Case-Study:

Energy Expenditure of a male and female tennis player during ATP/WTA and Grand Slam events measured by doubly labelled water

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Abstract

Understanding the total energy expenditure (TEE) for competition and training in sport are vital to ensure suitable nutritional strategies. This study assessed TEE of a world class male and female tennis player during competition at the highest level. Participants: Career high ranking, Female: Women's Tennis Association (WTA) top 10; Male: Association of Tennis Professionals (ATP) top 15. Methods: Doubly labelled water assessed TEE during a 17-day period analysed by day 1–7 (P1) and 7–17 (P2) which included a WTA/ATP tournament and culminated at the Wimbledon Championships. Daily training and match loads were assessed using a 10-point Borg scale multiplied by time. Match data were provided by video analysis and player tracking technology. Results: The TEE during P1 for the female player was 3383 kcal·day^{-1} (63.5 kcal·kg^{-1}) FFM with 362 points played over 241 min in three matches covering a distance of 2569 m, with an additional 875 min training. During P2, TEE was 3824 kcal·day^{-1} (71.7 kcal·kg^{-1}) FFM with 706 points played over 519 min during five matches, covering a distance of 7357 m with an additional 795 min training. The TEE during P1 for the male player was 3712 kcal·day^{-1} (56.3 kcal·kg^{-1}) FFM with 133 points played over 88 mins during one match covering 1125 m, with an additional 795 mins training. During P2, TEE was 5520 kcal·day^{-1} (83.7 kcal·kg^{-1}) FFM with 891 points played over 734 min during five matches, covering 10043 m, with an additional 350 min training. Conclusion: This novel data positions elite tennis, played at the highest level, as a highly energetic demanding sport, highlighting that nutritional strategies should ensure sufficient energy availability during competition schedules.

Key Words

Elite sport; Wimbledon; DLW, racket sport

Introduction

Tennis is a sport played world-wide and spectated by millions of people, with an almost continual schedule of competition throughout the calendar year. The Olympic tennis events and the four Grand Slam tournaments are considered the pinnacle of the sport which are played across grass, clay and hard court surfaces. During a Grand Slam schedule, successful players can expect to play 7 matches (typically ranging in duration from 1 – 5 hours) within a two-week tournament (1). Recovery time between matches is generally 24 – 48 h but it can be influenced by player schedules (participation in both singles and doubles) as well as delays to the match start times, the result of which could mean participation in multiple matches in a single day. In considering the intermittent activity profile, tennis is characterised by accelerations, sprints, rapid changes of direction, decelerations and prolonged rallies, with the maximal recruitment of musculature during shots and strokes (2, 3). These bouts of activity are interspersed with recovery periods between points (>20 s), changeovers (90 s) and at the conclusion of each set (120 s) in accordance with rules set by the International Tennis Federation (ITF) (4). Depending on the playing surface, player style and sex, the active periods or effective playing time during a match are found to be between 10 – 30% of total match time (3, 5 – 7). The individual characteristics of each playing surface (friction during ball to surface impact affecting ball speed and bounce trajectory) can influence match play and style, impacting the active periods and the locomotive demands (8 – 10).

Although the physical demands of tennis are now well documented, our understanding of the energetic demands (and associated nutritional requirements) are not as advanced. Indeed, previous research has estimated energy expenditure during match play using indirect calorimetry however the restrictive nature of such investigations limits the ecological validity (11). Using such approaches, the energy demands of male (12) and female (13) players during simulated match play has been reported as 568 ± 59 $kcal \cdot h^{-1}$ and 442 ± 60 $kcal \cdot h^{-1}$ respectively. Nonetheless, it remains to be determined whether such data is reflective of actual competitive tournament match play given the simulatory nature of data collection and the interference that the wearing of portable gas analysis equipment could have on the associated match intensity. From a nutritional perspective, there is also the definitive requirement to assess total daily energy expenditure (as opposed to match play *per se*) so that appropriate nutritional strategies can be tailored to sustain match play performance, promote recovery and support health over the duration of a typical two week tournament. For this purpose, we aimed to capture the energy requirements of world class players during a period that reflects the demands regularly faced by this level of player without manipulating or impacting their performance. In this regard, the doubly labelled water (DLW) method is a non-invasive and 'gold standard' approach to assess total energy expenditure (TEE) in free living individuals (14). This method has not yet been applied to elite tennis players over a time period comprising a physically demanding training and competitive schedule.

With this in mind, we aimed to quantify the daily energy demands of a world-class male and female tennis player during competition of the highest level. To this end, we studied both players during a 17 day period comprising participation in their respective ATP (Association of Tennis Professionals) and WTA (Women's Tennis Association) events as well as the Wimbledon Championships Grand Slam event.

Methods

An elite male and female professional tennis player volunteered to participate in this study (see Table 1). The study was approved by the local Ethics Committee of Liverpool John Moores University and both participants provided written informed consent before the study commenced. To respect anonymity, specific anthropometrical data are not provided.

****** TABLE 1 ABOUT HERE******

Study design

Data collection was conducted over a 17-day period (July 2019) comprising participation in both a WTA/ATP international tournament and the Wimbledon Championships Grand Slam tournament. Throughout data collection, the participants continued with their usual training and preparation with no changes made to their usual competition routines. Sample collection points were positioned to allow for the assessment of energy expenditure during the periods of days 1 – 7 (P1) and 7 – 17 (P2).

Measurement of Energy Expenditure Using Doubly Labelled Water

Daily energy expenditure was measured using the doubly labelled water technique (15). This method has been previously validated on multiple occasions by comparison to simultaneous indirect calorimetry in humans (reviewed in Speakman 1997) (16). Upon arrival at their training venues, the participants were weighed (Seca, Birmingham, UK) before providing a single baseline urine sample into a labelled sample pot before sealing. Following collection of a baseline 35ml urine sample to estimate background isotope enrichments, participants self-administered orally a weighed bolus dose of hydrogen (deuterium ^{2}H) and oxygen (^{18}O) stable isotopes (Cortecnet, Voisins-Le-Bretonneux, France) in the form of water ($^{2}H_2{}^{18}O$) (which was witnessed by the lead researcher) and the time of ingestion was recorded. Each participant was dosed in accordance to their body mass with a bolus of DLW weighed to four decimal places. Once administered, to ensure the entire dose had been ingested the glass vessel was refilled with tap water and also consumed. The following morning, the participants were weighed and asked to provide a 35ml sample of the second urine void of the day. Further second void urine samples were collected daily until day three, then continuing every 2 – 6 days with the last collection on day 17. Urine samples were split, half was analysed for hydration status (Osmocheck, Vitech Scientific Ltd. England) and half was encapsulated into glass capillaries to enable storage at ambient temperature during the field-based collection. Analysis of the isotopic enrichment of urine was performed blind, using a Liquid Isotope Water Analyser (Los Gatos Research, USA) (17). Initially the urine was vacuum distilled (18), and the resulting distillate was used for analysis. Samples were run alongside five laboratory standards for each isotope and international standards to correct delta values to parts per million (ppm). Daily isotope enrichments were $\log_e$ converted and the elimination constants (ko and kd) were calculated by fitting a least squares regression model to the $\log_e$ converted data (Figure 3.). The back extrapolated intercept was used to calculate the isotope dilution spaces (No and Nd). A two-pool model, specifically equation A6 from Schoeller et al., (1986) (19) as modified by Speakman (2021) (20), was used to calculate rates of CO_2 production.

$$rCO_2 = 0.4554 \cdot N \cdot [(1.007 \cdot k_o) - (1.043 \cdot k_d)] \cdot 22.26$$

$$TEE\ (MJ/d) = rCO_2 \cdot (1.106 + (3.94/RQ)) \cdot (4.184/10^3)$$

$$Kcal = MJ \cdot 238.85$$

Measurement of resting metabolic rate and physical activity level

Fat free mass was calculated from total body water analysis (^{18}O dilution space) using the doubly labelled water method for further inclusion into the Cunningham equation (21) to predict resting metabolic rate.

$$\text{Total body water (N)} = [(N_o/1.007) + (N_d/1.043)]/2$$

$$\text{Resting metabolic rate (RMR)} = (500 + 22) \cdot FFM$$

$$\text{Physical activity level (PAL)} = TEE/RMR$$

Quantification of activity loads and match data

Due to the current federations ruling for no worn coaching devices during competition, daily training and match play loads were assessed using a modified 10-point Borg scale for each session multiplied by the duration of the session to produce sRPE (AU) (22). This was a system the participants had extensive previous experience with. Distances covered during match play were collected from Hawk-eye (Hawk-Eye Innovations Ltd, Basingstoke, UK) player tracking data, IBM slamtracker data (wimbledon.com) and one match from external player tracking software (Hypercode). Match data was sourced from the national federation analysis department. All data were displayed for descriptive purposes and therefore are absolute individual values, matches played, points played, total match time, total match distance, total training time , sRPE, shot frequency and EE. Training was defined as all on-court training sessions, strength and conditioning sessions, pre-match preparation (away from match court) and match court warm ups.

Results

An overview of the training load, match load (and associated match metrics) and daily energy expenditure from the female player is displayed in Figure 1. Data presented in Figure 1 A-D represent the week comprising participation in the WTA tournament (P1) whereas data presented in Figure 1 E-H represent the period comprising participation in the Wimbledon Grand Slam event (P2). The daily energy expenditure in P2 was approximately 440 kcal·d^{-1} higher than P1, resulting in a PAL level of 2.3 and 2.0, respectively. When expressed relative to FFM, energy expenditure in P1 and P2 corresponded to 63.5 and 71.7 kcal·kg^{-1} FFM, respectively. In P1 the female played 3 matches with a mean duration of 80 ± 13mins (in a range of 74 – 96 mins) and covered a mean distance of 856 ± 140 m (in a range of 730 – 1006 m). During P2 the female played 5 matches with a mean duration of 103 ± 30 mins (in a range of 70 – 145 mins) and covered a mean distance of 1471 ± 449 m (in a range of 1002 – 2141 m).

****** FIGURE 1 ABOUT HERE******

Comparable data (and format of data presentation) for the male player is displayed in Figure 2 and shows energy expenditure in P2 to be approximately 1800 kcal·d^{-1} higher than P1, thus resulting in a PAL level of 2.8 and 2.2, respectively. When compared to the female player, daily TEE was comparable in P1 although it was approximately 1700 kcal·d^{-1} higher in P2. When expressed relative to FFM, energy expenditure in P1 and P2 corresponded to 56.3 and 83.7 kcal·kg^{-1} FFM, respectively.

In P1 the male played one match (over two days) with a duration of 88 min and covered 1125 m. During P2 the male played 5 matches with a mean duration of 129 ± 55 mins (in a range of 90 – 223 mins) and covered a mean distance of 2009 ± 1392 m (in a range of 866 – 4175 m). Urine sample collection points and the rate of isotope disappearance can be seen in Figure 3.

****** FIGURE 2 ABOUT HERE******

****** FIGURE 3 ABOUT HERE******

Discussion

In using the DLW method, we provide the first report to simultaneously assess the daily energy expenditure of a world class male and female professional tennis player. Importantly, our data collection period comprised a period of the season where both players competed in their respective ATP / WTA tournament as well as the subsequent Wimbledon Championships Grand Slam event. As such, our data provide a platform to establish optimal nutritional strategies for what is considered one of the most physically demanding periods of the annual tennis calendar.

In relation to the female player, we observed a daily TEE of 3383 kcal·day^{-1} and 3824 kcal·day^{-1} during P1 and P2 respectively. The increased TEE of approximately 440 kcal·day^{-1} in P2 is likely explained by greater tournament progression. Indeed, this greater tournament progression resulted in 344 more points won, 278 additional minutes playing time and almost 5km more distance completed when compared with P1. During P2, the observed mean match distance of 1471 ± 449 m was similar to previous reports from female tennis players during Grand Slam tournaments e.g., Wimbledon (1289 ± 568 m), the Australian Open (1339 ± 572 m), the US Open (1423 ± 589 m) and French Open (1452 ±

600 m) (23). Given the similarity in distances covered between previous research and the present case study, it is likely that our data are therefore representative of a typical grand slam event. In this regard, we consider our DLW data to provide the first genuine indication of energy expenditure during a Grand Slam week. The daily TEE of up to 3824 $kcal \cdot d^{-1}$ resulted in a PAL value ranging from 2.0 to 2.3, values that are associated with a 'vigorous lifestyle' (24). Although such PAL values agree favourably with the range (1.71 – 3.4) previously suggested for female athletes (25), it is noteworthy that such daily energy expenditure are greater than that reported in elite female distance runners (2826 ± 312 $kcal \cdot day^{-1}$) during training (26). Our data are similar to those values reported in elite lightweight rowers during heavy training (3957 ± 1219 $kcal \cdot day^{-1}$) yet remain lower than elite swimmers during heavy training (5593 ± 495 $kcal \cdot day^{-1}$) (26 – 28). The only available previous data on TEE using DLW that has included female tennis players reported a TEE of 2780 ± 430 $kcal \cdot day^{1}$, however, any comparison is hard to make as participant activity was not recorded, there was no information on the playing standard or ranking of the athletes and it was unclear if the data included actual competition (29). When comparing the female TEE relative to FFM (71.7 $kcal \cdot kg^{-1}$ FFM) to other sports, we show values higher than elite female distance runners (60.6 $kcal \cdot kg^{-1}$ FFM), similar to badminton (72.2 $kcal \cdot kg^{-1}$ FFM) and lower than elite lightweight rowing (84.4 $kcal \cdot kg^{-1}$ FFM) (26, 28, 30). Whilst our data can be used to inform nutritional guidelines, we readily acknowledge the requirement to conduct further studies using larger sample sizes and at various phases throughout the season.

The sample collection points for the male player allowed a split in the data analysis in a similar manner to the female athlete, thus also allowing for the calculation of TEE for P1 (training with one ATP International match) and P2 (training with ATP International and Grand-Slam competition). In this regard, P1 was mainly representative of a training week with little competition (only 88 mins). As such, the TEE reported during P1 (3712 $kcal \cdot day^{-1}$) was considerably less than P2 (5520 $kcal \cdot day^{-1}$) which included training and both ATP International and Grand Slam tournament match play. It is therefore apparent that there was a substantial difference in playing demands between P1 and P2 with over six times more points played in P2. As a consequence, training time during P1 was more than double that in P2. Nonetheless, despite this increase in training time, TEE in P1 was still 1808 kcal·day^{-1} less than P2 therefore highlighting the major contribution of match play in influencing the daily TEE of elite players. It is also noteworthy that the mean match duration during P2 was heavily influenced by the participation in a five set Grand Slam match, covering over 40% of the total weekly distance during this single match (4175 m). These daily fluctuations in the activity of professional tennis players emphasise the unique nature of this sport whereby the absolute activity is largely dependent on the 'competitiveness' of the game. This unpredictability of the sport (and associated influence on daily TEE) therefore necessitates the requirement for a targeted and flexible dietary approach to ensure that energy balance is maintained during the course of a tournament.

To contextualise the TEE of the male player, it is possible to compare the data to that reported using DLW from other professional sports. Indeed, we demonstrate that the absolute TEE was higher than English Premier League soccer players (3566 ± 585 kcal·day^{-1}) and similar to professional rugby league players (5374 ± 645 kcal·day^{-1}) during training and competition but lower than professional road cyclists during the Giro d'Italia stage race (6903 ± 764 kcal·day^{-1} using the DLW intercept method) (31–33). Currently no elite level tennis competition data using the DLW methodology exist to which comparisons can be made. Our male data positions tennis as an energetically demanding sport when considering the TEE relative to FFM (83.7 kcal·kg^{-1} FFM) to other sports, such as rugby league (70.1 kcal.kg^{-1} FFM), English Premier League soccer (54.9 kcal·kg^{-1} FFM). For the male player, we have calculated PAL values of 2.2 (P1) and 2.8 (P2). Although these values do not equal the upper limits of 4.0 reached by endurance athletes (24), our data appear to place male tennis players at the upper range when compared to PAL values from other sports (32, 34). These data for the first time propose a valid and accurate TEE for elite male and female tennis players with a PAL value that may be used to guide future dietary interventions.

The role of energy availability in supporting health and performance is well established (35, 36). In relation to the latter, the effects of carbohydrate (CHO) have been specifically highlighted in reducing both central and peripheral fatigue during tennis (37, 38). Although CHO metabolism was not directly investigated, the DLW data reported here can help to formulate macronutrient guidelines to achieve energy balance during a physically demanding competition period. For example, if protein intake was considered at a fixed amount of 1.8 g·kg·day^{-1}, fat at a fixed amount of 2 g·kg·day^{-1} the remaining caloric intake would be through CHO. For the female player, this would equate to ~6 g·kg·day^{-1} for P1 and ~7 g·kg·day^{-1} for P2. For the male player, this would equate to ~ 5g·kg·day^{-1} for P1 and ~11 g·kg·day^{-1} for P2. These values are in line with the CHO guidelines proposed by Burke et al., (2015), whereby values of 6 – 10 g·kg.day^{-1} for moderate to high intensity of 1 – 3 h·day^{-1} and 8 – 12 g·kg·day^{-1} for moderate to high intensity exercise of 4 – 5 h·day^{-1} are suggested (39). The practicalities at some tennis events mean that the ideal nutrition (macronutrient total, type and timing) is difficult. The issues with variable match duration, feeding opportunities and logistical challenges collectively highlight the requirement for bespoke player education programmes to ensure that players can self-monitor, source and administer their own nutrition. The high physical loading and daily TEE reported here is likely to also induce considerable glycogen depletion, the extent of which remains currently unknown. Such potentially high rates of glycolytic flux coupled with the short turnaround between games (e.g., 1 – 2 days) also demonstrates the requirement to maximise CHO availability in recovery from match play. The potentially high level of CHO dependency also lends itself to the in-competition feeding strategies typically associated with the endurance athlete (e.g., 30 – 90 g of CHO per hour depending on duration). The CHO cost of match play and the potential ergogenic effects of CHO feeding strategies also represent opportunities for further research.

As with all case-study accounts, the present data are not without limitations that are largely related to collecting data on elite athletes during international competition. To protect athlete confidentiality, age and anthropometrics were not reported, limiting the descriptive data presented. Energy intake was not recorded given the intense demands of a Grand Slam tournament and the invasive nature of such data collection at a time when the athletes needed be fully focussed on competition. A limitation of the DLW technique itself is the inability to report day-to-day variations in TEE, individual matches or training bouts. For example, we can presume the increased duration, distance and sRPE of the male player's final match day will have created a spike of TEE and increased mean TEE for the week but are unable to quantify to what degree. Additionally, the reduction in training load that accompanies increased competition demands is likely to lower daily TEE. Clearly, the requirement to quantify day-to-day variations in both energy intake and energy expenditure is a targeted area for future investigation. This case study provides an insight into the energy requirements of world class tennis players during a competitive period that reflected the demands regularly faced by players of the highest calibre. However, we acknowledge that larger scale studies are now required to comprehensively examine energy expenditure and availability of a wider group of professional tennis players.

In summary, we report for the first time the daily TEE of a male and female professional tennis player during a 17-day period of the highest level of competition. Our data present elite tennis as a highly energetic demanding sport in which the requirement to promote sufficient energy availability becomes readily apparent. Such data can therefore begin to provide a platform to formulate specific nutritional strategies (for on and off the court) and will hopefully stimulate further research in this area.

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References

1. Kovacs MS. Applied physiology of tennis performance. *Br J Sports Med*. 2006;40(5):381–5.
2. Reilly T, Palmer J. Investigation of exercise intensity in male singles lawn tennis. In: Reilly T, Hughes M, Lees A, editors. *Science and Racket Sports.* London: E & F N Spon, 1994. p. 10–13.
3. Christmass MA, Richmond SE, Cable NT, Arthur PG, Hartmann PE. Exercise intensity and metabolic response in singles tennis. *J Sports Sci*. 1998;16(8):739–47.
4. International Tennis Federation. ITF Rules of Tennis 2020. 2019;38.
5. Kovacs M. Training the Competitive Athlete. *Sports Med.* 2015;37(July):189–98.
6. Fernandez-Fernandez J, Sanz-rivas D, Mendez-villanueva A. A Review of the Activity Profile and Physiological Demands of Tennis Match Play. *Strength Cond J*. 2009;31(4):15–26.
7. Mendez-Villanueva A, Fernandez-Fernandez J, Bishop D, Fernandez-Garcia B, Terrados N. Activity patterns, blood lactate concentrations and ratings of perceived exertion during a professional singles tennis tournament. *Br J Sports Med*. 2007;41(5):296–300.
8. Girard O, Millet GP. Effects of the ground surface on the physiological and technical responses in young tennis players. *Sci racket Sport III*. 2004;43–8.
9. Martin C, Thevenet D, Zouhal H, et al. Effects of playing surface (hard and clay courts) on heart rate and blood lactate during tennis matches played by high-level players. *J Strength Cond Res*. 2011;25(1):163–70.
10. Brody H. Bounce of a tennis ball. *J Sci Med Sport.* 2003;6(1): 113–119.
11. Brechbuhl C, Brocherie F, Millet GP, Schmitt L. Effects of Repeated-Sprint Training in Hypoxia on Tennis-Specific Performance in Well-Trained Players. *Sport Med Int open*. 2018;2(5): 123–32.
12. Kilit B, Şenel Ö, Arslan E, Can S. Physiological responses and match characteristics in professional tennis players during a one-hour simulated tennis match. *J Hum Kinet*.

2016;50(2):83–92.

13. Novas AMP, Rowbottom DG, Jenkins DG. A practical method of estimating energy expenditure during tennis play. *J Sci Med Sport*. 2003;6(1):40–50.

14. Westerterp, KR. Doubly labelled water assessment of energy expenditure: principle, practice, and promise. *Eur J Appl Physiol.* 2017;117(7):1277–85.

15. Lifson N, McClintock R. Theory of use of the turnover rates of body water for measuring energy and material balance. *J Theor Biol*. 1966;12(1):46–74.

16. Speakman, J.R. (1997) Doubly-labelled water: theory and practice. Chapman and Hall London.

17. Berman ESF, Fortson SL, Snaith SP, et al. Direct analysis of δ2H and δ18O in natural and enriched human urine using laser-based, off-axis integrated cavity output spectroscopy. *Anal Chem*. 2012;84(22):9768–73.

18. Nagy KA. The Doubly Labeled Water (3HH18O) Method: a guide to its use. UCLA Publication no 12-1417, UCLA, Los Angeles, (CA) 1983.

19. Schoeller DA, Ravussin E, Schutz Y, Acheson KJ, Baertschi P, Jéquier E. Energy expenditure by doubly labeled water: Validation in humans and proposed calculation. *Am J Physiol - Regul Integr Comp Physiol* [Internet]. 1986;250(5 (19/5)) Available at https://journals.physiology.org/doi/abs/10.1152/ajpregu.1986.250.5.R823?rfr_dat=cr_pub++0pubmed&url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org doi:10.1152/ajpregu.1986.250.5.r823.

20. Speakman JR, et al. A standard calculation methodology for human doubly labeled water studies. *Cell Rep Med*. 2021;2(2):100203.

21. Cunningham JJ. A reanalysis of the factors influencing basal metabolic rate in normal adults. *Am J Clin Nutr*. 1980;33(11):2372–4.

22. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res*. 2001;15(1):109–15.

23. Cui Y, Gómez MÁ, Gonçalves B, Sampaio J. Performance profiles of professional female tennis players in grand slams. *PLoS One*. 2018;13(7):1–18.

24. Westerterp KR. Physical activity and physical activity induced energy expenditure in humans: Measurement, determinants, and effects. *Front Physiol*. 2013;4 APR(April):1–11.

25. Park J, Kazuko IT, Kim E, Kim J, Yoon J. Estimating free-living human energy expenditure: Practical aspects of the doubly labeled water method and its applications. *Nutr Res Pract*. 2014;8(3):241–8.

26. Schulz LO, Alger S, Harper I, Wilmore JH, Ravussin E. Energy expenditure of elite female runners measured by respiratory chamber and doubly labeled water. *J Appl Physiol*. 1992;72(1):23–8.

27. Trappe TA, Gastaldelli A, Jozsi AC, Troup JP, Wolfe RR. Energy expenditure of swimmers during high volume training. *Med Sci Sport Exerc* [Internet]. 1997;29(7) Available from: https://journals.lww.com/acsm-msse/Fulltext/1997/07000/Energy_expenditure_of_swimmers_during_high_volume.15.aspx. doi: 10.1097/00005768-199707000-00015.

28. Hill RJ, Davies PSW. Energy intake and energy expenditure in elite lightweight female rowers. *Med Sci Sports Exerc*. 2002;34(11):1823–9.

29. Ndahimana D, Lee SH, Kim YJ, et al. Accuracy of dietary reference intake predictive equation for estimated energy requirements in female tennis athletes and non-athlete college students: Comparison with the doubly labeled water method. *Nutr Res Pract*. 2017;11(1):51–6.

30. Watanabe E, Igawa S, Sato T, Miyazaki M, Horiuchi S, Seki K. 11 Energy expenditure measurement in badminton players during a training camp using doubly-labelled water. *Sci Racket Sport IV*. 2008;77.

31. Anderson L, Orme P, Naughton RJ, et al. Energy Intake and Expenditure of Professional Soccer Players of the English Premier League : Evidence of Carbohydrate Periodization. *Int J*

Sport Nutr Exerc Metab. 2017;228–38.

32. Morehen JC, Bradley WJ, Clarke J, et al. The assessment of total energy expenditure during a 14-day in-season period of professional rugby league players using the doubly labelled water method. *Int J Sport Nutr Exerc Metab*. 2016;26(5):464–72.

33. Plasqui G, Rietjens G, Lambriks L, Wouters L, Saris WHM. Energy Expenditure during Extreme Endurance Exercise: The Giro d'Italia. *Med Sci Sports Exerc*. 2019;51(3):568–74.

34. Sagayama H, Hamaguchi G, Toguchi M, et al. Energy Requirement Assessment in Japanese Table Tennis Players Using the Doubly Labeled Water Method. *Int J Sport Nutr Exerc Metab*. 2017;27(5):421–8.

35. Close GL, Hamilton DL, Philp A, Burke LM, Morton JP. New strategies in sport nutrition to increase exercise performance. *Free Radic Biol Med*. 2016;98:144–58.

36. Heaton LE, Davis JK, Rawson ES, et al. Selected In-Season Nutritional Strategies to Enhance Recovery for Team Sport Athletes: A Practical Overview. *Sport Med*. 2017;47(11):2201–18.

37. Hornery DJ, Farrow D, Mujika I, Young WB. Fatigue in Tennis. *Sport Med*. 2007;37(3):199–212.

38. Gomes R V., Moreira A, Coutts AJ, Capitani CD, Aoki MS. Effect of carbohydrate supplementation on the physiological and perceptual responses to prolonged tennis match play. *J Strength Cond Res*. 2014;28(3):735–41.

39. Burke LM, Hawley JA, Wong SHS, et al. Carbohydrates for training and competition Carbohydrates for training and competition. *J Sport Sci*. 2015;0414(October):37–41.

Figure and Tables Legends

Table 1. Participant standard, data collection information and resting metabolic rate (RMR).

Gender	Career high ranking	Activity during analysis	Total days	RMR (kcal·day^{-1})
Female	WTA Top 10 Singles	WTA Tournament (P1) Wimbledon Championships (P2) Supplementary training (throughout)	17 Day 1-7 (P1) Day 7-17 (P2)	1673
Male	ATP Top 15 Singles	ATP Tournament (P1) ATP Tournament & Wimbledon Championships (P2) Supplementary training (throughout)	17 Day 1-7 (P1) Day 7-17 (P2)	1951

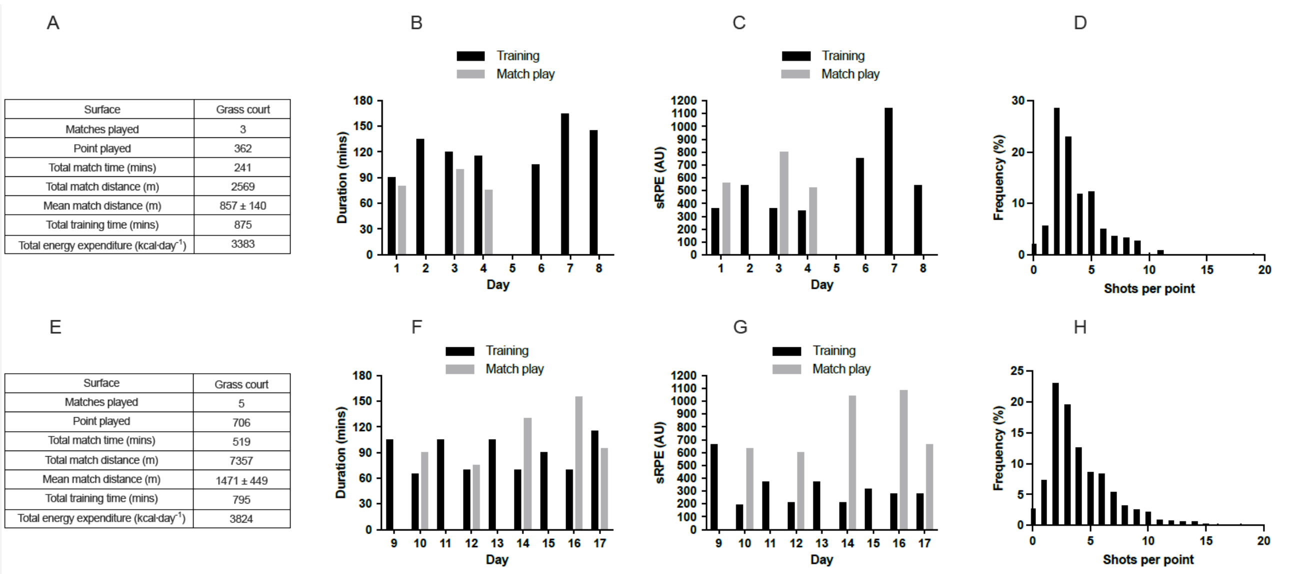

Figure 1. Female player total matches, points, durations, distances and EE for P1 WTA tournament (A) and P2 Grand Slam tournament (E), daily durations for P1 (B) and P2 (F), daily sRPE for P1 (C) and P2 (G), shot frequency for P1 (D) and P2 (H).

A

Surface	Grass court
Matches played	1 (over 2 days)
Point played	133
Total match time (mins)	88
Total match distance (m)	1125
Total training time (mins)	795
Total energy expenditure (kcal·day^{-1})	3712

E

Surface	Grass court
Matches played	5
Point played	891
Total match time (mins)	734
Total match distance (m)	10043
Mean match distance (m)	2009 ± 1392
Total training time (mins)	350
Total energy expenditure (kcal·day^{-1})	5520

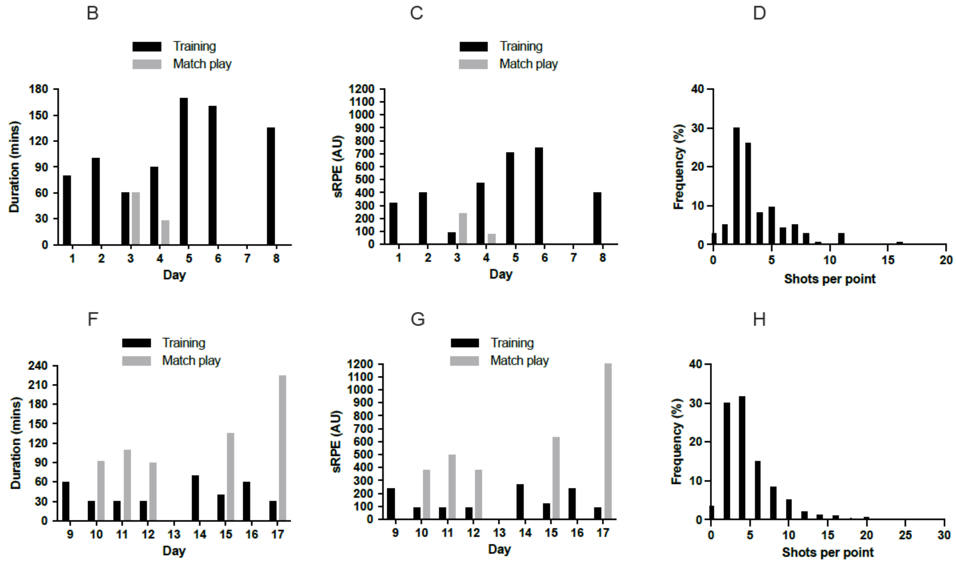

Figure 2. Male player total matches, points, durations, distances and EE for P1 ATP tournament (A) and P2 Grand Slam tournament (E), daily durations for P1 (B) and P2 (F), daily sRPE for P1 (C) and P2 (G), shot frequency for P1 (D) and P2 (H).

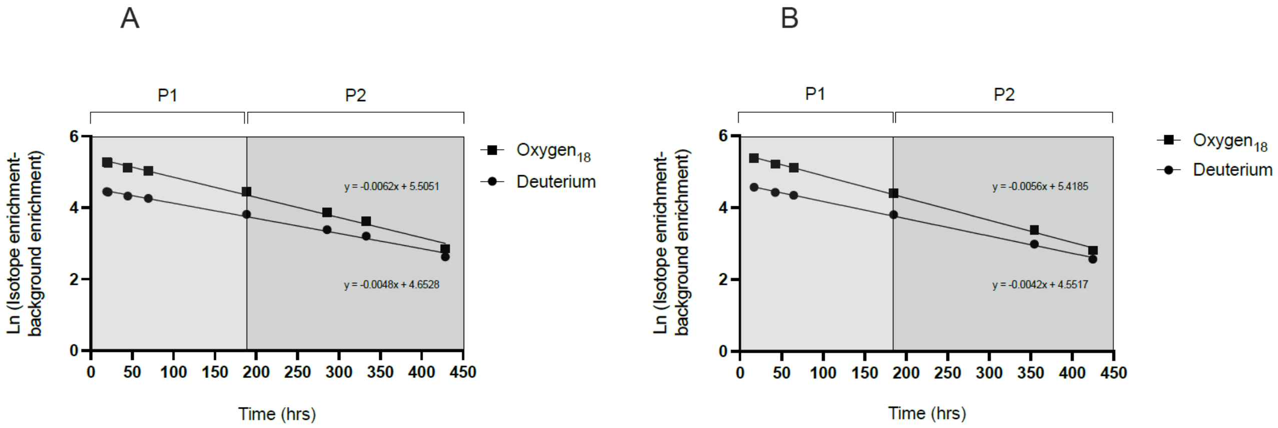

Figure 3. Male rate of isotope disappearance (A) and female rate of isotope disappearance (B).