Title: Cardiovascular responses of exercises performed within the extreme exercise domain

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Short Title: Cardiovascular responses of extreme exercise domain
Summary

Stroke volume (SV), heart rate (HR) and arterio-venous O2 difference (a–vO2diff) responses to heavy and severe-intensity exercise have been well documented; however, there is a lack of information on the SV, HR and a–vO2diff responses of work rates within extreme exercise domain. The aim of this study was, therefore, to focus on central and peripheral components of VO2 responses to exercises performed within the heavy, severe and extreme exercise domain.

Eight well-trained male cyclists participated in this study. Maximal O2 consumption (VO2max) and corresponding work rate (P@VO2max) were determined by multisession constant work rate exercises. Cardiovascular responses to exercises were evaluated by nitrous-oxide rebreathing method with work rates from 40% to 160% of P@VO2max. VO2max corresponded to 324±39.4 W; however, maximal SV responses occurred at 205±54.3 W (p<0.01). Maximal cardiac output (Q), HR, and a–vO2diff responses were revealed by the P@VO2max. VO2 response to exercise significantly decreased from severe-intense exercises to the first work rate of extreme exercise domain due to significant decreases in Q, SV, and HR responses (p<0.05), except a–vO2diff (p>0.05). Moreover, non-significant decreases in Q, SV, and a–vO2diff were evaluated as response to increase in work rate belonging to extreme work rates (p>0.05), except the HR (p<0.05). Work rates within the lower district of the extreme exercise domain have an important potential to improve peripheral component of VO2, while the P@VO2max seems the most appropriate intensity for aerobic endurance development as it maximizes the central component of VO2max.

Keywords: Arterio-venous O2 difference, cardiac output, heart rate, sports performance, stroke volume
Introduction

Exercise domains are classified as moderate, heavy, severe, and extreme [1,2]. The lactate threshold is accepted as the upper boundary of moderate exercise domain, while the maximal lactate steady-state is the upper boundary of heavy exercise domain [3,4]. The upper boundary of severe exercise domain is accepted as the highest intensity given the $\dot{V}O_2$ max ($I_{HIGH}$) [5–10]. If the $I_{HIGH}$ is exceeded, within the extreme exercise domain, $VO_2$ response to exercise does not attain $\dot{V}O_2$ max [9]. Aerobic power is one of the most important indicators of aerobic performance. Exercise $VO_2$ is related to the increase in stroke volume (SV), heart rate (HR) and arterio-venous O2 difference ($a$–$vO_2$diff). SV and HR, which produce the cardiac output (Q), are the central component of $VO_2$, while $a$–$vO_2$diff forms the peripheral component. The Q and SV rather than HR or $a$–$vO_2$diff are the key factors of the aerobic power [11] because maximal SV ($SV_{max}$) responses of non-elite athlete groups occur within the heavy exercise domain, but not within the severe exercise domain [12]. Conversely, maximal HR and $a$–$vO_2$diff have typically occurred within the severe exercise domain [13].

Extreme-intensity work rates have been used for aerobic adaptations, especially over the last two decades. It has been shown that very high intense, low volume training strategies have been used for a rapid improvement aerobic adaptation by increasing oxidative muscle capacity, carbohydrate/lipid metabolism and metabolic control during exercise [14–16]. Consequently, exercise modalities including supramaximal intensities referring to work rates greater than severe intensity exercises, e.g., 25-s × 12 repetitions with 1:4 workout/resting ratio at ~120-140% of power output corresponding to the maximal O2 utilize ($P@\dot{V}O_2_{max}$) given the $\dot{V}O_2_{max}$, have become popular in terms of aerobic endurance development [17–19]. Currently, even sprint intervals, e.g., 30-s × 6 bouts of exercise with 1:8 workout/resting ratio at 160% of $P@\dot{V}O_2_{max}$, have been used to improve both aerobic and anaerobic endurance [20]. However, although SV, HR and $a$–$vO_2$diff responses in heavy and severe intensity exercises have been well documented [21–23], there is a lack of information on SV, HR and $a$–$vO_2$diff responses of extreme exercises, i.e., 120%, 140%, and 160% of $P@\dot{V}O_2_{max}$, which have been typically used for endurance development [24]. The aim of this study was, therefore, to focus on central and peripheral components of $VO_2$ responses to exercises performed especially within the lower district of extreme exercise domain.

Methods

Participants
The study was approved by the University’s Research Ethics Committee (xxx university Ethics Committee, Chairman: xxx; Protocol no: 20478486-84; Date: 02.2015) and conducted based on the principles of the Declaration of Helsinki, except prior registration of the study in a database. Eight well-trained male cyclists participated in this study (age: 22 ± 2.2 years; body height: 178 ± 5.55 cm; body mass: 71.9 ± 8.24 kg). Cyclists were informed about the benefits and risks of the investigation just before signing an institutionally approved informed consent document to participate in the study. They had been training for ~7 years, and their training sessions corresponded to ~18 hour·wk⁻¹. The study was conducted after the competition season to minimise training effects or periodization and completed within four weeks. Additionally, the time of the day allocated for testing was standardised to minimise any effect of circadian variance for each volunteer. They were requested not to take part in any exhausting exercise during the study. None of the participants suffered from any injuries or had a known systemic disease, and they were not under the influence of any medication.

2.2 Experimental Design
Following familiarization session (Stage 1 in Figure 1), cyclists’ first and second ventilatory threshold (VT₁ and VT₂) were evaluated by a submaximal step incremental test. \( \dot{V}O_{2\text{max}} \) was determined by maximal step incremental test and constant work rate trail (Stage 2 in Figure 1). Multisession constant work rate exercises were applied to determine cyclists’ individual I\text{HIGH} levels (Stage 3 in Figure 1). Then, work rates ranged from 40 to 100% of P@\( \dot{V}O_{2\text{max}} \) were analysed to reveal exercise intensity associated with SV\text{max} (Stage 4 in Figure 1). Moreover, further two transition constant work rate exercises (i.e., 120-140-160% of P@\( \dot{V}O_{2\text{max}} \)) were conducted to determine cyclists’ \( \dot{V}O_{2} \), Q, SV, and a–\( V_{2\text{diff}} \) responses to exercises performed within the lower district of extreme exercise (Stage 5 in Figure 1) (Figure 1). The Q, SV, HR, and a–\( V_{2\text{diff}} \) values belonging to exercises were then analysed to test hypotheses. Each individual visited the laboratory for 16-18 days.

Procedures
Cardiac performance measurements and respiratory gas analyses
Q, SV, and a–\( V_{2\text{diff}} \) were conducted cardiac measurement system (Innocor Inno-500, Odense, Denmark), using a valid and reliable non-invasive inert gas rebreathing method (\( N_{2}O_{R\text{B}} \)) [25,26]. For this method \( N_{2}O \) (blood soluble gas) and \( SF_{6} \) (blood insoluble gas) gasses used and their approximate inspired concentrations were 0.5% and 0.1%, respectively. Rebreathing bag volume and bolus volume (volume of gas mixture, consisting of \( N_{2}O \), \( SF_{6} \) and \( O_{2} \)) were
regulated automatically by device. The rebreathing manoeuvre was performed typically using 5-7 breaths. The Innocor system calculates Q from the last two or three breaths of the manoeuvre [26,27]. SV responses belonging to each measurement was calculated by dividing Q by the HR. The Q data could not be recorded continuously during the tests, since N₂OORB method needs approximately 2-3-min for washout of N₂O between repeated measurements for the same individual. Soluble gas concentration was therefore checked just before and after each measurement. If the N₂O increased at the end of the test due to the recirculation, the measurement was recalculated with selected last two breaths after mixing. This calculation from two last breaths helps to avoid recirculation in N₂OORB measurements during supramaximal exercises [26,27]. At the beginning of the subsequent measurements, end-tidal gas values were checked. If N₂O and SF₆ were above 0.002% and 0.001% respectively, the subsequent test was delayed due to insufficient recirculation time and/or missing washout of the lungs between two measurements. Breath-by-breath gas exchanges were measured using the same system. Due to technical limitations, \( \dot{V}O₂ \) and \( \dot{V}CO₂ \) exchange was not recorded during the N₂OORB. Arteriovenous oxygen difference was calculated from Q and \( \dot{V}O₂ \) using the Fick Principle [28]. In addition to Polar heart rate monitoring system, HR responses were recorded via the pulse-oximeter equipment of the Innocor system and heart rate monitoring system (Polar RS400, Polar Electro Oy, Kempele, Finland). Device calibrations were undertaken according to the manufacturer’s instructions.

Familiarisation session and pilot studies

Familiarization sessions were performed to adapt the participants to electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands), cardiac measurement system, heart rate monitoring system and climatic chamber, which allows fixed special standard laboratory conditions (20 °C temperature, 20.8% O₂, <500 ppm CO₂, 50-60% relative humidity). For this purpose, incremental exercise consisted of four stages for each 5 min with ~60 W initial loading and ~30 W increments, terminated within 50% of maximal HR reserve predicted by Karvonen’s HR reserve formula, were conducted.

Step incremental test and constant work rate verification phase to elicit \( \dot{V}O₂\text{max} \)

Submaximal step incremental test consisted of four 5 min stages with ~25-30 W increments. The test initiated the work rates corresponding to 50-60% of maximal HR and terminated ~85% of maximal HR reserve predicted by Karvonen’s HR reserve formula. If ventilatory threshold was not seen within the submaximal step incremental test, procedure would continue with ~25-
30-W increments. After 30 min passive recovery, maximal step incremental tests were initiated with 4 min of cycling without resistance. Then, work-loads were increased by 30 W for each 2-min steps. Cyclists were allowed to reach a cadence between 90±10 rpm and were instructed to maintain this cadence until task failure. The test was terminated when the pedal rate fell below 80 rpm for more than 10 seconds despite the strong verbal encouragement. The validation of tests was checked by a plateau with an increase in $\dot{V}O_2 < 2.1 \text{ mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$, greater than 90% of age-predicted maximum HR (maximal HR= 220−age), 1.1 or above respiratory exchange ratio and rate of perceived exertion of 19-20 in Borg’s 15-point scale [29]. The VT$_1$ and VT$_2$ were found by the first and second breakpoints of $VE/VO_2$ (minute ventilation/oxygen consumption) vs. W [30,31].

In order to determine verified $\dot{V}O_2\text{max}$, constant work rate test was conducted on the limit of tolerance. The test was initiated at the power output given the highest 30-s mean value of $\dot{V}O_2$ obtained from the incremental step test. Test validation criteria of verification phases were accepted as the same with incremental tests. Cyclists were encouraged verbally throughout the tests. The highest 30-s averages of $\dot{V}O_2$ values were recorded as the cyclists’ $\dot{V}O_2\text{max}$, and corresponding power outputs were accepted as the P@$\dot{V}O_2\text{max}$.

**Determination of the highest work rate to elicit $\dot{V}O_2\text{max}$**

Individual work rates corresponding to the I$_{\text{HIGH}}$ were analysed by multisession constant work rate exercises to determine the lower district of extreme exercises. In those exercises, $\dot{V}O_2$ responses to exercise greater than 95% of $\dot{V}O_2\text{max}$ were analysed [32–34]. The I$_{\text{HIGH}}$ bound of a well-trained cyclist was accepted as the highest work rate that provides a $\dot{V}O_2$ value, which is still greater than 95% of $\dot{V}O_2\text{max}$ [8,34]. In order to obtain the I$_{\text{HIGH}}$, the first test was performed at P@$\dot{V}O_2\text{max} + 15$ W, and constant work rate tests were continued by +15 W intervals on different days.

**Determination of maximal stroke volume responses by constant work rate exercises**

Tests were conducted by constant work rate exercises performed from 40% to 100% of P@$\dot{V}O_2\text{max}$. The exercises competed on three different days; i) 40% - 60% and 90% of P@$\dot{V}O_2\text{max}$, ii) 70% and 80% of P@$\dot{V}O_2\text{max}$, iii) 50% and 100% of P@$\dot{V}O_2\text{max}$, respectively, using 15 min rests. Work rates from 40% to 70-80% of P@$\dot{V}O_2\text{max}$ were maintained for 10 min; in the meantime, three N$_2\text{ORB}$ were completed between 4:30-5:00, 7:00-7:30 and 9:30-10:00 minutes. Besides, 70-80% to 100% of P@$\dot{V}O_2\text{max}$ were sustained for 5-7 minutes, and N$_2\text{ORB}$ were accomplished between 2:30-3:00, 4:30-5:00 and 6:30-7:00 minutes, if the test was
prolonged [12]. Individual SV\textsubscript{max} (mL) and corresponding work rate (P@SV\textsubscript{max}), \(\dot{V}O_2\), Q, HR, and a\text{--}\text{vO}_2\text{diff} values were recorded.

\textit{Determination of cardiac output, stroke volume and arterio-venous O}_2\text{ difference responses of extreme exercises}

Extreme exercise trails were conducted by three different constant work rates with two transitions (i.e., 120\%, 140\%, and 160\% of P@\(\dot{V}O_2\text{max}\)). Firstly, for each cyclist, time to task failures and \(\dot{V}O_2\) responses of extreme exercise trails were determined without rebreathing applications on separate days. Then, these extreme exercise trails were repeated on different days in order to obtain Q, SV, and a\text{--}\text{vO}_2\text{diff} responses. Therefore, the N\textsubscript{2}O\textsubscript{RB} applications could be applied just before cyclists’ exhaustion of each extreme exercise trail. The highest \(\dot{V}O_2\), Q, SV, HR, and a\text{--}\text{vO}_2\text{diff} values of each extreme exercise were recorded, individually.

\textit{Statistical Analysis}

Results were evaluated using SPSS 21.0 (SPSS Inc., Chicago, USA). The Shapiro-Wilk test was applied to determine whether data were normally distributed or not. Differences between variables were assessed by repeated-measures ANOVA. Tukey’s honestly significant difference post hoc test was used to perform pairwise comparisons. In order to avoid the loss of statistical power, confidence interval adjustment was not performed for multiple pairwise comparisons. Effect size (ES) was analysed on the basis of mean and standard deviation. Cohen's effect sizes were categorised as trivial (0-0.2), small effect (0.2-0.5), medium effect (0.5-0.8), and a large effect (>0.8) [35]. Results with a p<0.05 were considered statistically significant.

\textit{Results}

Mean P@\(\dot{V}O_2\text{max}\) corresponded to 324±39.4 W; however, mean P@SV\textsubscript{max} responses of cyclists occurred at 205±54.3 W with the gap of ∼119 W (p<0.001). Indeed, individual P@SV\textsubscript{max} values of six cyclists corresponded an exercise intensity below the VT\textsubscript{2} and above the VT\textsubscript{1}, referring to heavy exercise domain, while only two of cyclists’ P@SV\textsubscript{max} values occurred at the first work rates of severe exercise domain (i.e., above the VT\textsubscript{2}) referring to significantly lower work rates than the P@\(\dot{V}O_2\text{max}\). Data belonging to work rates (P@SV\textsubscript{max}, P@\(\dot{V}O_2\text{max}\), 120\%, 140\% and 160\% of P@\(\dot{V}O_2\text{max}\)) corresponding to \(\dot{V}O_2\text{max}\), Q, SV, HR, and a\text{--}\text{vO}_2\text{diff} are presented in Table 1.
Work rates of 120%, 140%, and 160% of P@\(\dot{V}O_2\)max corresponded to 389±47.4, 454±55.1, and 519±63.2 W, respectively. Group mean of the I_HIGH was 358±48.9 W (i.e., ~111% of P@\(\dot{V}O_2\)max). Time to task failures of 120%, 140%, and 160% of P@\(\dot{V}O_2\)max corresponded to 164±34.2, 109±25.9, and 74.5±15.1 seconds, respectively. The highest HR and \(a–vO_2\)diff responses were revealed by the P@\(\dot{V}O_2\)max where the \(\dot{V}O_2\)max was obtained. Peak oxygen uptake at 120%, 140%, and 160% of P@\(\dot{V}O_2\)max exercises were significantly lower than the \(\dot{V}O_2\)max due to decreases in Q (Table 2), SV (Table 3) and HR (Table 4) responses. Additionally, significant \(a–vO_2\)diff decrements occurred only at 160% of P@\(\dot{V}O_2\)max compared to the P@\(\dot{V}O_2\)max (Table 5). Additionally, \(a–vO_2\)diff responses tended to decrease at 140% of P@\(\dot{V}O_2\)max compared to the P@\(\dot{V}O_2\)max. (\(p=0.076, d=0.73\)) (Table 2). Moreover, non-significant Q, SV, and \(a–vO_2\)diff decrements were evaluated within increasing work rates belonging to extreme exercise intensities (i.e., 120%, 140%, and 160% of P@\(\dot{V}O_2\)max); however, the \(\dot{V}O_2\) and HR decrements were significant at 120% to 160% of P@\(\dot{V}O_2\)max (\(p<0.05\)).

**Discussion**

It is known that very high intense and low volume training strategies have been used for a rapid improvement in aerobic performance [14–16]. Indeed, those adaptations can be induced by high-intensity exercises or sprints performed within extreme exercise domain due to increasing rate of blood flow within the resting periods between succeeding workouts and increasing rate of aerobic contribution during recovery period [36,37]. However, there is a lack of information on Q, SV, HR, and \(a–vO_2\)diff response of extreme exercises, which have been typically used for aerobic endurance development. Whereas, if there is an important SV response during high intensity exercises, central adaptations (i.e., Q and SV), besides peripheral adaptations (i.e., \(a–vO_2\)diff), may be ensured by high-intense exercises. Therefore, this study aimed to analyse central and peripheral components of \(\dot{V}O_2\) responses to exercises performed within the lower district of extreme exercise domain. The main results showed that there were expected \(\dot{V}O_2\) decrements at extreme exercises compared to the exercise corresponding to the P@\(\dot{V}O_2\)max due to significant decrease in Q, SV and HR responses of well-trained cyclists. However, \(a–vO_2\)diff responses were not different at extreme work rates (i.e., 120% and 140% of P@\(\dot{V}O_2\)max) than that of the P@\(\dot{V}O_2\)max. Consequently, none of the components of \(\dot{V}O_2\) come out predominant within varying extreme exercise intensities. Due to the increase in anaerobic contribution and shortening exercise duration, SV, HR, Q and \(a–vO_2\)diff response to exercises decreased together
with the small differences during extreme exercises (i.e., 120%, 140%, and 160% of P@VO\textsubscript{2max}) compared to the P@VO\textsubscript{2max} exercises.

Individual SV responses to exercise indicate that the SV pattern during maximal incremental or constant work rate protocols is greatly dependent on exercise intensity and duration. According to Lepretre et al. [38], VO\textsubscript{2max} is reached lower SV responses in heavy-intense constant exercises than severe intensity exhaustive exercises. Indeed, it was reported that a 6-min ramp incremental test that resulted in a significantly greater SV decrement that leads an important cardiac output decrease than a 12-min progressive exercise [39]. Conversely, Colakoglu et al. [40] showed that SV\textsubscript{max} responses of well-trained but non-elite athletes correspond to heavy-intense exercises, and if the number of steps or stage durations during incremental test increases or extents, cardiac performance significantly decreases based on cardiac fatigue. In fact, according to authors, short bouts of verification phases terminated by athletes’ exhaustion has been an important method to reveal a real VO\textsubscript{2max}. Indeed, the highest VO\textsubscript{2} means were reached by verification bouts when compared to step incremental exercises in this study (i.e., 62.7±6.31 mL·kg·min\textsuperscript{−1} vs. 61.3±5.21 mL·kg·min\textsuperscript{−1}; p<0.05, respectively).

It is known that SV responses to 4-8 minutes of constant work rate exercises reached maximal within 2-3 minutes and then decreased prior to fatigue, suggesting a central limitation (e.g., myocardial) to maximal aerobic power [41]. Indeed, there were greater SV responses at the first measurement rather than second N\textsubscript{2}O\textsubscript{RB} manoeuvre during severe exercises, and SV\textsubscript{max} response of each cyclist was attained within 2:30-3:00-min of exercise durations. However, due to technical limitation of the rebreathing system, N\textsubscript{2}O\textsubscript{RB} measurements could be applied only once during extreme exercises based on insufficient exercise durations. Moreover, due to shortening exercise duration at supramaximal constant work rates, rebreathing manoeuvre could not be applied at greater work rates than the 160% of P@VO\textsubscript{2max} (i.e., 180% and 200% of P@VO\textsubscript{2max}). Indeed, N\textsubscript{2}O\textsubscript{RB} measurements would be applied just before cyclists’ exhaustion rather than throughout workout sessions, and gas exchange parameters would not be measured during this time interval. Therefore, more accurate analyses for the supramaximal exercises can be made by measuring these parameters with direct methods (e.g., thermos-dilution methods). Additionally, only a limited number of well-trained cyclists could be recruited for this study. Thus, the results may not have general validity for the general population. Therefore, future studies may be focus on high-intensity training for female athletes or other disciplines.
Conclusion

Q, SV, and HR responses were significantly lower in extreme exercises compared to the P@\(\dot{V}O_{2\text{max}}\). Therefore, it can be said that severe exercise intensities (i.e., P@\(\dot{V}O_{2\text{max}}\) have more potential to improve aerobic power. However, none of the VO\(_2\) components (i.e., Q, SV, HR, and a–vO\(_2\)diff) come out predominant within varying extreme exercise intensities of well-trained cyclists. Moreover, a–vO\(_2\)diff responses were not different between P@\(\dot{V}O_{2\text{max}}\) and the exercises performed at 120% and 140% of P@\(\dot{V}O_{2\text{max}}\). Additionally, there was no dramatic decrease in any of the SV, HR, Q or a–vO\(_2\)diff responses during exercises performed at 120%, 140% and 160% of P@\(\dot{V}O_{2\text{max}}\). Only the decrement in HR response between 120% and 160% of P@\(\dot{V}O_{2\text{max}}\) was significant; however, the decreasing rate was negligible (3 beats per minute). It may be said that work rates within the lower district of extreme exercise domain (i.e., 120% of P@\(\dot{V}O_{2\text{max}}\) have an important potential to develop aerobic endurance by improving the peripheral components of the VO\(_2\).

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Table 1. The highest $\dot{V}O_2$, $Q$, $SV$, HR and $a-\dot{v}O_2^{\text{diff}}$ responses obtained from exercises performed at $P@SV_{\max}$, $P@VO_2^{\text{max}}$, 120% of $P@VO_2^{\text{max}}$, 140% of $P@VO_2^{\text{max}}$ and 160% of $P@VO_2^{\text{max}}$.

<table>
<thead>
<tr>
<th>Variables</th>
<th>$\dot{V}O_2$ (mL·min$^{-1}$·kg$^{-1}$)</th>
<th>$Q$ (L·min$^{-1}$)</th>
<th>$SV$ (mL)</th>
<th>HR (beats·min$^{-1}$)</th>
<th>$a-\dot{v}O_2^{\text{diff}}$ (mL)</th>
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</thead>
<tbody>
<tr>
<td>$P@SV_{\max}$</td>
<td>43±8.59</td>
<td>21.9±2.32</td>
<td>152±12.6</td>
<td>144.4±13.9</td>
<td>14.3±3.36</td>
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<tr>
<td>$P@VO_2^{\text{max}}$</td>
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<td>25.8±2.53</td>
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<td>190±7.08</td>
<td>17.3±0.5</td>
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<td>120% of $P@VO_2^{\text{max}}$</td>
<td>57.8±5.77</td>
<td>24.8±2.74</td>
<td>138±12.5</td>
<td>184±9.45</td>
<td>16.7±1.48</td>
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<tr>
<td>140% of $P@VO_2^{\text{max}}$</td>
<td>56.5±7.44</td>
<td>24.4±3.61</td>
<td>137±16.6</td>
<td>183±10.7</td>
<td>16.6±1.37</td>
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<td>160% of $P@VO_2^{\text{max}}$</td>
<td>54.5±6.55</td>
<td>24.2±3.41</td>
<td>136±14.3</td>
<td>181±11.8</td>
<td>16.1±0.72</td>
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</table>

$P@SV_{\max}$: Power output corresponding to maximal SV responses; $P@VO_2^{\text{max}}$: Power output corresponding to the $VO_2^{\text{max}}$; $VO_2$: O$_2$ utilize; $Q$: Cardiac output; $SV$: Stroke volume; HR: Heart rate; $a-\dot{v}O_2^{\text{diff}}$: Arterio-venous O$_2$ difference.
Table 2. Results of p and cohen’s d values of Q responses, obtained from exercises performed at P@SV_max, P@VO2max, 120% of P@VO2max, 140% of P@VO2max and 160% of P@VO2max

<table>
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<th>Variables</th>
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<th>140% of P@VO2max</th>
<th>160% of P@VO2max</th>
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<td>P@VO2max</td>
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<td>p=0.035</td>
<td>p=0.022</td>
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<tr>
<td></td>
<td></td>
<td>d=0.87</td>
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<td>120% of</td>
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<td>d=0.14</td>
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Q: Cardiac output; P@SV_max: Power output corresponding to maximal stroke volume; P@VO2max: Power output corresponding to the VO2max.
Table 3. Results of p and cohen’s d values of SV responses, obtained from exercises performed at P@SV\(_{\text{max}}\), P@VO\(_{2\text{max}}\), 120% of P@VO\(_{2\text{max}}\), 140% of P@VO\(_{2\text{max}}\) and 160% of P@VO\(_{2\text{max}}\)

<table>
<thead>
<tr>
<th>Variables</th>
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<th>120% of P@VO(_{2\text{max}})</th>
<th>140% of P@VO(_{2\text{max}})</th>
<th>160% of P@VO(_{2\text{max}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>P@SV(_{\text{max}})</td>
<td>p=0.01, d=0.95</td>
<td>p=0.002, d=1.73</td>
<td>p=0.009, d=1.28</td>
<td>p=0.001, d=1.89</td>
</tr>
<tr>
<td>P@VO(_{2\text{max}})</td>
<td>-</td>
<td>p=0.046, d=0.86</td>
<td>p=0.041, d=0.88</td>
<td>p=0.014, d=1.15</td>
</tr>
<tr>
<td>120% of P@VO(_{2\text{max}})</td>
<td>-</td>
<td>-</td>
<td>p=0.632, d=0.18</td>
<td>p=0.609, d=0.19</td>
</tr>
<tr>
<td>140% of P@VO(_{2\text{max}})</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>p=0.942, d=0.03</td>
</tr>
</tbody>
</table>

SV: Stroke volume; P@SV\(_{\text{max}}\): Power output corresponding to maximal stroke volume; P@VO\(_{2\text{max}}\): Power output corresponding to the \(\dot{V}O_{2\text{max}}\).
**Table 4.** Results of $p$ and Cohen’s $d$ values of HR responses, obtained from exercises performed at $P@SV_{\text{max}}$, $P@\dot{V}O_{2\text{max}}$, 120% of $P@\dot{V}O_{2\text{max}}$, 140% of $P@\dot{V}O_{2\text{max}}$, and 160% of $P@\dot{V}O_{2\text{max}}$

<table>
<thead>
<tr>
<th>Variables</th>
<th>$P@\dot{V}O_{2\text{max}}$</th>
<th>120% of $P@\dot{V}O_{2\text{max}}$</th>
<th>140% of $P@\dot{V}O_{2\text{max}}$</th>
<th>160% of $P@\dot{V}O_{2\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P@SV_{\text{max}}$</td>
<td>$p=0.001$</td>
<td>$p=0.001$</td>
<td>$p=0.001$</td>
<td>$p=0.001$</td>
</tr>
<tr>
<td></td>
<td>$d=3.06$</td>
<td>$d=2.21$</td>
<td>$d=2.08$</td>
<td>$d=1.81$</td>
</tr>
<tr>
<td>$P@\dot{V}O_{2\text{max}}$</td>
<td>-</td>
<td>$p=0.006$</td>
<td>$p=0.013$</td>
<td>$p=0.003$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$d=1.38$</td>
<td>$d=1.16$</td>
<td>$d=1.53$</td>
</tr>
<tr>
<td>120% of $P@\dot{V}O_{2\text{max}}$</td>
<td>-</td>
<td>-</td>
<td>$p=0.390$</td>
<td>$p=0.024$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$d=0.32$</td>
<td>$d=1.02$</td>
</tr>
<tr>
<td>140% of $P@\dot{V}O_{2\text{max}}$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$p=0.072$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$d=0.75$</td>
</tr>
</tbody>
</table>

HR: heart rate; $P@SV_{\text{max}}$: Power output corresponding to maximal stroke volume; $P@\dot{V}O_{2\text{max}}$: Power output corresponding to the $\dot{V}O_{2\text{max}}$. 
Table 5. Results of p and cohen’s d values of a−vO\textsubscript{2\text{diff}} responses, obtained from exercises performed at P@SV\textsubscript{max}, P@VO\textsubscript{2\text{max}}, 120% of P@VO\textsubscript{2\text{max}}, 140% of P@VO\textsubscript{2\text{max}} and 160% of P@VO\textsubscript{2\text{max}}

<table>
<thead>
<tr>
<th>Variables</th>
<th>P@VO\textsubscript{2\text{max}}</th>
<th>120% of P@VO\textsubscript{2\text{max}}</th>
<th>140% of P@VO\textsubscript{2\text{max}}</th>
<th>160% of P@VO\textsubscript{2\text{max}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>P@SV\textsubscript{max}</td>
<td>p=0.28</td>
<td>p=0.046</td>
<td>p=0.038</td>
<td>p=0.11</td>
</tr>
<tr>
<td></td>
<td>d=0.98</td>
<td>d=0.86</td>
<td>d=0.91</td>
<td>d=0.65</td>
</tr>
<tr>
<td>P@VO\textsubscript{2\text{max}}</td>
<td>-</td>
<td>p=0.215</td>
<td>p=0.076</td>
<td>p=0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d=0.48</td>
<td>d=0.73</td>
<td>d=2.9</td>
</tr>
<tr>
<td>120% of P@VO\textsubscript{2\text{max}}</td>
<td>-</td>
<td>-</td>
<td>p=0.899</td>
<td>p=0.244</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>d=0.05</td>
<td>d=0.46</td>
</tr>
<tr>
<td>140% of P@VO\textsubscript{2\text{max}}</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>p=0.133</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>d=0.14</td>
</tr>
</tbody>
</table>

a−vO\textsubscript{2\text{diff}}: Arteriovenous O\textsubscript{2} difference; P@SV\textsubscript{max}: Power output corresponding to maximal stroke volume; P@VO\textsubscript{2\text{max}}: Power output corresponding to the VO\textsubscript{2\text{max}}.
**Figure Legend**

**Figure 1.** Flow chart of experimental study design.

I-PO: Power output given the highest 30-s mean value of $\dot{V}O_2$ obtained from the incremental step test; $I_{\text{HIGH}}$: Highest constant intensity giving the $\dot{V}O_2_{\text{max}}$; $P@\dot{V}O_2_{\text{max}}$: Power output corresponding to the $\dot{V}O_2_{\text{max}}$; $SV_{\text{max}}$: Maximal stroke volume.