HEART RATE DEFLECTION POINT RELATES TO SECOND VENTILATORY THRESHOLD IN A TENNIS TEST

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ABSTRACT

The relationship between heart rate deflection point (HRDP) and the second ventilatory threshold (VT2) has been studied in continuous sports, but never in a tennis-specific test. The aim of the study was to assess the relationships between HRDP and the VT2, and between the maximal test performance and the maximal oxygen uptake (VO2max) in an on-court specific endurance tennis test. 35 high level tennis players performed a progressive tennis-specific field test to exhaustion to determine HRDP, VT2, and VO2max. Ventilatory gas exchange parameters were continuously recorded by a portable telemetric breath-by-breath gas exchange measurement system. HRDP was identified at the point at which the slope values of the linear portion of the time/HR relationship began to decline and was successfully determined in 91.4% of the players. High correlations (r = 0.79–0.96; p < 0.001) between physiological (Heart rate (HR), oxygen uptake (VO2)) and performance (Time, Stage and Frequency of balls (Ballf)) variables corresponding to HRDP and VT2 were observed. Ballf at the HRDP (BallfHRDP) was detected at 19.8 ± 1.7 shots·min⁻¹. Paired t-test showed no significant differences in HR (178.9 ± 8.5 vs. 177.9 ± 8.7 beats·min⁻¹ for HRDP vs. HRVT2, respectively) at intensities corresponding to HRDP and VT2. Maximal test performance and VO2max were moderately correlated (r = 0.56; p < 0.001). HRDP obtained from this specific tennis test can be used to determine the VT2, and the BallfHRDP can be used as a practical performance variable to prescribe on-court specific aerobic training at or near VT2.

Key Words: Specific endurance tennis test; on-court training; exercise prescription; aerobic performance.
INTRODUCTION

Tennis involves intermittent, high-intensity efforts interspersed with periods of low-intensity activity in which active and passive recovery periods take place (21). During match-play, energy demands alternate between metabolic systems for bouts of high-intensity work during points (intramuscular phosphates and glycolysis) and low-intensity work during rest intervals (oxidative metabolism) (30). Thus, it has been suggested that aerobic fitness (i.e. maximal oxygen uptake ($VO_{2\text{max}}$)) is an important component of tennis performance and enables the player not only to repeatedly generate explosive actions (e.g. strokes and on-court movements), but also ensures fast recovery between rallies, especially during long matches (2, 18, 19, 30).

The functional testing of tennis players’ performance can involve evaluation through both laboratory and field tests, and several tests have been developed in the last few years in order to determine the exercise capacity (i.e. $VO_{2\text{max}}$ or ventilatory thresholds (VT)) and technical performance of athletes with acceptable accuracy and under standardized conditions (18, 19, 28, 29). The measurement of breathing parameters during an exhaustive incremental test enables the assessment of two specific ventilatory changes that correspond to the first (VT$_1$) and second (VT$_2$) ventilatory thresholds. Although there is still an important debate on its theoretical basis, the VT$_2$ is an interesting parameter because it has been advanced to be a better marker of submaximal endurance performance than $VO_{2\text{max}}$ (7, 19, 33). The determination of VT$_2$ is important for the adjustment of exercise intensities in training programs (7, 22, 33), as it is an indicator of an athlete’s ability to perform at optimal intensities for extended periods (4). Moreover, previous research showed highly positive significant correlations between VT$_2$ and muscle fatigue (23) or endurance performance (12). Thus, VT$_2$ showed a moderate ability to predict tennis performance, with positive correlations.
reported between VT$_2$ and competitive level in high level male tennis players ($r = 0.55; p = 0.001$). Moreover, a large part (56%) of the variability found in their competitive level can be explained by the technical effectiveness (e.g., percentage of hits and errors during a test) obtained during an on-court performance test and the VT$_2$ (1).

To assess the VT$_2$, laboratory tests (i.e. treadmill tests) using ergospirometry equipment are usually conducted. However, during treadmill testing, the mode of exercise cannot simulate the intermittent demands of tennis and does not reflect the specific intra- and inter-muscular activity of both upper and lower limbs with respect to hitting and footwork (e.g. accelerations, decelerations, and changes of direction) (16, 18). In this regard, previous research showed that physiological responses changed when investigated under different movement conditions (i.e. sport-specific testing), with, for example, significantly lower VO$_{2\text{max}}$ values or significantly higher heart rate (HR) at the individual anaerobic threshold obtained in the laboratory testing than those measured under tennis-specific conditions (19, 29). On the other hand, to assess the VT$_2$, tennis players depend on the use of sophisticated ergospirometry equipment, and these costly tests are not specifically adapted to on-court specific tennis training demands (14). To be more precise in the prescription of specific endurance training, an on-court specific evaluation is needed, with the inclusion of not only performance parameters, but also exercise intensity parameters which could be easily incorporated into the training sessions.

Conconi et al. (8) established that the anaerobic threshold could be determined by a non-invasive field test based on the relationship of incremental running speed to HR. The speed ($S$) at which the linearity of the S-HR relationship was lost (deflection speed (Sd)) and the HR at Sd were defined as heart rate deflection point (HRDP). Although this method has been
criticized (6, 20, 31), it has been shown to be a valid method to determine aerobic performance in different continuous (i.e. swimming, cycling or skating) (6, 9), and also adapted for intermittent racket sports (i.e. badminton) sports (34). On the other hand, the relationship between HRDP and VT₂ has been studied in continuous sports (6, 13, 24), but never in intermittent racket sports through a tennis-specific test. We hypothesized that physiological and performance variables corresponding to HRDP, as determined from an on-court specific endurance tennis test in competitive tennis players, do not differ significantly from physiological and performance variables corresponding to VT₂. The confirmation of our hypothesis would indicate that this field test with HR monitoring, may be an accurate, simple, inexpensive and non-invasive method for aerobic testing, and justify the use of HRDP as specific on-court training intensity parameter at or near VT₂ in competitive tennis players. Thus, the aim of this study was to assess the relationship between HRDP and the VT₂, and between the maximal test performance and the $VO_{2\text{max}}$ in an on-court specific endurance tennis test.

**METHODS**

**Experimental Approach to the Problem**

To verify the usefulness of the HRDP as a predictor of VT₂ during a the tennis-specific test, a group of high level tennis players performed a modified version of a progressive, tennis-specific field test (29), which was recently shown to be reliable (1). Players were tested between February and April, in non-competitive periods and all tests were performed on an outdoor tennis court (i.e. GreenSet® surface). Temperature ranged from 18 to 23°C with stable environmental and wind conditions (i.e. air velocity < 2 m·s⁻¹, relative humidity 54.4–61.0% (Kestrel 4000 Pocket Weather Tracker, Nielsen Kellerman, Boothwyn, PA, USA)). Before each test, all the participants completed a 18-min standardized warm-up with 10 min
of jogging around the court, dynamic flexibility, forward, sideways, and backwards running, and acceleration runs; 5 min of ground strokes (players were asked to hit the balls to the center of the court); and 3 min of test familiarization, performing the test protocol at the lowest work load (frequency of balls ejected from the ball machine (Ballf) = 9 shots·min$^{-1}$). 3 to 5 min after the warm-up, the test began. Before any baseline testing, all participants attended two familiarization sessions to introduce the testing procedures and to ensure that any learning effect was minimal for the study measures. To reduce the interference of uncontrolled variables, all the subjects were instructed to maintain their habitual lifestyle and normal dietary intake before and during the study. The subjects were told not to exercise the day before a test and to consume their last (caffeine-free) meal at least 3 h before the scheduled test time.

**Subjects**

35 competitive male tennis players (mean ± SD: age 18.2 ± 1.3 years; height 1.83 ± 0.08 m; weight 72.8 ± 8.6 kg; body mass index 22.3 ± 1.4) with an International Tennis Number (ITN) ranging from 1 (elite) to 4 (advanced) (ITN 1 = 7 players; ITN 2 = 9 players; ITN 3 = 9 players; ITN 4 = 10 players) and corresponding to an Association of Professional Tennis Players (ATP) ranking between positions 600 and 1000, volunteered to participate in this study. The mean training background of the players was 6.6 ± 2.0 years, which focused on tennis-specific training (i.e. technical and tactical skills), aerobic and anaerobic training (i.e. on-court and off-court exercises), and strength training. Before any participation, the experimental procedures and potential risks were fully explained to the subjects, and they all provided written informed consent. The research committee of the local university approved the study.

**Procedures**
Specific Tennis Test

Participants had to hit balls coming from a ball machine (Pop-Lob Airmatic 104, France), alternating forehand and backhand strokes, cross court or down the line in a prescribed pattern (i.e. drive, topspin). The landing point for the balls was chosen about 2 m in front of the baseline, alternating balls to the right and the left corners. Slice-strokes were not allowed because we assumed that they might influence the positioning to the ball and therefore physiological responses and test reliability (1). The test began with a Ball rate of 9 shots·min⁻¹, which was increased by 2 shots·min⁻¹ every 2 minutes. The test ended at the player’s request or stopped by the researchers if the player was no longer able to fulfil the test criteria (i.e. the player was no longer able to perform strokes with acceptable stroke technique and precision, determined by the experienced researchers, through subjective observation). In this regard, we acknowledge that variability may exist with the testing protocol based on the coaches at hand.

In addition to the physiological measurements (ventilatory gas exchange and HR), an objective evaluation of the technical effectiveness (TE) was carried out. TE was calculated based on the percentage of hits and errors, and two performance criteria were defined: (1) Precision: the ball returned by the player had to bounce inside the target (i.e. 3.1 by 4.5 m square located 1 m from the service line and 1 m over the prolongation of the centre service line), and (2) Power: once the ball was bouncing inside the target, it had to go over the power line (located between 5 m from the centre of the baseline and 4 m from the side line), before bouncing a second time. A hit was considered successful when both performance criteria were fulfilled at once (precision and power). The ball machine was manually calibrated before each test and the device’s reliability was assessed by manual timing (mean CV of Ball rate = 3.5 ± 0.9 %) and using a radar device (Stalker ATS 4.02, USA) (mean Ball velocity = 68.6 ± 1.9 m/s).
km·h\(^{-1}\); CV of 2.7%). A minimum of 40 new tennis balls (Babolat Team\(^\circ\)) were used for each test.

**Physiological measurements**

Ventilatory gas exchange and HR were continuously recorded, beginning 2 min before the familiarization phase and finishing 5 min after the end of the test (recovery phase). Expired air was analysed continuously for gas volume (Triple digital-VI turbine), oxygen concentration (zirconium analyser), and carbon dioxide concentration (infrared analyser) using a portable gas analyzer (K4 b\(^2\), Cosmed, Italy). The portable measurement unit was carried by the player in the same way during all tests. HR monitoring (Polar, Kempele, Finland) was used alongside the Cosmed K4b\(^2\) system. Gas and volume calibration of the measurement device was done in the morning of each test session. Ambient air calibration occurred before each test. The mean HR of each completed minute of exercise was used to determine the HRDP, and was assessed by two experienced researchers who combined visual inspection and computer aided regression analysis. These observers did not have access to VT\(_2\) data at the time of the analysis. HRDP was determined following the methods of Mikulic et al. (24). HRDP was identified at the point at which the slope values of the linear portion of the time/HR relationship began to decline (Figure 1). The regression analysis of the HR time series was taken as the HR value closing the series which attained a maximum value of the Pearson’s regression coefficient (r) (6, 24).

****Insert Figure 1 near here****

The VT\(_2\) detection was done by analyzing the points of change in slope or breaks in linearity of ventilatory parameters (3), according to the model proposed by Skinner and MacLellan.
VT2 was established using the criteria of an increase in the ventilatory equivalent for carbon dioxide (VE/VE\textsubscript{CO2}), ventilatory equivalent for oxygen (VE/VE\textsubscript{O2}), and VE changes over time. VO\textsubscript{2max} was determined by the observation of a ‘plateau’ or levelling off in VO\textsubscript{2} or when the increase in VO\textsubscript{2} in two successive periods was less than 150 mL·min\textsuperscript{-1} (32). HR\textsubscript{max} was considered as the highest value reached during the final minute of the test. The variables obtained from the specific tennis test were physiological (HR (HRDP and HR\textsubscript{VT2}) and VO\textsubscript{2} (VO\textsubscript{2HRDP} and VO\textsubscript{2VT2})) and performance (Time (Time\textsubscript{HRDP} and Time\textsubscript{VT2}), Ballf (Ballf\textsubscript{HRDP} and Ballf\textsubscript{VT2}) and Stage (Stage\textsubscript{HRDP} and Stage\textsubscript{VT2})) parameters at corresponding HRDP and VT2, respectively.

**Statistical Analyses**

The values presented are expressed as mean ± standard deviation (SD). The normality of variables distribution was assessed by the Kolmogorov-Smirnov test. Paired t-test were used to discern any significant differences between the mean values of physiological and performance variables corresponding to HRDP and VT2. Pearson’s product moment correlation coefficient (r) demonstrated any significant relationship. When appropriate, a linear regression analysis was performed and the standard error of the estimation (SEE) was calculated. The differences were plotted against the average value for selected variables as suggested by Bland and Altman (5). Statistical significance was set a priori at p < 0.05. All statistical analyses were performed using SPSS for Windows 15.0 (SPSS Inc., USA).

**RESULTS**

A total of 198.3 ± 29.8 hits were made per test, of which 63.3 ± 9.2 % fulfilled the criteria of precision and power and were considered to be successful. The rest were considered errors (36.7 ± 9.2 %). HRDP was successfully determined in 32 of the 35 subjects analysed.
(91.4%), with the rest of the subjects showed a linear relationship between load and HR. Table 1 shows the data obtained for selected physiological and performance variables at HRDP and VT2 and their maximum values. HRDP, $\dot{V}O_2$HRDP, BallHRDP and TimeHRDP represented 92.4, 88.8, 86.7 and 75.1% of the maximum values, respectively. HRVT2, $\dot{V}O_2$VT2, BallVT2 and TimeVT2 represented 91.8, 85.6, 81.8 and 72.7% of the maximum values, respectively. No differences were found for HR (178.9 ± 8.5 vs. 177.9 ± 8.7 beats·min$^{-1}$ for HRDP vs. HRVT2, respectively) corresponding to HRDP and VT2, while there were differences in the remaining physiological ($\dot{V}O_2$HRDP - $\dot{V}O_2$VT2) ($p < 0.001$) and performance (TimeHRDP vs. TimeVT2; BallHRDP - BallVT2; StageHRDP - StageVT2) ($p < 0.05$ - 0.001) variables analysed. Strong and significant ($p < 0.001$; $r = 0.79$–0.96) correlations were found for all variables corresponding to HRDP and VT2.

**Insert Table 1 near here**

**Insert Figure 2 near here**

Figure 2 shows the relationship between HRDP and VT2 with a line of identity and a line of best fit for (a) HR, (b) Time, and (c) $\dot{V}O_2$. The Bland and Altman plots for the comparison are shown in Figure 3. The differences observed between $\dot{V}O_2$HRDP vs. $\dot{V}O_2$VT2 (0.12 L·min$^{-1}$; $p = 0.001$) and Time (19.7 s; $p = 0.03$) are relatively moderate when plotted against the average values in accordance with the Bland-Altman method (Figure 3). In addition, for all Time and 97% of $\dot{V}O_2$ and HR comparisons of the individual values were within the limits of agreement.

**Insert Figure 3 near here**
\( \overline{VO_2}_{\text{max}} \) was moderately and significantly correlated to the maximal test performance variables (Last stage achieved \((r = 0.56; p < 0.001)\) and Time \((r = 0.49; p < 0.05)\)).

**DISCUSSION**

The main purpose of the present study was to assess the relationship between HRDP and \( \overline{VO_2}_{\text{max}} \), and related physiological and performance variables, in a group of high-level tennis players. The results shows that the HRDP obtained from an on-court specific endurance test can be used to determine the \( \overline{VO_2}_{\text{max}} \). There was a strong relationship \((r = 0.79-0.96)\) between \( \overline{VO_2}_{\text{max}} \) and all the physiological and performance variables corresponding to HRDP (i.e. \( \overline{VO_2}, \) HR, Ball\(_t\) or Time). Moreover, the HRDP was not significantly different from the values at \( \overline{VO_2}_{\text{max}} \). Results also showed a moderate relationship between \( \overline{VO_2}_{\text{max}} \) and the final stage of the test \((r = 0.56)\), with the main performance variable obtained in the test, Ball\(_{\text{HRDP}}\), suggested as a useful parameter which can be used to prescribe on-court training. Thus, HRDP could provide interesting information in order to prescribe specific aerobic training in tennis players.

Exercise prescription is one of the most important tools for the management of training programs and it has been suggested the greatest training benefits occur when the training stimulus simulates the specific movement patterns and physiological demands of the sport \((26)\). The inclusion of field testing with the analyses of physiological and performance variables may be routinely used to accurately prescribe aerobic exercise in a context appropriate to the game \((18, 29)\). In order to measure the submaximal and maximal aerobic (i.e., \( \overline{VO_2}_{\text{max}} \)) power in tennis, during the last decade, different protocols have been conducted with an acceptable accuracy and under standardized conditions \((10, 18, 19, 29)\). Although in the present study there was a significant correlation between the last test stage and...
\( VO_{2\text{max}} \) \((r=0.56)\), which is consistent with previous tennis research \((18, 19)\), it can be hypothesized that there is a limited predictive validity of \( VO_{2\text{max}} \) based on the maximal test performance, due to technical efficiency limitations (i.e., specific movements and strokes) \((1)\). Thus, the final stage reached in the test would heavily rely on each player’s individual motor and technical efficiency. However, while this test shows limitations in the predictive validity of \( VO_{2\text{max}} \), on the other hand shows a good ecological and content validity (i.e., a specific sport context, with tennis-specific movements (strokes and footwork)) compared with non-specific tests. These findings highlight the usefulness of the present field test including physiological (i.e., \( \% VO_{2\text{max}} \) and VT) and performance (i.e., percentage of successful hits in the test or TE) measurements in high-level tennis players \((1)\).

The HRDP method is a non-invasive measurement related to the anaerobic threshold \((6)\), relatively simple to implement without very expensive materials, easy to perform repeatedly within days, and may be easily incorporated into training session. In the present study, HRDP was determined in most of the cases \((91.4\%)\), similar to the results obtained in badminton players \((94.1\%)\) \((34)\). HRDP represented 92.4\% of \( HR_{\text{max}} \), within the ranges observed in literature \((88 \text{ to } 94\%)\) \((6)\). HRDP is not significantly different from the values at \( VT_2 \) \((p > 0.05)\) and this two variables occurred with a slightly Time difference \((p = 0.03)\). The Bland-Altman analysis suggests an acceptable concordance with the HRDP method for the measurement of the \( VT_2 \) field tests among tennis players. The differences in performance (Time) and physiological (HR and \( V\dot{O}_2 \)) variables between HRDP and \( VT_2 \) were relatively minor to moderate, when plotted against the average values, as there is an equal overestimation vs. underestimation (Figure 3). The Bland-Altman plots shows a moderate difference between the physiological and performance measures between HRDP and \( VT_2 \). This little bias is in accordance with other studies comparing HRDP and physiological
Results showed significant correlations between the physiological measurements (HR and $\dot{V}O_2$) corresponding to VT$_2$ and HRDP ($r = 0.87–0.96; p < 0.05$), which is similar to previous studies conducted in continuous sports (6, 8, 13, 24), and a study conducted with male badminton players (34). Although these correlations do not necessarily imply cause and effect, the relationship between HR and VT$_2$ may provide an index for training prescription at or near these exercise intensities (11), which represent the capacity of the athletes to utilize an important part of their $VO_{2\text{max}}$ (i.e., endurance) (13). Moreover, HRDP may indicate changes in training status over time and the relative effectiveness of training programmes implemented (6). Therefore, coaches can use the HRDP obtained from this specific test to determine or evaluate their VT$_2$ throughout the season.

Despite advances in training prescription for linear endurance events, very little has been developed for team or racket sports despite their huge popularity. In these sports, a major question has been whether practice drills can be modified to incorporate both technical elements in conjunction with targeted physiological training stimuli (25). The correlations found between test performance variables (Time, Stage and Ball$_t$) at HRDP and VT$_2$ ($r = 0.79–0.81; p < 0.05$), suggest that they can be used as practical tools for prescribing on-court aerobic training. In this regard, these variables (i.e. Ball$_t$) allow to incorporate both technical (i.e. precision, depth or directions of forehand and backhand strokes) and physiological (i.e. $\%$Ball$_{HRDP}$) training stimuli and better control the training load (i.e. number of strokes or movements per work period).
Physiological stress in tennis is associated with the elevation of HR, which reflects the effort expended during short, intense bouts of play (21). The relative intensity for HRDP and HR_{VT2} recorded in the test, are higher than the mean values reported during the active phases of tennis play (86.2 ± 1.0% of HR_{max}) (17, 21). However, these values are lower than those observed during long and fast rallies, reflecting phases of high activity (~100% of HR_{max}). Thus, the intensity corresponding to the HRDP and HR_{VT2} is within the range of intensities presents during the tennis matches, especially in the case of long and fast rallies with phases of high activity.

This study was carried out with an homogeneous sample of high level tennis players (ITN:1-4), which ensured that technical proficiency might have minimal impact on the physiological and performance variables evaluated. However the results found are not generalizable to all kind of tennis players, is possible that a lower skill levels imply different relationships between HRDP and the VT_{2}, or between the maximal test performance and the VO_{2max}. In this regard, more research is needed to observe these relationships in players with different competitive levels.

In conclusion, this study has shown that the HRDP obtained from an on-court specific endurance test can be used to determine the VT_{2} in competitive tennis players. Strong correlations were found between the VT_{2} and physiological and performance variables corresponding to HRDP (i.e. VO_{2}, HR, Ball_{f} or Time) during the test, with the HRDP is not significantly different from the HR_{VT2}. Moreover, the Ball_{fHRDP} can be used as a practical performance variable to precisely and individually prescribe on-court specific aerobic training at the intensity corresponding at or near VT_{2}. There is a limited predictive validity of VO_{2max} based on the maximal test performance.
PRACTICAL APPLICATIONS

It has been suggested that in order to appropriate develop the cardiorespiratory fitness, the use of interval-training sessions eliciting similar or above competition match play intensity has to be considered (15, 25). Thus, Ball$_{HRDP}$ can be used as a practical performance variable to prescribe on-court moderate, close to the VT$_2$ or HRDP levels (i.e., 80–100% Ball$_{HRDP}$; ~15–19 shots·min$^{-1}$; stage ~3–5) and high, close to the $\dot{V}O_2$max levels (i.e., 100–120% Ball$_{HRDP}$; ~19–23 shots·min$^{-1}$; stage ~5–7) intensity interval training (1, 15).

REFERENCES


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FIGURE LEGENDS

FIGURES

Figure 1. Time / Heart rate (HR) relationship with the heart rate deflection point (HRDP) for 1 subject.

Figure 2. Correlation between the variables corresponding to heart rate deflection point (HRDP) and second ventilatory threshold (VT$_2$) with the line of identity (dashed) and line of best fit (solid dashed) for (a) heart rate, (b) time, (c) oxygen uptake.

Figure 3. Bland-Altman plots with estimated mean bias and 95% limits of agreement for difference in (a) heart rate (beats·min$^{-1}$), (b) time (s), and (c) oxygen uptake (L·min$^{-1}$) corresponding to heart rate deflection point (HRDP) and second ventilatory threshold (VT$_2$), plotted against the mean.

TABLES

Table 1. Basic performance (Time, Stage and Ball) and physiological (HR, $\dot{V}$O$_2$) variables (mean ± SD) of tennis players corresponding to maximal work (MAX), second ventilatory threshold (VT$_2$) and heart rate deflection point (HRDP) obtained during a specific endurance tennis test; paired sample $t$-test ($p$) for differences in variables corresponding to VT$_2$ and HRDP, and correlation coefficient (r) between variables corresponding to VT$_2$ and HRDP.
<table>
<thead>
<tr>
<th></th>
<th>MAX</th>
<th>VT₂</th>
<th>HRDP</th>
<th>VT₂ – HRDP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time (s)</strong></td>
<td>820.7 ± 91.3</td>
<td>597.2 ± 69.2</td>
<td>616.9 ± 85.5</td>
<td>0.033</td>
</tr>
<tr>
<td><strong>Stage (#)</strong></td>
<td>6.6 ± 0.8</td>
<td>4.7 ± 0.6</td>
<td>5.1 ± 0.8</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Ballf (shots·min⁻¹)</strong></td>
<td>22.7 ± 1.6</td>
<td>18.6 ± 1.3</td>
<td>19.8 ± 1.7</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>HR (beats·min⁻¹)</strong></td>
<td>193.6 ± 7.4</td>
<td>177.9 ± 8.7</td>
<td>178.9 ± 8.5</td>
<td>0.219</td>
</tr>
<tr>
<td><strong>Vo₂ (mL·kg⁻¹·min⁻¹)</strong></td>
<td>57.3 ± 5.9</td>
<td>49.1 ± 5.8</td>
<td>50.9 ± 6.3</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Vo₂ (L·min⁻¹)</strong></td>
<td>4.19 ± 0.66</td>
<td>3.56 ± 0.61</td>
<td>3.68 ± 0.62</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Ballf = Frequency of balls; HR = Heart rate; Vo₂ = oxygen uptake. *All correlation coefficients (r) are significant at a level p < 0.001.
The graph shows the relationship between HR (beats·min⁻¹) and time (s), with two linear equations:

1. For lower values:
   \[ y = 0.961x + 117.16 \]
   \[ r^2 = 0.996 \]
   Time before HRDP

2. For higher values:
   \[ y = 0.134x + 113.34 \]
   \[ r^2 = 0.968 \]
   Time after HRDP

HRDP indicates the Heart Rate Decline Point.