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Movement analysis and metabolic profile of tennis match play: comparison between hard courts and clay courts

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ABSTRACT
This study aimed to define the movement analysis and metabolic model in tennis on hard courts and clay courts. Twenty-four tennis players were equipped with a 15 Hz GPS and a Polar H7 and played a match on each playing surface. The average duration of matches was 76 Å± 24 (C) and 69 Å± 17 min (H). The maximum heart rate (HRmax) was 185 Å± 14 (C) and 178 Å± 10 bpm (H), the average heart rate (HRav) was 144 Å± 14 (C) and 139 Å± 12 bpm (H). The average metabolic power (MPav) was 3.93 Å± .34 (C) and 3.70 Å± .34 W Å~ kg−1 (H) (ES = .72, C > H, +6%). The ANOVA and the post hoc showed significant differences regarding the considered parameters on both the surfaces. The t-test highlighted significant surface-related differences (ES = .88, C > H, +26%) concerning accelerations performed between 50 and 60% of the maximum value, decelerations between 40 and 50% of the maximum (ES = 1.28, H > C, +37%), metabolic power between 0 and 10 W Å~ kg−1 (ES = .71, H > C, +1%), and 10 and 20 W Å~ kg−1 (ES = .78, C > H, +15%).

1. Introduction
The homologated surfaces for international tournaments are synthetic resin, sometimes also concrete, grass and clay, which can be red or green. They are classified into five categories depending on game-speed: slow pace, medium-slow pace, medium pace, medium-fast pace, fast pace (Rules of Tennis, 2016). Consequently, varying the type of court can lead to some modifications pertaining to organic-muscular and perceptual-kinetics parameters, but in this regard, the literature provides conflicting opinions. It has been demonstrated that rally duration is 22% longer on clay compared to hard courts, resulting in a greater work/rest ratio, while variations in playing surfaces do not bring about differences concerning oxygen consumption (Murias, Lanatta, Arcuri, & Laino, 2007). These data confirm the outcomes which emerged from O’Donoghue and Liddle (1998), in which the average duration of a tennis match is about 90–120 min on grass or concrete and from 120 to 180 min on clay. Nevertheless, the technical-tactical evolution of recent years has led to more similar playing times on both hard and clay courts (Fabre, Martin, Gondin, Cottin, & Gerlot, 2012). As
a result of the frequent active and passive recovery periods, the average effective playing time corresponds to 24% of the total (Christmass, Richmond, Cable, Arthur, & Hartmann, 1998; Botton, Hautier, & Eclache, 2011; Smekal et al., 2001) and it further decreases after the third consecutive day of match play (Gescheit et al., 2016). The average duration of rallies is about 5 s (Smekal et al., 2001; Botton et al., 2011), whereas 56% of them last from 1 to 6 s and 18% from 6 to 9 s (Mendez-Villanueva, Fernández-Fernandez, Bishop, Fernández-Garcia, & Terrados, 2007), with an average of 2 s of rest per each second of work (Christmass et al., 1998; Murias et al., 2007). When analysing tennis bioenergetics, the big explosiveness required by strokes and the numerous changes of direction, on average 3–5 in each rally and up to 500 in the entire match, have to be considered (Roetert & Kovacs, 2011). This induces the consequent involvement of the anaerobic metabolism (Reid & Schneiker, 2008), while the aerobic one proves to be priority (Baiget, Fernández-Fernández, Iglesias, Vallejo, & Rodríguez, 2014; Murias et al., 2007; Smekal et al., 2001), especially in the management of fatigue and the recovery after each point (Kovacs, 2006). Accordingly, blood lactate accumulation is near to anaerobic threshold levels (Christmass et al., 1998; Mendez-Villanueva et al., 2007), and is greater during service games (Mendez-Villanueva et al., 2007) with no surface-related differences (Murias et al., 2007). Oxygen uptake varies between 44 and 55% VO_{2\text{max}} (Botton et al., 2011) and it is 6/7% greater in those athletes with a more offensive playing style (Bekraoui, Fargeas-Gluck, & Léger, 2012), despite the fact that net play in modern tennis has been considerably reduced by the increasing game speed (Aburachid, Morales, & Greco, 2013). The average heart rate in a match is between 150 and 182 bpm (Smekal et al., 2001); the average peak (HR_{\text{peak}}) in rallies has been quantified at 86 ± 1% of the maximum heart rate of the athletes (HR_{\text{max}}) (Christmass et al., 1998), while the average value (HR_{\text{av}}), the total distance and the distance run in each single point are greater on clay courts compared to hard courts (Murias et al., 2007). The use of GPS technology is believed to be of fundamental importance for the description of movement patterns, covered spaces and speed in many intermittent sports (MacLeod, Morris, Nevill, & Sunderland, 2009). The reliability of GPS has been demonstrated to rise proportionally with displacement distance (Coutts & Duffield, 2010; Petersen, Pyne, Portus, & Dawson, 2009). Vickery et al. (2014) found no horizontal dilution of positioning using 15 Hz devices, unlike the results obtained with 5–10 Hz versions. The validity of the instrument closely depends on sampling frequency, the speed and the duration of the task (Aughey, 2011). Duffield, Reid, Baker, and Spratford (2010) demonstrated that a 5 Hz GPS seems more accurate for monitoring distance and speed of high intensity displacements in limited areas compared to 1 Hz devices, in contrast with Jennings, Cormack, Coutts, Boyd, and Aughey (2010) who consider these devices unreliable for the measurement of changes of direction and linear sprints, while an increased sample rate improves validity and reliability of GPS device. Furthermore, it is affirmed that the validity of a 5 Hz GPS for speed tracking is optimal with 30–40 m displacements and lower with shorter distances, regardless on the presence of changes of directions (Buchheit et al., 2014). The quantification of the number and the intensity of accelerations and decelerations is fundamental in order to design training programmes according to the physiological demand of any sport (Cummins, Orr, O’Connor, & West, 2013). Devices with a sampling frequency of more than 10 Hz boast greater reliability and accuracy in the description of brief and intermittent non-linear sprints (Castellano, Casamichana, Calleja-Gonzáles, San Román, & Ostojic, 2011). Galé-Ansodi, Castellano, and Usabiaga (2016) were the first to investigate surface-related differences monitoring under-14 and under-12 tennis.
players by means of GPS technology and their outcomes revealed that hard court games are characterised by higher intensity effort compared to clay courts. Therefore, the purpose of this study was to analyse the movement variables and the metabolic model, examining also potential surface-related differences, among post-pubertal tennis players, by using 15 Hz GPS along with heart rate monitors.

2. Methods

2.1. Participants

Twenty four tennis matches were played by 12 nationally ranked male players, with limited international experiences, whose age was $16 \pm 3$ years, height $179 \pm 6$ cm, weight $69 \pm 11$ kg, years of competitive experience $9 \pm 3$ and who have $5 \pm 2$ training sessions each week for a total amount of $14 \pm 9$ h. Three days before every match, participants were asked to maintain their usual habits during their daily life and intense training sessions were avoided and they agreed to take part in the study by signing an informed consent form.

2.2. Variables

Galé-Ansodi et al. (2016) took into consideration the following biomechanical parameters: distance covered, maximum and average speed, distance covered per minute, acceleration distance covered, acceleration distance covered per minute, percentage of acceleration distance covered and distance covered per minute in speed range. In the present study, the parameters of speed (SP), heart rate (HR), acceleration (ACC) and deceleration (DEC), obtained from data gathered during the matches, were examined. For each one of them, the maximum peak of the athletes was registered, and from this the relative percentages were calculated. Starting from the average values of the peaks and percentages of the players, different intensity thresholds were identified. Taking into account speed (SP) and heart rate (HR), the percentage of the total time spent in each zone was measured, while, with reference to accelerations (ACC) and decelerations (DEC), the number of events performed between various intensities was recorded. Hoppe, Baumgart, and Freiwald (2016) examined the metabolic power of both adolescent and adult tennis players. The instantaneous metabolic power (MP) is the quantification of the amount of energy required per unit of time to reconstitute the ATP utilised during performance on the bases of oxidative process; it is expressed in equivalent $O_2$ units regardless of the actual oxygen consumptions because the latter could be greater, equal of smaller compared to the effective metabolic power (Prampero (di), Botter, & Osgnach, 2015). In the present study, this parameter has been monitored to support the assessment of the player load by analysing the time spent in each intensity threshold. Afterwards, the average of the values of all the athletes was calculated.

2.3. Procedures

Experimental sessions began with the usual warm-up that each player carries out before tournament matches, followed by a specific technical 5-min warm-up reflecting those that take place before official matches in accordance with international tennis regulations (Rules of Tennis, 2016). These warm-ups are used to practise various strokes, such as baseline
shots, volleys and serves. Subsequently, a match was played to best of three sets, with 20 s of rest between points, 90 s to change ends and 120 s between sets, in full compliance with federation rules (Rules of Tennis, 2016). The athletes concluded the test with their individual cool-down. Each pair of players disputed a match on each playing surface according to a counterbalanced experimental design, always alternating the type of court on which each pair played the first of the two matches. Four new balls (Wilson US Open, Chicago, IL, U.S.A) were used for each match. During play, players were allowed to drink water and weather conditions were ambient (17–24 °C). During the matches, the participants were equipped with a GPS SPI HPU device (GPSports, Canberra; Australia) for tracking movement variables with a sampling frequency of 15 Hz (15 samples per second, dimensions 74 × 42 × 16 mm, weight 66 g), positioned with a sports bib provided by the manufacturer inside a specific cavity between the shoulder blades. Heart rate was monitored by using a Polar® H7 heart rate sensor (Polar Electro Italia SrL, Casalecchio di Reno, Bologna, Italy). Data were collected by means of the manufacturer’s software TEAM AMS (GPSports, Canberra, Australia). Since GPS reliability has been widely assessed in literature, the author did not consider it necessary to verify it. The only criterion adopted was that subjects wore the same device during the match on the red clay and the hard court. Indeed, due to lower inter-unit reliability it is advisable that athletes use the same device within any research design in order to avoid inter-unit errors (Duffield et al., 2010; Vickery et al., 2014).

2.4. Statistical analysis

The data are presented as mean and standard deviation (±SD). The D’Agostino-Pearson test was used to verify data for normality and parametric statistical calculations were applied. The paired t-test was utilised to investigate differences regarding the same players on the two different surfaces. The differences pertaining to the various intensity thresholds of the parameters considered were analysed by means of one-way variance analysis (ANOVA) with Tukey’s post hoc. The significance level was set at p < .05. For interpretation of the meaningfulness of differences, effect sizes (ES) were calculated and interpreted accordingly: .2 to <.6, small; .6 to <1.2, medium; 1.2 to <2.0, large; 2.0 to <4.0, very large; and ≥4.0, extreme large (Hopkins, Marshall, Satterharn, & Hanin, 2009).

3. Results

The average duration of matches was 76 ± 24 and 69 ± 17 min on clay (C) and hard courts (H), respectively. The maximum heart rate (HRmax) was 185 ± 14 bpm on clay courts (C) and 178 ± 10 bpm on hard courts (H), while the average heart rate (HRav) was 144 ± 14 bpm and 139 ± 12 bpm on clay (C) and hard courts (H), respectively, with no significant surface-related differences. The average metabolic power (MPav) was 3.93 ± .34 W × kg⁻¹ on clay (C) and 3.70 ± .34 W × kg⁻¹ on hard (H) (p < .05, ES = .72, C > H, +6%). The ANOVA and the post hoc showed significant differences regarding the considered parameters both on clay courts (C) and on hard courts (H) (Tables 1 and 2). The t-test also highlighted significant differences (p < .05, ES = .88, C > H, +26%) concerning accelerations performed between 50 and 60% of the maximum value, decelerations between 40 and 50% of the maximum (p < .05, ES = 1.28, H > C, +37%) and metabolic power between 0 and 10 W × kg⁻¹ (p < .05, ES = .71, H > C, +1%), and 10 and 20 W × kg⁻¹ (p < .05, ES = .78, C > H, +15%), while the
The playing surface did not significantly influence the other parameters taken into consideration (Table 3).

4. Discussion

Unlike previous studies (Christmass et al., 1998; Murias et al., 2007; Smekal et al., 2001), the authors decided not to limit the duration of the match, but rather to have the athletes play a regulation match. The purpose of this research was to determine the performance model in competitive tennis, investigating also potential differences induced by the playing surface. The mutations in speed have been analysed with a particular focus on accelerations and decelerations, because, in tennis, it is possible to perform sprints of great intensity without high accelerations (Dwyer & Gabbett, 2012), but also unexpected high intensity changes of direction without reaching maximum speeds. This is due to the reduced

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Notes: The first column lists the considered parameters, the second and the fourth the comparisons between the zones, the third and the fifth the significant differences on clay courts and hard courts, respectively.

*p <.05; **p <.01; ***p <.001.
Table 2. Differences between the number of events of accelerations (ACC) and decelerations (DEC) performed in the various intensity thresholds both on clay courts (C) and hard courts (H) during the match.

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<td>60–70% vs. 70–80%</td>
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<td></td>
</tr>
<tr>
<td>60–70% vs. 80–90%</td>
<td>***</td>
<td>60–70% vs. 80–90%</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>60–70% vs. 90–100%</td>
<td>***</td>
<td>60–70% vs. 90–100%</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>70–80% vs. 90–100%</td>
<td>0.01</td>
<td>70–80% vs. 90–100%</td>
<td>***</td>
<td></td>
</tr>
</tbody>
</table>

| Decelerations | | | |
| 40–50% vs. 50–60% | 0.01 | 40–50% vs. 50–60% | *** |
| 40–50% vs. 60–70% | 0.01 | 40–50% vs. 60–70% | *** |
| 40–50% vs. 70–80% | 0.01 | 40–50% vs. 70–80% | *** |
| 40–50% vs. 80–90% | 0.01 | 40–50% vs. 80–90% | *** |
| 40–50% vs. 90–100% | 0.01 | 40–50% vs. 90–100% | *** |
| 50–60% vs. 60–70% | 0.01 | 50–60% vs. 60–70% | *** |
| 50–60% vs. 70–80% | 0.01 | 50–60% vs. 70–80% | *** |
| 50–60% vs. 80–90% | 0.01 | 50–60% vs. 80–90% | *** |
| 50–60% vs. 90–100% | 0.01 | 50–60% vs. 90–100% | *** |
| 60–70% vs. 90–100% | 0.01 | 60–70% vs. 90–100% | *** |

Notes: The first column lists the considered parameters, the second and the fourth the comparisons between the zones, the third and the fifth the significant differences on clay courts and hard courts, respectively.

*p < .05; **p < .01; ***p < .001.

Dimensions of the tennis court and frequent sprints starting from a stationary position (Reid, Duffield, Dawson, Baker, & Crespo, 2008). The playing time proved to be similar on both the surfaces, confirming the evolution which has characterised tennis in recent years, with an increment in physical, technical and tactical abilities that is progressively reducing the gap between total playing time on clay and hard courts. Rallies are much shorter than the past, as reflected in the increasing importance of serves and returns, in particular among male tennis players (Reid, Morgan, & Whiteside, 2016): when an ace or a winning return is performed, the points end with a single shot played by each player (O’Donoghue, 2002). While, at professional level, 70% of service points are won when the first serve is valid, only 50% are won when a second serve is required (Hizan, Whipp, & Reid, 2011). Moreover, most first-serve returns have been demonstrated to be directed towards a central area, whereas second-serve returns are preferably aimed towards the corners (Hizan, Whipp, Reid, & Wheat, 2014), confirming the wide influence of technical efficacy on physical performance. Taking into account statistics pertaining to the top 100 players of the world, on average they win four service games out of five and one game out of five when they receive; in addition, they serve more aces than double faults and win more points when the first serve is valid, and when they return a second serve in games in which they are receiving (Reid, McMurtrie, & Crespo, 2010). Galé-Ansodi et al. (2016) found significant surface-related differences among under-12 and under-14 tennis players: they cover more distance per minute on hard courts as well as performing more accelerations and recording greater maximum and average speed compared to clay courts. However, in this study, in most cases
the parameters evaluated among post-pubertal players did not show significant differences concerning the playing-surface. These are a consequence of the sample, which included high-level Italian players, with a limited international experience, accustomed, consequently, to playing mainly on clay courts compared to hard courts, where they adopt a tactical behaviour similar to that they use on clay. Furthermore, the differences between this study and Galé-Ansodi et al. (2016) can be explained by the older participants involved in this research, in keeping with Hoppe et al. (2016) which demonstrated that adults reach higher values of speed, accelerations and metabolic power compared to adolescent players on red clay courts. In this research, the greater percentage of the total time was spent between the

Table 3. Percentage of the time spent in the various zones of heart rate (HR), speed (SP) and metabolic power (MP) and number of accelerations (ACC) and decelerations (DEC) performed at the various intensities.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intensity</th>
<th>Range (C)</th>
<th>% time – number of events (C)</th>
<th>Range (H)</th>
<th>% time – number of events (H)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heart rate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40–50%</td>
<td>74–93 bpm</td>
<td>1.03%</td>
<td>71–89 bpm</td>
<td>.42%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>50–60%</td>
<td>93–111 bpm</td>
<td>4.13%</td>
<td>89–107 bpm</td>
<td>4.61%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>60–70%</td>
<td>111–130 bpm</td>
<td>13.30%</td>
<td>107–125 bpm</td>
<td>15.28%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>70–80%</td>
<td>130–148 bpm</td>
<td>29.88%</td>
<td>125–143 bpm</td>
<td>31.88%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>80–90%</td>
<td>148–167 bpm</td>
<td>35.92%</td>
<td>145–160 bpm</td>
<td>37.88%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>90–100%</td>
<td>167–185 bpm</td>
<td>15.77%</td>
<td>160–178 bpm</td>
<td>10.36%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40–50%</td>
<td>7.38–9.23 km/h</td>
<td>56.25%</td>
<td>7.57–9.47 km/h</td>
<td>56.96%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>50–60%</td>
<td>9.23–11.07 km/h</td>
<td>24.91%</td>
<td>9.47–11.36 km/h</td>
<td>23.23%</td>
<td>.06</td>
<td></td>
</tr>
<tr>
<td>60–70%</td>
<td>11.07–12.92 km/h</td>
<td>11.40%</td>
<td>11.36–13.25 km/h</td>
<td>11.73%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>70–80%</td>
<td>12.92–14.76 km/h</td>
<td>4.77%</td>
<td>13.25–15.15 km/h</td>
<td>5.06%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>80–90%</td>
<td>14.76–16.61 km/h</td>
<td>1.82%</td>
<td>15.15–17.04 km/h</td>
<td>1.96%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>90–100%</td>
<td>16.61–18.45 km/h</td>
<td>.87%</td>
<td>17.04–18.93 km/h</td>
<td>1.11%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td><strong>Accelerations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40–50%</td>
<td>1.75–2.19 m/s/s</td>
<td>67%</td>
<td>1.7–2.12 m/s/s</td>
<td>59%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>50–60%</td>
<td>2.19–2.63 m/s/s</td>
<td>43%</td>
<td>2.12–2.55 m/s/s</td>
<td>34%</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>60–70%</td>
<td>2.63–3.06 m/s/s</td>
<td>25%</td>
<td>2.55–2.97 m/s/s</td>
<td>23%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>70–80%</td>
<td>3.06–3.5 m/s/s</td>
<td>14%</td>
<td>2.97–3.39 m/s/s</td>
<td>13%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>80–90%</td>
<td>3.5–3.94 m/s/s</td>
<td>5%</td>
<td>3.39–3.82 m/s/s</td>
<td>7%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>90–100%</td>
<td>3.94–4.38 m/s/s</td>
<td>3%</td>
<td>3.82–4.24 m/s/s</td>
<td>3%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td><strong>Decelerations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40–50%</td>
<td>1.75–2.19 m/s/s</td>
<td>118%</td>
<td>1.7–2.12 m/s/s</td>
<td>162%</td>
<td>.02</td>
<td></td>
</tr>
<tr>
<td>50–60%</td>
<td>2.19–2.63 m/s/s</td>
<td>60%</td>
<td>2.12–2.55 m/s/s</td>
<td>78%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>60–70%</td>
<td>2.63–3.06 m/s/s</td>
<td>32%</td>
<td>2.55–2.97 m/s/s</td>
<td>38%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>70–80%</td>
<td>3.06–3.5 m/s/s</td>
<td>19%</td>
<td>2.97–3.39 m/s/s</td>
<td>23%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>80–90%</td>
<td>3.5–3.94 m/s/s</td>
<td>10%</td>
<td>3.39–3.82 m/s/s</td>
<td>12%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>90–100%</td>
<td>3.94–4.38 m/s/s</td>
<td>6%</td>
<td>3.82–4.24 m/s/s</td>
<td>6%</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td><strong>Metabolic Power</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–10 W/kg</td>
<td>94.54%</td>
<td>0–10 W/kg</td>
<td>95.23%</td>
<td>.04</td>
<td>.04</td>
<td></td>
</tr>
<tr>
<td>10–20 W/kg</td>
<td>4.02%</td>
<td>10–20 W/kg</td>
<td>3.49%</td>
<td>.02</td>
<td>.02</td>
<td></td>
</tr>
<tr>
<td>20–35 W/kg</td>
<td>1.11%</td>
<td>20–35 W/kg</td>
<td>.94%</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35–55 W/kg</td>
<td>.30%</td>
<td>35–55 W/kg</td>
<td>.26%</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;55 W/kg</td>
<td>.04%</td>
<td>&gt;55 W/kg</td>
<td>.05%</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: In the first column, the four parameters examined are listed, in the second the percentage of maximum intensity, in the third and in the fifth, the values corresponding to the various percentages of the considered parameters on clay courts (C) and hard courts (H), respectively. The fourth and the sixth report the time spent in the various zones of heart rate, speed and metabolic power and the number of accelerations and decelerations performed on clay courts (C) and hard courts (H), respectively. The seventh shows the significant differences emerging from the t-test pertaining to the comparison between the various parameters on the two different playing surfaces. The highlighted lines refer to the threshold in which the players spend the most of the times or perform the most of the events during a match.
40–50%, 50–60% and 60–70% areas of average speed, compared to superior intensities; the number of accelerations and decelerations performed between 40 and 60% of the maximum speed was larger than in other thresholds. This was due to the reduced dimensions of the tennis court which do not allow athletes to reach high speeds (Reid et al., 2008), with the likelihood that players play many strokes in a row with no displacements or one to two steps (Weber, 2001), performing unexpected side or frontal sprints only when the opponent suddenly changes rhythm in order to try to win the point. The outcomes of the present research reveal that, during a match on clay, tennis players spend 36 and 30% of the total playing time between 80 and 90% and 70–80% of the maximum heart rate (HR\text{max}), respectively, while 38 and 32% at the same intensities on hard courts. Furthermore, on clay, 16% of the total playing time is spent between 90 and 100% of the maximum heart rate (HR\text{max}), while on hard courts the figure is 11%. These slim differences, brought about by short rallies, which do not always permit the achievement of maximum values, and by the intermittent nature of tennis (Botton et al., 2011; Christmass et al., 1998; Mendez-Villanueva et al., 2007; Smekal et al., 2001), can be related to the greater duration of rallies on this surface, and identify the ideal intensities for specific training. Nevertheless, higher values are often reached in longer points (Girard & Millet, 2008) or when unexpected variations of speed or accelerations from a stationary position are required. Indeed, despite the intermittent nature of tennis, heart rate has been proved to remain elevated above pre-exercise value as a result of the physical effort performed in high-intensity periods as well as the adrenergic response to the psychological strain (Davey, Thorpe, & Williams, 2003). Considering all of the above, it is possible to infer that energy supply in points is mainly anaerobic (Botton et al., 2011), specifically alactacid in the initial part and glycolytic in the final moments of particularly long points, or when repeated and rapid changes of directions are performed in a series of consecutive and intense rallies (Girard & Millet, 2008). In these demanding periods, break points, a technical term describing a point with which the player returning serve can win the game, are also included; it has been demonstrated that the number of points won by the receiver is greater when he is playing a break point compared to a non-decisive point, in which less physical effort is required (O’Donoghue, 2012). The same authors believe that players who compete for more break points can be subjected to higher levels of fatigue both in the same match and throughout the entire tournament. Rally duration as such does not bring about blood and muscle lactate accumulation (Christmass et al., 1998; Mendez-Villanueva et al., 2007), also because the intervention of the aerobic metabolism during recovery partially pays the oxygen debt (Novas, Rowbottom, & Jenkins, 2003), remaining the priority metabolism for energy supply (Reid et al., 2008). The key to hitting a stroke successfully is to use the proper mechanics and to remain balanced while doing so, thus allowing the player to use proper technique on every shot and to prepare quickly for the next one (Roetert & Ellenbecker, 2007). Therefore, speed, accelerations and decelerations are the most important ability to this aim. This study brings to the light how the playing surface does not influence running speed: during a match, players spend more than 90% of the time moving with a speed between 40 and 70% of the maximum speed (Sp\text{max}), corresponding to 7 and 13 km × h\textsuperscript{-1}. Taking into account accelerations (ACC), on both surfaces, more than half of the events have been performed between 1.7 and 2.63 m × s\textsuperscript{-2}, the equivalent of 40 and 60% of the maximum value (ACC\text{max}). The only significant difference emerges in the 50–60% area, where the number of accelerations is 26% higher on clay courts, where rally duration is greater. The longer rally duration could also account for the
higher average metabolic power (MP) on this surface, as well as the metabolic power expressed between 10 and 20 W × kg⁻¹, while the same parameter evaluated between 0 and 10 W × kg⁻¹ is slightly higher on hard courts, as a result of the shorter rallies. The numerous starts from a stationary position caused by the reduced dimensions of tennis courts, as mentioned above, do not allow a repetition of maximum performance many times in a match, thus making the number of events in the other zones uniform on both the surfaces. The number of decelerations (DEC) is significantly higher on hard courts (+37%) between 40 and 50% of the maximum value – corresponding to −1.7 and −2.19 m × s⁻² – while it remains high, though not significant, between 50 and 90%. The main reason is the option to slide to decelerate before impacting the ball on clay, which is not possible on hard courts, as a result of the lower friction force (Starbuck, Stiles, Urà, Carré, & Dixon, 2017) and the greater horizontal forces (Damm et al., 2011).

5. Conclusions

The results of this study provide for the description of parameters rarely considered before among post-pubertal tennis players. In the past, not many authors analysed the performance model in tennis by using GPS devices; this was the aim of this study along with the investigation of potential differences pertaining to the heterogeneity of playing surfaces. Except for the greater average metabolic power on clay, only a few of the data obtained, in the same playing time, are subjected to the influence of the playing surfaces among high-level post-pubertal tennis players.

6. Practical applications

- Small changes in the mode of execution of typical exercise drills produce considerable metabolic and coordinative differences, so coaches should define accurately the training goals (Ferrauti, Pluim, & Weber, 2001).
- Intermittent exercise by means of interval training could be an indication for the creation of tennis-specific endurance protocols. The introduction of shuttle runs reproducing the real steps performed before and during strokes, instead of traditional sprints, could be a good solution to make endurance ability as close as possible to the physical demands of a real match. By manipulating total work time, it is possible to work at the same intensity required during a match but with greater quantity, accustoming athletes to maintaining their optimal technical-motor efficiency also in presence of progressive fatigue conditions caused by particular long matches.
- Muscle strength, on the other hand, can be trained under an endurance system with circuit training, whose aim depends on the period of the annual macrocycle. In this latter, the intermittent nature of tennis is stimulated by the execution of high-intensity exercises, and the recovery time between them corresponds to the one needed to go from one station to the next, with the ultimate goal to train local muscular endurance (Reid & Schneiker, 2008).
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Disclosure statement

No potential conflict of interest was reported by the authors.

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