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The effect of court surfaces on physiological responses and game activities of recreational senior tennis players

El efecto de las superficies de la cancha sobre las respuestas fisiológicas y las actividades de juego de los tenistas recreativos de mayor edad

O efeito das superfícies da quadra nas respostas fisiológicas e atividades de jogo de jogadores idosos de tênis recreativo

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Abstract: Previous research has predominantly focused on the effects of different court surfaces on the performance responses of professional and young tennis players. However, studies concerning recreational senior tennis players are limited. Therefore, the purpose of this study was to investigate the effects of hard-court (HC) and clay-court (CC) surfaces on the game activities and physiological responses of recreational senior tennis players. Twenty-two recreational senior tennis players (44.2 ± 3.3 years) played two singles matches each, one on an HC and the other on CC, with heart rate responses and time-motion characteristics (TMC) monitored via portable GPS devices. Video recordings revealed variables including effective playing time (EPT), rally duration (DR), strokes per rally (SPR), and rest time between rallies (RT). The results show significant differences between the court surfaces: on CC, players exhibited a higher-average heart rate (152.8 ± 20.3 beats per min vs. 143.7 ± 18.5 on HC, $p < 0.001$), longer rally durations (12.4 ± 8.5 sec vs. 8.1 ± 7.8 on HC, $p < 0.001$), and increased total distance covered (3027.9 ± 396 m vs. 2647.6 ± 378 on HC, $p < 0.001$). Additionally, HC induced significantly faster rally speeds compared to CC (0.70 ± 0.25 shots/s vs. 0.59 ± 0.17 on CC, $p < 0.001$). These results suggest that CC are associated with higher physiological responses and require more game activity from the players than HC. This study contributes to the understanding of how the court surface impacts middle-aged recreational players, indicating that training and preparation should be adapted to meet the unique demands of different court surfaces.

Keywords: tennis for older people, physiology, recreational sports, tennis surfaces.

Resumen: Las investigaciones previas se han centrado, predominantemente, en los efectos de las diferentes superficies de las canchas sobre las respuestas de rendimiento de los jugadores de tenis profesionales y jóvenes. Sin embargo, los estudios sobre jugadores de tenis recreativos de mayor edad son limitados. Por lo tanto, el propósito de este estudio fue investigar los efectos de las superficies de canchas duras (CD) y canchas de arcilla (CA) sobre

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las actividades de juego y las respuestas fisiológicas de jugadores de tenis recreativos de mayor edad. Veintidós jugadores de tenis recreativos de mayor edad (44.2 ± 3.3 años) jugaron dos partidos individuales cada uno, uno en una CD y el otro en una CA, se monitorearon las respuestas de la frecuencia cardíaca y las características de tiempo-movimiento (CTM) por medio de dispositivos GPS portátiles. Las grabaciones de video revelaron variables que incluyen tiempo efectivo de juego (TEJ), duración del *rally* (DR), golpes por *rally* (GR) y tiempo de descanso entre *rallies* (TD). Los hallazgos indicaron diferencias significativas entre las superficies de las canchas: en CA, los jugadores exhibieron una frecuencia cardíaca promedio más alta (152.8 ± 20.3 latidos por minuto vs. 143.7 ± 18.5 en CD, $p < .001$), duraciones de *rally* más largas (12.4 ± 8.5 segundos vs. 8.1 ± 7.8 en CD, $p < 0.001$) y una distancia total cubierta mayor (3027.9 ± 396 metros vs. 2647.6 ± 378 en CD, $p < .001$). Además, las CD indujeron velocidades de *rally* significativamente más rápidas en comparación con las CA (0.70 ± 0.25 tiros/s vs. 0.59 ± 0.17 en CA, $p < .001$). Estos resultados sugieren que las CA están asociadas con respuestas fisiológicas más altas y requieren más actividad de juego de los jugadores que las CD. Este estudio contribuye a la comprensión de cómo la superficie de la cancha impacta a los jugadores recreativos de mediana edad, e indica que el entrenamiento y la preparación deben adaptarse para satisfacer las exigencias especiales de las diferentes superficies.

Palabras clave: tenis para personas mayores, fisiología, deportes recreativos, superficies para tenis.

Resumo: Pesquisas anteriores concentraram-se predominantemente nos efeitos de diferentes superfícies de quadra nas respostas de desempenho de tenistas profissionais e juvenis. No entanto, os estudos sobre jogadores idosos de tênis recreativo são limitados. Portanto, o objetivo deste estudo foi investigar os efeitos das superfícies de quadra dura (QD) e saibro (QS) nas atividades de jogo e nas respostas fisiológicas de jogadores idosos de tênis recreativo. Vinte e dois jogadores idosos de tênis recreativo ($44,2 \pm 3,3$ anos) jogaram duas partidas individuais cada, uma em QD e outra em QS, as respostas da frequência cardíaca e as características tempo-movimento (CTM) foram monitoradas através de dispositivos GPS portáteis. As gravações de vídeo revelaram variáveis, incluindo tempo efetivo de jogo (TEJ), duração do *rally* (DR), tacadas por *rally* (GR) e tempo de descanso entre *rallies* (TD). Os resultados indicaram diferenças significativas entre as superfícies das quadras: na QS, os jogadores exibiram uma frequência cardíaca média mais alta ($152,8 \pm 20,3$ batimentos por minuto vs. $143,7 \pm 18,5$ em CD, $p < 0,001$), durações de *rally* mais longas ($12,4 \pm 8,5$ segundos vs. $8,1 \pm 7,8$ em CD, $p < 0,001$) e maior distância total percorrida ($3.027,9 \pm 396$ metros vs. $2.647,6 \pm 378$ em CD, $p < 0,001$). Além disso, as QDs induziram velocidades de *rally* significativamente mais rápidas em comparação com as QDs ($0,70 \pm 0,25$ disparos/s vs. $0,59 \pm 0,17$ em CA, $p < 0,001$). Estes resultados sugerem que as QDs estão associadas a respostas fisiológicas mais elevadas e exigem mais atividade de jogo dos jogadores do que as QDs. Este estudo contribui para a compreensão de como a superfície da quadra impacta os jogadores recreativos de meia-idade e indica que o treinamento e a preparação devem ser adaptados para atender às demandas especiais das diferentes superfícies.



Palabras-chave: t nis para idosos, fisiologia, esportes recreativos, superficies de t nis.

1. Introduction

Successful tennis performance demands a variety of skills, including varying speeds, acceleration, deceleration, changing direction, striking, sprinting, and leveraging upper arm strength (Fernandez-Fernandez et al., 2006; Kilit et al., 2018; Reid et al., 2013). Additionally, tennis involves an anaerobic mechanism that necessitates aerobic rest, demanding short bursts of intense activity during prolonged periods of intense exercise interspersed with rest or low-intensity activity (Gal -Ansodi et al., 2016; Hoppe et al., 2014; Kilit & Arslan, 2017). Male and female tennis players have been observed to cover distances between 1.2–3.4 km, engage in 10–25% of their activities at high intensity, and maintain an average heart rate of 160 bpm during simulated tennis matches (Hoppe et al., 2014; Kilit & Arslan, 2017; Pluim et al., 2023; Reid et al., 2013). Moreover, game activities such as rally duration (approximately 5-8 seconds), effective game time (about 18-26%), rest periods between rallies (around 18 seconds), strokes per rally (approximately 3-5), and match duration (about 73-90 min) have been quantified, offering a comprehensive view of the exertion levels match play (Fernandez-Fernandez et al., 2006; Kilit et al., 2018; Pluim et al., 2023). The type of court surface significantly influences these physical demands (Kilit & Arslan, 2018; Reid et al., 2013). Furthermore, the interplay of physical, technical, and tactical elements under varying game conditions influences performance responses in both simulated and actual match scenarios (Hoppe et al., 2014; Martin et al., 2011; Murias et al., 2007).

The dynamics of matches are significantly impacted by the type of court surface, such as clay and hard courts, as previous studies have indicated. These influences alter gameplay dynamics and have various implications for players (Kilit et al., 2016; Martin et al., 2011; Reid et al., 2013). Hard courts are associated with a fast playing surface that facilitates quicker ball bounces or slides and shorter rallies. In contrast, clay courts are known to slow down the game, resulting in longer rallies and a slower pace, which can significantly affect player performance and strategies (Gal -Ansodi et al., 2016; Martin et al., 2011; Murias et al., 2007; Reid et al., 2013). The importance of surface type in tennis is underscored by extensive studies of variations in time-motion properties and match characteristics across different court surfaces (Chapelle et al., 2017; Fernandez-Fernandez et al., 2010; Gal -Ansodi et al., 2016; Martin et al., 2011; Murias et al., 2007; O'Donoghue & Ingram, 2001; Pereira et al., 2016; Ponzano & Gollin, 2017; Reid et al., 2013). However, apart from these structural (court surface type) conditions, the physical characteristics or performance levels of tennis players may also vary according to age categories (Fernandez-Fernandez et al., 2009; Hoppe et al., 2014; Murias et al., 2007).

Unlike professional young and adult tennis players, seniors (aged 35 - 45 years and over) generally experience a decline in physical activity and health with the aging process. Therefore, the cardiovascular system becomes less efficient with aging (Marks, 2006). Additionally, senior players face a higher risk of injury due to decreased flexibility and muscular strength as they age. It is important to design appropriate training programs to minimize these risks and improve performance (Leach & Abramowitz, 1991; Marks, 2006; Sobel et al., 1995). Moreover, some research suggests that regular training may play an important role in reducing



cardiovascular decline or maintaining aerobic fitness in senior tennis players (Vodak et al., [1980](#)). In the literature, similar training programs or tennis workouts designed to maintain or improve the level of physical conditioning have been found to have positive effects on the physical and mental health of senior players (Caserta et al., [2007](#); Marks, [2006](#); Pluim et al., [2007](#); Vodak et al., [1980](#)). Furthermore, senior players, in particular, experience significant health benefits, including marked improvements in aerobic capacity, lipid profiles, and bone density, as well as reduced risks of cardiovascular disease and mortality (Marks, [2006](#); Pluim et al., [2007](#); Vodak et al., [1980](#)). These benefits may enable tennis to provide adult participants with a level and quality of exercise consistent with recommended standards for cardiovascular fitness (Fernandez-Fernandez et al., [2009](#)). Additionally, long-term participation in tennis is related to improvements in aerobic power, body composition, and muscle strength (Caserta et al., [2007](#); Marks, [2006](#); Pluim et al., [2007](#); Swank et al., [1998](#); Vodak et al., [1980](#)). Despite these benefits, playing recreational tennis is associated with some risks, particularly in relation to the playing surface, where a higher incidence of injuries on hard courts has been reported, highlighting the need for careful selection of surfaces to minimize injury risks, especially among senior players (Girard et al., [2007](#); Martin & Prioux, [2015](#); Pluim et al., [2018](#)).

Although extensive research has demonstrated physiological responses, time-motion, and match characteristics across different durations, genders, and levels of performance, studies focusing on the effects of different court surfaces on recreational senior players remain limited (Galé-Ansodi et al., [2016](#); Kilit & Arslan, [2018](#); Martin et al., [2011](#); Reid et al., [2013](#)). Therefore, this study aims to examine the influence of hard and clay court surfaces on the physiological responses and time-motion characteristics of recreational senior tennis players during simulated matches.

2. Methods

Participants

Twenty-two recreational senior tennis players, with an average age of 44.2 ± 3.3 years, body height of 178.3 ± 6.6 cm, and body mass of 79.3 ± 7.1 kg, volunteered to participate in this study. At the time of the study, their training experience averaged between 6–10 hours per week, and their International Tennis Numbers (ITN) ranged from 6 to 8 (intermediate and recreational players). Their estimated maximum oxygen uptake (VO_{2max}) from the Hit and Turn Tennis test (HTTT) was calculated at 46.9 ± 3.1 ml·kg⁻¹·min⁻¹. The inclusion criteria were, (i) an age of 40 - 50 years (middle-aged tennis players- Turkish Tennis Federation (TTF) ([2024](#)) recognizes the senior category as players aged 30 and over), (ii) a minimum of the last two years of regular tennis match play (singles or double). Participants were excluded if there were, (iii) suffering acute injuries or, (iv) not-playing tennis matches. Signed informed consent was obtained from all participants prior to data collection and after the study protocol was reviewed by The Social and Humanities Research Ethics Committee of the University of Tokat Gaziosmanpasa University, Tokat, Turkey]and approved on September 26, 2023 according to the document “Protocol code: E-33490967-044-342163-15.10”.

Procedures

A randomized crossover design was used in this study. Participants attended two sessions for on-court assessments and simulated singles tennis match play. Portable GPS



units, along with notational analysis of simulated tennis matches, were utilized to monitor the players' performance. Each player was recorded individually, with their movements and strokes monitored throughout the match activities. To prevent mismatches in fitness level and technical skill during match play, pairs were evenly matched based on their VO_{2max} and ITN test score (for the singles category, two tennis players played one match). Players competed in two singles tennis matches (with the same opponents in both matches), each decided by the best of three sets: one match was played on clay courts (CC) and the other on hard courts (HC), with the order determined randomly (Kachel et al., [2015](#)). In total 22 tennis matches, 11 matches were played on CC and 11 matches on HC. Each session began with a standardized 10-minute warm-up consisting of jogging, stretching, and jumping (Kilit & Arslan, [2017](#)). All matches were performed on outdoor tennis courts-both CC and HC-at the same times (Drust et al., [2005](#)) from 17:00 to 20:00, using "Wilson Grand Slam" tennis balls. Outdoor conditions were similar for both CC and HC matches, with average temperatures around 25 ± 2 °C (25 ± 2 °C for both CC and HC matches) and average humidity levels around $30\% \pm 4\%$.

Test Procedures

The players' height and body weight were assessed with a Seca stadiometer (accurate to 0.1 mm) and a Seca 803 electronic scale (accurate to ± 0.1 kg). The ITN test was used in this study to determine players' tennis levels. This test is an objective on-court assessment tool based on tennis-specific tasks such as ball control, accuracy, and power. The assessment evaluates groundstroke depth, groundstroke accuracy, volley depth, serve, and mobility. The ITN is a rating system where players are rated on a scale of 10 levels (ITF, [2004](#)). ITN 1 represents high-performance players, ITN 2, 3, and 4 advanced players, ITN 5, 6, and 7 intermediate players, and ITN 8, 9, and 10 recreational players (ITN, [2016](#)). To estimate their maximum heart rate (HR_{max}) and VO_{2max} for adult males, The HTTT was performed according to the procedures explained by a previous study (Ferrauti et al., [2011](#)).

The formula for calculating VO_{2max} is:

$$VO_{2max} = 30.0 + 2.00 \times (\text{player finish level in HTTT}) \text{ (Ferrauti et al., [2011](#)).$$

Matches were played on outdoor HC and CC. Before each match, subjects performed a self-selected warm-up that included game-specific actions. All 22 matches followed the best-of-three-sets format according to the International Tennis Federation (ITF) rules and were played in a random order (ITF, [2024](#)). A portable device (Bioharness 3, GPS Sports Systems Ltd., Annapolis, USA) with integrated 10 Hz GPS units (BT-Q818XT, QStarz, Taipei, Taiwan) was used to assess each player's physiological (heart rate) and kinematic (speed and total distance) responses (Johnstone et al., [2012](#); Kilit & Arslan, [2017](#)). After the matches, the data were processed using Omni Sense Analysis v.4.0 software. Four speed zones were defined for analysis: walking (W, 0–7.0 km.h⁻¹), low-intensity running (LIR, 7.01–12.0 km.h⁻¹), moderate-intensity running (MIR, 12.01–18.0 km.h⁻¹), and high-intensity running (HIR, 18.01–24.00 km.h⁻¹) (Kilit & Arslan, [2017](#)). During match play, the average duration (in seconds) and distance covered (in meters) within these speed categories for each player were systematically measured (Fernandez-Fernandez et al., [2009](#); Kilit & Arslan, [2017](#)). To analyze tennis matches, two full high-definition video cameras (Sony HDR-CX240 Full HD, Japan) were used to record each player's individual match performances (Fernandez-Fernandez et al., [2008](#)). All



matches were analysed using the Kinovea 0.9.5 video analysis software (www.kinovea.org) by the same experienced researcher (Fernandez-Fernandez et al., 2007; Kilit & Arslan, 2017). The observer was tested for reliability using a test–retest protocol of analyzing and coding the parameters twice, interspaced by 20 days. The intra-class correlation test (ICC) revealed a value of 0.88-0.94, suggesting an excellent reliability. The following match data variables were calculated for each game: duration of rallies in seconds (DR), rest time in seconds excluding change-overs (RT), strokes per rally (SPR) (long rally (9+ shots); medium rally (5–8 shots); short rally (1–4 shots), including serves), and effective playing time (EPT) as a percentage of the total time the ball was play (Fernandez-Fernandez et al., 2007; Kilit & Arslan, 2017; Prieto-Lage et al., 2022). The rally speed was determined by dividing the total shots per rally by the rally duration. The rally duration commenced with the service of the ball and concluded either when a fault occurred or a point was won (Kachel et al., 2015).

Statistical analysis

The normality of the data was confirmed using the Kolmogorov-Smirnov test with Lilliefors correction prior to conducting parametric tests. The mean percentage of points played (per match) within each rally length category was also calculated for both CC and HC. Differences between the matches played on HC and CC were assessed using a paired t-test. Statistical analyses were performed using IBM SPSS Statistics (version 22), with a significance level set at $P < 0.05$. Effect sizes were quantified using Cohen's d with the following thresholds: trivial (0.2), small (0.6), moderate (1.2), large (2.0), and very large (>2.0) (Hopkins et al., 2009). The intra-class correlation coefficient (ICC) was employed to determine the test-retest reliability of the match characteristics. Inter-individual variability in physiological responses and match characteristics between the matches on HC versus CC was quantified using the coefficient of variation (CV%).

3. Results

The statistical analyses depicted in Figures 1 and 2, and Tables 1, 2, and 3 illustrate the differences in heart rate, time-motion, and match characteristics between clay court and hard court.

The results indicate that the clay court surface induced significantly higher match characteristics compared to the hard court surface in terms of total points (1256 vs. 951), total games (219 vs. 179), total sets (28 vs. 23), average points (114.1 ± 21.3 vs. 86.5 ± 21.2), average games (19.9 ± 3.9 vs. 16.3 ± 3.1), and average sets (2.5 ± 0.5 vs. 2.1 ± 0.3) ($p < 0.05$).

Table 1 presents the match characteristics for both court types. The results indicate that clay court surface induced higher match characteristics in terms of SPR ($p = 0.003$; $t = -3.11$; 95% CI: -3.1 to -0.7), DR ($p < 0.001$; $t = -3.95$; 95% CI: -6.4 to -2.1), and EPT ($p < 0.001$; $t = -6.18$; 95% CI: -5.9 to -2.9). However, for RT, the data showed a significant increase on hard court surface compared to clay court surface ($p = 0.003$; $t = 3.10$; 95% CI: 1.6 to 7.6).



Table 1.

Match characteristic variables analysed on hard court surface and clay court surface

| Variables | CC | | HC | | Mean difference | Cohens d and Rating |
|-----------|-----------|--------|-------------|--------|-----------------|---------------------|
| | Mean ± SD | CV (%) | Mean ± SD | CV (%) | | |
| SPR (n) | 6,4±4,0* | 62.5 | 4.5±3,8 | 84.4 | 1.9 | 0.48; Small |
| DR (s) | 12,4±8,5* | 68.5 | 8.1±7,8 | 96.3 | 4.3 | 0.52; Small |
| RT (s) | 26.1±24,4 | 93.5 | 30.7±23,8 Ω | 77.5 | -4.6 | 0.19; Trivial |
| EPT (%) | 25.4±2,2* | 8.7 | 20.9±2.1 | 10.0 | 4.5 | 2.09; Very Large |

SPR = strokes per rally; DR = rally duration; RT = rest time; EPT = effective playing time; * Significant difference from HC; Ω Significant difference from CC; CC = clay court surface; HC = hard court surface; SD = standard deviation; CV =coefficient of variation. Source. The authors.

Comparative analysis of clay court and hard court surfaces show significant variations in rally duration (Figure 1). There are a greater number of medium and long rallies on clay court, while hard court feature more short rallies.

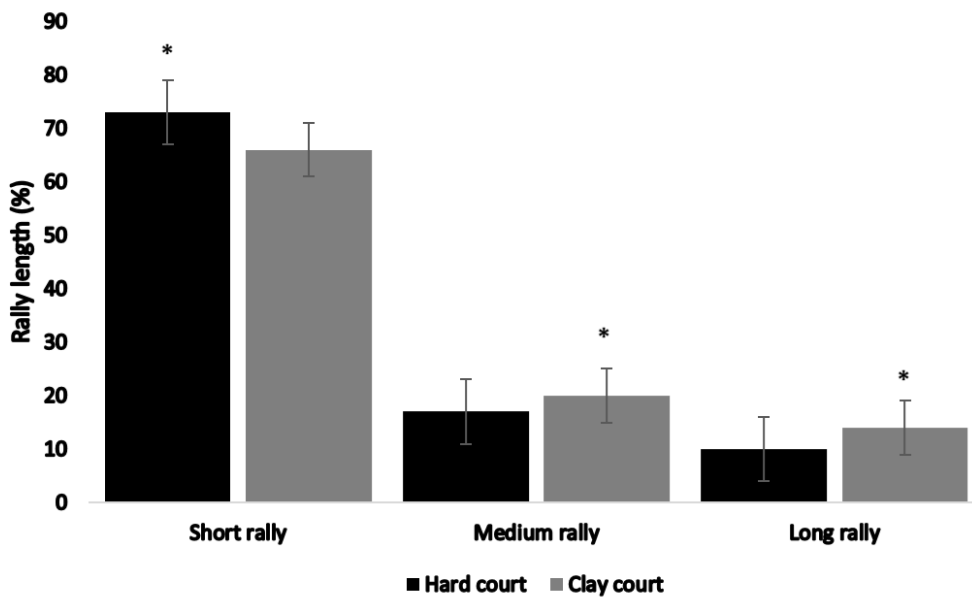


Figure 1. Mean percentage of points played within each rally length for clay court and hard court. *Significant difference hard court and clay court, $p < 0.05$. Source: the authors.

Figure 2 presents the rally speed (shots/s) of recreational senior tennis players in matches played on clay court surface versus hard court surface. The results showed that rally speeds were faster on hard court compared to clay court.

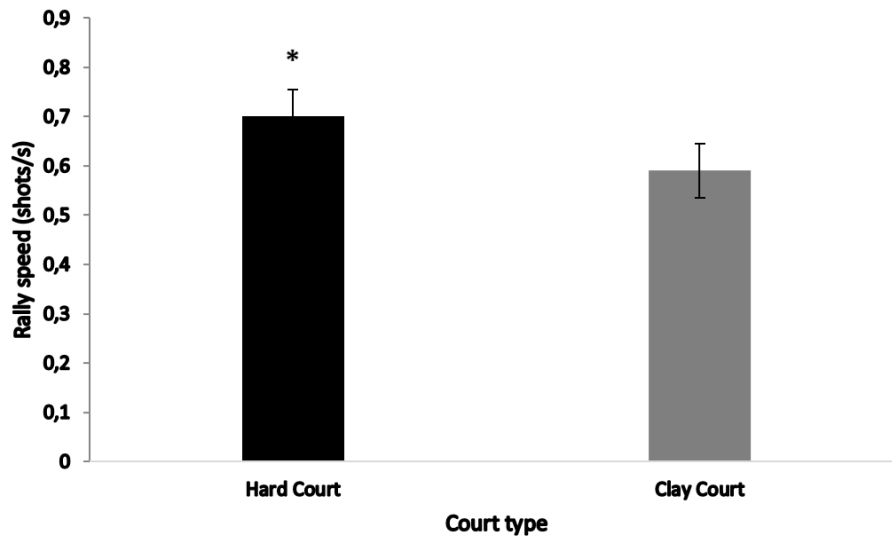


Figure 2. Rally speed of senior tennis players on clay court and hard court. *Significant difference hard court and clay court, $p < 0.05$. Source: the authors

Table 2 shows the physiological responses and time-motion characteristics of clay court surface and hard court surface. Results indicate that playing on clay court surface elicited higher match characteristics compared to hard court surface in several areas: HR_{mean} ($p < 0.001$; $t = -8.86$; 95% CI: -11.0 to -7.0), $\%HR_{max}$ ($p < 0.001$; $t = -9.15$; 95% CI: -6.4 to -4.1), speed ($p = 0.005$; $t = -2.79$; 95% CI: -0.5 to -0.1), TD ($p = 0.001$; $t = -3.67$; 95% CI: -595.6 to -164.9), W ($p = 0.009$; $t = -2.92$; 95% CI: -593.6 to -95.9), LIR ($p = 0.005$; $t = -3.18$; 95% CI: -93.3 to -18.9), MIR ($p = 0.004$; $t = -3.33$; 95% CI: -42.0 to -9.4).

Table 2.

Physiological and time-motion variables analysed on hard court surface and clay court surface

| Variables | CC | | HC | | Mean difference | Cohens <i>d</i> and Rating |
|---------------------------------------|---------------------|--------|--------------------|--------|-----------------|----------------------------|
| | Mean \pm SD | CV (%) | Mean \pm SD | CV (%) | | |
| HR_{mean} (beat·min ⁻¹) | 152.8 \pm 20.3* | 13.3 | 143.7 \pm 18.5 | 12.9 | 9.1 | 0.46; Small |
| $\%HR_{max}$ (%) | 75.7 \pm 10.2* | 13.5 | 70.4 \pm 10.2 | 14.5 | 5.3 | 0.51; Small |
| Speed (km.h ⁻¹) | 2.4 \pm 2.1* | 87.5 | 2.1 \pm 1.9 | 90.5 | 0.3 | 0.14; Trivial |
| TD (m) | 3027.9 \pm 396* | 13.1 | 2647.6 \pm 378 | 14.3 | 380.3 | 0.98; Moderate |
| W (m) | 2774.8 \pm 397.3* | 14.3 | 2430.1 \pm 417.8 | 17.2 | 344.7 | 0.84; Moderate |
| LIR (m) | 218.9 \pm 61.8* | 28.2 | 162.8 \pm 56.3 | 34.6 | 56.1 | 0.94; Moderate |
| MIR (m) | 70.0 \pm 19.3* | 27.6 | 44.3 \pm 21.0 | 47.4 | 25.7 | 1.27; Large |
| HIR (m) | NR | NR | NR | NR | NR | NR |

HR_{mean} = mean heart rate; $\%HR_{max}$ = Percentage of maximum heart rate; TD = total distance; W = walking; LIR = low-intensity running; MIR = moderate-intensity running; HIR = high-intensity running; NR = not reported; * Significant difference from the HC test; CC = clay court surface; HC = hard court surface; SD = standard deviation; CV =coefficient of variation. Source: the authors.

Table 3 Shows the average duration senior tennis players spend in each speed category during matches on clay court surface and hard court surface, where $p < 0.05$ indicates statistical significance. During matches on clay court, players spent significantly more time on average in total match duration ($p < 0.009$; $t = 2.88$; 95% CI: 201.6 to 1240.2), W ($p < 0.016$; $t = 2.61$; 95% CI: 133.0 to 1173.7), LIR ($p < 0.001$; $t = 3.92$; 95% CI: 41.1 to 133.6), and MIR ($p < 0.011$; $t = 2.78$; 95% CI: 6.6 to 45.9) compared to hard court.

Table 3.

Mean duration in each speed zone during matches on clay court surface and hard court surface.

| Variables | CC | | HC | | Mean difference | Cohens <i>d</i> and Rating |
|-----------|-----------|--------|-----------|--------|-----------------|----------------------------|
| | Mean ± SD | CV (%) | Mean ± SD | CV (%) | | |
| TMD (s) | 4092±792* | 19.4 | 3371±729 | 21.6 | 721 | 0.94; Moderate |
| W (s) | 3751±768* | 20.5 | 3098±752 | 24.3 | 653 | 0.85; Moderate |
| LIR (s) | 294±85* | 28.9 | 206±77 | 37.4 | 88 | 1.08; Moderate |
| MIR (s) | 83±28* | 33.7 | 57±28 | 49.1 | 26 | 0.92; Moderate |
| HIR (s) | NR | NR | NR | NR | NR | NR |

TMD = total match duration; W = walking; LIR = low-intensity running; MIR = moderate-intensity running; HIR = high-intensity running; NR = not reported; *Significant difference from the HC; CC = clay court surface; HC = hard court surface; SD = standard deviation; CV =coefficient of variation. Source: the authors.

4. Discussion

This study aimed to investigate the effects of different court surfaces on the physiological responses and game activities of recreational senior tennis players. The findings revealed that the CC induced higher match characteristics in terms of total match duration, strokes per rally, rally duration, and effective playing time, with the exception of rest time, compared to the HC. Additionally, a greater percentage of medium and long rally durations was observed on CC, whereas a higher percentage of short rally durations was recorded on HC. Moreover, rally speeds (shots/s) were faster on HC compared to CC. Furthermore, playing on CC elicited higher match characteristics in terms of heart rate (mean and percentage), running speed, total distance cover, and distances covered by speed categories than on a HC. Notably, during matches on CC, players spent significantly more time in each speed category compared to HC. These results indicate a significant impact of court surface on tennis players' performance and suggest that different surfaces may affect senior players' physiological responses and game dynamics in distinct ways.

In the literature, numerous studies have explored the relationship between physiological responses and game characteristics in tennis players across different age categories (junior, professional, and senior). Several of these studies indicate that varying playing conditions and court surfaces can significantly affect physiological responses and game activity (Chapelle et al., [2017](#); Martin et al., [2011](#); Reid et al., [2013](#)). While a few studies have reported conflicting



results regarding the impact of different tennis court surfaces on physiological responses (Chapelle et al., [2017](#); Hornery et al., [2007](#); Ponzano & Gollin, [2017](#)), the majority of evidence suggests that CC generally impose higher physiological demands on players, predominantly those in the youth and adult categories. Moreover, a significant body of research indicates that physiological responses can be markedly different on clay courts compared to HC. For instance, Martin et al. ([2011](#)) and Murias et al. ([2007](#)) found that average heart rates were significantly higher on CC, recording 154 ± 12 bpm and 143 ± 22 bpm respectively, compared to 141 ± 9 bpm and 135 ± 21 bpm on HC. Additionally, findings from Reid et al. ([2013](#)) highlighted increased physiological strain on clay, with significant effects on heart rate and lactate production compared to HC. Supporting these results, research by Fernandez-Fernandez et al. ([2010](#)) and Kilit & Arslan ([2018](#)) indicates that the total distance covered and stroke characteristics are more demanding on clay surfaces.

Different from these studies on veteran players, the study by Fernandez-Fernandez et al. ([2009](#)) analyzed the match performances of senior and recreational veteran tennis players on outdoor CC. The results showed no significant differences in VO_{2max} and heart rate of advanced and recreational veteran tennis players (24.5 ± 4.1 ml.kg⁻¹.min⁻¹ vs. 23.3 ± 3 ml.kg⁻¹.min⁻¹; 148.3 ± 11.5 bpm vs. 149.8 ± 8.4 bpm, respectively). However, advanced players covered more distance compared to recreational veteran players (3569 ± 532 m vs. 3174 ± 226 m, respectively). This highlights tennis as a beneficial cardiovascular exercise for middle-aged adults, promoting strategic movement and enhancing cardiovascular health. In other investigations into the dynamics of tennis matches, significant variations have been observed in the cardiovascular responses of female tennis players to strenuous matches based on age. While younger players, aged 15 to 30 years, maintain a consistent heart rate throughout the match, veteran players, aged 40 to 51 years, exhibit a progressive increase in heart rate, which peaks towards the end of the match (Therminarias et al., [1990](#); Therminarias et al., [1991](#)). This trend is likely due to age-related changes in the cardiovascular system, which may cause experienced players to experience a rise in heart rate during intense play.

Additionally, the physiological profiles of middle-aged tennis players, both male and female, aged between 31 and 55 years, have been systematically examined. Findings indicate that regular participation in tennis positively impacts cardiorespiratory health and overall fitness levels, helping to mitigate the decline in aerobic power commonly associated with aging (Vodak et al., [1980](#)). Moreover, playing tennis has been shown to contribute to improved aerobic fitness, favorable lipid profiles, and enhanced bone health in senior players, while also reducing the risk of cardiovascular diseases and mortality (Mansencal et al., [2011](#); Marks, [2006](#); Martin & Prioux, [2015](#); Pluim et al., [2007](#)). Senior tennis players display numerous physiological benefits, such as enhanced reaction times, swift decision-making abilities, and potentially improved cardiac functions, all stemming from long-term engagement in the sport. However, they encounter challenges such as decreased muscle mass, balance, and flexibility, which necessitate tailored training programs to mitigate injury risks and maintain performance levels (Caserta et al., [2007](#); Mansencal et al., [2011](#); Rotella & Bunker, [1978](#); Sariman et al., [2018](#)). Training programs focused on speed, agility, and core strength are particularly beneficial for seniors, as they help counteract the general fitness decline associated with aging (Gunay & Kolayis, [2020](#); Miller et al., 2001).

During tennis matches, players covered distances of approximately 2.5–3 km at various running speeds on both CC and HC. On both surfaces, the majority of the running was at the



lowest speed category, with walking accounting for approximately 85-95% of the total time. The findings from our study suggest that CC exhibit more intense performance characteristics compared to HC, including longer rally durations—specifically medium and long rally lengths—higher heart rates, greater distances covered, and increased running speed across all speed categories. These results indicate that playing on clay demands more significant physical effort from players, leading to more vigorous cardiovascular exercise. Such conditions are likely to positively influence the overall cardiorespiratory and endurance capacities of senior players, potentially enhancing their health and physical resilience.

Tennis is played on a variety of surface types, each with distinct properties such as friction coefficient, ball speed, and shock absorption. These variations lead to different injury risks. Higher impact forces on the lower extremity during play, coupled with an increased coefficient of friction between the athlete and the court, predispose athletes to lower-extremity injuries (Leach & Abramowitz, [1991](#); Marks, [2006](#); Yurgil et al., [2021](#)). CC, known for their slower pace, give players more time to reach the ball, potentially reducing the incidence of acute injuries. However, the longer duration of points and matches on CC could increase the risk of overuse injuries. Conversely, HC, facilitating a faster game pace with a lower bounce, require quick reactions and movements. This may lead to a higher risk of acute injuries due to increased stress on joints and muscles (Martin & Prioux, [2015](#)). In the literature, it has been widely observed that senior tennis players who have spent the majority of their careers on hard courts tend to experience more knee problems (Kulund et al., [1979](#); Martin & Prioux, [2015](#); Pluim et al., [2018](#); Yurgil et al., [2021](#)). Furthermore, research suggests that for recreational players, conditioning programs should be designed to gradually enhance physical fitness and resilience, focusing on improving aerobic capacity, muscular strength, and flexibility (Sariman et al., [2018](#); Yurgil et al., [2021](#)). Such an approach not only enhances the overall tennis playing experience for recreational athletes but also minimizes the risk of injuries, which is particularly crucial for preserving health and mobility in older age groups (Fernandez-Fernandez et al., [2009](#)).

Another finding from our study was that rally speeds were higher and game times shorter on HC, indicating faster strokes and more dynamic transitions in the game. This environment could improve players' reaction times and rapid movement capabilities, thus positively affecting neuromuscular coordination and overall agility. However, the higher rally speed and impact forces associated with HC could increase the risk of injuries, especially among senior players.

Certain limitations inherent to our study should be noted. Firstly, the research was conducted with recreational senior male tennis players; therefore, the results may not be generalizable to players of different ages, genders, and skill levels. Additionally, our study did not consider the influence of playing on other surfaces, such as grass or indoor courts. Another limitation is the exclusion of specific movement types in our analysis, such as jumps, turns, accelerations, and decelerations. Furthermore, while GPS devices are widely recognized as the most popular and convenient method for measuring exercise intensity, speed, and distance covered, they exhibit significant limitations (ICC = .70–.99; CV = 1.1–24.8%), especially in activities characterized by short durations and high intensity. Therefore, it is advisable for readers to consider the margin of error inherent in these measuring instruments when evaluating the results of this study (Duffield et al., [2010](#); Kilit et al., [2017](#)).



5. Conclusions

The findings of this study demonstrate that playing on CC elicits higher physiological responses, movement speeds, and game attributes compared to HC. Specifically, male senior tennis players on CC exhibited a longer match duration, increased velocity, and covered greater distances across various speed zones compared to those on HC. Moreover, CC promoted higher stroke counts and better timing. In contrast, rally speeds were higher and game times shorter on HC, indicating faster strokes during play. These results strongly suggest that the playing surface directly influences the physical responses of senior tennis players. Ultimately, this study enhances our understanding of how different court surfaces affect the physiological responses and game performance of recreational senior male tennis players.

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