Application of four different football match analysis systems: A comparative study

MORTEN B. RANDERS1, IÑIGO MUJIKA2, ADAM HEWITT3, JUANMA SANTISTEBAN4, RASMUS BISCHOFF1, ROBERTO SOLANO5, ASIER ZUBILLAGA6, ESA PELTOLA5, PETER KRUSSTRUP1, & MAGNI MOHR1

1Department of Exercise and Sport Sciences, University of Copenhagen, Copenhagen, Denmark, 2USP Araba Sport Clinic, Vitoria-Gasteiz, Basque Country, Spain, 3Australian Institute of Sport, Canberra, ACT, Australia, 4Medical Services, Athletic Club Bilbao, Bilbao, Spain, 5Aspire Academy for Sports Excellence, Doha, Qatar, and 6Faculty of Physical Activity and Sport Sciences, University of the Basque Country, Bilbao, Spain

(Accepted 20 October 2009)

Abstract
Using a video-based time–motion analysis system, a semi-automatic multiple-camera system, and two commercially available GPS systems (GPS-1; 5 Hz and GPS-2; 1 Hz), we compared activity pattern and fatigue development in the same football match. Twenty football players competing in the Spanish second and third divisions participated in the study. Total distance covered during the match for the four systems was as follows: 10.83 ± 0.77 km (semi-automatic multiple-camera system, n = 20), 9.51 ± 0.74 km (video-based time–motion analysis system, n = 17), 10.72 ± 0.70 km (GPS-1, n = 18), and 9.52 ± 0.89 km (GPS-2, n = 13). Distance covered by high-intensity running for the four systems was as follows: 2.65 ± 0.53 km (semi-automatic multiple-camera system), 1.61 ± 0.37 km (video-based time–motion analysing system), 2.03 ± 0.60 km (GPS-1), and 1.66 ± 0.44 km (GPS-2). Distance covered by sprinting for the four systems was as follows: 0.38 ± 0.18 km (semi-automatic multiple-camera system), 0.42 ± 0.17 km (video-based time–motion analysing system), 0.37 ± 0.19 km (GPS-1), and 0.23 ± 0.16 km (GPS-2). All four systems demonstrated greater (P < 0.05) total distance covered and high-intensity running in the first 15-min period and less (P < 0.05) total distance covered and high-intensity running during the last 15-min period than all other 15-min intervals, with a reduction (P < 0.05) in high-intensity running from the first to the last 15-min period of 46 ± 19%, 37 ± 26%, 50 ± 26%, and 45 ± 27% for the semi-automatic multiple-camera system, video-based time–motion analysis system, GPS-1, and GPS-2, respectively. Our results show that the four systems were able to detect similar performance decrements during a football game and can be used to study game-induced fatigue. Rather large between-system differences were present in the determination of the absolute distances covered, meaning that any comparisons of results between different match analysis systems should be done with caution.

Keywords: GPS, multiple-camera system, time–motion analysis, high-intensity running, fatigue, soccer

Introduction
In association football (i.e. soccer), where prolonged intermittent exercise is performed in combination with brief periods of maximal and near maximal effort exercise, players have highly complex movement patterns that are unpredictable and dictated by numerous variables (Andersson, Ekblom, & Krustrup, 2008; Di Salvo et al., 2007; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krustrup, Andersson, Kirkendall, & Bangsbo, 2008; Mohr, Krustrup, & Bangsbo, 2003; Rampinini et al., 2007a; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007b; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2008; Rienzi, Drust, Reilly, Carter, & Martin, 2000). Due to the multifactorial requirements for success in football, many attempts have been made to elucidate the physiological demands of football match-play based upon estimates of distance covered and fluctuations in running intensity throughout a game (Bangsbo, Norregaard, & Thorsoe, 1991; Mohr et al., 2003; 2008; Rampinini et al., 2007a). Video-based time–motion analysis has been applied widely (Bangsbo et al., 2007a; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007b; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2008; Rienzi, Drust, Reilly, Carter, & Martin, 2000). Due to the multifactorial requirements for success in football, many attempts have been made to elucidate the physiological demands of football match-play based upon estimates of distance covered and fluctuations in running intensity throughout a game (Bangsbo, Norregaard, & Thorsoe, 1991; Mohr et al., 2003; 2008; Rampinini et al., 2007a). Video-based time–motion analysis has been applied widely (Bangsbo et al., 2007a; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007b; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2008; Rienzi, Drust, Reilly, Carter, & Martin, 2000). Due to the multifactorial requirements for success in football, many attempts have been made to elucidate the physiological demands of football match-play based upon estimates of distance covered and fluctuations in running intensity throughout a game (Bangsbo, Norregaard, & Thorsoe, 1991; Mohr et al., 2003; 2008; Rampinini et al., 2007a). Video-based time–motion analysis has been applied widely (Bangsbo et al., 2007a; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007b; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2008; Rienzi, Drust, Reilly, Carter, & Martin, 2000). Due to the multifactorial requirements for success in football, many attempts have been made to elucidate the physiological demands of football match-play based upon estimates of distance covered and fluctuations in running intensity throughout a game (Bangsbo, Norregaard, & Thorsoe, 1991; Mohr et al., 2003; 2008; Rampinini et al., 2007a). Video-based time–motion analysis has been applied widely (Bangsbo et al., 2007a; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007b; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2008; Rienzi, Drust, Reilly, Carter, & Martin, 2000). Due to the multifactorial requirements for success in football, many attempts have been made to elucidate the physiological demands of football match-play based upon estimates of distance covered and fluctuations in running intensity throughout a game (Bangsbo, Norregaard, & Thorsoe, 1991; Mohr et al., 2003; 2008; Rampinini et al., 2007a). Video-based time–motion analysis has been applied widely (Bangsbo et al., 2007a; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007b; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2008; Rienzi, Drust, Reilly, Carter, & Martin, 2000).
et al., 1991; Krustrup et al., 2003; Mohr et al., 2003; Reilly & Thomas, 1976) and such analyses have provided evidence that the distance covered at high intensity depends on playing position, standard of competition, physical capacity of the player, and physical performance of the opponent (Krustrup et al., 2003; Mohr et al., 2003; Rampinini et al., 2007a). Furthermore, time–motion analyses have shown that the performance of players deteriorates after the most intense periods of the game, at the beginning of the second half and towards the end of a game (for a review, see Mohr, Krustrup, & Bangsbo, 2005). Fatigue develops during a football match both transiently following short-term high-intensity sequences and towards the end of a game (Bangsbo, Iaia, & Krustrup, 2007; Bangsbo & Mohr, 2005; Mohr et al., 2003, 2008); however, it is unclear whether the same fatigue patterns will be detected with different match analysis systems.

Advances in technology have allowed new methods of assessing movement patterns in football, including the multiple-camera method (Di Salvo et al., 2007; Rampinini et al., 2007a, 2007b, 2008) and global positioning systems (GPS; Coutts & Duffield, 2008; Edgecomb & Norton, 2006; Kirkendall, Leonard, & Garrett, 2004). In comparison to time-consuming video-based time–motion analysis, these new match analysis systems have greater objectivity and some of them a higher time–resolution, which allows a more comprehensive study of locomotion patterns in football. However, no studies have tested this assertion by combining simultaneously video-based time–motion analysis, semi-automatic multiple-camera systems, and GPS monitoring in the same football match. Due to the unpredictable and indiscrete nature of movement patterns in football, to date there is no “gold standard” method for determining movement patterns and workload in the sport. However, information about possible differences between the aforementioned systems is highly warranted. Edgecomb and Norton (2006) compared a GPS system with a manual computer-based tracking system to estimate distances covered on an Australian Rules Football field and showed that the GPS system overestimated true values by ~4.8% compared with a calibrated trundle wheel. This evaluation of distances covered was not, however, performed during a training session or competitive game and movement at different speeds was not compared.

In the present study, we compared a video-based time–motion analysis system, a semi-automatic multiple-camera system, and two commercially available GPS systems in their ability to monitor activity patterns and fatigue development in the same football match.

Methods

Participants

Twenty highly trained outfield football players from the development programme of a professional club and currently competing in the Spanish second and third divisions took part in the study. Players’ age, body mass, and stature (mean ± s) were 19.3 ± 1.2 years, 73.6 ± 5.3 kg, and 1.79 ± 0.06 m, respectively. The players were regular starters in their respective teams and were representative of all outfield playing positions. The players had a Yo-Yo IR1 performance of 2950 ± 425 m, a vertical countermovement jump height of 44 ± 4 cm, and an average 30-m sprint speed of 7.19 ± 0.02 m·s⁻¹. All players were informed of the risks and discomfort associated with the experiment before providing their written consent to participate. The study followed the Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the Ethics Committee of the University of the Basque Country (UPV-EHU).

Experimental design

A test-game (two halves of 47.5 min separated by 15 min of normal half-time) between the two teams was arranged by the researchers. The game was played 7 days after the last game of the competitive season. The game took place at San Mamés Stadium (Bilbao, Basque Country) at noon at an average temperature of ~30°C, which was determined from continuous readings provided by a station of the Basque Service of Meteorology (Euskalmet) situated ~1 km from the stadium. The pre-game and half-time procedures, as well as the coaching during the game, were similar to a competitive game. The players’ activity profiles were assessed during the entire game by a video-based time–motion analysis system (VTM: Bangsbo et al., 1991; Mohr et al., 2003), the Amisco® multiple-camera semi-automatic passive tracking system (MCS: Di Salvo et al., 2007), and two commercially available global positioning systems (GPS-1: Edgecomb & Norton, 2006; GPS-2: Coutts & Duffield, 2008). The data analysis and treatment for the four systems were performed by researchers in four different countries, and the different investigators were blinded to all other results. The researchers evaluated the ability of each system to track player movement and to detect changes during the game. Furthermore, the four systems were compared in terms of their capability to measure distances covered at different speeds.
**Time–motion analysis**

Each player was video-recorded individually close up throughout the entire match. The 20 digital video cameras (GR-D23E, JVC, Japan) were positioned at the side of the pitch, at the level of the midfield line, at a height of about 25 m and at a distance of 30–40 m from the touchline. The videotapes were later replayed on a monitor for computerized coding of activity patterns. The following locomotor categories were adopted: standing (0 km·h⁻¹), walking (6 km·h⁻¹), jogging (8 km·h⁻¹), low-speed running (12 km·h⁻¹), moderate-speed running (15 km·h⁻¹), high-speed running (18 km·h⁻¹), sprinting (30 km·h⁻¹), and backward running (10 km·h⁻¹). The locomotor categories were chosen in accordance with Bangsbo et al. (1991). Thus, the time for the player to pass pre-markers in the grass, the centre circle, and other known distances was used to calculate the speed for each activity of locomotion. All time–motion analyses were performed by the same experienced observer, who has analysed more than 400 matches. The reproducibility of the results obtained by time–motion analysis has been determined, and no systematic differences were observed in test–retest analysis of the same match. The intra-individual variations in walking, low-intensity running, high-intensity running, and backward running were 2, 5, 3, and 3%, respectively (Krustup & Bangsbo, 2001). The inter-individual variation in results obtained by two independent experienced observers was never more than 4% in any of the locomotor activities (Bangsbo et al., 1991). The above activities were later divided into four locomotor categories: (1) standing; (2) walking; (3) low-intensity running, encompassing jogging, low-speed running, and backward running; and (4) high-intensity running, consisting of moderate-speed running, high-speed running, and sprinting. The frequency and duration of each activity were recorded and data are presented for 5-, 15-, 45-, and 90-min periods. The distance covered for each activity within each interval was determined as the product of the total time and mean speed for that activity. The total distance covered during a match was calculated as the sum of the distances covered during each type of activity. To be able to compare time–motion analysis with the other three systems, the above-mentioned categories included specific speed intervals: standing (0–2 km·h⁻¹), walking (2–7 km·h⁻¹), jogging (7–9 km·h⁻¹), low-speed running (9–13 km·h⁻¹), moderate-speed running (13–16 km·h⁻¹), high-speed running (16–22 km·h⁻¹), and sprinting (≥ 22 km·h⁻¹).

**Amisco® multiple-camera system**

The Amisco® system is a multiple-camera match analysis system (Amisco Pro®, version 1.0.2, Nice, France). The movements of all 20 outfield players were observed during the entire game by eight stable, synchronized cameras positioned at the top of the San Mamés Stadium (Bilbao, Basque Country) at a sampling frequency of 25 measures a second. Signals and angles obtained by the encoders were sequentially converted into digital data and recorded on six computers for post-match analyses. From the stored data, the distance covered, time spent in the different movement categories, and the frequency of occurrence for each activity were determined by Athletic Mode Amisco Pro®, Nice, France (Di Salvo et al., 2007). Match analyses were used to distinguish between the same intensity categories as described in the time–motion analysis section.

**Global positioning system**

The GPS technology was originally designed for military use, but recently it has been applied to the analysis of performance in football. Edgecomb and Norton (2006) compared a GPS system with a manual computer-based tracking system to estimate distances covered on an Australian Football field and showed relatively minor variations. The system uses signals from at least three Earth–orbiting satellites to determine the position and calculate movement speeds and distances. Two different commercially available GPS units (MinimaxX v2.0, Catapult, Scoresby, Australia, and GPSports SPI Elite, Canberra, Australia) were placed on the player’s upper back, one inside a neoprene pouch attached to a harness around the player’s shoulders, the other inside another pouch sewn into a sleeveless under-shirt. The receivers were placed as recommended by the manufacturers and were not occluded. Based on signals from at least three satellites, the receiver is able to calculate and record data on position, time, and speed with a time-resolution of 5 and 1 Hz for the two systems (GPS-1 and GPS-2, respectively). Both systems used the GPS Doppler data. The data from each receiver were treated in the same manner and data were extracted using proprietary software (Minimavx analyse software v2.5, GPSport team AMS v1.2.1.12). Match analyses were also carried out considering the above-mentioned intensity categories.

**Statistical analysis**

Differences between the distances covered in the first and second halves were determined using Student’s paired t-test. To keep a high number of participants, the four systems were compared in pairs using Student’s paired t-test. Differences in activities between 15-min periods in the match were determined using a one-way repeated-measures
analysis of variance (ANOVA). In the case of a significant difference between time periods, a Tukey’s post hoc test was used to identify the points of difference. To compare the systems, correlation coefficients were determined and tested for significance using Pearson’s regression test. Furthermore, the coefficient of variation (CV) was used as a measure of intra-individual variation within different locomotor categories between the match analysis systems and was calculated as the standard deviation of the difference between the four systems divided by the mean and multiplied by 100 (Atkinson & Nevill, 1998). Data are presented as means ± standard deviation (s). Statistical significance was set as P < 0.05. Bonferroni correction was used for the multiple paired t-test resulting in P < 0.008 when the four systems were compared and P < 0.012 when three systems were compared. Due to technical problems some players’ data were lost, which means that the number of participants differs depending on which systems are being compared.

Three video recordings (VTM) were lost due to technical problems. Data from two GPS-1 receivers were lost because the transmitters stopped recording during the game, whereas five GPS-2 receivers stopped recording during the game and data from two receivers were affected by noise.

Results

Activity pattern

Total distance covered ranged from 9.51 ± 0.74 km measured with the video-based time–motion analysis system to 10.83 ± 0.77 km measured with the semi-automatic multiple-camera system (Table I). Distance covered in high-intensity running and sprinting ranged from 1.61 ± 0.38 km (time–motion analysis) to 2.65 ± 0.53 km (multiple-camera system) and from 0.23 ± 0.16 km (GPS-2) to 0.42 ± 0.17 km (time–motion analysis), respectively (Table I). Distance covered at low-intensity running ranged from 2.93 ± 0.62 km (GPS-2) to 3.60 ± 0.54 km (multiple-camera system), whereas walking ranged between 4.40 ± 0.37 km (GPS-2) and 5.13 ± 0.85 km (GPS-1). The multiple-camera system, GPS-1, and GPS-2 determined a distance covered at 0–2 km ⋅ h⁻¹ that refers to the category “standing”, ranging from 0.08 ± 0.02, 0.48 ± 0.03, and 0.31 ± 0.09 km, respectively, whereas time–motion analysis considers movement at this speed as “standing” and considers the distance to be 0. Total running distance, which corresponds to the total distance covered excluding distance covered by walking and the distance covered in the category “standing”, ranged from 6.23 ± 0.99 km (multiple-camera system) to 4.77 ± 0.96 km (GPS-2) (Table I).

Peak distance covered in a 5-min interval was 0.71 ± 0.04, 0.64 ± 0.04, 0.73 ± 0.06, and 0.61 ± 0.06 km for the multiple-camera system, time–motion analysis, GPS-1, and GPS-2, respectively. The peak distance covered in high-intensity running was 0.25 ± 0.04, 0.18 ± 0.04, 0.22 ± 0.05, and 0.18 ± 0.05 km for these four systems, respectively (Figure 1), whereas the peak sprint distance reached 0.06 ± 0.02, 0.06 ± 0.02, 0.07 ± 0.02, and 0.05 ± 0.02 km, respectively.

Table I. Total distance covered, high-intensity running, distance covered by sprinting, low-intensity running, and total running distance throughout the entire game measured with the semi-automatic multiple-camera system (MCS), the video-based time–motion analysis system (VTM), GPS-1 and GPS-2 (mean ± s).

<table>
<thead>
<tr>
<th>System</th>
<th>n</th>
<th>Total distance (km)</th>
<th>High-intensity (km)</th>
<th>Sprinting (km)</th>
<th>Low-intensity (km)</th>
<th>Total running (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCS</td>
<td>20</td>
<td>10.83 ± 0.77</td>
<td>2.65 ± 0.53</td>
<td>0.38 ± 0.18</td>
<td>3.60 ± 0.54</td>
<td>6.23 ± 0.99</td>
</tr>
<tr>
<td>VTM</td>
<td>17</td>
<td>9.51 ± 0.74</td>
<td>1.61 ± 0.37</td>
<td>0.42 ± 0.17</td>
<td>3.41 ± 0.53</td>
<td>5.02 ± 0.58</td>
</tr>
<tr>
<td>GPS-1</td>
<td>18</td>
<td>10.72 ± 0.70</td>
<td>2.03 ± 0.60</td>
<td>0.37 ± 0.19</td>
<td>3.08 ± 0.54</td>
<td>5.10 ± 1.08</td>
</tr>
<tr>
<td>GPS-2</td>
<td>13</td>
<td>9.52 ± 0.89</td>
<td>1.66 ± 0.44</td>
<td>0.23 ± 0.16</td>
<td>2.93 ± 0.62</td>
<td>4.77 ± 0.96</td>
</tr>
<tr>
<td>MCS vs. GPS-1</td>
<td>18</td>
<td>10.85 ± 0.81</td>
<td>*2.66 ± 0.56</td>
<td>0.37 ± 0.18</td>
<td>*3.62 ± 0.57</td>
<td>*6.25 ± 1.04</td>
</tr>
<tr>
<td>VTM vs. GPS-2</td>
<td>10</td>
<td>9.51 ± 0.83</td>
<td>1.58 ± 0.37</td>
<td>*0.42 ± 0.18</td>
<td>*3.37 ± 0.59</td>
<td>*4.95 ± 0.71</td>
</tr>
<tr>
<td>VTM vs. GPS-1</td>
<td>15</td>
<td>*9.52 ± 0.78</td>
<td>1.58 ± 0.34</td>
<td>0.39 ± 0.17</td>
<td>*3.49 ± 0.50</td>
<td>5.07 ± 0.60</td>
</tr>
<tr>
<td>GPS-1</td>
<td>15</td>
<td>10.73 ± 0.67</td>
<td>1.94 ± 0.56</td>
<td>0.35 ± 0.19</td>
<td>2.99 ± 0.47</td>
<td>4.92 ± 0.95</td>
</tr>
<tr>
<td>MCS vs. GPS-2</td>
<td>12</td>
<td>*10.84 ± 0.99</td>
<td>*2.61 ± 0.66</td>
<td>*0.36 ± 0.22</td>
<td>*3.68 ± 0.68</td>
<td>*6.26 ± 1.24</td>
</tr>
<tr>
<td>GPS-2</td>
<td>12</td>
<td>9.56 ± 0.92</td>
<td>1.65 ± 0.46</td>
<td>0.23 ± 0.16</td>
<td>2.95 ± 0.64</td>
<td>4.80 ± 0.99</td>
</tr>
<tr>
<td>MCS vs. VTM</td>
<td>17</td>
<td>*10.75 ± 0.72</td>
<td>*2.62 ± 0.49</td>
<td>0.40 ± 0.18</td>
<td>3.50 ± 0.43</td>
<td>*6.08 ± 0.85</td>
</tr>
<tr>
<td>VTM</td>
<td>17</td>
<td>9.51 ± 0.74</td>
<td>1.61 ± 0.38</td>
<td>0.42 ± 0.17</td>
<td>3.41 ± 0.53</td>
<td>5.02 ± 0.58</td>
</tr>
<tr>
<td>GPS-1 vs. GPS-2</td>
<td>11</td>
<td>*10.76 ± 0.90</td>
<td>2.00 ± 0.76</td>
<td>0.36 ± 0.23</td>
<td>3.04 ± 0.65</td>
<td>5.04 ± 1.34</td>
</tr>
</tbody>
</table>

*Significant difference between two systems (P < 0.001); † No significant difference between two systems (0.008 < P < 0.05).
Comparing the systems

The multiple-camera system measured a longer total distance covered during the whole match compared with time–motion analysis (12%, \(n = 17, P < 0.001\)) and GPS-2 (12%, \(n = 12, P < 0.001\)), whereas no difference was observed between the multiple-camera system and GPS-1 \((n = 18, P > 0.4\)). In addition, GPS-1 registered a longer total distance than time–motion analysis (13%, \(n = 15, P < 0.001\)) and GPS-2 (10%, \(n = 11, P < 0.001\)), but there was no difference between time–motion analysis and GPS-2 (Table I).

The GPS-1 system measured more walking than the multiple-camera system \((5.13 \pm 0.85 \text{ vs. } 4.51 \pm 0.31 \text{ km, } n = 18, P < 0.01)\) and time–motion analysis \((5.28 \pm 0.86 \text{ vs. } 4.45 \pm 0.47 \text{ km, } n = 15, P < 0.01)\) but not GPS-2 \((5.19 \pm 0.91 \text{ vs. } 4.44 \pm 0.40 \text{ km, } n = 12, P = 0.019)\). No differences between the three other systems were observed. The multi-camera system recorded a longer \((P < 0.001)\) total running distance compared with time–motion analysis \((17\%, n = 17)\), GPS-1 \((18\%, n = 18)\), and GPS-2 \((23\%, n = 12)\), whereas there were no differences between the latter three systems (Table I).

The multi-camera system did not differ from time–motion analysis in the distance covered at low-intensity running over 90 min, but it recorded more \((P < 0.001)\) low-intensity running than GPS-1 \((15\%, n = 18)\) and GPS-2 \((20\%, n = 13)\). Both GPS-1 and GPS-2 showed less \((P < 0.001)\) low-intensity running than time–motion analysis \((14\%, n = 15 \text{ and } 16\%, n = 11, \text{ respectively})\), but there was no difference between GPS-1 and GPS-2 (Table I).

The multi-camera system measured more \((P < 0.001)\) high-intensity running than the other three systems (time–motion analysis: 39%, \(n = 17\); GPS-1: 24%, \(n = 18\); GPS-2: 37%, \(n = 13\)). Moreover, the distance covered in high-intensity running as measured by GPS-1 tended to be longer \((P = 0.025)\) than with time–motion analysis \((23\%, n = 15)\) and GPS-2 \((17\%, n = 12, P = 0.067)\), whereas no difference was observed between time–motion analysis and GPS-2. The GPS-2 system tracked less \((P < 0.001)\) distance while sprinting than the multiple-camera system \((38\%, n = 12)\) and time–motion analysis \((36\%, n = 10)\), and there was a tendency for this compared with GPS-1 \((39\%, n = 11, P = 0.048)\). No differences were observed between GPS-1, time–motion analysis, and the multiple-camera system (Table I).

Total distance covered, distance covered at low intensity, and distance covered in high-intensity running for the whole match measured with the multiple-camera system correlated with time–motion analysis, GPS-1 and GPS-2; GPS-2 correlated with time–motion analysis and GPS-1; whereas no correlation was found between time–motion analysis and GPS-1. Distance covered when walking measured with the four systems did not correlate with each other (Table II). The distance covered when sprinting over the entire match did not correlate with the four systems (Table II).

Figure 1. Peak high-intensity running in a 5-min period, the following 5 min, average values of the remaining 5-min periods, and the relative change from peak to the next 5-min period measured with the semi-automatic multiple-camera system (MCS, \(n = 20\)), the video-based time–motion analysis system (VTM, \(n = 17\)), GPS-1 \((n = 18)\), and GPS-2 \((n = 13)\). Data are means \(\pm\) standard deviations. *Significantly different from VTM and GPS-2 \((P < 0.001)\). ‡Significantly different from VTM and GPS-2 \((P < 0.008)\). #Significantly different from all other systems \((P < 0.001)\).
<table>
<thead>
<tr>
<th></th>
<th>Total distance covered during 90 min</th>
<th>Distance covered with walking during 90 min</th>
<th>Low-intensity running during 90 min</th>
<th>Sprinting distance during 90 min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MCS</td>
<td>VTM</td>
<td>GPS-1</td>
<td>GPS-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MCS</td>
<td>VTM</td>
<td>GPS-1</td>
<td>GPS-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: MCS vs. GPS-1, n = 18; VTM vs. GPS-2, n = 10; VTM vs. GPS-1, n = 15; MCS vs. GPS-2, n = 12; MCS vs. VTM, n = 17; GPS-1 vs. GPS-2, n = 11.

MCS = semi-automatic multiple-camera system; VTM = video-based time–motion analysis system.
Sprint velocity and frequency

Peak sprint velocity was higher as measured with GPS-1 (range 31.0–48.5 km·h⁻¹) than with the multiple-camera system (range 27.2–35.6 km·h⁻¹) (35.4 ± 4.3 vs. 32.2 ± 2.0 km·h⁻¹, n = 16, P < 0.017) and GPS-2 (range 22.4–32.6 km·h⁻¹) (34.3 ± 2.8 vs. 28.9 ± 2.8 km·h⁻¹, n = 12, P < 0.01). Furthermore, the multiple-camera system showed a higher peak velocity than GPS-2 (32.5 ± 2.1 vs. 29.1 ± 2.8 km·h⁻¹, n = 13, P < 0.001; Figure 2). Peak running velocity measured with the multiple-camera system correlated with GPS-2 (r = 0.87, n = 13, P < 0.001), whereas neither GPS-1 and the multiple-camera system nor GPS-1 and GPS-2 were correlated (P > 0.05). The number of sprints recorded was 19.9 ± 8.7, 28.2 ± 10.2, 26.7 ± 9.4, and 14.7 ± 8.8 for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively. Time-motion analysis recorded more sprints than the multiple-camera system (29.1 ± 10.4 vs. 19.9 ± 8.9, n = 16, P < 0.001) and GPS-2 (28.4 ± 10.8 vs. 14.2 ± 8.9, n = 12, P < 0.001), while GPS-1 detected more (P < 0.001) sprints than the multiple-camera system (27.9 ± 9.1 vs. 19.5 ± 8.8) and GPS-2 (28.2 ± 9.6 vs. 15.1 ± 8.9). No difference was observed between time-motion analysis and GPS-1 or between GPS-2 and the multiple-camera system.

Fatigue indicators

Total distance covered and distance covered in high-intensity running in the second half assessed with the multiple-camera system, time-motion analysis, GPS-1, and GPS-2 were lower (P < 0.001) than in the first half for all systems (7.4 ± 8.8%, 10.4 ± 7.5%, 7.2 ± 7.5%, 10.1 ± 6.7% and 20.0 ± 19.1%, 27.2 ± 19.6%, 20.2 ± 20.8%, 21.9 ± 18.3%, respectively; Figure 3). Time-motion analysis and GPS-1 detected significantly (P < 0.001) less distance covered with sprinting during the second half compared with the first (27.3 ± 28.5% and 38.6 ± 26.1%, respectively; Figure 3), whereas distance while sprinting in the second half tended to be lower for GPS-2 (P = 0.089) with no difference between the two halves for the multiple-camera system (Figure 3).

In the first 15 min of the game, the total distance measured was 1.95 ± 0.15, 1.76 ± 0.18, 2.06 ± 0.17, and 1.69 ± 0.15 km for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively, all of which were higher (P < 0.001) than for all other 15-min intervals. Furthermore, the total distance covered during the last 15 min (1.46 ± 0.18, 1.24 ± 0.17, 1.46 ± 0.11, and 1.26 ± 0.17 km for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively) was lower (P < 0.01) than for all other 15-min intervals.

The distance covered in high-intensity running in the first 15 min was 0.58 ± 0.13, 0.37 ± 0.13, 0.47 ± 0.13, and 0.38 ± 0.12 km for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively, all of which were higher than in all other 15-min intervals (P < 0.001). Furthermore, a shorter distance was recorded while in high-intensity running during the last 15 min than in all other 15-min intervals (0.26 ± 0.10, 0.12 ± 0.07, 0.22 ± 0.14, and 0.16 ± 0.09 km for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively; P < 0.01). The game-fatigue index (i.e. the difference in high-intensity running during the first and the last 15 min of the game) was 45.7 ± 19.1%, 37.4 ± 26.4%, 49.9 ± 25.7%, and 44.7 ± 27.2% for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively, which were not significantly different from each other (P > 0.45).

In the first 15-min period, the distance covered while sprinting was 0.08 ± 0.04, 0.09 ± 0.05, 0.08 ± 0.05, and 0.06 ± 0.04 km measured for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively. This was more than during the last 15 min of the match (0.03 ± 0.04, 0.03 ± 0.03, 0.04 ± 0.05, and 0.02 ± 0.02 km, respectively; P < 0.01).

To compare the ability of the four systems to detect changes in workload during the game, the total distance covered in the first 15-min period was used as the reference. The total distances covered in the remaining 15-min periods, all of which were lower than during the first 15-min period, were expressed relative to the reference interval. No difference was found between the four systems for 15–30, 45–60, 60–75 or 75–90 min, whereas GPS-1 detected less (P < 0.01) distance covered than the multiple-camera system, time-motion analysis, and GPS-2 in the 30–45 min period (77.4 ± 6.8% vs. 87.7 ± 4.8%, 86.0 ± 6.5%, and 89.1 ± 4.9%, respectively; Figure 4a). When the first 15-min period was used as reference and high-intensity running in the remaining 15-min periods was calculated as a percentage of the first 15-min interval, no differences were observed between the multiple-camera system, time-motion analysis, and GPS-1 in any of the 15-min periods (Figure 4b).

The peak distance covered with high-intensity running in a 5-min period was 247 ± 42, 184 ± 42, 217 ± 51, and 178 ± 52 m for the multiple-camera system, time-motion analysis, GPS-1, and GPS-2, respectively (Figure 1). In the next 5-min period, the amount of high-intensity running was determined to be 142 ± 73, 95 ± 43, 125 ± 54, and 87 ± 51 m for
the multiple-camera system, time–motion analysis, GPS-1, and GPS-2, respectively, which correspond to 57 ± 29%, 51 ± 20%, 57 ± 20%, and 42 ± 20% of the peak distance, respectively. These values were not different from the average distances covered in high-intensity running during all other 5-min periods (136 ± 29, 81 ± 19, 103 ± 32, and 84 ± 35 m, respectively). Although the multiple-camera system measured a greater peak distance covered at high intensity than time–motion analysis and GPS-2 (P < 0.001) but not GPS-1 (P = 0.027), the relative difference between the peak and the next 5-min period did not differ.

Discussion

For the first time, the present study compared four match analysis methods during the same
football match. This comparison was warranted, since video-based time–motion analysis systems, semi-automatic multiple-camera systems, and different GPS systems have been applied in the literature and in many top football clubs. No “gold standard” method exists, but a comparison of the most frequently used tracking methods makes it possible to compare findings from different studies. The major findings of the present study were that the four systems detected similar decreases in running distances during the game, whereas rather large between-system differences were observed in the absolute distances covered within each locomotor category. Thus, each of the respective systems appears to be able to examine movement patterns during football games, whereas absolute values reported for running distances seem to be highly dependent on the system and these differences should be taken into account when comparing results collected with different systems.

Several studies using different locomotion tracking systems have reported values of 9–12 km for total distance covered during football games (Bangsbo, 1994; Bangsbo et al., 1991; Di Salvo et al., 2007; Mohr et al., 2003; Rampinini et al., 2007a, 2007b, 2008; Reilly & Thomas, 1976; Rienzi et al., 2000). It

Figure 4. (a) Total distance covered and (b) high-intensity running in 15-min periods measured with the semi-automatic multiple-camera system (MCS, n = 20), the video-based time–motion analysis system (VTM, n = 17), GPS-1 (n = 18), and GPS-2 (n = 13). Period 0–15 min is set to 100 and the rest of the 15-min periods are presented as a percentage of the 0–15 min period. Data are means ± standard deviations.

*Significant different from the other three systems: P < 0.001.
is unclear, however, how exact these distances are. In the present study, the semi-automatic multiple-camera system and GPS-1 (5 Hz) measured a total distance covered around 1 km longer than the video-based time–motion analysis system and GPS-2 (1 Hz). The major contributor to the total distance covered was walking, which makes up one-third to one-half of the total distance covered in a game, and since distance covered by walking by the different systems was highly variable, this explains part of the observed differences in absolute distances covered between the systems. The GPS-1 system measured walking distance to be 0.6–0.7 km longer than the other three systems, which explains most of the difference in total distance between the GPS-1 and video-based time–motion analysis system and GPS-2. Distance covered in the walking category is not that important a variable for evaluation of the physical loading of a football game. Therefore, total running distance was also compared within the systems. The semi-automatic multiple-camera system assessed a total running distance ~1 km longer than the other systems. When the four systems were compared within the low-intensity running category, the semi-automatic multiple-camera system and video-based time–motion analysis system measured ~0.5 km more low-intensity running than the two GPS systems. Moreover, the amount of low-intensity running was correlated between all systems except between the video-based time–motion analysing system and GPS-1, suggesting that the difference between these two systems lies within this category. No difference was observed between the semi-automatic multiple-camera system and video-based time–motion analysis system measured ~0.5 km more low-intensity running than the two GPS systems. Moreover, the amount of low-intensity running was correlated between all systems except between the video-based time–motion analysing system and GPS-1, suggesting that the difference between these two systems lies within this category. No difference was observed between the semi-automatic multiple-camera system and video-based time–motion analysis system, demonstrating that the main difference in total running distance between those two systems is to be found within the intense running categories. The video-based time–motion analysis system has a category for backward and sideways running that is not a separate category in the other three systems. This category is encompassed in low-intensity running and almost all backward and sideways running is performed within this speed category (7–13 km · h⁻¹). However, it is possible that some backward and sideways running is performed at higher speed, but this is considered to be a minor part.

High-intensity running in a football game is likely to be the most important measurement for physical match performance (Bangsbo, 1994; Bangsbo, Mohr, & Krstrup, 2006; Drust, Atkinson, & Reilly, 2007; Krstrup et al., 2003; Mohr et al., 2005; Rampinini et al., 2007b, 2008). High-intensity running during a game correlates with intense intermittent test performance (Krustrup et al., 2003, 2005, 2006; Rampinini et al., 2007a). Moreover, the amount of high-intensity running in a game is sensitive to seasonal variations (Mohr et al., 2003; Rampinini et al., 2007b) and training interventions (Helgerud, Engen, Wisloff, & Hoff, 2001; Impellizzeri et al., 2006; Krstrup & Bangsbo, 2001). Mohr and colleagues (2003, 2008) showed that both male and female elite players cover a markedly greater distance in high-intensity running than players of a lower standard of play. However, Rampinini et al. (2008) have recently shown that high-intensity running with the ball and technical skills may be more important for success.

In the present study, the distance covered in high-intensity running measured by the semi-automatic multiple-camera system measured was 0.6–1.0 km longer than for the three other systems. The distance covered in high-intensity running measured with the semi-automatic multiple-camera system was 2.65 km, which is 9% and 39% more than reported for video-based time–motion analysis for Italian top-class and Danish intermediate professional football players, respectively (Mohr et al., 2003).

The distance in high intensity running recorded with the video-based time–motion analysis system and GPS-2 in the present friendly game was 1.61 and 1.66 km, which is lower than previously reported, whereas the distance recorded by GPS-1 (2.03 km) was within the range often reported for professional football players during competitive games (Di Salvo et al., 2007; Mohr et al., 2003). The peak distance covered with high-intensity running in a 5-min period ranged from 184 to 247 m. This is similar to or longer than reported for high-class football players measured with a video-based time–motion analysis system (Mohr et al., 2003). The difference in high-intensity running between the video-based time–motion analysis system, the semi-automatic multiple-camera system, and GPS-1 was not due to differences in sprinting distance, since no differences were observed between the three systems. On the other hand, the GPS-2 system detected a sprint distance that was 0.15–0.20 km less than the other systems, which partly explains the differences in high-intensity running between GPS-2 and GPS-1. The GPS-2 system has a time-resolution of 1 Hz, which could explain the difference in sprint distance between this system and GPS-1 and the semi-automatic multiple-camera system, since the average 30-m sprint speed was 7.19 ± 0.04 m · s⁻¹. Although most sprints are performed directly forwards, there is sometimes a change of direction (Bloomfield, Polman, & O’Donoghue, 2007), which could cause problems for GPS-2 measuring distances covered at high speed. The GPS-2 system measured a lower maximal sprinting speed than GPS-1 and the semi-automatic multiple-camera system, which could also indicate that 1 Hz is an insufficient time-resolution.
when measuring high-speed activities. In line with this, GPS-2 measured only about 50–75% of the number of sprints detected by the other three systems.

A common finding in studies of activity patterns in football is large individual variation between players, which among other things is associated with playing position (Bangsbo et al., 1991; Di Salvo et al., 2007; Krustup et al., 2005; Mohr et al., 2003; 2008; Reilly & Thomas, 1976), physical capacity (Bangsbo et al., 1991; Krustup et al., 2005; Mohr et al., 2003; Rampinini et al., 2008), and the opponent (Rampinini et al., 2007b). Despite the differences in absolute distances between the systems in the present study, moderate to strong correlations were observed between nearly all systems, indicating that the systems are capable of measuring individual movement patterns. Match analysis has been used to examine fluctuations in exercise intensity and indications of fatigue in several studies (Andersson et al., 2008; Bangsbo, 1994; Bangsbo & Mohr, 2005; Bangsbo et al., 1991; Di Salvo et al., 2007; Ekblom, 1986; Krustup et al., 2005; Mohr et al., 2003, 2008; Rampinini et al., 2007a, 2007b, 2008; Reilly & Thomas, 1976; Saltin, 1973; Van Gool, Van Gerven, & Boutmans, 1988). These studies report differences between the two halves of a game with the work rate decreasing in the second half. In support of these studies, all four systems demonstrated that both total distance covered and high-intensity running declined in the second half compared with the first. On the other hand, only two systems recorded a significantly lower sprinting distance in the second half compared with the first. Fatigue has been suggested to develop during the final 15 min of an elite football game (Bangsbo et al., 2006; Mohr et al., 2005), since the distance covered in total by high-intensity running and sprinting has been shown to decline substantially in this period (Bangsbo & Mohr, 2005; Krustup et al., 2005; Mohr et al., 2003, 2008), which is reflected in a deterioration in physical performance (Krustup et al., 2006; Mohr, Krustup, Nybo, Nielsen, & Bangsbo, 2004). In the present study, all four systems showed that total distance covered, total running distance, and distance covered in high-intensity running were lower during the last 15 min of the game than in any other 15-min period. Usually the first 15 min of a game sees the highest work rates (Mohr et al., 2003, 2005, 2008). In support of this, total distance covered by running and by high-intensity running was higher during the first 15 min than in any other 15-min interval during the game, indicating that all systems can detect fluctuations in intensity during a football game. A game-fatigue index was calculated based on the relative difference in high-intensity running between the first and last 15-min period. The game-fatigue index was not different (37–50%; P > 0.6) between the four tracking systems, indicating that all systems can be used to examine performance decrements during a football game.

Using match analysis, Mohr et al. (2003, 2008) showed that fatigue develops temporarily during a game, which is further supported by Krustup et al. (2006). Thus, in the studies of Mohr and colleagues it was evident that the amount of high-intensity running covered in the 5-min period after the peak 5-min intervals was lower than the game average. In the present study, the peak period was located in the same period with all systems. In addition, the decline in match performance from the peak 5-min period to the following 5 min was the same in all systems (41–49%). Thus, it appears that peak intensity periods and temporary fatigue can be assessed by all four systems used in the present study.

In conclusion, all four systems were able to detect performance decrements during a football game and can be applied to study development of fatigue in elite football. Our results also revealed rather large between-system differences in the determination of the absolute distances covered, implying that any comparison of results using different match analysis systems should be done with caution.

Acknowledgements

The authors would like to thank the players and the coaching staff of Athletic Club Bilbao for their participation, effort, and support. Acknowledgement is also due to the Faculty of Physical Activity and Sport Sciences, University of the Basque Country (UPV-EHU), for providing technical support for video recordings for time–motion analysis.

References


