Title: **Physiological, perceptual and technical responses to on-court tennis training on hard and clay courts.**

ABSTRACT:

The aim of this study was to investigate the effect of court surface (clay v hard-court) on technical, physiological and perceptual responses to on-court training. Four high-performance junior male players performed two identical training sessions on hard and clay courts, respectively. Sessions included both physical conditioning and technical elements as led by the coach. Each session was filmed for later notational analysis of stroke count and error rates. Further, players wore a global positioning satellite device to measure distance covered during each session; whilst heart rate, countermovement jump distance and capillary blood measures of metabolites were measured before, during and following each session. Additionally a respective coach and athlete rating of perceived exertion (RPE) were measured following each session. Total duration and distance covered during of each session were comparable ($P>0.05$; $d<0.20$). While forehand and backhands stroke volume did not differ between sessions ($P>0.05$; $d<0.30$); large effects for increased unforced and forced errors were present on the hard court ($P>0.05$; $d>0.90$). Furthermore, large effects for increased heart rate, blood lactate and RPE values were evident on clay compared to hard courts ($P>0.05$; $d>0.90$). Additionally, while player and coach RPE on hard courts were similar, there were large effects for coaches to underrate the RPE of players on clay courts ($P>0.05$; $d>0.90$). In conclusion, training on clay courts results in trends for increased heart rate, lactate and RPE values, suggesting sessions on clay tend towards higher physiological and perceptual loads than hard courts. Further, coaches appear effective at rating player RPE on hard courts, but may underrate the perceived exertion of sessions on clay courts.

Key words: workload, racquet sports, RPE, stroke count,

INTRODUCTION

The activity profile of tennis match-play and training has attracted research interest for more than two decades. [15,24,25] The sport has been shown to involve short, intensive work periods interspersed with recoveries of variable length.[14,15,25] Specifically, tennis involves predominant anaerobic energy supply during brief, higher-intensity efforts and aerobic energy system supply to meet the energetic demands of lower intensity locomotion.[6,15] Naturally, with tennis played across multiple surfaces, investigators have also attended to the effect of surface on the physiological and performance characteristics of match-play; although less attention has been paid to training scenarios.[7,9] The two court surfaces that feature most prominently on the professional tournament calendars are clay and acrylic (hard). With high-performance players involved in substantial volumes of on-court training [7], there is a lack of evidence-based information to inform the effect on court surface on the content and structure of training. [7, 9] To this end, little research has focused on the physiological, perceptual and technical demands of tennis training, and more particularly, how these parameters are affected by court surface. With this in mind, tennis practitioners currently suggest that clay court surfaces elicit greater training demands than hard courts; although few studies substantiate such hypotheses with tennis specific outcomes. [7, 9]

Previous research outlines differences in the playing characteristics of match-play due to court surface. [7, 9, 12, 17, 19, 20] Specifically, match-play on clay courts, which possess higher friction coefficients and coefficients of restitution than hard courts, are punctuated by longer rallies, a higher number of strokes per rally, and a predominance of topspin shot selection.[12] These differences may then help to explain the increased mean heart rate and blood lactate values reported on clay compared to hard court match-play.[17] With respect to training on different surfaces, Fernandez-Fernandez et al.[7] recently reported no differences in heart rate or oxygen consumption (VO_2) between the same drills performed on clay and carpet, respectively. These authors suggest the similarities in groundstroke speeds were due to controlled release by a ball machine, which blunted the tactical variations used by players on the different surfaces; and led to few physiological differences being observed. [7] More specifically, Murias et al.[19] reported increased lactate values from training on clay compared to hard courts, speculating the increased values resulted from a more physically demanding load on clay courts. Conversely, while Girard and Millet[9] reported that longer duration rallies resulted in greater distance covered per point, no differences in post-match lactate values were present between hard and clay surfaces at the end of the match-play session. Such equivocal findings may stem from differences in the methodology of ball delivery during the on-court session and/or timing of blood measures.[17] Specifically, Fernandez-Fernandez et al.,[7] suggest that differing physiological responses due to court surface may be exacerbated during a coach-led session as ball delivery is varied based on court movements compared to the constant feed of a ball machine.

Accordingly, it is intuitive for the training of tennis players to be tailored to the surface characteristics of upcoming tournaments. While there is little empirical evidence describing the effect of court surface on training responses,[17,23] the literature is replete with anecdotes of coaches planning training to resemble the match-play demands experienced on different court surfaces. Interestingly however, with training time at a premium and most experienced coaches and trainers acknowledging the need to prepare with the characteristics of the surface in mind; it is not uncommon for training to involve the same drills, independent of court surface. With this in mind, the aim of this study was to compare the technical, physiological and perceptual responses of players completing the "same" training session on hard and clay court surfaces, respectively. It was hypothesized that training on a clay court surface would result in an increased physiological and perceptual load than compared to training on a hard court.

METHODS

Experimental Approach to the Problem:

All players were familiar with the drills performed, the court surfaces, as well as the data collection measures and procedures; having variously participated in like data collection sessions. On two occasions, participants performed identical coach-led, on-court, tennis-specific training sessions on either clay or hard court surfaces. Sessions were conducted in a randomized order and separated by a 48 h recovery period. Training sessions were conducted at the same time of day on each occasion (09:00) during a pre-competition training block prior to a series of tournaments to be played on both court surfaces. Respective sessions were conducted on a Plexi-cushion hard court (considered of medium court surface rating by the International Tennis Federation [ITF]) or a European clay court (considered of slow court surface rating by the ITF). Each training session was identical and consisted of two parts; 1) an initial on-court conditioning component, followed by 2) a coach-led technical component. As described later, the conditioning component consisted of 20-min of tennis-specific movement and footwork drills. Following a 10-min recovery, players then participated in the coach-led technical component of training, consisting of a fixed duration (90 min) of the same on-court training drills and technical content with the same tennis specific equipment (ie tennis shoes, balls, rackets etc) on each occasion. Measures of movement demands from global positioning satellite (GPS) devices and stroke volumes from video footage were recorded throughout each session to quantify those characteristics of training volume. Further, physiological measures of heart rate and capillary blood markers of metabolism and perceptual measures of perceived exertion and muscle soreness were also recorded before, during and at the cessation of each session. Participants were required to attend each testing session in a rested state, refraining from intense physical activity in the previous 12 h and the ingestion of food or caffeine in the 2 h prior to testing. All participants completed a food diary before the first testing session and then maintained this standardised diet and fluid consumption for the subsequent testing sessions. Environmental conditions on each respective day of testing were 15 ± 1 v 14 ± 1°C, 41 ± 4 v 45 ± 4 % Relative Humidity and 16 ± 2 v 15 ± 2°C Wet Bulb Globe Index (Questtemp°15, Quest, USA).

Subjects:

Six high-performance tennis players from the Tennis Australia – Australian Institute of Sport Pro Tour program volunteered as participants for this study; however due to injury or sickness only 4 subjects completed both sessions. The 4 subjects had a mean ± standard deviation (SD) age, mass and height of 17 ± 1 yr, 74.2 ± 5.7 kg and 182.3 ± 4.2 cm. All players held professional senior tennis rankings and competed in approximately 25-30 tournaments per year, routinely performing 2-3 training sessions per day during training phases. All players were fully informed of the experimental procedures prior to providing written and verbal Informed Consent and Ethics were approved by the Institutional Ethics in Human Research Committee.

Procedures:

Training session:

The same training session was used on each respective court surface and led by the same coach. One court of each surface was used respectively, with two players per court under the direction of a designated coach. Coaches conferred prior to each session to ensure the same drill content was delivered for the same amount of time. As alluded to above, the conditioning component of the session involved a standardised 10-min warm-up consisting of on-court, low-intensity aerobic exercise followed by tennis-specific dynamic movement patterns and static stretching. Following the warm up, players performed 20-min of structured, intermittent-sprint exercise involving tennis-specific footwork patterns. Repeated efforts of cross-court sprint efforts from doubles line to doubles line involving changes of direction within the tram lines and service box, separated by walk recoveries, were performed. Following a 10-min recovery, players then performed a 90-min coach-led technical training component consisting of 4 tennis drills and 1 tennis-specific conditioning drill. The tennis drills were common to this training squad, are known to feature in on-court training programmes of professional players[16] and are commensurate with drills often prescribed in other on-court performance training.[8] A specific outline of respective drills is provided in Table 1.

Movement analyses:

Throughout both training sessions, movement distances were quantified by a 5Hz GPS (MinimaxX, Catapault, Australia) device worn between the scapulae of each player in a customised harness. Players wore the same GPS device for both sessions. Distance of player motions were reported for the overall session as a quantification of external load completed by the players in each session. Previous research reports the co-efficient of variation (CV) of 1Hz systems for total distance as <5%, although for tennis-specific movements, the reliability of 1 and 5Hz GPS measures is poorer at 5 – 15%,[3,5] and as such represents a limitation of this study. All devices were activated 20-min prior to data collection to allow acquisition of satellite signals. Further, at all times, an 'open' sky was present and there were no obstructions, ensuring clear space for satellite acquisition. Speed was calculated post hoc by customised software (MinimaXX; v28.5 Logan Software). Given the previous research suggesting lower reliability of GPS devices for measures of on-court movement for tennis, only total distance as a measure of external load is reported as this has been reported to have the highest accuracy and reliability.[5] During respective sessions, a mean number of 7±1 satellites were acquired and an acceptable HDOP and VDOP of 2.76±0.6 and 1.65±0.3 were present, respectively.

Technical skill analyses:

All sessions were filmed by a digital video camera (DSR-PDX10P, Sony, Japan) located 5-m above the court surface and 6-m behind the baseline. Sessions were viewed later and notated to code for the number of forehands and backhands, forced and unforced errors, as well as error ratios.[12] Coding was performed using customised software (The Tennis Analyst, Version V4.05.284, Fair Play Pty Ltd, Australia), and repeated on two occasions for four sessions to determine the co-efficient of variation (CV=0.07%).

Physiology:

On arrival, participants were required to provide a mid-stream urine sample to measure urine specific gravity (USG) (Refractometer, Atago, Japan) as an indicator of hydration status. Throughout both the respective on-court conditioning and ensuing skill based training sessions; heart rate was continuously recorded via a heart rate monitor (Memory Belt, Suunto. Finland) downloaded on customised software (Firstbeat Sports v2.1.0.1, Firstbeat, UK) and reported as mean and peak heart rate for each session and respective drills. To determine changes in blood markers of metabolites and oxygen saturation, capillary blood samples were collected at rest and immediately following the conditioning session and drill 3 of the training session. A 100 μl sample of capillary blood was obtained from an earlobe with a sterilized lancet and collected in sterile, single use collection cartridges (i-stat CG8+, Abbott, NJ, USA) to measure lactate, pH, Bicarbonate (HCO_3) and partial pressure of oxygen (pO_2) (i-stat portable clinical analyser, Abbott, USA). To determine peak lower-body power, repeated unweighted counter movement jumps (CMJ) were performed using a linear position transducer (Fitness Technology, Adelaide, Australia) and Ballistic Measurement System software (Fitness Technologies, Adelaide, Australia) to determine maximal displacement. Repeated bouts of 5 CMJ were performed pre-exercise in a rested state and then again following the conditioning and technical sessions respectively on a concrete based floor. Jumping technique was controlled through a standardised jumping technique and use of a dowel rod placed across the shoulders to eliminate arm swing.[2] The linear position transducer was calibrated prior to data collection by the use of a known displacement distance (1.0 m).

Perceptual:

Prior to, following the completion of the conditioning session, each respective tennis drill and 15-min following the conclusion of the session, a Rating of Perceived Exertion (RPE) was obtained from players using the CR-10 Borg scale.[1] Additionally, a rating of Muscle Soreness was obtained prior to and 10-min following each session using a 1 - 10 Likert scale for rating of whole body muscle soreness (0 - no pain to 10 - most severe pain). Further, throughout the tennis session and 15-min following the session, coaches were asked to rate their perception of each athlete's load (RPE) following each drill.

Statistical Analyses:

Data are reported as mean ± SD. A repeated measures two-way ANOVA (condition x time) was performed to determine differences in physiological and perceptual response based on court surface. Due to the small number but high-performance nature of the population, it is acknowledged that this study is underpowered; accordingly effect size analyses (Cohen's d) were conducted to determine the magnitude of effect of court surface on training responses. An effect size was classified as trivial (<0.20), small (0.20-0.49), moderate (0.50-0.79) or large (>0.80).

RESULTS

Motion analysis:

Total distance covered for the two respective conditions were 4.82 ± 0.69 v 4.79 ± 0.75 km for hard and clay court, respectively. There was no significant difference and a small effect size between the distance covered of respective court surface sessions ($P>0.05$; $d=0.26$).

Technical skill analyses:

There were no significant differences and trivial effect sizes ($P>0.05$; $d<0.25$) for the duration of the respective drills throughout the training session (Table 2). Post-session notational analysis data for volume and proficiency of technical performance is detailed in Table 2. Total stroke volume demonstrated no significant difference and trivial effects between hard and clay courts for any drill ($P>0.05$; $d<0.10$). Furthermore, respective forehand and backhand stroke volume did not significantly differ and had trivial to small effects for hard and clay surfaces for all drills ($P>0.05$, $d<0.20$). Forced errors tended to be consistently greater on hard court with large effect sizes for all drills ($P>0.05$, $d>0.8$). Similarly, unforced errors on hard court surfaces were punctuated by large effect sizes for drills 2 and 3 ($P>0.05$; $d=0.9$-1.6). Unforced error rate (%) for each drill did not differ and indicated small effect sizes ($P>0.05$; $d<0.28$) between respective surfaces. When data was combined to provide total session volume there were no significant differences and trivial effect sizes ($P>0.05$; $d<0.25$) for both forehand and backhand shot count. However, forced error count was significantly greater for hard court surfaces ($P=0.02$, $d=2.4$), whilst unforced error rate demonstrated a large effect for increased errors on hard surfaces ($P>0.05$, $d=0.8$).

Physiology:

Pre-training USG's were 1.021 ± 0.002 and 1.020 ± 0.002 for hard and clay court sessions respectively, and did not differ between respective court sessions ($P>0.05$; $d=0.25$). Peak (190±15 v 189±15 bpm) and mean heart rates (143±13 v 142±10 bpm, for hard and clay respectively) for the overall session did not differ between surfaces and showed only small effect sizes ($P>0.05$; $d<0.30$). However, large effect sizes were evident ($d>1.20$; Figure 1) for higher mean heart rates on the clay court following the conditioning session and drill 1, respectively. The court-based sessions resulted in significantly increased capillary blood lactate and reduced pH, HCO_3 and pO_2 as a result of the respective sessions ($P<0.05$; Table 3); however, no significant differences were evident between hard or clay court surfaces for any blood measure of lactate, pH, HCO_3 or pO_2 (Table 3; $P>0.05$). Large effect sizes were evident for higher lactate ($d=1.50$) values on the clay court following the conditioning session and drill 3, although all other effect sizes were small to trivial ($d<0.30$). Finally, no significant differences and small to moderate effect sizes were present between conditions for maximal CMJ distance at any time point (Figure 2; $P>0.05$; $d<0.50$).

Perceptual:

Post-drill RPE did not differ between court surfaces ($P>0.05$; Figure 3), although a large effect size for higher RPE was present following the conditioning session and drills 2 and 3 on the clay court ($d=1.1$ and 2.0, respectively). For the hard court session, there was no significant difference and trivial effect sizes ($P>0.05$; $d<0.20$) between player and coach RPE for the respective drills. While no significant differences ($P>0.05$) were present between coach and player RPE for the clay court session, large effect sizes ($d>1.20$) suggest lower subjective coach RPE of the session, particularly for drill 3 (Figure 3). Finally, post-session rating of MS was not significantly different ($P>0.05$; $d=0.29$) between court surfaces (4.6±2.4 v 4.1 v 2.7 arbitrary units, for hard and clay court respectively).

DISCUSSION

The aim of the current study was to assess the effect of court surface (clay v hard) on the technical, physiological and perceptual responses to on-court training in high-performance junior players. Results suggest that sessions did not differ for total stroke count, either for forehand or backhand on the two court surfaces; although, a large effect for increased (forced) errors was observed on the hard court. Large effects were also observed for increased heart rate and lactate values during clay sessions, pointing to increased physiological load on clay courts. Moreover, players perceived sessions on clay to have higher RPE than hard courts, despite coaches seeming to underrate the internal load of drills on clay. Accordingly, despite similarities in the external load measures of distance covered and stroke volume, it seems there may be subtle differences in technical performance (ie., in stroke mechanics and velocity), as well as in more discrete measures of movement (like step count, intensity and frequency of changes in direction); resulting in elevated internal load of training on clay courts compared to hard courts.

Prior to further discussion of these results, it is noteworthy to highlight methodological limitations present in the current study. These limitations include the small subject number, the use of GPS measures to determine external load and the reduced control of sessions due to coach-led feeding of the drills. Combined, these limitations are acknowledged as reducing the convictions and interpretation of the findings. However, the subject population was from a single squad of high-performance junior players and as such, only small subject numbers were available. Further, despite the reported limitation in GPS data for tennis;[5] there are currently few validated methods readily available to measure distance or speed of movement for tennis. Furthermore, total distance is regularly highlighted as the most accurate measure of those reported, with measures of velocity in higher bands reported to have CV's >20%, we have chosen to only report total distance (CV<10%).[3, 5] Finally, although sessions were coach-led, the same coach controlled each respective session for the same players; which also represents an ecologically valid environment for normal practice.

As a session-based measure of external load, total distance covered and time on court during respective sessions did not differ between the court surfaces; while stroke volume also did not differ between court surfaces. To the knowledge of the researchers, no previous studies have reported technical outcomes for training sessions based on court surface, yet practical experience would point to tennis increasingly following trends observed in other sports by attempting to quantify different aspects of training load.[22, 13] In recent times, this has manifested in selected coaching groups or Federations establishing notational systems to monitor the number of shots that individual players hit within sessions as a measure of external load. Previously, both Girard and Millet[9] and Johnson and McHugh[12] have reported that competitive match-play on clay results in longer rallies, longer point durations and increased stroke volume than hard courts. Training environments tend to be more structured than competitive match-play, and accordingly, the overt difference in technical performance due to court surface seems smaller. That said, despite similar stroke volumes, the current study observed trends for increased errors, particularly forced, on hard court surfaces. As drills were continuous (with a constant supply of balls provided to coaches) in nature until the designated breaks, players tended to move straight to the next rally or ball. Conceptually this elevated error rate within the same total stroke count would appear consistent with past research reporting increased ball velocities and subsequent increased time under pressure being a characteristic of hard court play.[21] Although training duration, stroke volume and distance covered were all similar between surfaces, an increased number of errors may still alter the duration of continued exertion of effort and consequently, any change to the continuity of the training session may affect the physical demands of the session.

The on-court training sessions were physically demanding as observed by duration of time on court (~120 min), and significant increases in heart rate and blood lactate.[10] The current study suggests trends for increased heart rate and lactate values on the clay court, despite similar time on court, stroke count and total distance covered. Whilst elevated physiological responses for the same total stroke volume may infer altered stroke velocities or mechanical demands on respective surfaces, without such measures this remains speculative. However, previous research also reports increased mean heart rate and blood lactate values on clay compared to hard courts during tennis match-play.[19, 17] These differences have been explained in relation to the duration and type of tactical and therefore technical play that epitomizes clay court match-play. The higher friction coefficients and coefficients of restitution noted on clay courts[7] often slow the speed of play, resulting in greater duration of individual points and hence, possible increased physical efforts within respective points; although, not all research reports increased physiological load on clay surfaces.[9] In the present study, as abovementioned, the reduced volume of errors observed on clay court surfaces during particular drills may have altered the continuity of training efforts; potentially leading to the noted trends for increased physiological load. Despite these trends, the physiological differences were small and no differences were noted in lower-body power following the session. Accordingly, it may be that during similar training sessions, the influence of court surface on technical proficiency and ensuing physiological load may only be subtle (i.e. stroke effort based on incoming ball velocity); although the lack of any measurement of these factors and the small sample size of the study is acknowledged as a limitation in the interpretation of these findings.

Interestingly, few studies report the effect of court surface on perceptual markers of load or perceptions of fatigue in tennis.[6, 11] Reports from competitive match-play data suggest RPE's in the range of 9 -17 depending on the duration and stroke volume of rallies.[18] Although players may regulate match intensities based on perceived effort rather than physiological stress.[10] Not unexpectedly, there were large effects for increased player RPE values during the clay court session, despite the same time on-court and total distances covered. Similar results were observed for heart rate and lactate values during clay court sessions, suggesting the trends for increased physiological load may be noted by players when reporting perceptual load of the session. Mendez-Villanueva et al.[18] also noted that when match-play rallies were of greater duration and increased stroke count, both lactate and RPE values were increased. Whether the reduced number of errors noted for clay court surfaces results in more pronounced or prolonged intra-drill efforts is unknown, but this contention would appear consistent with the previously highlighted match-play data.[20, 12, 9] Regardless, from these data, the subtleties of training load on different court surfaces may be differentiated by perceived exertion and so justify the further investigation of RPE as a marker of training load.

Finally, the monitoring of markers of training load are designed to allow coaches and conditioning staff to appropriately implement, monitor and tailor training programs to ensure optimal physical and technical performance.[4] However, the uptake and use of load monitoring can often be viewed suspiciously by many coaches. The present study also sought to determine whether coaches had a similar perception of load as their players. Overall, RPE measures were similar between players and coaches for the training session; however, there was a trend for greater RPE differences throughout the clay court training session. Specifically, coaches tended to rate the perceived load as lower than the players on clay courts. When combined with the noted trends for increased physiological and perceptual markers during the clay session, the greater discrepancy between coach and player RPE on clay may highlight the potential use of markers of load during training to ensure closer alignment of planned and actual training program prescription.[4] The relationships between coach, player and objective markers of load and the ensuing effect of training session or court surface may require further investigation to appreciate the dose – response nature of on-court training.

In conclusion, for the same training session on hard and clay courts there were no differences in total distance or stroke volume. However, clay courts resulted in fewer errors compared to the increased (forced) error rate noted on hard courts. Furthermore, training on clay courts resulted in trends for higher heart rate, lactate and RPE values. Accordingly, it may be that sessions on clay result in higher actual (physiological) and perceived loads than on hard court, possibly due to subtle changes in the continuity of the session. Finally, coaches rate a similar player exertion level as athletes for training on hard courts, but may under-rate the perceived exertion of training on clay courts.

PRACTICAL APPLICATIONS

There is limited evidence available to inform coaches and players in regard to the physical, technical and perceptual demands of training on different court surfaces. In this context, it seems there are subtle differences in the technical proficiency and physiological load when training on clay compared to hard courts. Specifically, coaches should be aware of the possible increased continuity of hitting during clay court drills, and the potential increase in physical and perceptual load compared to the same session on a hard court. Given the divergence of coach v athlete RPE on clay, the monitoring of internal load following sessions may be of practical relevance.

ACKNOWLEDGEMENTS

The authors would like to express our thanks to the coaches, particularly Brent Larkham, and players of the Tennis Australia – Australian Institute of Sport program for their involvement in this study. The authors declare that they have no conflict of interest. The results of this study do not constitute endorsement of the product by the authors or the National Strength and Conditioning Association.

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Figure Legends

Figure 1: Mean and peak ± SD heart rates for conditioning (Cond) and technical on-court training drills for clay and hard court surfaces, respectively.
[#] Large effect (d>0.8) compared to Hard court.

Figure 2: Mean ± SD maximal counter movement jump distance at rest and following the conditioning and technical training session on clay and hard court surfaces, respectively.
No significant differences (P>0.05) and small effect sizes (d<0.20)

Figure 3: Mean ± SD A) player rate of perceived exertion (RPE) for hard and clay courts B) player and coach RPE for hard court and C) player and coach RPE for clay court conditioning (post-cond) and training drills, respectively.
[#] Large effect (d>0.8) compared to Hard court or player RPE, respectively.