Check for updates

Original research article

International Journal of Sports Science & Coaching

Analysis of the physiological response in junior tennis players during short-term recovery: Understanding the magnitude of recovery until and after the 25 seconds rule

International Journal of Sports Science & Coaching
1–9
© The Author(s) 2022

Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/17479541221110677
journals.sagepub.com/home/spo

Jorge E Morais[1,2], José A Bragada[1,2], Rui Silva[3], Alan M Nevill[4], Fabio Y Nakamura[5] and Daniel A Marinho[2,6]

Abstract

Literature lacks evidence about the physiological recovery of tennis players between points. This study aimed to: (i) verify the heart rate (HR) and oxygen uptake ($\dot{V}O_2$) recovery variance in young tennis players from the end of a tennis drill until the 25-s mark and onwards (65-s limit), performed at several intensities, and (ii) test the curve fitting that better characterizes the players' HR and $\dot{V}O_2$ recovery, from the end of the drill until the 65-s mark. The sample was composed of 13 male tennis players (age: 16.80 ± 1.61 years) recruited from a National Tennis Association. Players were instructed to perform a drill test ("two-line drill wide mode") based on an intensity increment protocol. Three levels of intensity were used based on the reserve HR and $\dot{V}O_2$. A significance level effect was observed on the $HR_{reserve}$ and $\dot{V}O_{2reserve}$ ($P < .001$). At all three levels of intensity, the first 25 s were enough to significantly ($P < .001$) recover the $HR_{reserve}$ and $\dot{V}O_{2reserve}$. The same significance trend ($P < .001$) was maintained until the 65 s but with a lower magnitude over time. Overall, the HR and $\dot{V}O_2$ curve fitting indicated a cubic relationship at the three levels of intensity (except the $\dot{V}O_2$ at the first level). Considering the specific test performed, players significantly elicited their physiological profile for every additional 10 s (after the 25-s rule) in the three levels of intensity performed. Despite this being a drill test and not a competitive point, coaches, players, and tennis organizations should be aware of these findings.

Keywords

Ball-throwing machine, heart rate, oxygen uptake, skill

Introduction

More than ever, athletes and coaches understand the importance of training and all aspects related to training programs to achieve optimal performance.[1,2] This quest for high performances has led athletes and coaches to constantly seek any advantage that can improve performance. Often these advantages are based on types of training that can bring out the athletes' specific physical fitness,[3] technical skills,[4] tactics,[5] or even their mindset.[6]

On the other hand, recovery is also a key factor in any training program or competition, as it allows the athlete to undergo a restorative process over time, both physically and psychologically.[7] Recovery allows the body to adapt to the stress associated with exercise by restoring muscle glycogen and aiding in the repair time of body tissues.[8] Literature reports three types of recovery: (i) immediate – is the recovery

Reviewer: Jan Carboch (Charles University, Czech Republic)

[1]Department of Sports Sciences, Instituto Politécnico de Bragança, Bragança, Portugal
[2]Research Centre in Sports, Health and Human Development (CIDESD), Covilhã, Portugal
[3]Associação de Ténis do Porto, Porto, Portugal
[4]Faculty of Education, Health, and Wellbeing, University of Wolverhampton, Wolverhampton, UK
[5]Research Center in Sports Sciences, Health Sciences and Human Development (CIDESD), University of Maia (ISMAI), Maia, Portugal
[6]Department of Sports Sciences, University of Beira Interior, Covilhã, Portugal

Corresponding author:
Jorge E Morais, Department of Sports Sciences, Instituto Politécnico de Bragança, Campus Sta. Apolónia, Apartado 1101, 5301-856, Bragança, Portugal.
Email: morais.jorgestrela@gmail.com

that occurs between rapid, time-proximal finite efforts (e.g. when a runner has one leg in immediate recovery between each stride); (ii) short-term recovery – recovery between exercises or sports movements that allow rest (e.g. recovery between interval sprints or between weight training sets); and (iii) training recovery – recovery between successive workouts or competitions (e.g. two-a-day workouts or sports that have more than one competition on the same day – heats and finals).[9]

In the specific case of tennis, it can be considered that during a tennis match players can be under two types of recovery: immediate and short-term. The former corresponds to the recovery between strokes, and the latter to the recovery between points or games. Unlike most sports, tennis has a restrictive rule that after each point within the same game, players have a 25-s limit time between points.[10] Specifically, the server has a 25-s limit between the points. The receiver should play at the pace of the server, but the server should play at a reasonable pace.[10] It was suggested that this rule has two key roles: (i) it allows the players to recover, and (ii) promotes a match with continuity, that is, with as few non-game moments as possible.[11] However, in recent years several questions have been raised in the tennis community and referees' sensibility to this rule as an official watch has been in use since 2019.[10–12] In addition to factors extrinsic to players (e.g. weather conditions, or any other issue that does not allow the match to carry on in a regular way), it could be argued that whenever players exceed this time limit, they are trying to promote greater physical or mental recovery or to "disturb" their opponent. Based on men's Grand Slam data between 2000 and 2017, a study observed that players took an average time of 19–20 s between points.[12] The same study indicated that the average time between points increased after long rallies, and even more in "big" points. In these years (2000–2017), the time allowed between the points was the 20 s. In Grand Slams, the 25-s rule came into effect in 2018 (implemented to ITF tournaments and junior international tournaments later).[10] Nowadays (i.e. from 2018 onwards) it must be also pointed out that the time between the points is also surface dependable and correlates with the rally duration.[13]

Studies have analyzed the physiological profile (heart rate – HR; oxygen uptake – $\dot{V}O_2$) of tennis players and their immediate and short-term recovery.[14,15] Furthermore, Duffield et al.[16] have investigated the effects of combining several recovery procedures on physical, physiological, and perceptual recovery after a two-a-day on-court training and match-play sessions (i.e. training recovery). Another study aimed to assess the effect of the recovery duration in intermittent training drills on metabolic and coordination variables.[17] However, there is no information on the physiological recovery of tennis players between points or any other exercise drill that can simulate a tennis point. In the past, it has been indicated that the longer time between points at the French Open was related to longer durations of clay-court rallies.[18] Thus, it can be stated that the recovery between points plays a key role in the performance of the players and an increase in the intensity of the game leads the players to take some extra time for the recovery.

Therefore, the main aims of this study were to: (i) verify the HR and $\dot{V}O_2$ recovery variance in young tennis players from the end of a tennis drill until the 25-s mark and onwards (65-s limit), performed at several intensities, and; (ii) test the curve fitting that better characterizes the players HR and $\dot{V}O_2$ recovery, from the end of the drill until the 65-s mark. It was hypothesized that: (i) players would significantly recover their HR and $\dot{V}O_2$ after 25 s at low and moderate intensity, but not at the highest intensity, and; (ii) HR and $\dot{V}O_2$ recovery would present a cubic fitting at all intensities.

Methods

Participants

The sample was composed of 13 male tennis players (age: 16.80 ± 1.61 years; body mass: 62.77 ± 6.17 kg; height: 176.46 ± 5.32 cm). The players were recruited from a National Tennis Association. They were members of their national squad and participated regularly in international tournaments. All the players were ranked in the top 30 of their country's age group. At the time of data collection, they were at the end of a training cycle preparing to compete in a major competition. They were tested individually in three consecutive days. The tests were conducted after school and without any extra physical activity. Previous day they had a standard training. The inclusion criteria for the participants were: (1) being national level players in their age-group (Tier 3);[19] (2) having participated in daily training sessions from the beginning of the season, and (3) presenting no injury since the beginning of the season. All participants had more than six years of competitive experience and trained 5–6 sessions per week. Parents or guardians and players signed an informed consent form. All procedures were in accordance with the Declaration of Helsinki regarding human research, and the institutional Ethics Board approved the research design (N.° 75/2022).

Protocol

Players were wearing their competition gear and clothes. Before starting the drill test, they were instructed to perform a 15-min standardized warm-up. Within this time, a two-minute adaptation phase with the release of balls to the central area of the court (minimal lateral displacement). After 10 minutes of passive rest, the athletes were instructed to perform the drill test "two-line drill

wide mode" at the lowest ball frequency used. Players were familiarized with the drill test prior to data collection. This is a tennis drill commonly used by tennis players which alternates between hitting a wide forehand (right side of the court), then a wide backhand (left side of the court). Balls were thrown at constant velocity (mean: ~78 km/h) with a ball machine (Spinfire 2 Pro, Melbourne, Australia). As mentioned before, the ball machine alternated the direction of the ball always in the same sequence, that is, right side and left side of the court. Whenever the ball was directed to the right and left sides of the court, players were instructed to perform a forehand and a backhand stroke, respectively. They had to hit balls in a topspin drive pattern with a previously set landing mark. They were told to hit the ball with the best possible velocity/accuracy ratio, that is, simulating a competitive point.[20] Figure 1 shows the test drill performed.

An incremental test with five stages was used. In all stages, the ball machine setting was the same. The throwing interval of the ball was used to control the incremental test. The ball throwing was set at: (i) first stage – 12 balls/min; (ii) second stage – 14 balls/min; (iii) third stage – 16 balls/min; (iv) fourth stage – 18 balls/min, and; (v) fifth stage – 20 balls/min. Thus, a higher number of balls per minute promoted a greater energy demand. Each stage was performed for two minutes. After each stage, players were instructed to perform a 75-s passive recovery (standing still). The drill test ended when the players' fulfilled all stages and in the final stage the HR was higher than 95% of the maximum HR (see *Physiological assessments* section). In all players, this criterion was accomplished. The drill test could also end with the players' voluntary exhaustion or interrupted by the researchers if: (i) the players felt exhausted or failed to hit the ball twice in a row, or; (ii) the players was no longer able to perform strokes with an acceptable execution technique and a demise in velocity/precision, as determined by experienced coaches through subjective observation.[20] Those were the players personal coaches. They had experience in personal coaching and with their country's national squad (under-14 and elite national squad). All tests were conducted in an indoor hard court and under the same conditions to ensure standardized playing conditions. Players performed the drill test with Wilson W Team Trainers balls.

Physiological assessments

Before the drill test, the HR at rest was measured for 10 min while the players were sitting in silence. The $\dot{V}O_2$ at rest was considered to be 1 MET (metabolic equivalent of task; 1 MET = 3.5 mL/kg/min).[21] During the entire drill test, the player's HR was monitored with a HR monitor (Polar H9, Kempele, Finland). Immediately after each stage, athletes were instructed to hold their breath until the mask was placed. During recovery, breath-to-breath gas exchange ventilatory values were continuously being recorded using the Metalyzer 3B system (Cortex Biophysik, Leipzing, Germany). The $\dot{V}O_2$ was measured for 65 s. Gas and volume calibration of the equipment were performed before each test according to the manufacturer's instructions. The HR was measured during the entire protocol (drill test and recovery time). The $\dot{V}O_2$ was measured only during the recovery time. Thus, the $\dot{V}O_2$ at the end of each stage was estimated through backwards extrapolation through individual linear regression based on the HR–$\dot{V}O_2$ relationship. Mean records of the first 25 s and every additional 10 s were measured and registered (until a 65-s limit). Linear regression R^2 ranged between 0.654 and 0.982 in stage #1, between 0.773 and 0.998 in stage #2, between 0.820 and 0.991 in stage #3, between 0.661 and 0.999 in stage #4, and between 0.867 and 0.997 in stage #5.

As aforementioned, the $\dot{V}O_2$ during the drill test was measured by backwards extrapolation. Thus, based on the HR criteria, one can consider that all players reached the maximum $\dot{V}O_2$ in the last stage of the drill test. All players reached more than 95% of the age-related maximum HR.[22] The two most used criteria were applied: (i) maximum HR = 220 – age,[21] and; (ii) maximum HR = 208–0.7 * age.[23] Additionally, the fatigue scale was also applied.[24] In the last stage of the drill test, all players indicated that they were 99% fatigued according to the scale. Afterwards, the players' data were grouped into levels based on their HR reserve ($HR_{reserve}$) and $\dot{V}O_2$ reserve ($\dot{V}O_{2reserve}$) percentages, respectively. Three levels were used: (i) <80% (level 1); (ii) from 81% to 93% (level 2), and; (iii) > 93% (level 3).[25] For each target percentage, the following equation was used: $HR_{reserve}$ or $\dot{V}O_{2reserve}$ = ((maximum – resting) * target percentage) + resting. This was done to normalize the players' intensity in relation to their $HR_{reserve}$ and $\dot{V}O_{2reserve}$ during each stage of the drill test.

Data analysis

The Shapiro–Wilk and Levene tests were used to test the assumptions of normality and homoscedasticity, respectively. The mean plus one standard deviation was computed as descriptive statistics.

Recovery, for both HR and $\dot{V}O_2$ independently, was assessed with the repeated measures ANOVA. A level effect was tested with the LSD correction to understand whether there were significant ($p < .05$) differences between level intensities. The variance effect size (eta square – η^2) was computed and interpreted as: (i) without effect if $0 < \eta^2 < 0.04$; (ii) minimum if $0.04 \leq \eta^2 < 0.25$; (iii) moderate if $0.25 \leq \eta^2 < 0.64$; and (iv) strong if $\eta^2 \geq 0.64$.[26] For each level, the Bonferroni post-hoc test was used to verify significant differences between each pairwise ($p < .05$). The mean difference (MD) with 95%

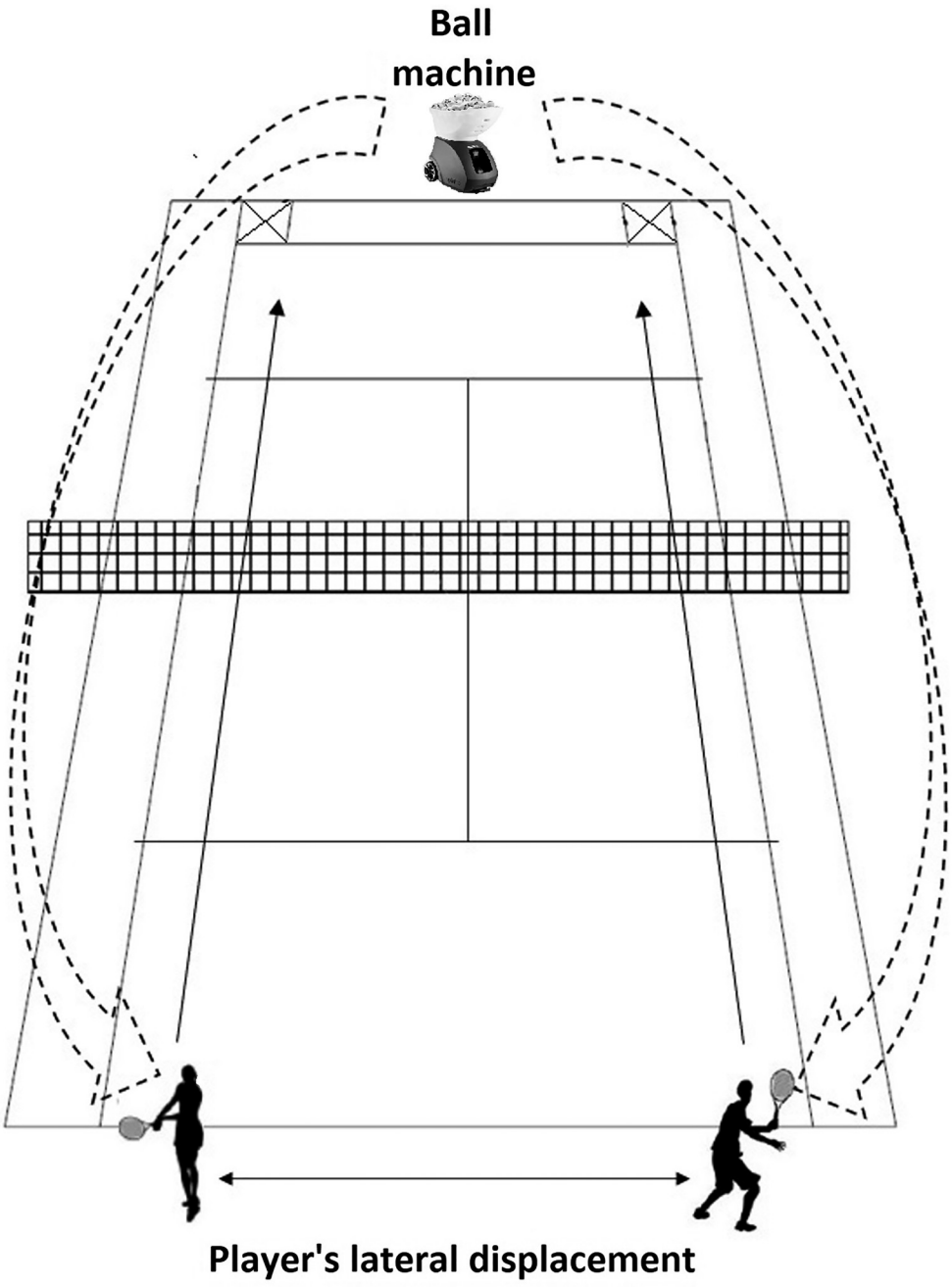

Figure 1. Schematic of the test drill performed. Dash arrows represent the throwing balls from the machine. One ball to the right side of the court, another to the left side. Solid arrows represent the down-the-line topspin strokes performed by the players. On the right side of the court the players performed forehands, and on the left side back backhands. The square marked with a cross served as a reference for the stroke.

confidence intervals (95CI) was calculated. The Cohen's d was computed to verify the magnitude of the effect size, and it was interpreted as: (i) small if $0.20 \leq d < 0.49$; (ii) moderate if $0.5 \leq d < 0.79$; and (iii) large if $d \geq 0.80$.[27]

For each intensity level, the curve fitting was used to model the HR–time and $\dot{V}O_2$–time data spread by assigning the "best fit" function through the recovery period. This was performed based on the HR and $\dot{V}O_2$ estimated during the drill test, the initial 25 s of recovery, and afterwards by each 10 s until the 65-s limit. Linear, quadratic, and cubic fits were tested. Trendline, 95CI, 95% of prediction interval (95PI), and standard error of estimation (SEE) were calculated. The SEE was used as a goodness-of-fit indicator to compare the models (i.e. linear, quadratic, and cubic), as it demonstrates how precise model predictions are by using the units of the dependent variable (i.e. it indicates

how far the data points are from the regression line on average). Lower values of SEE denote that the distances between the data points and the fitted values are narrower.

Results

Players presented an average maximum HR of 195.65 ± 9.43 beats/min and a $\dot{V}O_{2max}$ of 42.22 ± 5.09 mL/kg/min. A significance level effect was observed for the $HR_{reserve}$ ($F = 8.34$, $p < .001$, $\eta^2 = 0.22$) and $\dot{V}O_{2reserve}$ ($F = 4.91$, $p < .001$, $\eta^2 = 0.02$). Moreover, post-hoc tests indicated significant differences between all levels ($p < .001$) for both $HR_{reserve}$ and $\dot{V}O_{2reserve}$. At the end of the first level, players reached 71.96 ± 6.34% and 69.00 ± 7.67% of their maximum $HR_{reserve}$ and $\dot{V}O_{2reserve}$, respectively. At the end of the second level, players reached 86.49 ± 4.20% and 87.04 ± 4.10% of their maximum $HR_{reserve}$ and $\dot{V}O_{2reserve}$, respectively. At the end of the third level, players reached 97.47 ± 2.87% and 97.34 ± 3.29% of their maximum $HR_{reserve}$ and $\dot{V}O_{2reserve}$, respectively.

Table 1 and Figure 2 present the response of the $HR_{reserve}$ (Figure 2 – panel A) and $\dot{V}O_{2reserve}$ (Figure 2 – panel E) by level, and respective pairwise comparisons. For both $HR_{reserve}$ and $\dot{V}O_{2reserve}$, the third level (highest intensity) was the one presenting the highest variance. In all three levels of intensity, the first 25 s were enough to significantly ($p < .001$) recover the $HR_{reserve}$ and $\dot{V}O_{2reserve}$. For every additional 10 s, the trend remained the same in both $HR_{reserve}$ and $\dot{V}O_{2reserve}$. That is, by each 10 s of recovery and until the 65th second, players still significantly recover but with a lower magnitude over time.

Figure 2 also presents the absolute HR–time and absolute $\dot{V}O_2$–time curve fitting by level. In the first level (lowest intensity: <80%), the HR indicated a cubic fitting (SEE = 13.139) and the $\dot{V}O_2$ a linear fitting (SEE = 3.953). In the second level (from 81% to 93% of intensity), both the HR (SEE = 11.523) and $\dot{V}O_2$ (SEE = 4.029) indicated a cubic fitting. In the third level (>93% of intensity), the HR (SEE = 9.663) and $\dot{V}O_2$ (SEE = 3.412) also presented a cubic fitting. Overall, visual observation shows that near the 25-s mark, the players' HR and $\dot{V}O_2$ began to decline sharply across all three levels. The HR–time curve demonstrated a decrease in recovery after the 55-s mark at all three levels. Regarding the $\dot{V}O_2$–time curve at the first level, the recovery "pace" maintained the magnitude from the end of the drill until the 65-s mark. At levels two and three, the trend was like the HR (decrease in the recovery "pace" from the 55-s mark onwards), but not as sharp.

Discussion

This study aimed to verify HR and $\dot{V}O_2$ recovery in young tennis players from the end of a standardized tennis drill until the 25-s mark and onwards (65-s limit) at various intensities. We also tested the curve fitting that better characterized the players' HR and $\dot{V}O_2$ recovery, from the end of the drill until the 65-s mark, at the same intensities. Main results indicate that at all three levels of intensity, the players significantly recovered after the first 25 s and this trend was maintained until the 65th second (both $HR_{reserve}$ and $\dot{V}O_{2reserve}$). Overall, the HR–time and $\dot{V}O_2$–time curve fitting indicated a cubic relationship at all three levels of intensity, except for the $\dot{V}O_2$ at the lowest intensity level (linear relationship).

The topic of recovery in tennis has solid information on several techniques that tennis players can use to recover from tennis practices, matches or tournaments.[28,29] As already mentioned, it is not possible to find information on how tennis players recover between points. Nonetheless, Seiler et al.[30] indicated that highly trained athletes may recover faster (i.e. short-term recovery) than their less trained counterparts, regardless of the exercise intensity. Our data showed that young tennis players were able to significantly recover their HR and $\dot{V}O_2$ after 25 s when performing at all three levels of intensity. The most comparable study about this topic aimed to understand how a typical intermittent drill used by elite tennis players affected the recovery duration of metabolic demands and their stroke and running performance.[17] The authors indicated that running speed and stroke quality are highly dependent on recovery time. That is, when the recovery time is too short, the running speed for stroke preparation and the stroke speed decrease, while stroke accuracy is maintained. To maintain optimal running speed and stroke skill, players should be able to rest at least 15 s.[17] Thus, it seems that the 25-s rule is enough to elicit a significant recovery in the players' HR and $\dot{V}O_2$ at various exercise levels or training intensity.

Nevertheless, it should be noted that from the initial 25 s, players were able to significantly recover their HR and $\dot{V}O_2$ every 10 additional seconds at the three intensity levels. However, after the 35-s mark, a lower magnitude over time was observed, that is, the number of beats or oxygen uptake recovered every 10 s decreased over time. This trend was also noted in endurance trained male adults.[31] The authors showed that during one minute of recovery, the athletes recovered on average 31.0 beats/min during the first 30 s of recovery and 21.0 beats/min during the second set of 30 s. Conversely, for the same 30-s sets, others indicated that elite athletes recovered 16 and 20 beats/min in the first and second 30-s set, respectively.[32] This distinct trend can be related to differences in age or exercise/sport type.[33,34] Thus, one can indicate that HR recovery can be highly dependent of the type of exercise/sport performed. In the specific case of tennis, and despite the magnitude of recovery observed, players still significantly recovered their $HR_{reserve}$ and $\dot{V}O_{2reserve}$ every 10 additional seconds. This was remarkably noticed by the $HR_{reserve}$ in the first 10 additional seconds (i.e. between

Table 1. Variance effect of the $HR_{reserve}$ and $\dot{V}O_{2\ reserve}$ during the recovery, and pairwise comparison during the specified recovery intervals.

					Pairwise comparison				
		F	*p*	η^2	0 s vs 25 s	25 s vs 35 s	35 s vs 45 s	45 s vs 55 s	55 s vs 65 s
$HR_{reserve}$ [%]	Level 1	84.98	<.001	0.90	MD = 10.28 (95CI: 5.33–15.24) $p < .001$; $d = 1.61$	MD = 13.16 (95CI: 8.72–17.60) $p < .001$; $d = 1.95$	MD = 7.45 (95CI: 2.09–12.81) $p = .006$; $d = 1.04$	MD = 7.33 (95CI: 2.10–12.56) $p = .005$; $d = 0.84$	MD = 3.25 (95CI: 0.70–5.80) $p = .011$; $d = 0.32$
	Level 2	201.84	<.001	0.93	MD = 7.07 (95CI: 4.87–9.27) $p < .001$; $d = 1.56$	MD = 11.57 (95CI: 8.48–14.66) $p < .001$; $d = 1.91$	MD = 7.23 (95CI: 4.99–9.46) $p < .001$; $d = 0.96$	MD = 5.06 (95CI: 3.10–7.01) $p < .001$; $d = 0.63$	MD = 3.84 (95CI: 2.01–5.67) $p < .001$; $d = 0.46$
	Level 3	471.77	<.001	0.94	MD = 5.73 (95CI: 4.69–6.77) $p < .001$; $d = 1.73$	MD = 8.47 (95CI: 7.20–9.74) $p < .001$; $d = 1.79$	MD = 5.49 (95CI: 4.32–6.65) $p < .001$; $d = 0.90$	MD = 4.99 (95CI: 3.99–5.98) $p < .001$; $d = 0.71$	MD = 4.50 (95CI: 3.56–5.43) $p < .001$; $d = 0.59$
$\dot{V}O_{2\ reserve}$ [%]	Level 1	244.83	<.001	0.94	MD = 14.61 (95CI: 10.87–18.34) $p < .001$; $d = 1.93$	MD = 8.65 (95CI: 3.45–13.84) $p < .001$; $d = 1.16$	MD = 9.38 (95CI: 6.80–11.97) $p < .001$; $d = 1.36$	MD = 6.59 (95CI: 3.58–9.59) $p < .001$; $d = 0.95$	MD = 6.46 (95CI: 3.86–9.07) $p < .001$; $d = 0.94$
	Level 2	349.57	<.001	0.96	MD = 15.33 (95CI: 11.31–19.35) $p < .001$; $d = 2.89$	MD = 10.86 (95CI: 4.28–17.44) $p = .001$; $d = 1.52$	MD = 10.56 (95CI: 8.30–12.82) $p < .001$; $d = 1.21$	MD = 10.42 (95CI: 8.20–12.64) $p < .001$; $d = 1.13$	MD = 8.05 (95CI: 5.77–10.33) $p < .001$; $d = 0.95$
	Level 3	585.15	<.001	0.96	MD = 16.11 (95CI: 12.60–19.61) $p < .001$; $d = 3.22$	MD = 8.79 (95CI: 5.23–12.35) $p < .001$; $d = 1.37$	MD = 11.04 (95CI: 9.13–12.95) $p < .001$; $d = 1.59$	MD = 11.09 (95CI: 9.36–12.82) $p < .001$; $d = 1.41$	MD = 8.39 (95CI: 7.10–9.68) $p < .001$; $d = 0.98$

F = F-ratio; *p* = significance level; η^2 = eta square (effect size index); MD = mean difference; 95CI = 95% confidence interval; *d* = Cohen's d (effect size index).

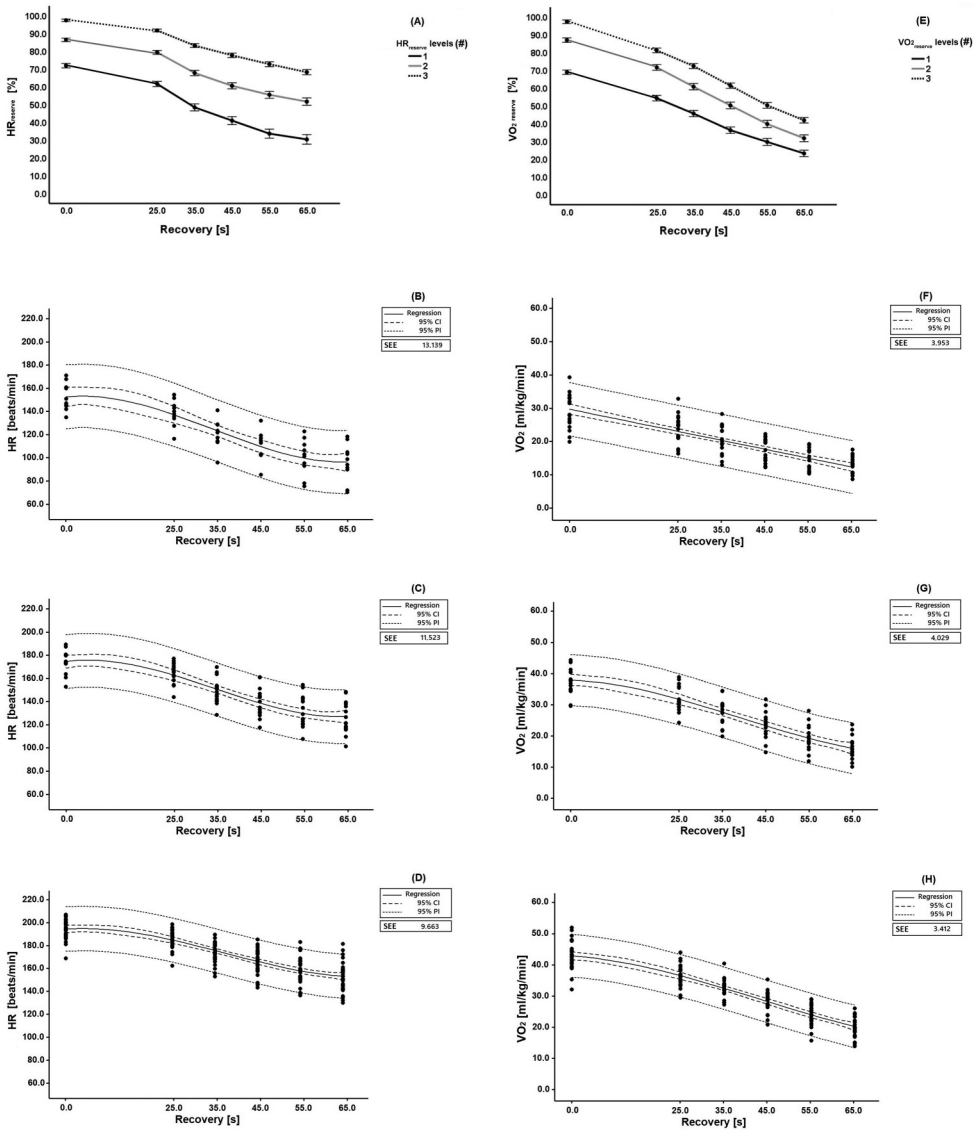

Figure 2. Panels A and E represent the heart rate reserve ($HR_{reserve}$) and oxygen uptake reserve ($\dot{V}O_{2reserve}$) response across the intensity levels. It is also presented the curve fitting models for the heart rate (HR) (panel B – level 1; panel C – level 2; panel D – level 3) and oxygen uptake ($\dot{V}O_2$) (panel F – level 1; panel G – level 2; panel H – level 3) for each level. Abbreviations: 95CI = 95 confidence intervals; 95 PI = 95 prediction intervals; SEE = standard error of estimation.

the 25th and 35th second). Indeed, at all three levels, the magnitude of recovery of the $HR_{reserve}$ was higher between the 25th and 35th second than in the initial 25 s after the drill. Thus, whenever tennis players overcome the 25-s rule between points, they are significantly eliciting their physiological profile. Moreover, failing to keep the 25-s rule gives an advantage also to the opponent. In the professional tournaments, the 25-s limit starts: (i) when the chair umpire announces the score (usually waiting for the spectators to stop applauding after long rallies), or; (ii) if the player was at the net at the end of the rally, then the countdown starts when the player reaches the baseline (this adds more time to recover, additionally to the 25-s rule).[10] Therefore, this procedure limits the 25-s rule and not many time violations are issued.

Fitting data indicated an overall cubic trend in both absolute HR and $\dot{V}O_2$ at all three levels of intensity. Immediately after the drill, tennis players began to slowly recover their HR and $\dot{V}O_2$ until the initial 10–15 s. From that moment until the 25-s mark, a sharp and fast recovery was noted. This trend was maintained until the ~50-s mark. Afterwards, there was a tendency for the HR rate recovery to decrease over time (but not the $\dot{V}O_2$, which maintained the previous rate of recovery). A study by Baiget et al.[35] demonstrated the actual HR and $\dot{V}O_2$ profile of elite-level tennis players during simulated tennis matches. Despite

noticing ups and downs in both variables, one cannot rigorously indicate the recovery time between points. However, in other sports (specifically soccer and hockey) that are also characterized by short-term recovery, athletes have shown to recover their HR quite similarly as our tennis players until the 30-s mark.[36] After the initial 30 s, these athletes were able to maintain their rate of recovery until the one-minute mark (the deflection point is maintained until the one-minute mark). Conversely, the athletes analyzed in the present study are not under the initial deflection point nearly after the 45-s mark. This can be due to: (i) differences in age (our sample consisted of younger players); (ii) sport-specific physiological demands, and; (iii) differences in the physiological profile (our sample had a meaningfully lower maximum $\dot{V}O_2$). Indeed, it was observed that athletes with a higher maximum $\dot{V}O_2$ recovered their HR faster at the 10-s and 30-s mark than those with a lower one.[36] Thus, it is possible to confirm that in a sport that allows a 25-s recovery time between points, a higher $\dot{V}O_{2max}$ can be determinant for a faster recovery within such time.

Overall, it must be highlighted that tennis players significantly recover their HR and $\dot{V}O_2$ after 25 s, and even with a larger magnitude until the 35th second. After that moment, recovery starts to decrease. Thus, whenever the 25-s rule is broken, they are significantly enhancing their physiological profile. It was also observed that until the 65th second of rest, players recovered their $HR_{reserve}$ and $\dot{V}O_{2reserve}$ in 41.47% and 45.69% (level 1), 34.77% and 55.22% (level 2), and 29.18% and 55.42% (level 3), respectively. As mentioned above, the tennis officials should enforce this rule not providing an advantage to one player if he/she is delaying the time between the points. Additionally, this can also give insights about the recovery profile of tennis players between matches where a 90-s rest is allowed. Coaches and players should be aware of the importance of this data for the periodization of their training. Training sets that elicit an increase in $\dot{V}O_{2max}$ may be helpful to increase the rate of recovery based on a higher aerobic fitness.[37,38] As the main limitations, it can be considered that the duration of points during an official game may be substantially lower than the duration simulated in this study to increase and stabilize HR and $\dot{V}O_2$. Players may reach such specific values of HR and $\dot{V}O_2$ after the long rallies only. The average rally time is about 5–7 s, and more than 60% of rallies are finished within four to five shots.[13,39] Moreover, accumulated fatigue was not considered in the present study. Thus, future studies may be conducted where: (i) players' fatigue is considered, and testing the players' recovery after a set of exercises at different intensities, and; (ii) understand this recovery phenomenon in several competitive levels and categories in both sexes.

Conclusion

Junior tennis players were able to significantly recover their HR and $\dot{V}O_2$ in the initial 25 s of recovery. From the 25-s mark onwards, players were still able to significantly recover their HR and $\dot{V}O_2$ every 10 additional seconds at all three levels of intensity. Moreover, the first 35-s mark seems to be crucial, that is, the first 10 s after the 25-s mark allowed. From this mark onwards, the recovery rate tends to decrease. At least in junior players, exceeding the 25-s mark allows them to elicit (consciously or not) their physiological profile. Tennis officials should be aware of this phenomenon, because during a tennis match, players try to have some extra time for recovery. This is a situation that happens in all tennis levels and categories. Allowing tennis players to get extra time has a direct and positive effect on their recovery, which can indicate an advantage.

Acknowledgements

This work is supported by national funds (FCT - Portuguese Foundation for Science and Technology) under the project UIDB/DTP/04045/2020.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Fundação para a Ciência e a Tecnologia (grant number UIDB/DTP/04045/2020).

ORCID iDs

Jorge E Morais https://orcid.org/0000-0002-6885-0648
Alan M Nevill https://orcid.org/0000-0003-0506-3652

References

1. Crespo M, Botella-Carrubi D and Jabaloyes J. Coaches' perceptions of innovation programs of the Royal Spanish Tennis Federation. *Int J Sports Sci Coach* 2021; 16: 1293–1304.
2. Mujika I, Halson S, Burke LM, et al. An integrated, multifactorial approach to periodization for optimal performance in individual and team sports. *Int J Sports Physiol Perform* 2018; 13: 538–561.
3. Brechbuhl C, Schmitt L, Millet GP, et al. Shock microcycle of repeated-sprint training in hypoxia and tennis performance: case study in a rookie professional player. *Int J Sports Science Coach* 2018; 13: 723–728.
4. Koopmann T, Faber I, Baker J, et al. Assessing technical skills in talented youth athletes: a systematic review. *Sports Med* 2020; 50: 1593–1611.
5. Klaus A, Bradshaw R, Young W, et al. Success in national level junior tennis: tactical perspectives. *Int J Sports Sci Coach* 2017; 12: 618–622.
6. Katagami E and Tsuchiya H. Effects of social support on athletes' psychological well-being: the correlations among received support, perceived support, and personality. *Psychol* 2016; 7: 1741–1752.

7. Kellmann M, Bertollo M, Bosquet L, et al. Recovery and performance in sport: consensus statement. *Int J Sports Physiol Perform* 2018; 13: 240–245.
8. Ivy JL. Regulation of muscle glycogen repletion, muscle protein synthesis and repair following exercise. *J Sports Sci Med* 2004; 3: 131.
9. Bishop PA, Jones E and Woods AK. Recovery from training: a brief review: brief review. *J Strength Cond Res* 2008; 22: 1015–1024.
10. ITF. ITF Rules of Tennis. Online Referencing, https://www.itftennis.com/media/4421/2021-rules-of-tennis-english.pdf (2022, assessed 10 February 2022).
11. Kolbinger O, Großmann S and Lames M. A closer look at the prevalence of time rule violations and the inter-point time in men's Grand Slam tennis. *J Sports Analytics* 2019; 5: 75–84.
12. Kovalchik S. Why the tennis "serve clock" may be a waste of time. *Significance* 2018; 15: 36–39.
13. Carboch J, Siman J, Sklenarik M, et al. Match characteristics and rally pace of male tennis matches in three grand slam tournaments. *Phys Act Rev* 2019; 7: 49–56.
14. Murias JM, Lanatta D, Arcuri CR, et al. Metabolic and functional responses playing tennis on different surfaces. *J Strength Cond Res* 2007; 21: 112–117.
15. Wiewelhove T, Szwajca S, Busch M, et al. Recovery during and after a simulated multi-day tennis tournament: combining active recovery, stretching, cold-water immersion, and massage interventions. *Eur J Sport Sci*. 2021; [Epub ahead of print].
16. Duffield R, Murphy A, Kellett A, et al. Recovery from repeated on-court tennis sessions: combining cold-water immersion, compression, and sleep interventions. *Int J Sports Physiol Perform* 2014; 9: 273–282.
17. Ferrauti A, Pluim BM and Weber K. The effect of recovery duration on running speed and stroke quality during intermittent training drills in elite tennis players. *J Sports Sci* 2001; 19: 235–242.
18. Fernandez J, Mendez-Villanueva A and Pluim BM. Intensity of tennis match play. *Br J Sports Med* 2006; 40: 387–391.
19. McKay AK, Stellingwerff T, Smith ES, et al. Defining training and performance caliber: a participant classification framework. *Int J Sports Physiol Performan* 2022; 17: 317–331.
20. Brechbuhl C, Girard O, Millet GP, et al. On the use of a test to exhaustion specific to tennis (TEST) with ball hitting by elite players. *PLoS One* 2016; 11: e0152389.
21. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000; 32: S498–S516.
22. American College of Sports Medicine. *ACM's guidelines for exercise testing and prescription*. Philadelphia, PA: Lippincott, 2006.
23. Tanaka H, Monahan KD and Seals DR Age-predicted maximal HR revisited. *J Am Coll Cardiol* 2001; 37: 153–156.
24. Micklewright D, Gibson ASC, Gladwell V, et al. Development and validity of the rating-of-fatigue scale. *Sports Med* 2017; 47: 2375–2393.
25. Seiler S and Tønnessen E. Intervals, thresholds, and long slow distance: the role of intensity and duration in endurance training. *Sportscience* 2009; 13: 32–53.
26. Ferguson CJ. An effect size primer: a guide for clinicians and researchers. *Prof Psychol Res Pr* 2009; 40: 532–538.
27. Cohen J. *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, NJ: Lawrence Earlbaum Associates, 1988.
28. Kovacs MS and Baker LB. Recovery interventions and strategies for improved tennis performance. *Br J Sports Med* 2014; 48: i18–i21.
29. Ojala T and Häkkinen K. Effects of the tennis tournament on players' physical performance, hormonal responses, muscle damage and recovery. *J Sports Sci Med* 2013; 12: 240.
30. Seiler S, Haugen O and Kuffel E. Autonomic recovery after exercise in trained athletes: intensity and duration effects. *Med Sci Sports Exerc* 2007; 39: 1366–1373.
31. Danieli A, Lusa L, Potočnik N, et al. Resting heart rate variability and heart rate recovery after submaximal exercise. *Clin Auton Res* 2014; 24: 53–61.
32. Ostojic SM, Stojanovic MD and Calleja-Gonzalez J. Ultra short-term heart rate recovery after maximal exercise: relations to aerobic power in sportsmen. *Chin J Physiol* 2011; 54: 105–110.
33. Durmić T, Đjelić M, Gavrilović T, et al. Usefulness of heart rate recovery parameters to monitor cardiovascular adaptation in elite athletes: the impact of the type of sport. *Physiol Int* 2019; 106: 81–94.
34. Suzic Lazic J, Dekleva M, Soldatovic I, et al. HR Recovery in elite athletes: the impact of age and exercise capacity. *Clin Physiol Funct Imaging* 2017; 37: 117–123.
35. Baiget E, Fernandez-Fernandez J, Iglesias X, et al. Tennis play intensity distribution and relation with aerobic fitness in competitive players. *PLoS One* 2015; 10: e0131304.
36. Watson AM, Brickson SL, Prawda ER, et al. Short-term heart rate recovery is related to aerobic fitness in elite intermittent sport athletes. *J Strength Cond Res* 2017; 31: 1055–1061.
37. Genevois C. The importance of aerobic fitness for tennis: a review (part 1). *ITF Coach Sport Sci Rev* 2019; 27: 20–22.
38. Kilit B and Arslan E. Effects of high-intensity interval training vs. On-court tennis training in young tennis players. *J Strength Cond Res* 2019; 33: 188–196.
39. Filipcic A, Crespo M and Filipcic T. Practice and match workload of a female tennis player in two annual seasons: a single-case study. *Int J Sports Sci Coach*. 2022; [Epub ahead of print].