

## CLINICAL SCIENCE

# The slope of the oxygen pulse curve does not depend on the maximal heart rate in elite soccer players

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**INTRODUCTION:** It is unknown whether an extremely high heart rate can affect oxygen pulse profile during progressive maximal exercise in healthy subjects.

**OBJECTIVE:** Our aim was to compare relative oxygen pulse (adjusted for body weight) curves in athletes at their maximal heart rate during treadmill cardiopulmonary exercise testing.

**METHODS:** A total of 180 elite soccer players were categorized in quartiles according to their maximum heart rate values (n = 45). Oxygen consumption, maximum heart rate and relative oxygen pulse curves in the extreme quartiles, Q1 and Q4, were compared at intervals corresponding to 10% of the total duration of a cardiopulmonary exercise testing.

**RESULTS:** Oxygen consumption was similar among all subjects during cardiopulmonary exercise testing; however subjects in Q1 started to exhibit lower maximum heart rate values when 20% of the test was complete. Conversely, the relative oxygen pulse was higher in this group when cardiopulmonary exercise testing was 40% complete (p<.01). Although the slopes of the lines were similar (p=.25), the regression intercepts differed (p<.01) between Q1 and Q4. During the last two minutes of testing, a flat or decreasing oxygen pulse was identified in 20% of the soccer players, and this trend was similar between subjects in Q1 and Q4.

**CONCLUSION:** Relative oxygen pulse curve slopes, which serve as an indirect and non-invasive surrogate for stroke volume, suggest that the stroke volume is similar in young and aerobically fit subjects regardless of the maximum heart rate reached.

**KEYWORDS:** Cardiopulmonary exercise testing; Maximum oxygen consumption; Ramp protocol; Athletes; Soccer.

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## INTRODUCTION

Adult athletes competing primarily in aerobic modalities are characterized by higher levels of maximum cardiac output and aerobic power when compared with non-athletes or those who participate in predominantly anaerobic modalities.<sup>1-3</sup> As the heart rate (HR) accelerates during exercise, there is a reduction in the duration of the cardiac cycle, especially in diastole, and consequently, ventricular filling time is also reduced. Thus, it has been hypothesized that end-diastolic volume is limited in some individuals by progressively higher HR levels, potentially resulting in an

increase in blunted stroke volume (SV) during exercise as a result of the Frank-Starling mechanism.<sup>4</sup>

The ratio between oxygen consumption (VO<sub>2</sub>) and HR defines the oxygen pulse (O<sub>2</sub> pulse), which according to the Fick equation, is numerically equal to the product of SV and arteriovenous O<sub>2</sub> concentration difference.<sup>5-7</sup> Thus, because VO<sub>2</sub> and HR tend to increase linearly but at different rates based on exercise intensity, the shape of the O<sub>2</sub> pulse curve will reflect the relative differences in the magnitude of the incremental adjustments in these variables. Because the shape of the curve representing the arteriovenous O<sub>2</sub> difference does not vary appreciably between healthy individuals subjected to an incremental exercise protocol,<sup>5</sup> O<sub>2</sub> pulse reflects SV (i.e., the effective blood volume ejected from the left ventricle with each heart beat).<sup>8-11</sup> This phenomenon occurs even more consistently in high-performance athletes.<sup>8</sup> Therefore, it is possible to analyze the behavior of SV by following the O<sub>2</sub> pulse curve during progressively more intense exercise, e.g., during cardiopulmonary exercise

testing (CPET) performed with a ramp protocol. Although some studies<sup>12-14</sup> suggest that increases in SV may be limited at higher HR levels, there is evidence<sup>15, 16</sup> that this does not actually occur in the last few minutes of CPET and that the SV may continue to increase up to the end of an exercise protocol in which intensity is progressively increased.

To establish a better physiological understanding of these responses, we evaluated a large group of professional soccer players from whom expired gases were sampled every ten seconds, and continuous electrocardiograms were recorded during a maximally progressive exercise test. We compared the O<sub>2</sub> pulse curves throughout CPET between two groups of athletes with high and low maximum HR values. Our hypothesis was that the O<sub>2</sub> pulse curves would have similar slopes but different intercepts. This would suggest that SV, reflected by the O<sub>2</sub> pulse curves, would behave similarly during progressive exercise testing, regardless of the magnitude of the maximum HR achieved. In addition, we sought to describe a normal pattern for the relative O<sub>2</sub> pulse curves for young, healthy individuals with high aerobic fitness during a CPET performed using a treadmill ramp protocol in which only the velocity was continuously increased.

## MATERIALS AND METHODS

### Sample

We retrospectively analyzed the results of sports medicine evaluations of 180 professional soccer players from first-division clubs in Brazil (n=151) and Angola (n=29) that were overseen by our research team between 2005 and 2010. We started with a total sample of 189 players and excluded those who a) did not provide valid data for a true maximal CPET, i.e., due to poor motivation and/or limiting muscle/joint pain; or b) were prescribed any medication that could affect the physiological response to exercise.

The players included in this study were evaluated immediately after the holidays, which is the typical time for pre-season assessment. In the preceding week, subjects did not participate in any formal training or competition. Subjects underwent a specialized medical evaluation aimed at identifying relevant diseases or clinical conditions that could affect their performance or competitive eligibility. Any abnormalities in the resting electrocardiogram were identified and, when necessary, confirmed as physiological adaptations based on clinical findings and echocardiography.<sup>17</sup> After this medical evaluation, all athletes were cleared for professional soccer training and competition. The mean age, weight and height of the players were 24 ± 4 years, 75 ± 8 kg and 178 ± 6 cm (mean ± standard deviation), respectively. All players provided informed consent explicitly authorizing the evaluation and use of the data (excluding identifiable information) for research and statistical purposes.

### Maximum Cardiopulmonary Exercise Testing

All players were assessed using the same ramp protocol on an ATL Master treadmill (Inbrasport; Porto Alegre, Brazil) programmed to achieve a maximum duration of 10 to 15 minutes. After one minute at 5.5 km/h, the velocity was rapidly increased to 8 km/h and then increased by 0.1 km/h every 7.5 s (0.8 km/h every minute). Considering that the sport of soccer is played on a level field, we

intentionally did not incline the treadmill. The criteria we adopted to ensure a maximal test were a) achievement of maximum voluntary exhaustion, despite verbal encouragement, accompanied by a maximum effort sensation (a grade of 10 on the Borg scale); and b) a respiratory exchange ratio greater than 1.10.

### Ventilatory and HR measurements

Ventilatory and HR data were collected starting at the third minute of the CPET, at a velocity of 8.8 km/h. We eliminated data collected during the first two minutes, which included the initial walking and running phases. We disregarded these initial phases, which comprise the transition between rest and exercise, because the responses during that time tended to be non-linear.

HR was measured every 10 s from a continuous recording on a single derivation (using CC5 or CM5 chest leads) measured by a digital Micromed electrocardiograph with the Elite ErgoPC software versions 3.2.1.5 or 3.3.6.2 (Micromed; Brasília, Brazil). Later, in an effort to eliminate artifacts, the HR values were visually compared, and when there was a difference between two consecutive measurements that exceeded five beats, the values were confirmed on the electrocardiographic tracing and, if appropriate, corrected from the reading of five R-R intervals (cardiac cycles). In about 3% of the readings, excess electrocardiographic tracing artifacts hindered this measurement and, as a result, the HR values were interpolated. The greatest observed HR value over a 10-s interval during the CPET was considered to be the maximum achieved HR.

Ventilatory expired gas was collected using a preVent<sup>®</sup> pneumotachograph (MedGraphics; Saint Paul, United States) with the aid of a nose clip and was expressed every 10 s by a VO<sub>2000</sub> metabolic analyzer (MedGraphics; Saint Paul, United States), which was calibrated with known gas concentrations before and after the CPET. The values were corrected as necessary. The O<sub>2</sub> pulse values were collected every 10 s during the maximum CPET and divided by the athlete's body weight to provide the relative O<sub>2</sub> pulse. To facilitate reading of the data, the relative O<sub>2</sub> pulse values were multiplied by 100. To minimize the intrinsic variability of ventilatory measurements, the maximum relative VO<sub>2</sub> and the maximum relative O<sub>2</sub> pulse were defined as the highest mean values obtained from a 10-s interval during the maximum CPET.

### Data processing

The CPET data were analyzed at intervals equaling 10% of the maximum effective running time (as previously explained) for each player, corresponding to approximately one-minute time intervals. This approach allowed us to compare data at specific intervals regardless of the final treadmill speed achieved. To test the hypothesis of this study, the players were divided into quartiles according to their maximum HR values. For this initial analysis, we considered the extreme quartiles, Q1 and Q4, to represent the lowest and highest maximum HR values.

### Statistical analysis

The results of CPET for Q1 and Q4 were compared in two distinct ways: 1) analyzing the HR, relative VO<sub>2</sub> and O<sub>2</sub> pulse values at intervals representing 10% of each individual's running time using a two-way ANOVA (with group and % of the CPET duration as factors) with Bonferroni

post-hoc procedures as needed; and b) using the coefficient of determination, slope and intercept for the linear regressions of the relative O<sub>2</sub> pulse curves; these were compared using Student's t-test.

To determine the normal standards for relative O<sub>2</sub> pulse curves in young, healthy individuals with high aerobic fitness, we analyzed data from all 180 players, regardless of the maximum recorded HR. The coefficient of determination, slope and intercept of each relative O<sub>2</sub> pulse curve were also calculated following the same criteria adopted for the quartiles.

In addition, we verified the plateau frequency in the VO<sub>2</sub> and relative O<sub>2</sub> pulse curves during CPET in these elite soccer players. The VO<sub>2</sub> curve was considered to have reached a plateau when the difference between the averages of the measurements for the last two minutes of the CPET was less than 1.4 mL O<sub>2</sub>·kg<sup>-1</sup>·min<sup>-1</sup>. This criterion for defining a plateau in the VO<sub>2</sub> curve is similar to what has been used in previous studies,<sup>3,18</sup>. The O<sub>2</sub> pulse curve was considered to have reached a plateau when an absence or decrease at this variable was observed in the last two minutes of CPET. The plateau frequencies between the groups were compared using a chi-squared test to determine whether this behavior could be influenced by extreme HR values. The same procedure was applied to test the hypothesis that there was no difference between Q1 and Q4 with respect to the positions played by each player. For this analysis, the players were divided according to the following positions: goalkeepers, defenders, midfielders and forwards. Finally, we assessed the relationship between maximum HR and age using a linear regression analysis.

We considered p<0.05 as the criterion for statistical significance. All descriptive data are presented as mean and standard deviation, and the data from the inferential analyses are reported as the mean and standard error of the mean. The analyses were performed using Prism software version 5.01 (GraphPad; San Diego, United States).

## RESULTS

### Comparison between groups

Among the 180 soccer players included in this study, there was an inverse and relatively weak relationship between age and maximum HR ( $r = -.23$ ;  $p < .01$ ). Table 1 shows the demographic data and cardiopulmonary responses for the entire sample and for Q1 and Q4 based on the maximum CPET results. Participants in Q1 were slightly older ( $p < .01$ ), although the mean difference was only two years.

The relative VO<sub>2</sub> did not significantly differ between the subjects in Q1 and Q4 at any of the CPET time intervals. Starting when 20% of the CPET duration was complete, the HR was lower among the participants in Q1. Conversely, the relative O<sub>2</sub> pulse was higher in the Q1 when 40% of the CPET duration was complete ( $p < 0.01$ ) (Figure 1).

The linear regression model for the relative O<sub>2</sub> pulse fit equally well for both quartiles, as shown by the high coefficients of determination ( $0.69 \pm 0.03$  and  $0.67 \pm 0.02$  for the first and fourth quartiles, respectively). The values of the slope and the intercepts of the relative O<sub>2</sub> pulse curves for participants in Q1 (lower maximum HR values) were  $0.015 \pm 0.001$  and  $23.2 \pm 0.5$ , respectively, and for participants in Q4 (higher maximum HR values), they were  $0.014 \pm 0.001$  and  $21.1 \pm 0.6$ , respectively. Whereas the relative O<sub>2</sub> pulse curve slopes were virtually identical between the quartiles ( $p = .25$ ), the curve intercepts differed ( $p < .01$ ).

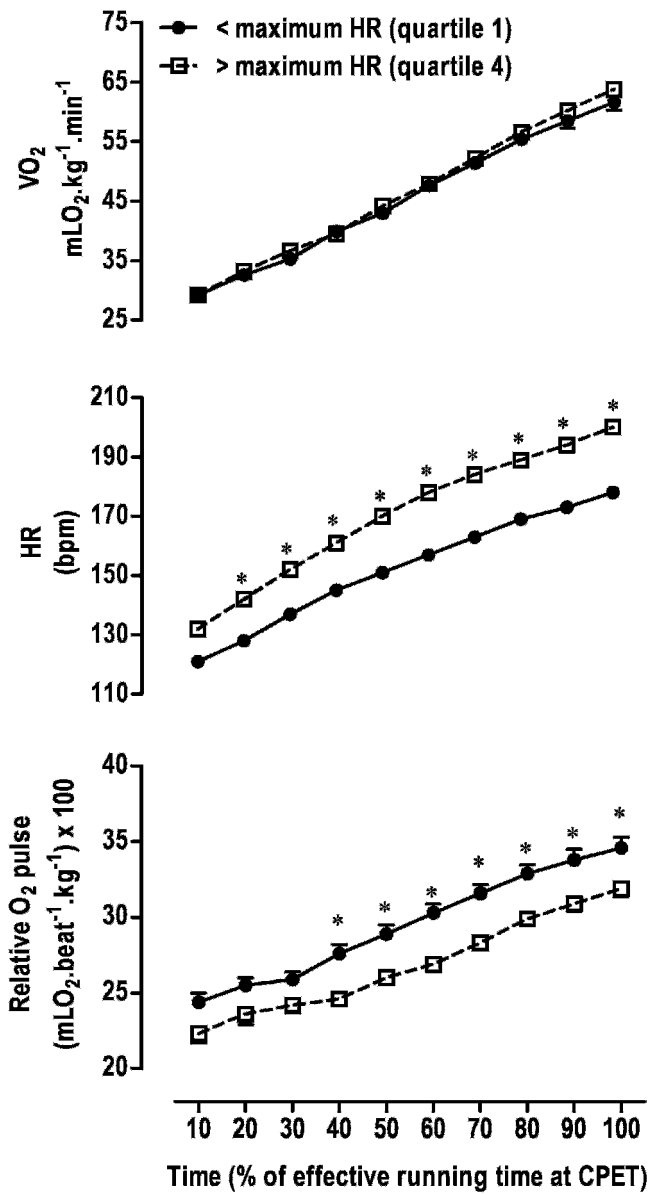
### Normal values for the relative O<sub>2</sub> pulse curve

The average exercise time during CPET was  $13.2 \pm 1.2$  min. The maximal relative O<sub>2</sub> pulse ( $\times 100$ ) value was  $33.4 \pm 4.0$  mL O<sub>2</sub>·beat<sup>-1</sup>·kg<sup>-1</sup>. The coefficient of determination, slope and intercept for the relative O<sub>2</sub> pulse curves were  $0.68 \pm 0.18$ ,  $0.014 \pm 0.006$  and  $23.0 \pm 3.2$ , respectively. Figure 2 shows the behavior of the relative VO<sub>2</sub>, HR and

**Table 1 - Demographic characteristics and exercise responses during CPET in the entire sample and for the Q1 and Q4 quartiles.**

| VARIABLE   | Total<br>n = 180             | Q1<br>n = 45                 | Q4<br>n = 45                 | p-value |
|--|------------------------------|------------------------------|------------------------------|---------|
| Age (years)  | 24 ± 0.3<br>(16-35)          | 26 ± 0.6<br>(18-35)          | 23 ± 0.6<br>(19-35)          | 0.007*  |
| Weight (kg)  | 75.1 ± 0.6<br>(54.0-102.0)   | 75.1 ± 1.0<br>(59.4-89.0)    | 77.2 ± 1.3<br>(54.0-102.0)   | 0.197   |
| Height (cm)  | 178.3 ± 0.5<br>(161.8-193.4) | 179.3 ± 1.0<br>(167.8-193.4) | 180.2 ± 1.0<br>(161.8-190.8) | 0.506   |
| Max treadmill speed (km/h)   | 18.5 ± 0.1<br>(15.2-21.0)    | 18.3 ± 0.2<br>(15.2-20.0)    | 18.6 ± 0.1<br>(16.0-20.8)    | 0.101   |
| Rest heart rate (bpm)  | 58 ± 1<br>(39-98)            | 57 ± 1<br>(40-80)            | 63 ± 2<br>(43-98)            | 0.009*  |
| Max HR (bpm)   | 190 ± 1<br>(164-216)         | 178 ± 1<br>(164-183)         | 202 ± 1<br>(196-216)         | <0.001* |
| VE (L·min <sup>-1</sup> )  | 119 ± 1.4<br>(74-189)        | 112 ± 3.0<br>(74-155)        | 124 ± 2.2<br>(85-155)        | 0.002*  |
| Max VO <sub>2</sub> (mL O <sub>2</sub> ·kg <sup>-1</sup> ·min <sup>-1</sup> )                      | 62.7 ± 0.5<br>(40.9-82.0)    | 64.4 ± 1.2<br>(42.7-83.0)    | 66.7 ± 1.1<br>(52.3-85.7)    | 0.188   |
| Max O <sub>2</sub> pulse (mL O <sub>2</sub> ·beat <sup>-1</sup> )                                  | 25.0 ± 0.3<br>(16.6-34.2)    | 25.7 ± 0.5<br>(18.0-34.2)    | 24.3 ± 0.4<br>(16.6-30.3)    | 0.041*  |
| Max relative O <sub>2</sub> pulse (mL O <sub>2</sub> ·beat <sup>-1</sup> ·kg <sup>-1</sup> ) x 100 | 33.4 ± 0.3<br>(23.6-45.1)    | 34.3 ± 0.7<br>(23.6-43.9)    | 31.7 ± 0.5<br>(25.9-39.8)    | 0.003*  |

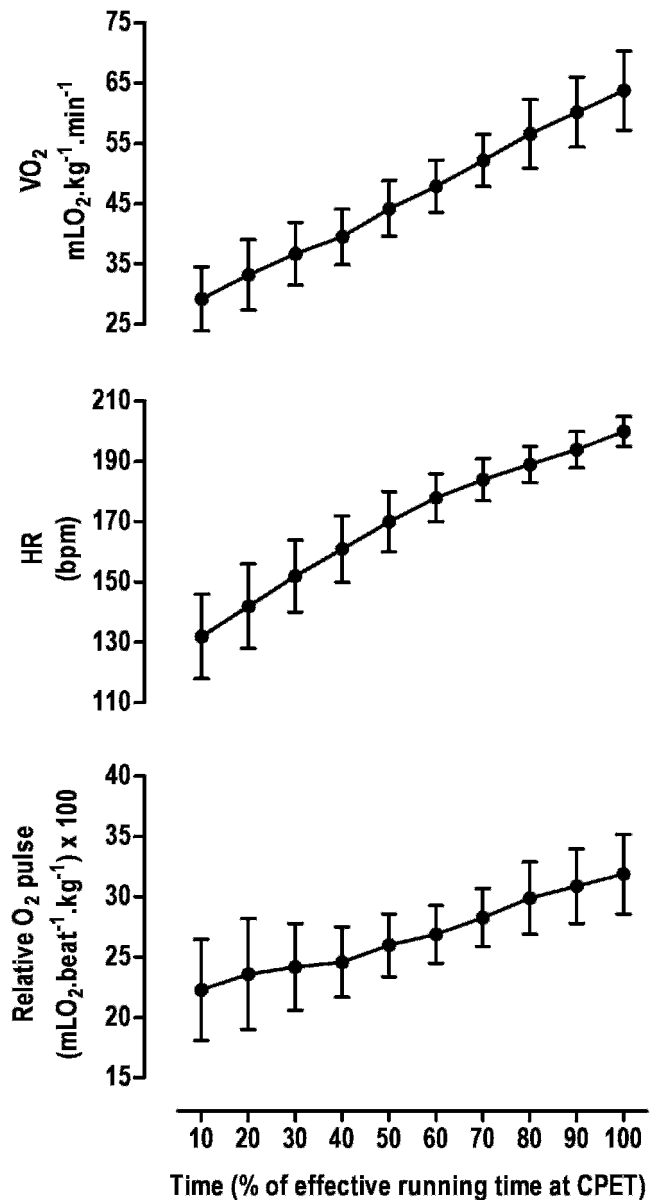
Values are expressed as mean ± SEM (minimum-maximum). Max HR, maximum heart rate; VE, minute ventilation; Max VO<sub>2</sub>, maximum oxygen consumption; Max O<sub>2</sub> pulse, maximum oxygen pulse; First quartile (Q1), < maximum HR; Fourth quartile (Q4), > maximum HR. \* - significant difference between Q1 and Q4 ( $p < 0.05$ ).



**Figure 1** - Heart rate, oxygen consumption and oxygen pulse curves during maximal cardiopulmonary exercise testing for athletes at extreme quartiles of maximum heart rate (n = 45). Error bars represent the standard error of the mean.

relative O<sub>2</sub> pulse in response to the increase in treadmill velocity. Each value is plotted as a percentage of the maximum CPET running time.

The VO<sub>2</sub> curves for a total of 67 (37%) subjects reached a plateau according to the criterion defined for this study, and the average relative VO<sub>2</sub> variation between two consecutive minutes was  $2.2 \pm 2.1 \text{ mL O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ . Among the subjects whose VO<sub>2</sub> curves reached a plateau, 10 were from Q1, and 17 were from Q4 (p = .17); the remaining players were in Q2 and Q3. Similarly, when the entire sample of 180 soccer players was considered, a plateau was observed for the relative O<sub>2</sub> pulse values at the end of CPET in 20% of the study participants, including 9 from Q1 and 14 from Q4. As previously described, these subjects showed no increase or reduction in this variable during the last two minutes of

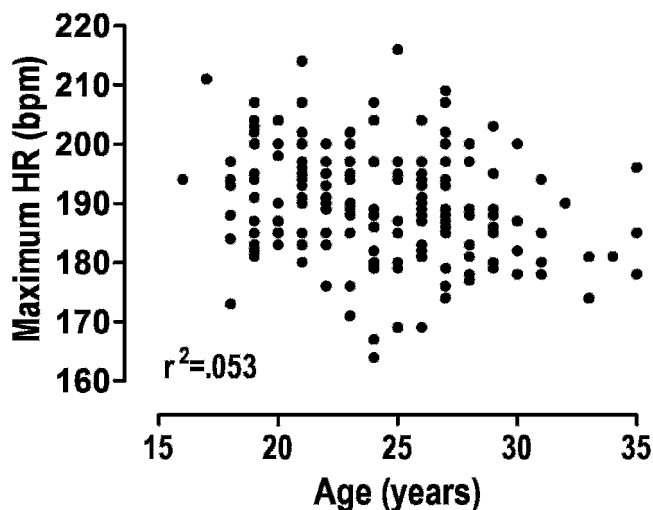


**Figure 2** - Heart rate, oxygen consumption and oxygen pulse curves for soccer players during maximal cardiopulmonary exercise testing (n = 180). Error bars represent the standard deviation of the mean.

CPET (p = 0.33). Additionally, the positional roles on the soccer field were similar between Q1 and Q4 (p = .87).

## DISCUSSION

This study assessed trends in VO<sub>2</sub>, HR and the relationship between these two variables among healthy young male athletes with high aerobic fitness under controlled exercise conditions, in which the intensity was gradually increased to a maximum level. We compared these responses between athletes at high and low extremes of maximum HR values. The results indicate that the relative VO<sub>2</sub> levels at all of the intervals analyzed as percentages of the total exercise time were not significantly different between the groups. Nevertheless, as expected, HR values



**Figure 3** - Relationship between maximum heart rate (HR) values and age in a sample of 180 professional soccer players.

were lower in the group with a lower maximum HR starting at the time point corresponding to 20% of the CPET; consequently, starting at the time point corresponding to 40% of the CPET, we observed an opposite trend in the relative  $O_2$  pulse curve. Specifically, the participants in Q1, who had lower maximum HR values, had higher average relative  $O_2$  pulse values when compared with the participants in Q4. Figure 1 shows the behavior of  $VO_2$ , HR and relative  $O_2$  pulse expressed as a percentage of the duration of the running time in the CPET. Considering the adequacy of the linear regression models for analyzing the relative  $O_2$  pulse curves as indicated by the high coefficients, we were able to compare the intercepts and slopes of the curves for the two groups, which had similar slopes and distinct intercepts.

Interestingly, as illustrated in Figure 3, our results show a weak inverse relationship between the maximum HR and the age of the players, supporting the idea that, although maximum HR tends to decrease with age, this may vary considerably between young individuals and is poorly predicted by general formulae. We therefore chose to analyze the subjects of this study using quartiles that were assigned based on the maximal HR achieved during CPET regardless of age.

We found that the trends for the relative  $VO_2$  were similar for both groups and that they remained directly related to the exercise intensity during the CPET despite the variability in the HR and relative  $O_2$  pulse values. Thus, although there was a difference between the relative  $O_2$  pulse curves observed in the extreme quartiles, HR compensated for this discrepancy at most of the intervals defined as the percentage of the maximal CPET time; i.e., we observed lower HR values in the group with higher relative  $O_2$  pulse values. As shown in Figure 1, even at the earliest intervals of the CPET, when relative  $O_2$  pulse and HR did not differ statistically between the extreme quartiles, participants in Q1 already had a lower HR and higher relative  $O_2$  pulse. Other studies have shown<sup>19-21</sup> a strong association between  $VO_2$  and cardiac output in incremental exercise tests. This suggests that both  $VO_2$  and cardiac output should have been similar between the groups during the CPET. Thus, even with the differences in HR and relative  $O_2$  pulse

between the groups, there were no differences in the demand of the active muscles for oxygen at any time point, and there were no marked differences in mechanical efficiency. In addition, the lack of differences between the slopes of the relative  $O_2$  pulse curves suggests that these trends were not affected by differing maximum HR values and that the proportion of the increase in the relative  $O_2$  pulse did not vary between the groups during the CPET. On the other hand, the intercept of the relative  $O_2$  pulse curves was significantly lower in the group with higher maximal HR values, suggesting that changes in cardiac output in response to incremental increases in exercise intensity occurred with a proportionally smaller SV.

For some of the soccer players in both groups, a pronounced plateau or decreasing pattern was observed in the relative  $O_2$  pulse curve. The reason for this is that, whereas HR tends to present a linear pattern throughout the CPET,  $VO_2$  often damps during the last minutes. When exercise intensity exceeds the anaerobic threshold, a higher proportion of the energy produced will come from anaerobic metabolism, which allows the subject to tolerate the increase in exercise intensity without any further increase in  $VO_2$ . In this context, HR continues to increase throughout the entire CPET duration, whereas  $VO_2$  follows a less steep pattern or even keeps constant, resulting in a plateau of the relative  $O_2$  pulse. Because the  $O_2$  pulse can be considered a surrogate for SV, this finding corroborates the observations described in other studies<sup>15,16,21-23</sup> that suggest a trend of continuously increasing SV in high-performance athletes during a maximal CPET. For example, Gledhill et al.<sup>15</sup> reported a continuous increase in SV in elite cyclists during a maximum CPET. Notably, the athletes in the Gledhill study had high HR values (180-190 bpm), which were comparable to those found in the athletes who participated in the present study. Similarly, Zhou et al.<sup>16</sup> observed that in elite long-distance runners, the SV increased (by approximately 52 mL) between light and maximum exercise intensities during CPETs. Although it may be possible to observe a continuous SV increase during a CPET with increasing intensity, these studies analyzed individuals with a higher maximal aerobic power than that found in our sample of professional soccer players. Based on these results, we sought to compare the SV behavior in individuals with similar aerobic conditioning to our sample. Vanfraechem<sup>21</sup> assessed 17 well-trained soccer players at 25%, 50% and 75% of the maximum  $VO_2$  and reported an SV increase of 37% between 50% and 75% of the maximal aerobic capacity. This suggests that it is possible to produce increases in SV during more intense exercise in healthy individuals with high aerobic fitness. Thus, in different studies and populations with similar or even greater aerobic fitness, the linear pattern of the SV response to increasingly intense exercise appears to be feasible, at least for the large majority of the subjects, despite the significant reduction in the ventricular filling time that occurs during a very intense effort.

It is important to mention that these studies' results are in contrast the conventional view that SV tends to plateau starting at 40-50% of maximum  $VO_2$  in progressive exercise tests.<sup>12,13,24</sup> In some of these studies,<sup>12,13</sup> the aerobic conditioning of the subjects was relatively low. Boutcher et al.,<sup>24</sup> however, also failed to observe increases in SV during the final stage of the CPET even among trained subjects, although it was concluded that there were

differences in the SV when comparing non-trained, active and aerobically-trained men. However, a detailed analysis of these responses revealed that the HR was only analyzed to 150 bpm due to excessive movements that hindered the continuity of data collection, and the authors were unable to observe whether the SV increased beyond that point.

As our sample was composed only of individuals with a high level of aerobic conditioning ( $\text{VO}_2 = 66.2 \pm 7.4 \text{ mL O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ), it is likely that their inotropic and lusitropic cardiac characteristics prevented the SV from being substantially limited at the end of the CPET, even in individuals with high HR values. Studies on cardiac structure<sup>25,26</sup> show significant differences in the posterior wall and interventricular septum thickness in the heart and differences in the dimensions of the left ventricular in aerobically trained individuals cavity when compared with apparently healthy sedentary individuals. These findings could contribute to the preservation of a high SV in conjunction with a highly elevated HR at peak exercise. Additionally, it has been argued<sup>16,27</sup> that a lower resistance offered by the pericardium in aerobically trained individuals may explain an elevated end-diastolic volume and a potential for further increases in SV by the Frank-Starling mechanism, even in the final minutes of the CPET. Data obtained in dogs appear to show that this mechanism is physiologically possible,<sup>28</sup> as these animals were able to generate an increase in the end-diastolic volume and SV after pericardiotomy.

The characteristics of the  $\text{O}_2$  pulse curve were previously analyzed by other authors<sup>29</sup> who scored  $\text{O}_2$  pulse curve behavior according to reference values. However, the criteria they adopted appear to be subjective and oversimplify the phenomenon; moreover, this method has not been adopted in other studies since its original publication. Another objective of this study was to define a standard for the relative  $\text{O}_2$  pulse curve in young, healthy males with high aerobic fitness. Although the  $\text{O}_2$  pulse has been consistently reported in the literature in absolute terms ( $\text{mL O}_2 \cdot \text{beat}^{-1}$ ),<sup>7,8,10,30,31</sup> it is known that obese individuals have higher submaximal  $\text{VO}_2$  values when compared with non-obese individuals at the same exercise intensity due to gravity effects and the greater effort that is required for obese individuals to run at a fixed velocity.<sup>5</sup> Thus, although two individuals may have the same maximum  $\text{O}_2$  pulse, their functional capacity (measured by maximum running speed) can vary significantly. Therefore, to avoid the influence of body dimension variability on  $\text{O}_2$  pulse values, we analyzed this variable relative to body weight ( $\text{mL O}_2 \cdot \text{beat}^{-1} \cdot \text{kg}^{-1}$ ), as was recently done in other studies of our group.<sup>7,23,32</sup> Therefore, our reported relative  $\text{O}_2$  pulse values allow the extrapolation of the results to a wider range of individuals and situations. Our results indicate that relative  $\text{O}_2$  pulse is quasi-linear throughout a CPET. This was somewhat less evident in the last two minutes, and it was independent of the final maximum treadmill speed or the magnitude of the maximum HR.

One final salient observation was that the presence of a plateau in  $\text{VO}_2$  is rather uncommon, as it occurs in only about one third of the players. This is consistent with other studies that have reported similar percentages for  $\text{VO}_2$  plateaus when trained individuals were evaluated.<sup>1,3</sup> Concerning relative  $\text{O}_2$  pulse curves, a flattening or decrease in the last two minutes of CPET was seen in 36 (20%) of the 180 players. Additionally, our data indicate that the

occurrence of plateaus in the  $\text{VO}_2$  and relative  $\text{O}_2$  pulse curves was not significantly influenced by the magnitude of the maximal HR achieved in these professional male soccer players.

This study has several limitations. Importantly, we did not directly measure cardiac output, arteriovenous  $\text{O}_2$  differences or SV. Therefore, the behavior of the SV can only be inferred from the relative  $\text{O}_2$  pulse data. In addition, we did not acquire invasive readings of the mean arterial pressure during CPET. These readings could contribute to a better understanding of the mechanisms that allow an increase in SV in young individuals with good to excellent aerobic conditioning. Additional studies employing other methodologies for data collection are necessary to further understand these issues.

## CONCLUSION

The major finding of this study is that a shorter diastolic filling time, as seen in young, healthy and fit athletes with high maximum HR values, did not influence the shape of the relative  $\text{O}_2$  pulse curve, suggesting that the SV profile was likely to be unaffected. Relative  $\text{O}_2$  pulse also tended to increase in a linear fashion throughout a maximal CPET. However, in 20% of these young, healthy and aerobically fit soccer players, regardless of the maximal HR achieved, the relative  $\text{O}_2$  pulse curve did not increase in the last two minutes of CPET, which suggests that there is some physiological limitation of stroke volume in these individuals.

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