Estimated metabolic and mechanical demands during different small-sided games in elite soccer players

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Abstract

The present study examined the extent to which game format (possession play, SSG-P and game with regular goals and goalkeepers, SSG-G) and the number of players (5, 7 and 10 a-side) influence the physical demands of small-sided soccer games (SSGs) in elite soccer players. Training data were collected during the in-season period from 26 English Premier League outfield players using global positioning system technology. Total distance covered, distance at different speed categories and maximal speed were calculated. In addition, we focused on changes in velocity by reporting the number of accelerations and decelerations carried out during the SSGs (divided in two categories: moderate and high) and the absolute maximal values of acceleration and deceleration achieved. By taking into account these parameters besides speed and distance values, estimated energy expenditure and average metabolic power and distance covered at different metabolic power categories were calculated. All variables were normalized by time (i.e., 4 min). The main findings were that the total distance, distances run at high speed (>14.4 km h⁻¹) as well as absolute maximum velocity, maximum acceleration and maximum deceleration increased with pitch size (10v10 > 7v7 > 5v5; p < .05). Furthermore, total distance, very high (19.8–25.2 km h⁻¹) and maximal (>25.2 km h⁻¹) speed distances, absolute maximum velocity and maximum acceleration and deceleration were higher in SSG-G than in SSG-P (p < .001). On the other hand, the number of moderate (2–3 m s⁻²) accelerations and decelerations as well as the total number of changes in velocity were greater as the pitch size decreased.

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http://dx.doi.org/10.1016/j.humov.2014.05.006
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dimensions decreased (i.e., 5v5 > 7v7 > 10v10; \( p < .001 \)) in both SSG-G and SSG-P. In addition, predicted energy cost, average metabolic power and distance covered at every metabolic power categories were higher in SSG-P compared to SSG-G and in big than in small pitch areas (\( p < .05 \)). A detailed analysis of these drills is pivotal in contemporary football as it enables an in depth understanding of the workload imposed on each player which consequently has practical implications for the prescription of the adequate type and amount of stimulus during exercise training.

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1. Introduction

Small-sided games (SSGs) represent a common form of conditioning in soccer (Brandes, Heitmann, & Müller, 2012; Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011; Iaia, Rampinini, & Bangsbo, 2009) serving as an effective alternative to traditional interval training for enhancing a player’s soccer-specific endurance (Hill-Haas, Coutts, Rowsell, & Dawson, 2009; Impellizzeri et al., 2006). In addition to replicating the specific movement patterns associated with match-play such methods have the advantage of concurrent physical, cognitive and technical/tactical development (Brandes et al., 2012; Casamichana, Castellano, & Castagna, 2012; Hill-Haas et al., 2011; Mallo & Navarro, 2008).

In light of their growing popularity, a comprehensive understanding of the stimulus imposed on players during these drills is required in order to optimise the training adaptation. Manipulating variables such as the playing area, number of players and rules of the game influences the workload of SSGs (Brandes et al., 2012; Castellano, Casamichana, & Dellal, 2013; Dellal et al., 2012; Hill-Haas et al., 2011). For example, a larger pitch size and low number of players increases the strain incurred (Casamichana & Castellano, 2010; Dellal et al., 2011; Hill-Haas et al., 2011; Kelly & Drust, 2009). However, to date information concerning the load associated with SSGs has been predominantly assessed via heart rate (HR), blood lactate ([La]) and rating of perceived exertion (RPE) (Hill-Haas et al., 2011; Rampinini et al., 2007). It has been demonstrated that SSGs containing smaller numbers of players elicit greater HR, blood lactate and perceptual responses (Hill-Haas et al., 2011) that were also higher on medium and large pitch sizes compared with small pitches (Hill-Haas et al., 2011; Rampinini et al., 2007). The evolution of global positioning systems (GPS) now permits valid and reliable estimates of the external load incurred during SSGs (Brandes et al., 2012; Casamichana & Castellano, 2010; Castellano et al., 2013; Dellal et al., 2011). In this regard, recent studies reported that the largest game format is associated with a greater range of distances traveled at high speeds (Casamichana & Castellano, 2010; Hill-Haas et al., 2011). In addition, the total distance covered at high speed was higher when the number of ball contacts allowed was reduced (Dellal et al., 2011).

However, despite extensive research, to date there is still a general lack of load-related information on typical soccer drills used with elite players (e.g., SSG-P). In particular, little is known about some crucial physical (e.g., accelerations and decelerations) components taxed within drills of different type and size. The unpredictable and multifactorial nature of these conditioned games involving among others a great number of explosive actions and changes in velocity, implies a higher complexity in the quantification of the workload. Therefore, novel insight about the mechanisms taxed and the physiological demands imposed is warranted. Recent studies by Gaudino et al. (2013b, 2014), have indeed demonstrated that the physical requirements during SSGs are more demanding than suggested in much of the early literature based on running speed alone, and these differences are even greater when SSGs are played in small pitches. Previous investigations (di Prampero et al., 2005; Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010), have shown that the energy expenditure and distance covered at different metabolic power categories better inform about the true physical demands imposed on players, as this method takes into account accelerations and decelerations besides speed and distance values (di Prampero et al., 2005; Gaudino et al., 2013b, 2014; Osgnach...
et al., 2010). In addition, it was reported that during soccer matches the number of maximal accelerations performed is ~8-fold greater than sprints (Varley & Aughey, 2013). However, to the best of our knowledge no study has yet adopted such an approach to quantify the metabolic and mechanical demands of different SSGs in elite soccer. In addition, no comparisons exist for these parameters between possession play (SSG-P) and small-sided games played with regular goals and goalkeepers (SSG-G) in elite soccer. An in-depth information about the consistency and knowledge of work rates targeted with certain drills would enable a better understanding of the physiological objectives to target in order to stimulate the physical components of match performance.

Thus, the aim of this study was to provide a detailed analysis during SSGs of different size (5v5, 7v7 and 10v10) and format (SSG-P vs. SSG-G), with special focus on mechanical metric (e.g., number and intensity of changes in velocity) as well as physical parameters such as predicted energy expenditure and metabolic power scores in elite soccer players. A more comprehensive quantification of the workload would optimize the selection of appropriate conditioning drills, which consequently would impact upon the injury prevention strategies and physical preparation of elite soccer players.

2. Methods

2.1. Players and drills observations

Twenty-six soccer players competing in the English Premier League and UEFA Champions League (age = 26 ± 5 years; height = 182 ± 7 cm; body mass = 79 ± 5 kg) took part in the study during the in-season competition period. A total of 873 individual drill observations were undertaken on outfield players (goalkeepers were excluded) with a median of 32 observations per players (range = 7–52). Two different formats of SSGs were analyzed: small-sided games played with goalkeeper and regular goals (SSG-G) and collective possession play only (SSG-P) where the objective was to keep the ball for longer than the opposing team. In addition, three variations of each SSG format were examined: 5v5 (player observations = 92 and 215 for SSG-G and SSG-P, respectively), 7v7 (player observations = 124 and 85) and 10v10 (player observations = 208 and 149). By considering the presence of the goalkeepers in SSG-G, the pitch dimensions in SSG-P slightly changed in order to keep the area per player almost unvaried (Table 1). Each drill was performed in a continuous regime, under the supervision, coaching and motivation of several coaches in order to keep up a high work-rate (Rampinini et al., 2007). During all the analyzed SSGs a maximum of two touches of the ball per person were allowed. Offside rule was not applied during the SSGs. In any cases the ball was always available by prompt replacement when hit out of the play (Castellano et al., 2013; Dellal et al., 2011, 2012). During training before the experimental period, players frequently performed both SSGs formats which ensured a good level of familiarisation. All sessions were performed on the same pitch. In addition, all exercises were carried out at the same time of the day in order to limit the effects of the circadian variations on the measured variables (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005). SSGs were completed after a standardized 20-min warm up. Given different drill duration, the parameters taken into account for the statistical analysis were normalized by time (i.e., 4 min). All players were notified of the aim of the study, research procedures, requirements, benefits and risks before giving written informed consent. The Ethics Committee of the University of Milan approved the study.

Table 1

<table>
<thead>
<tr>
<th>Drill</th>
<th>Pitch dimension (m)</th>
<th>Pitch area (m²)</th>
<th>Area per player (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5v5 SSG-G</td>
<td>30 x 30</td>
<td>900</td>
<td>75</td>
</tr>
<tr>
<td>7v7 SSG-G</td>
<td>45 x 35</td>
<td>1575</td>
<td>98</td>
</tr>
<tr>
<td>10v10 SSG-G</td>
<td>66 x 45</td>
<td>2970</td>
<td>135</td>
</tr>
<tr>
<td>5v5 SSG-P</td>
<td>27 x 27</td>
<td>729</td>
<td>73</td>
</tr>
<tr>
<td>7v7 SSG-P</td>
<td>37 x 37</td>
<td>1369</td>
<td>98</td>
</tr>
<tr>
<td>10v10 SSG-P</td>
<td>52 x 52</td>
<td>2704</td>
<td>135</td>
</tr>
</tbody>
</table>
2.2. Data collection

The players’ physical activity during each training session was monitored using portable global positioning system (GPS) technology (GPSports, SPI-Pro X, Canberra, Australia). This version of the SPI Pro (6 g tri-axial accelerometer sampling at 100 Hz integrated; size = 48 × 20 × 87 mm; mass = 76 g) provides raw position, velocity and distance data at 15 Hz (15 samples per second). For the purpose of this study, every three raw data points was averaged to provide a sampling frequency of 5 Hz (Gaudino et al., 2013b, 2014). A particular vest was tightly fitted to each player, placing the receiver between the scapulae. All devices were always activated 15-min before the data collection to allow acquisition of satellite signals (Maddison & Ni Mhurchu, 2009). The minimum acceptable number of available satellite signals was 8 (range 8–11) (Varley, Fairweather, & Aughey, 2012; Waldron, Worsfold, Twist, & Lamb, 2011). Data was eliminated on days when the satellite signal was below this value. In addition, in order to avoid inter-unit error players wore the same GPS device for each training session (Buchheit et al., 2014; Jenninngs, Cormack, Coutts, Boyd, & Aughey, 2010). This type of system has previously been shown to provide valid and reliable estimates of instantaneous velocity during acceleration, deceleration, and constant velocity movements (Barbero-Alvarez, Coutts, Granda, Barbero-Alvarez, & Castagna, 2010; Portas, Harley, Barnes, & Rush, 2010; Varley et al., 2012; Waldron et al., 2011). This instrument has previously been used in order to quantify the number of accelerations during elite Australian soccer matches (Varley & Aughey, 2013). However, as 5-Hz GPS may slightly underestimate instantaneous velocity during acceleration or high-speed movements any reported values in this investigation are the minimum of what a player would actually undertake during the analyzed drill (Varley et al., 2012).

Through the use of this instrument drill duration, total distance covered and distance covered in the different speed categories was calculated using a custom Excel spreadsheet from instantaneous raw data of time, speed and distance available from the SPI Pro X software Team AMS (GPSports SPI Pro X, Canberra, Australia). In the same program instantaneous acceleration values were calculated by dividing the change in speed by time. Finally, the mathematical model proposed by di Prampero et al. (2005) were also integrated in the custom spreadsheet in order to calculate total estimated energy expenditure, average metabolic power, and distance covered in different metabolic power categories as reported in previously studies using GPS technology (Gaudino, Gaudino, Alberti, & Minetti, 2013a; Gaudino et al., 2013b, 2014).

2.3. Physical performance

The following activities were calculated during each drill: total distance (TD), total high speed running (TS; >14.4 km h⁻¹), high speed (HS; 14.4–19.8 km h⁻¹), very high speed (VHS; 19.8–25.2 km h⁻¹) and maximal speed (MS; >25.2 km h⁻¹) running distance (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009). Only the accelerations and decelerations lasting at least 1 s (Δt = 1) were taken into account in this study and analyzed as number of efforts. In addition, in accordance to the categories previously used during match analysis (Akenhead, Hayes, Thompson, & French, 2013; Osgnach et al., 2010), and based on new findings by Minetti, Gaudino, Seminati, and Cazzola (2013) which demonstrated the substantial constancy of running metabolic cost at speed oscillating up to ~1 m s⁻², in the present investigation only changes in velocity >2 m s⁻² and <−2 m s⁻² were considered. Consequently, the following four categories were selected: moderate (MD; −2 to −3 m s⁻²) and high (MD; <−3 m s⁻²) deceleration and moderate (MA; 2–3 m s⁻²), and high acceleration (HA; >3 m s⁻²) (Osgnach et al., 2010). Moreover, absolute maximal values of speed (in km h⁻¹), acceleration and deceleration (in m s⁻²) reached during the exercises were calculated.

With regards to the predicted metabolic parameters, total energy expenditure (EC) and average metabolic power (Pₑₑₑₑ) were calculated (di Prampero et al., 2005). In addition, Pₑₑₑₑ categories were defined as: distance covered (m) at high power (HP; from 20 to 35 W kg⁻¹), elevated power (EP; from 35 to 55 W kg⁻¹) and maximal power (MP; >55 W kg⁻¹) (di Prampero et al., 2005; Gaudino et al., 2013b). Total distance covered at high Pₑₑₑₑ (TP; >20 W kg⁻¹) was also analyzed as an indicator of the high intensity distance covered (Gaudino et al., 2013b, 2014).
2.4. Statistical analysis

Data are presented as mean ± standard deviation. A two-way ANOVA for repeated measures was performed in order to understand the main effect of the format type (SSG-G or SSG-P) and the number of the players involved (5, 7 or 10 a-side) on the physical parameters between drills. Significant main effects and interaction between factors were followed up with a least significant difference (LSD) post hoc test (Perneger, 1998). Statistical significance was set at \( p < .05 \). Simple effect size (ES), estimated from the ratio of the mean difference to the pooled standard deviation, was also calculated. Effect size values of 0.2, 0.5 and 0.8 were considered to represent small, moderate and large differences respectively (Vincent, 1999). The statistical analysis were performed using the software SPSS (version 19.0, IBM, Somers, USA).

3. Results

3.1. Distance and speed categories

The TD and the distance covered at different speeds in each SSG are reported in Table 2. TD was greater when the area per player increased in both SSG-G and SSG-P (10v10 > 7v7 > 5v5; \( p < .01 \)). A similar trend (i.e., 10v10 > 7v7 > 5v5) was noted for the TS (\( p < .001, \text{ES} > 1.0 \)), HS (\( p < .001, \text{ES} > 0.6 \)), VHS (\( p < .001, \text{ES} > 1.0 \)) distances and absolute maximal speed (\( p < .001; \text{ES} > 1 \)) in both SSG-G and SSG-P. In addition, MS distance was more elevated in the 10v10 as compared to 7v7 and 5v5 in both SSG-G and SSG-P (\( p < .001, \text{ES} > 0.7 \); Table 2).

Greater TD was covered in SSG-P irrespective of the number of players involved (\( p < .001, \text{ES} > 0.5 \)). No significant differences were found between SSG-G and SSG-P for the TS and HS distances, while VHS and MS distances were greater in SSG-G (\( p < .001, \text{ES} > 0.7 \) and \( p < .001, \text{ES} > 1.0 \), respectively; Table 2). Differently to the other speed parameters, the absolute maximal velocity reached was systematically higher in SSG-G compare to SSG-P irrespective of drill sizes (\( p < .001, \text{ES} > 1.0 \)).

3.2. Changes in velocity

The key detailed parameters related to changes in velocity are presented (mean ± SD) in Table 3. The total number of changes in velocity, the number of MA and MD increased as the size of both SSG-P and SSG-G decreased (i.e., 5v5 > 7v7 > 10v10; \( p < .001, \text{ES} > 0.5 \)). The number of HA and HD was similar between different drill sizes (\( p > .05 \)) in both SSG-G and SSG-P. On the other hand, the

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance and speed parameters obtained during the SSGs. Results have been normalized by time (for a 4 min period) and then expressed as mean ± SD.</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>5v5 SSG-G</td>
</tr>
<tr>
<td>TD (m)</td>
</tr>
<tr>
<td>TS (m)</td>
</tr>
<tr>
<td>HS (m)</td>
</tr>
<tr>
<td>VHS (m)</td>
</tr>
<tr>
<td>MS (m)</td>
</tr>
<tr>
<td>Max Speed (km h(^{-1}))</td>
</tr>
</tbody>
</table>

\( \text{TD} = \text{total distance}; \text{TS} = \text{total high speed running (}>14.4 \text{ km h}^{-1}\); \text{HS} = \text{high speed (14.4–19.8 km h}^{-1}\); \text{VHS} = \text{very high speed (19.8–25.2 km h}^{-1}\); \text{MS} = \text{maximal speed (>25.2 km h}^{-1}\). *Significant difference (\( p < .001 \).
maximum rate of absolute acceleration and deceleration was generally observed in the larger SSGs irrespective of drill format (i.e., 10v10 > 7v7 > 5v5; \( p < .05, \text{ES} > 0.3 \) for accelerations and \( p < .001, \text{ES} > 0.6 \) for decelerations; Table 3).

The total number of changes in velocity was generally similar between SSG-G and SSG-P with the exception of 5v5 SSG where a greater value was observed in SSG-P compared to SSG-G (\( p = .03, \text{ES} = 0.4 \)). In particular, also the number of MA, HA, MD and HD was similar between all SSG-G and SSG-P drills (\( p > .05 \)). Otherwise, the maximal absolute values of acceleration and deceleration were greater in SSG-G compared to SSG-P independent of drill size (\( p < .001, \text{ES} > 0.9 \); Table 3).

### 3.3. Predicted metabolic parameters

Predicted metabolic data are reported in Table 4. Total energy cost (EC) and the average metabolic power (\( P_{\text{met}} \)) showed the same trend in both SSG-G and SSG-P being higher in 10v10 compared to 7v7.

### Table 3

Detailed drills characteristics based on changes in velocity. Results have been normalized by time (for a 4 min period) and then expressed as mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>5v5 SSG-G</th>
<th>5v5 SSG-P</th>
<th>7v7 SSG-G</th>
<th>7v7 SSG-P</th>
<th>10v10 SSG-G</th>
<th>10v10 SSG-P</th>
<th>Follow-up tests (LSD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total changes in velocity (No.)</td>
<td>20 ± 5</td>
<td>22 ± 5</td>
<td>18 ± 3</td>
<td>18 ± 5</td>
<td>14 ± 3</td>
<td>16 ± 3</td>
<td>5v5 &gt; 7v7 &gt; 10v10^*</td>
</tr>
<tr>
<td>MA (No.)</td>
<td>8 ± 1</td>
<td>9 ± 2</td>
<td>7 ± 2</td>
<td>8 ± 2</td>
<td>6 ± 1</td>
<td>6 ± 2</td>
<td>5v5 &gt; 7v7 &gt; 10v10^*</td>
</tr>
<tr>
<td>HA (No.)</td>
<td>2 ± 1</td>
<td>1 ± 0</td>
<td>2 ± 1</td>
<td>1 ± 1</td>
<td>1 ± 0</td>
<td>1 ± 1</td>
<td>7v7 = 10v10</td>
</tr>
<tr>
<td>Max Acc (m s(^{-2}))</td>
<td>3.4 ± 0.3</td>
<td>3.2 ± 0.4</td>
<td>3.7 ± 0.3</td>
<td>3.3 ± 0.4</td>
<td>3.8 ± 0.2</td>
<td>3.4 ± 0.3</td>
<td>7v7 &gt; 5v5^*</td>
</tr>
<tr>
<td>MD (No.)</td>
<td>8 ± 2</td>
<td>9 ± 2</td>
<td>7 ± 2</td>
<td>8 ± 3</td>
<td>6 ± 1</td>
<td>6 ± 1</td>
<td>10v10 &gt; 7v7 &gt; 5v5</td>
</tr>
<tr>
<td>HD (No.)</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>5v5 = 7v7 = 10v10</td>
</tr>
<tr>
<td>Max Dec (m s(^{-2}))</td>
<td>3.8 ± 0.3</td>
<td>3.5 ± 0.4</td>
<td>4.1 ± 0.3</td>
<td>3.7 ± 0.3</td>
<td>4.5 ± 0.3</td>
<td>3.9 ± 0.4</td>
<td>10v10 &gt; 7v7 &gt; 5v5^*</td>
</tr>
</tbody>
</table>

Total changes in velocity = total number of changes in velocity (i.e., sum of accelerations and decelerations >2 m s\(^{-2}\)); MA = number of moderate accelerations (2–3 m s\(^{-2}\)); HA = number of high accelerations (>3 m s\(^{-2}\)); MD = number of moderate decelerations (2–3 m s\(^{-2}\)); HD = number of high accelerations (>3 m s\(^{-2}\)). ^Significant difference (\( p < .001 \)); *significant difference (\( p < .05 \)).

### Table 4

Predicted metabolic parameters related to the six different SSGs. Results have been normalized by time (for a 4 min period) and then expressed as mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>5v5 SSG-G</th>
<th>5v5 SSG-P</th>
<th>7v7 SSG-G</th>
<th>7v7 SSG-P</th>
<th>10v10 SSG-G</th>
<th>10v10 SSG-P</th>
<th>Follow-up tests (LSD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total EC (kJ kg(^{-1}))</td>
<td>2.8 ± 0.4</td>
<td>2.9 ± 0.3</td>
<td>2.8 ± 0.3</td>
<td>3.0 ± 0.3</td>
<td>2.9 ± 0.2</td>
<td>3.1 ± 0.4</td>
<td>10v10 &gt; 7v7 &gt; 5v5^*</td>
</tr>
<tr>
<td>Avg ( P_{\text{met}} ) (W kg(^{-1}))</td>
<td>12.2 ± 1.7</td>
<td>12.9 ± 1.1</td>
<td>12.4 ± 1.3</td>
<td>13.3 ± 1.2</td>
<td>12.8 ± 1.0</td>
<td>13.5 ± 1.6</td>
<td>10v10 &gt; 7v7 &gt; 5v5^*</td>
</tr>
<tr>
<td>TP Distance (m)</td>
<td>84 ± 21</td>
<td>88 ± 13</td>
<td>92 ± 17</td>
<td>100 ± 18</td>
<td>106 ± 15</td>
<td>118 ± 24</td>
<td>5v5 &gt; 7v7 &gt; 10v10^*</td>
</tr>
<tr>
<td>HP Distance (m)</td>
<td>48 ± 12</td>
<td>50 ± 8</td>
<td>53 ± 10</td>
<td>58 ± 11</td>
<td>62 ± 10</td>
<td>70 ± 14</td>
<td>10v10 &gt; 7v7 &gt; 5v5^*</td>
</tr>
<tr>
<td>EP Distance (m)</td>
<td>17 ± 5</td>
<td>18 ± 5</td>
<td>18 ± 5</td>
<td>20 ± 5</td>
<td>22 ± 5</td>
<td>23 ± 6</td>
<td>5v5 &gt; 7v7 &gt; 5v5^*</td>
</tr>
<tr>
<td>MP Distance (m)</td>
<td>19 ± 6</td>
<td>20 ± 4</td>
<td>21 ± 5</td>
<td>22 ± 5</td>
<td>23 ± 4</td>
<td>25 ± 6</td>
<td>10v10 &gt; 7v7 &gt; 5v5^*</td>
</tr>
</tbody>
</table>

EC = energy cost; \( P_{\text{met}} \) = metabolic power; TP = total high power (>20 W kg\(^{-1}\)); HP = high power (20–35 W kg\(^{-1}\)); EP = elevated power (35–55 W kg\(^{-1}\)); MP = maximal power (>55 W kg\(^{-1}\)). ^Significant difference (\( p < .001 \)); *significant difference (\( p < .01 \)); *significant difference (\( p < .05 \)).
and 5v5 while no differences were found between the last two drills (10v10 > 7v7 = 5v5; \( p < .01, \) ES > 0.3 and \( p < .05, \) ES > 0.1, for EC and \( P_{\text{met}} \), respectively). Distance covered at TP, HP, EP and MP increased with drill size (i.e., 10v10 > 7v7 > 5v5; \( p < .01, \) ES > 0.3). All predicted metabolic parameters (i.e., EC, \( P_{\text{met}} \), TP, HP, EP and MP) were greater in SSG-P compared with SSG-G (\( p < .05, \) ES > 0.2; Table 4).

4. Discussion

The major findings of the present study were that the total distance, distances covered above 14.4 km h\(^{-1}\) as well as absolute maximum speed, acceleration and deceleration were bigger when the area per player increased (10v10 > 7v7 > 5v5) with the total distance, very high and maximal speed distances, absolute velocity and maximum acceleration and deceleration achieved being greater in the small-sided games (SSG-G) when compared with possessions (SSG-P). Conversely, the number of moderate acceleration and decelerations as well as the total number of changes in velocity were higher when the pitch dimensions decreased (i.e., 5v5 > 7v7 > 10v10) in both SSG-G and SSG-P. In addition, all the predicted metabolic parameters (EC, \( P_{\text{met}} \), TP, HP, EP and MP) were systematically higher in SSG-P when compared with SSG-G, and in big versus small pitch areas.

To the best of our knowledge this is the first study which analyzes comprehensively the estimated metabolic (EC, average \( P_{\text{met}} \) and distance covered at different \( P_{\text{met}} \)) and mechanical (number of changes in velocity, accelerations and decelerations) demands of different small-sided games and possessions in top-class soccer players. A detailed analysis of these drills is pivotal in contemporary football as it enables an in depth understanding of the workload imposed on each player, which consequently has practical implications for the prescription of the adequate type and amount of stimulus during exercise training.

The total distance, distances covered at high speed (\( >14.4 \) km h\(^{-1}\)) and high power (\( >20 \) W kg\(^{-1}\)) as well as the average metabolic power were greater when the pitch area increased, which is in line with previous studies reporting more elevated exercise intensities with larger pitch area and reduced number of players or ball contacts allowed per individual possession (Casamichana & Castellano, 2010; Castellano et al., 2013; Dellal et al., 2011; Hill-Haas et al., 2011; Kelly & Drust, 2009). On the contrary, the moderate as well as the total number of changes in velocity became higher as the pitch dimension decreased (Fig. 1). This suggests that small areas of play taxes different physiological components of

![Fig. 1. Very high speed distance covered (\( >19.8 \) km h\(^{-1}\), in meters) and the total number of changes in velocity (i.e., sum of accelerations and decelerations>2 m s\(^{-2}\)) performed during the 6 different SSGs (mean ± SD).]
performance when compared to big areas, which are not detectable by measuring the distances covered and speed attained. Furthermore, accelerations and decelerations tended to be greater in the SSG-P compared with SSG-G, possibly due to the multidirectional effect of the possession drills. In contrast, if there are goals such as in the SSG-G, the players will automatically be more linear in their movement patterns due to having a direction to target. The importance of changing velocity is supported by recent findings showing that in professional players 18% of the total distance during a soccer match is generally obtained by accelerating or decelerating at >1 m s\(^{-2}\) while 7.5%, 4.3% and 3.3% is covered at 1–2 m s\(^{-2}\), 2–3 m s\(^{-2}\) and >3 m s\(^{-2}\), respectively (Akenhead et al., 2013). It therefore appears clear that in addition to kinematic (i.e., running speeds) and cardiovascular variables (i.e., heart rate), there is also a mechanical load component given by accelerating and decelerating which plays a role and requires to be taken into account in the quantification of the total workload placed upon the players. Thus, where mechanical load is the focus, specific physiology may not be targeted with drills in opened spaces involving many components, whereas ball possessions in small areas such as 4v4 and 5v5 may aid to achieve this purpose. In these situations it is just as important to expose players to the necessary overload to ensure they can withstand the mechanical stresses competitive matches impose upon them.

A different trend is observed when the aim is taxing maximal acceleration, maximal deceleration and maximal speed, being more pronounced in bigger pitches and during small-sided games with goalkeepers, than in possessions (Fig. 2). This indicates that big spaces and “opened nature” games are required in order to hit these targets. However, the number of times players reach the peak intensity during changes in velocity is quite reduced as only 34% of the sprint efforts during soccer games are preceded by maximal acceleration, while the 85% of maximal accelerations had a final velocity <4.17 m s\(^{-1}\) (Varley & Aughey, 2013).

A novelty from our study was the use of a mathematical model for calculating the estimated energy expenditure and metabolic parameters during different types of small-sided games. This approach was previously utilized for analyzing official games (Osgnach et al., 2010) and training sessions (Gaudino et al., 2013b, 2014). In accordance with these investigations, we observed a greater distance run at high power (>20 W kg\(^{-1}\)) than high speed (>14.4 km h\(^{-1}\)), not only during SSG-G, as reported by Gaudino et al. (2014), but also in SSG-P, with the difference getting more pronounced as the pitch dimensions decreased (5v5 > 7v7 > 10v10; Fig. 3). This indicates that the use of power zones become

Fig. 2. Maximal acceleration (m s\(^{-2}\)), maximal deceleration (m s\(^{-2}\)) and maximal speed (km h\(^{-1}\)) reached during the 6 SSGs analyzed (mean ± SD).
a more accurate tool than speed thresholds especially when assessing the demands of games played in small areas. On the other hand, both the energy expenditure and the distances run at high power increase when the pitch area gets bigger. This can be explained by the fact that the estimated metabolic parameters are influenced also by the speed, despite the number of changes in velocity being greater in “small” SSGs, the bigger distance covered at high speed in wide areas also allows the achievement of higher metabolic values (Fig. 3). The average metabolic power and high power distances were systematically higher in the SSG-P than in SSG-G played with the same number of players which is in accordance with observations showing that the inclusion of goalkeepers reduced the tempo of the game as players performed less high intensity running and increased low-intensity activities (Hill-Haas et al., 2011; Mallo & Navarro, 2008). Similarly, Castellano et al. (2013), investigating the differences on physiological and physical demands between two different game format, possession play (SSG-P) and regulation goals and goalkeepers (SSG-G), reported greater values of heart rate, total distance covered and distance covered at high speed in SSG-P. In addition, a previous study by Dellal et al. (2012) showed RPE values to be lower during the free play SSGs. Thus, all together these seem to suggest that possessions rather than games with goalkeepers are preferred when the aim is the maintenance of a higher average intensity. Conversely, in situations such as 5v5 and 7v7, the distance run at high speed is stimulated more during games than possessions, but it becomes greater in SSG-P when playing 10v10. Overall, with the exception of absolute maximal speed, acceleration and decelerations, 10v10 possessions in medium-big areas may represent an effective stimulus for training the vast majority of the metabolic and mechanical parameters involved in football performance. However, regardless of the physiological components taxed, all small-sided games included in the present study produced an average intensity close to, or above, the one registered during competitive games, and therefore represent a valid tool to develop match specific fitness.

In the present study the heart rate was not recorded, however the aim was focusing on the external load (estimated metabolic and mechanical variables) and future studies are warranted to assess the internal responses of different small-sided games in relation to the external parameters.

Our investigation has important practical implications as it provides novel guidelines on how to utilize scientific information to maximize the training and delivery of field-based sessions to elite soccer players. We have shown that different game formats generate different metrics and therefore target different physical components of performance. The approach is therefore to overload specific areas of physiology in isolation rather than stimulating to lesser degrees every component within the same

![Fig. 3. TS (total high speed running; i.e., >14.4 km h⁻¹), TP (total high power; i.e., >20 W kg⁻¹) distance covered (m) and P_{met} (average metabolic power; in W kg⁻¹) reached during the 6 SSGs (mean ± SD).](image-url)
As a consequence, during field based conditioning, it is paramount that training load is fully understood and appropriate for the intended physiological and performance adaptations.

In summary, the main findings from the present study were that the total distance, distances run at high speed as well as absolute maximum velocity, acceleration and deceleration increased with big pitch dimensions (10v10 > 7v7 > 5v5). Furthermore, the total distance, very high and maximal speed distances, absolute velocity and absolute maximum acceleration and deceleration were higher in SSG-G than in SSG-P. On the other hand, the number of moderate acceleration and decelerations as well as the total number of changes in velocity were greater as the pitch dimensions decreased (i.e., 5v5 > 7v7 > 10v10) in both SSG-G and SSG-P. In addition, all the predicted metabolic parameters ($EC, P_{max}$, TP, HP, EP and MP) were more elevated in SSG-P compared to SSG-G and in big than in small pitch areas. Thus, in conclusion, small-sided games represent an appropriate and efficient training model to stimulate all the specific physical aspects of playing football. Future studies should be designed to estimate the metabolic and mechanical variables of soccer SSGs specific to different playing positions.

Acknowledgements

No financial support was received for this investigation. No professional relationships with companies or manufacturers of the measurement tools used in this research exist. The author would like to thank Dr. A. J. Strudwick for his invaluable assistance in this study.

References


