number and quality of computer software applications for coding and analysis (Noldus et al., 2000; Courtney, 2002; Dabanch et al., 2002; Shiokawa et al., 2003; Jonsson, 2004; Jonsson et al., 2004; Castellano et al., 2005; Perea, 2008; Castellano et al., 2008a) and systems for image capture and digitisation

(Ohashi et al., 2002; Ekin et al., 2003; Wan et al., 2003; Ren et al., 2004; Wang et al., 2004; Xu et al., 2004; Leoand et al., 2005; Ren et al., 2006; Gedikli et al., 2007). These new technologies are enabling real-time tracking of own and opposing player actions during match-play, both at the individual and the collective levels, as well as the movements of the referee and the ball (Weston et al., 2011).

Material and time costs remain high, as the video footage recorded must be dumped to computer for processing and analysis of every frame for each individual player, and the images subsequently converted for calculation of total distances and speeds, with some operations requiring manual adjustment. Barros et al. (2007) have described that use of an automatic tracking system (DVideo, Campinas, Brazil) requires up to 6 hours of parallel processing on 4 computers to segment the images, 4 additional hours to track each individual player, and a further 6 hours for manual corrections and calibrations. The tracking method recognises the player in every picture in 94% of cases, with a 1.4% error in distance covered (Figueroa et al., 2006).

Other authors, however, argue that this form of image-based tracking technology requires further development for application to team sports, as no fully autonomous system has yet been released on the market. According to Barris and Button (2008), sudden changes in direction and collisions between players undermine the "clean movement" model on which the DLT (Direct Linear Transformation) algorithms used are based (Shiokawa y cols, 2003), making manual adjustments necessary before the captured data can be processed. Reilly (2005) also expresses the view that the reliability of this technology has not yet been formally established despite currently being adopted by many professional soccer clubs, and that small errors in data collection may have a significant effect on how those data are interpreted. Lastly, Edgecomb and Norton (2006) have observed that the distances reported using computer-based video-analysis are overestimated by 5.8%, while distances measured using GPS are overestimated by 4.8%.

By way of example, Randers et al. (2010) examined the activity and fatigue of 20 soccer players over a match and compared the results obtained using four different systems: a manual video-based time-motion analysis system (VTM, Bangsbo et al., 1991), a semi-automatic system (AMISCO Pro®, Nice, France), and two GPS receivers with resolutions of 5 Hz (MinimaxX® v2.0, Catapult, Scoresby, Australia) and 1 Hz (SPI Elite®, GPSports, Canberra, Australia) respectively. Significantly, all the systems detected similar falls in the distance covered by players between the first and the second halves of the match ($p < 0.001$), which indicates that they can all be used to analyse game patterns reliably. However, there were significant differences among the absolute values measured by each system for distances covered at different speeds, an aspect that should be taken into account when comparing results obtained with different systems. Harley et al. (2011) also found significant differences in distances run at different speeds by 6 professional players during match-play ($p < 0.05$) when comparing the results obtained using a semi-automated video-

based system (ProZone Sports Ltd., Leeds, UK) and a GPS receiver (MinimaxX® v2.0, Catapult, Scoresby, Australia).

Nonetheless, the advantages of automated systems over manual systems mean that studies of soccer are increasingly being conducted using the former method (Zubillaga, 2006; Barros et al., 2007; Di Salvo et al., 2007; Rampinini et al., 2007; Zubillaga et al., 2007; Bradley et al., 2009a; Bradley et al., 2009b; Di Salvo et al., 2009; Plestina et al., 2009; Rampinini et al., 2009; Carling, 2010; Vigne et al., 2010; Castellano et al., 2011; Redwood-Brown et al., 2012).

Bloomfield et al. (2005) argue that, irrespective of the equipment used, researchers are observing an insufficient number of movements – fewer than eight – to establish the complex characteristics that determine physical demand in modern sport with the necessary level of detail. They also hold that, historically, studies have reported frequencies, totals and means of individual motions, but failed to recognise the different physiological demands resulting from the interaction of movements. In this connection, the Bloomfield Movement Classification (BMC) (Bloomfield et al., 2004) has been put forward as a validated method for time-motion analysis applicable to team sports including soccer (Bloomfield et al., 2007b). It defines 14 modes of timed motion, 3 non-timed movements, 14 directions, 4 intensities, 5 turning categories and 7 on-the-ball actions.

Other studies are undertaken with the aim of appraising player and team behaviour at the technical and tactical level rather than in physical and physiological terms, which makes the observational methodology a particularly suitable option (Castellano et al., 2008b). This approach also allows choosing an analysis technique to fit the observational design selected. The authors who pursue this line of research in the field of soccer apply either sequential analysis of delays (Ardá and Anguera, 2000; Silva et al., 2005) or a system based on an analysis of polar coordinates (Castellano and Hernández-Mendo, 2003), which requires a preliminary taxonomy of playing field formats and category schemes for game action observation.

The introduction of the time factor to soccer research – which had traditionally been limited to descriptive studies based on movement frequency observation – enabled sequential analysis and the detection of behavioural patterns, both of which constitute the basic variables of observational analysis. Systematic observation and recording reveals that the actions performed in soccer are repetitive. Thus, the number, frequency and complexity of the patterns detected means that soccer players' behaviour must be more structured than may appear to the naked eye (Anguera, 2004).

Among the current software for observational analysis, ThemeCoder® (PatternVision Ltd., Reikiavik, Iceland) is a coding application that operates after obtaining digitised recordings and generates files that can be imported into the application Theme® (PatternVision Ltd., Reikiavik, Iceland), which detects time

patterns (T-patterns) using the algorithm developed by Magnusson (1996, 2000). The chief contribution of T-patterns has been enabling the discovery of specific types of time structures in player behaviour that are difficult to detect by means of standard statistical methods (Borrie et al., 2001; Borrie et al., 2002), and prove particularly useful in the analysis of team sports such as soccer (Anguera, 2004; Bloomfield et al., 2005; Jonsson et al., 2006). Other applications designed for observational analysis include The Observer® XT (Noldus Information Technology, Leesburg, VA, USA), SOF-CODER® (Jonsson, 2004), Match Vision Studio® v.3.0 and SOCCAF® v2.0 (Perea, 2008), and MOTS® (Castellano et al., 2008a)

5. CONCLUSIONS

The systems currently available on the market for analysing soccer player performance make up a diverse range of products, each catering for specific needs. The choice among them is determined by the type of analysis intended to be carried out, with a key distinction usually being drawn between those focusing on physical and physiological aspects and those focusing on technical and tactical aspects. The systems may be classified according to the type of player-tracking performed during match-play and/or training: by means of GPS, video recording and editing, or computer-aided automated image processing. GPS is a reliable, proven system for quantifying soccer players' training load and recording different types of motions and body movements in real time. However, it can only be used in training sessions, as the regulations prevent the necessary devices being worn by players in official competitions. Manual video-editing and creation applications, whether they are based on standard analysis or on observational analysis, facilitate the real-time recording of physical actions and player behaviour when used as notation systems, although their results can be affected by the observer's subjectivity and level of training. Meanwhile, automated image tracking systems and computer-aided motion analysis provide a much larger volume of physical and technical-and-tactical data on own and opposing players in real time, and for this reason are being increasingly resorted to by professional soccer clubs. However, this technology has certain drawbacks, such as its high cost in terms of time and material and the need to make manual adjustments to remedy its inaccuracies in some situations.
None of the systems analysed can therefore be considered the standard technology for player and match analysis, as their reliability and accuracy have not been proven in all circumstances, particularly in studies that compared running speeds and distances. This, added to the absence of any common criteria in the classification and recording of movements and actions, suggests that these technologies are still at an early stage of development and need further improvement.

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