CARDIOPULMONARY EXERCISE TEST: A CASE REPORT

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Introduction

Cardiopulmonary Exercise Test (CPET) is used on a wide spectrum in clinical and exercise settings. It involves making the subject work against gradually increasing exercise intensity until volitional exhaustion is achieved or limiting signs / symptoms start appearing. CPET provides a comprehensive and integrated assessment of the respiratory, cardiovascular, skeletal and metabolic system responses to exercise, and hence is considered gold standard for cardiorespiratory functional assessment(Herdy *et al.,* 2016).

Diminished exercise tolerance is an important marker of underlying cardiac, respiratory or neuromuscular diseases. CPET is a non-invasive procedure that provides a wealth of information that can be used to determine the cause of exercise limitations or unexplained dyspnea and outperforms various invasive and non-invasive procedures like ischemic markers or hemodynamic pressures as measure of cardiac performance. Apart from its applications for screening cardiac abnormalities and risk stratification(Gibbons, Mitchell, Wei, Blair, & Cooper, 2000), it is an important cornerstone for exercise prescription and measurement of efficacy of training in clinical, healthy and athletic population. Owing to the tremendous research in the past decade, the use of CPET is rapidly increasing in apparently healthy individuals and sports medicine. CPET has been proved reliable and valid method for determining exercise capacity in healthy adults(Eriksen, Tolstrup, Larsen, Grønbæk, & Helge, 2014). CPET is an important tool for optimizing training, screening cardiac abnormalities and monitoring the progression in exercise capacity in sports and exercise physiology. Pre-exercise test health screening and risk stratification is an important step in exercise and should always precede CPET to ensure safety(Thompson, Arena, Riebe, & Pescatello, 2013).

Aims and Objectives

The aims of this report are

1. To determine the exercise capacity of the participant
2. To identify the primary cause of exercise limitation
3. To decide an optimal training zone for him

With the objective of improving his endurance and performance in recreational sports i.e. football.

Methods

To determine the maximal exercise capacity of the participant, an incremental cycle exercise test using a ramp protocol(Myers et al., 1991; Whipp, Davis, Torres, & Wasserman, 1981) was conducted. The test was performed on the General Electric ergometer eBike cycle ergometer, connected to a breath Analyzer (Oxycon Prometabolic System). A continuous ramp pattern was used as it ensures steady and smooth increase in workload. The breath analyzer was calibrated using a 3L calibration syringe to achieve 20.93 ± 0.03% O2 and 0.03 ± 0.02% CO_2. (Balady *et al.,* 2010).The estimated ramp for the participant was calculated using the (Buchfuhrer *et al.,* 1983) guidelines to 25 Watts/min. The heart rate was monitored using a polar heart rate monitor and modified placement(Mason & Likar, 1966) 12 lead ECG connected to Marquette Hellige Cardiosmart ECG monitoring system.

The participant is a 26-year-old non-smoker without any diagnosed cardiovascular or pulmonary disease. He is a recreational football player and follows a moderate intensity workout involving aerobic and strength training thrice a week. The test was performed in the biomechanics lab under the supervision of trained exercise physiologists. The participant was advised to wear comfortable sportswear and shoes for the test. Before commencing the test, participant was informed about the test procedure, his responsibilities during the test, safety, potential discomfort and risks associated with the procedure. He was advised he must make a maximal effort, but the test can be stopped at any time if he experiences discomfort. He was familiarized with the test equipment, ensured about the data protection and encouraged to ask questions about the test before giving written consent to participate. After pre-test screening, participant's anthropometric data (Table 1), resting heart rate and RPE was recorded on the case report form. Resting ECG was recorded in supine followed by test position i.e. sitting on the cycle ergometer. A Hans Rudolph mask with mouthpiece connected to the breath analyzer is then strapped across his face, making sure that it creates a seal preventing outside side to enter in the mask. The participant was discouraged from talking during the test as this affects the gas exchange variables.

Table.1. Anthropometric characteristics of the participant

Age (years)	Gender	Height (cm)	Weight (kg)	BMI (kg/m²)	Fat Free Mass (kg)
26	Male	185	87.10	25.46	71.48

The test began with 3 minutes of unloaded cycling followed by a standard and steady increase in ramp 25W every minute till exhaustion was achieved. The participant was instructed to maintain speed of 60-70 rpm when cycling. HR and RPE was recorded in the last 5 second of unloaded cycling, every minute in the loaded cycling phase and up to 5 mins of recovery using 20-point Borg's scale. The participant being apparently healthy, systolic BP and SPO2 were not recorded, however the participants HR and ECG was monitored continuously throughout the test and recovery period. The respiratory data was registered by the breath analyzer. By the end of the test, the participate was given verbal encouragement to give his maximum effort. The test was terminated when the participant could not continue further at the required speed and highest perceived fatigue levels were achieved (RPE- 20). During the recovery period the participant was encouraged to continue cycling for few minutes at minimum resistance followed by no resistance before stopping the exercise to ensure active recovery and prevent peripheral pooling of blood. The basal parameters returned to resting values after 4 mins of stopping exercise test. To supplement the data obtained from CPET, spirometry was also performed.

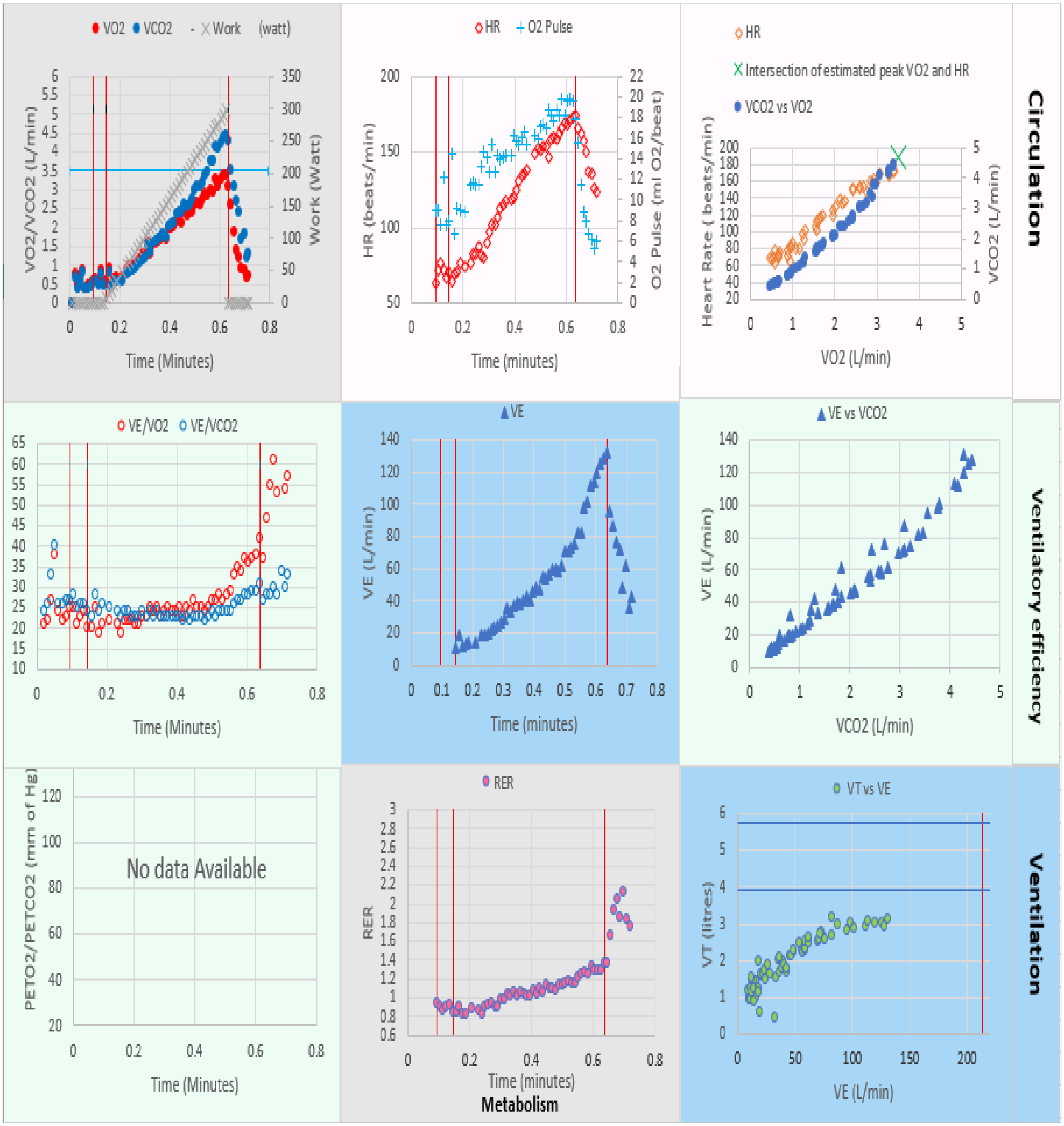
Results

The data so obtained was then examined to verify if the participant achieved his maximal efforts and used to plot graphs on the 9-panel plot. In the absence of any gold standard in current literature, the test was considered maximal as all four maximal effort criteria by (Nichols, Taylor, & Ingle, 2015) were satisfied.

Table.2. Maximal effort criteria

- ☑ Failure of heart rate to increase with further increases in exercise intensity (achieving >85% of age-predicted maximal heart rate is a well-recognized indicator of patient effort)
- ☑ A plateau in VO2 (or failure to increase by 150 ml/min) with an increased workload
- ☑ A respiratory exchange ratio (= VCO2/VO2) at peak exercise >1.10
- ☑ A rating of perceived exertion >17 on the 6–20 Borg scale or >9 on the 0–10

The highest values of VO_2 and HR obtained on visual interpretation of the raw data in the last 30 secs of exercise and first 15 secs of recovery were averaged to determine the peak VO_2 and HR. The information obtained from the test is displayed in the standardized 3 X 3 graphic array display, the 9-panel plot as described by Wasserman et al. (2012). Fixed time frame data averaging method – at 15 seconds interval; was used to select data points for the graph. Since some of the data required for the 9 panels was not available, it was not possible to plot all 9 graphs. Panel 7 could not be plotted as oxygen saturation and the end tidal O_2 and CO_2 tension values were not recorded, while the panel 5 is incomplete due to unavailability of SBP values. Figure.1. displays the 9-panel plot, each graph from this plot is later viewed and explained individually for better interpretation of the information on the graphs. The graphs in panel 1, 2, 4, 5 and 8 are all plotted with time on the X-axis, however as workload increases linearly with time, we will obtain exactly similar graphs if they are plotted with workload on X-axis, hence when comparing similar variables against workload, the same graphs are referred, unless there is a need for separate graph with workload.



Maximal exercise test of healthy 26-year-old male participant. Nine-panel plot graphical display according to (Wasserman et al., 2011) , with a 15-second averaging of the data. Panel 2 and 3 reflect circulatory parameters (red areas). Panels 5 and 9 show ventilatory parameters (blue areas). Panels 4 and 6 reflects parameters of ventilatory efficiency (green areas). Panel 8 reflects general metabolic changes. Panel 1 has a central role in determining the exercise capacity. The vertical lines in the panels 1, 2, 4, 5 and 8 indicate, from left to right, the start of unloaded pedaling phase, the start of incremental work rate increase, and the end of exercise phase, respectively. The horizonal blue line in panel 1 indicates the predicted peak VO_2. The horizontal blue lines in panel 9 represents Ventilatory capacity (VC) and Inspiratory capacity (IC) from above downwards while the vertical red line marks the Maximum Voluntary Ventilation (MVV).

Figure.1. The nine-panel plot

Peak Oxygen uptake

As seen in Figure.2, the oxygen uptake increases steadily with time throughout the test and a clear plateau in VO2 curve is reached towards the end of ET. The peak VO_2 achieved by the participant is 3.4L/min (39.03 ml/kg/min) which is 97.69% of his predicted peak VO_2 calculated using the Wasserman et al. equation [3.5 L/min (40.18 ml/kg/min)]. The VO_2- WR slope was 10.18 (Figure.3.)

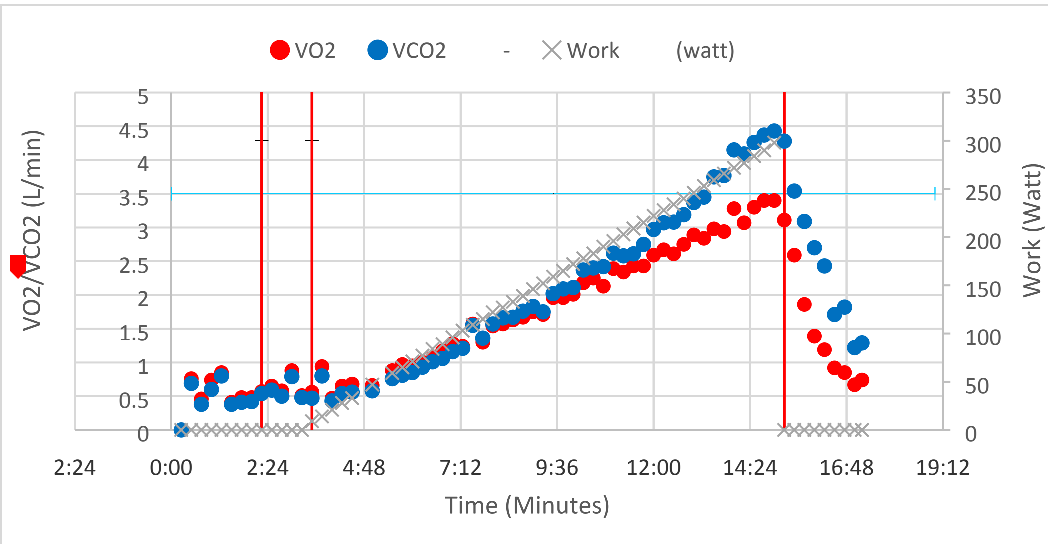


Figure.2. Panel-1: Rate of change of VO_2, VCO_2 and WR

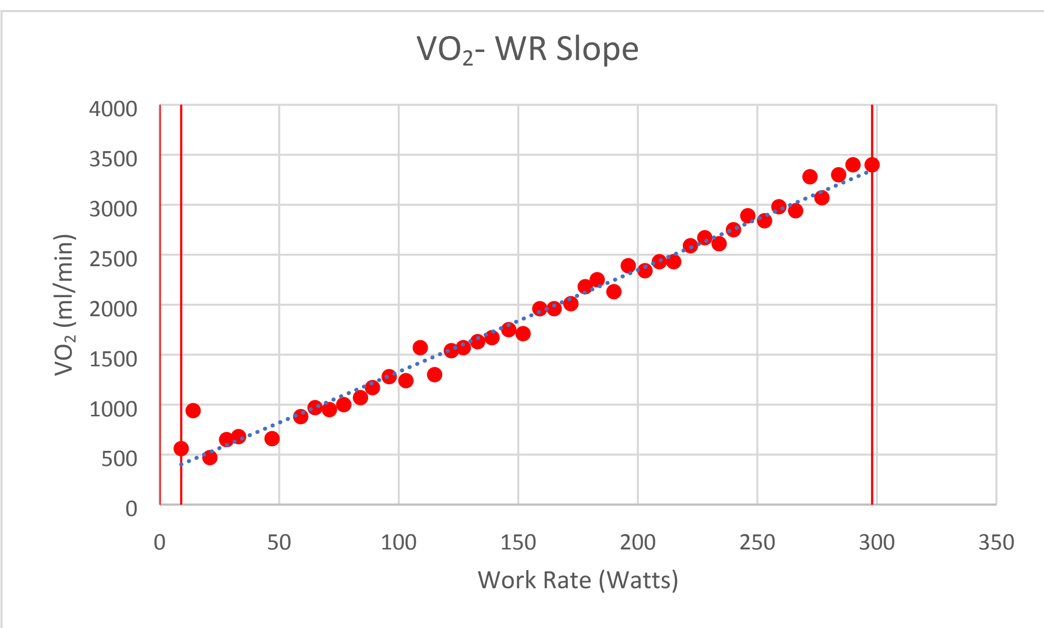


Figure.3. VO_2 response to increasing workload

Ventilatory Anaerobic threshold (VAT)

Ventilatory threshold is the point in CPET where ventilatory parameters exhibit a threshold like response during progressive exercise i.e. ventilation starts to increase at a faster rate than VO_2; it is thought to be a reflection of the concpet of anaerobic threshold (Wasserman et al, 2012).The VAT was determined primarily by the V-slope method. As seen from the graph, the VCO_2 increases linearly in relation to VO_2 in the initial part of the exercise, and then the rate of rise VCO_2 exceeds that of VO_2 creating a breakpoint in the graph. The VAT is identified at the point of intersection of the two best fit lines across the data points, which corresponds to around 1.8L O_2 /min for our participant. That is 20.66ml/kg/min which is 52.93% of his peak VO_2.

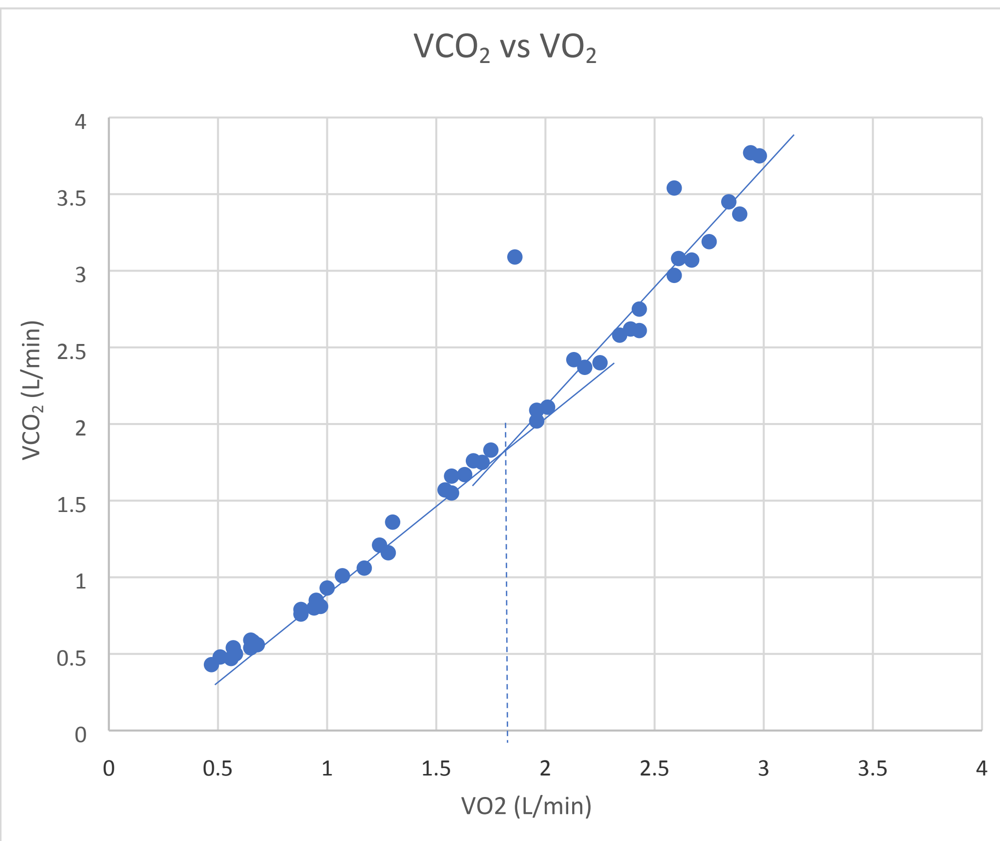


Figure.4. The V-Slope method for identifying the ventilatory threshold.

To improve the approximation of VAT, the presence of VAT can also be identified using 9-panel plot. As seen from figure.5, the ventilatory equivalents for both O_2 and CO_2 remain stable through the early part of exercise and then start increasing steadily, with the increase in VE/VO_2 coming before the VE/VCO_2. The point at which the VE/VO_2 starts increasing while the VE/VCO_2 still remains constant or decreases denotes the VAT, corresponding to approximately 9 mins in the ET at the value of VE/VO_2 being 23. This is equal to VO_2 of 1.75 L/min (20.09ml/kg/min), approximately equal to that determined by V-slope method.

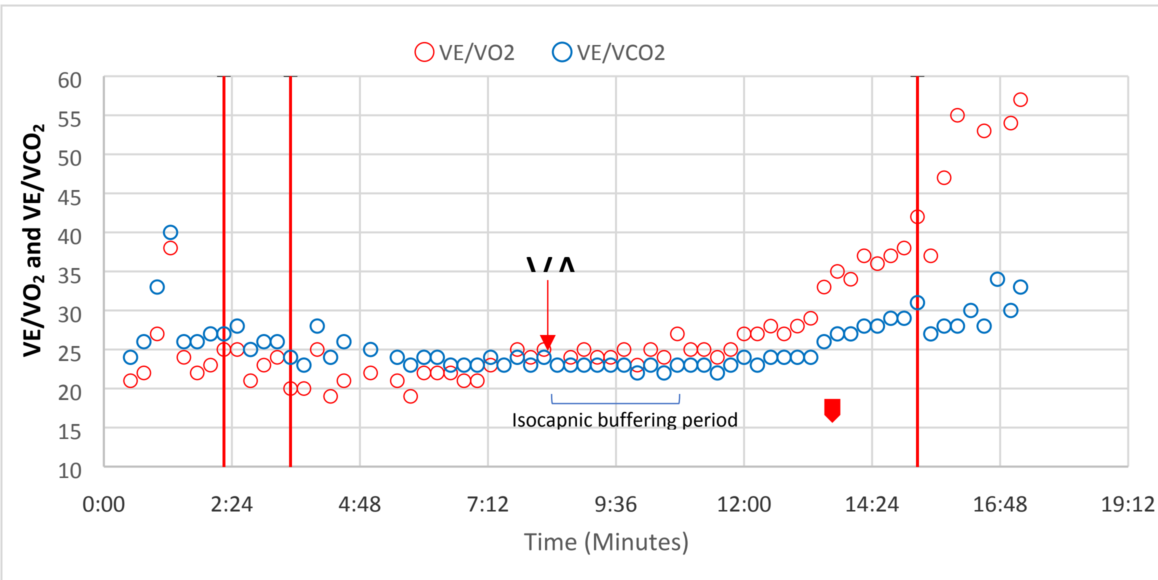


Figure.5. Using changes in Ventilatory equivalents as a mean to identify whether ventilatory threshold is present.

In response to increasing workload, VCO_2 (Figure.2) and VE (Panel-5) increase in a linear pattern at low work rates and changes to curvilinear pattern at high work rates, while VO_2(figure.2) continues to increase in a linear pattern. Therefore, if we plot the ventilatory equivalents against workload; as VE/VO_2 increases-VE/VCO_2 remains constant for a brief period, this marks the isocapnic buffering period. As the workrate increases further, the ventilatory stimulation is intensified in response to reducing pH, the respiratory compensation for metabolic acidosis begins and is reflected by increase in VE/VCO_2 and further increase in VE/VO_2.

Heart Rate Response

The HR response to CPET can be observed in Figure 6. We see a steady increase in HR over time throughout the ET and a similar gradual decrease in recovery period. The O_2 pulse on the other hand rises and falls immediately at the start of exercise and recovery period respectively. In figure.7, we observe a linear increase in HR over VO_2, with the curve approaching the point of intersection of predicted maximum HR and VO2 for the participant. The HRR at the end of ET was 15 beats. The HR max achieved was 174 beats/min that is 92.06% of age predicted HR $_{max.}$(Gellish et al., 2007)

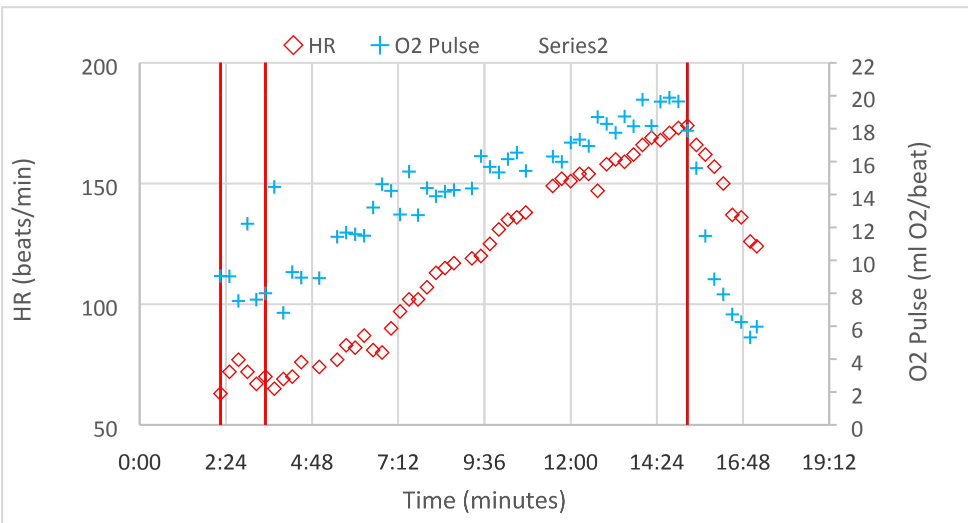


Figure.6. Panel-2: HR and O_2 pulse across time

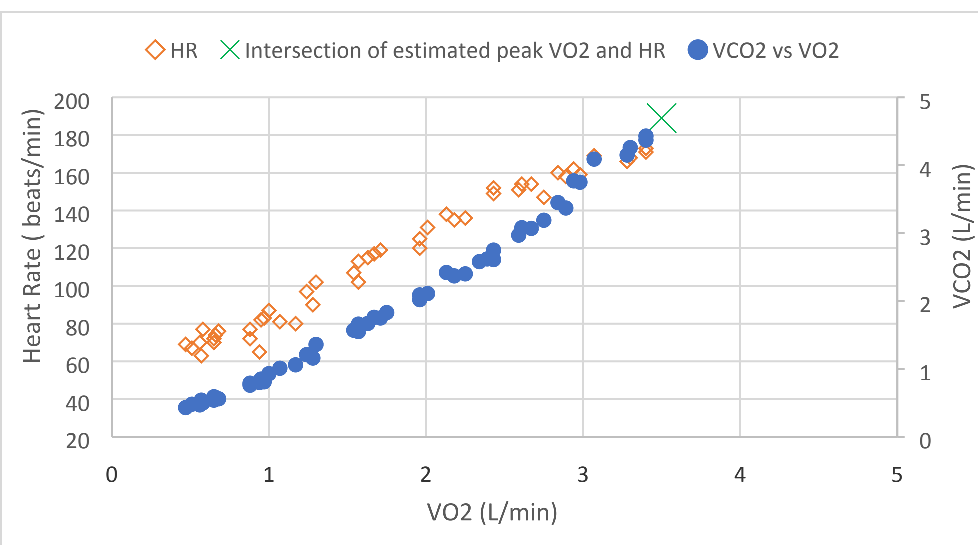


Figure.7. Panel-3: HR and VCO_2 against VO_2

Ventilatory efficiency

The ventilatory efficiency can be visualized in figure.8, we observe VE shows a linear relationship with VCO2 through most part of the exercise, however close to maximal exercise the linearity between VE and VCO2 starts changing, this marks the respiratory compensation point (RCP). The slope of the VE/VCO_2 curve below RCP is 23.71 and the Y axis intercept of the plot is positive, which explains the decreasing VE/VCO_2 during exercise(P-4). The VE/VO_2 slope being a better prognostic indicator than OUES (Arena et al., 2007) was primarily used to determine the ventilatory efficiency. However, the absolute OUES for him was also determined and was 2743.9.

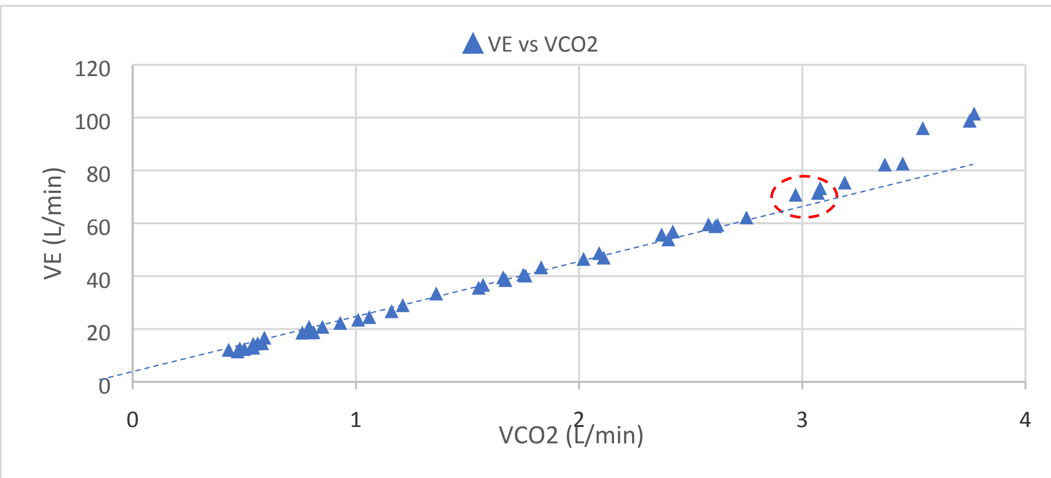


Figure.8. Panel-6: Ventilatory efficiency; The area covered by the red circle marks the RCP.

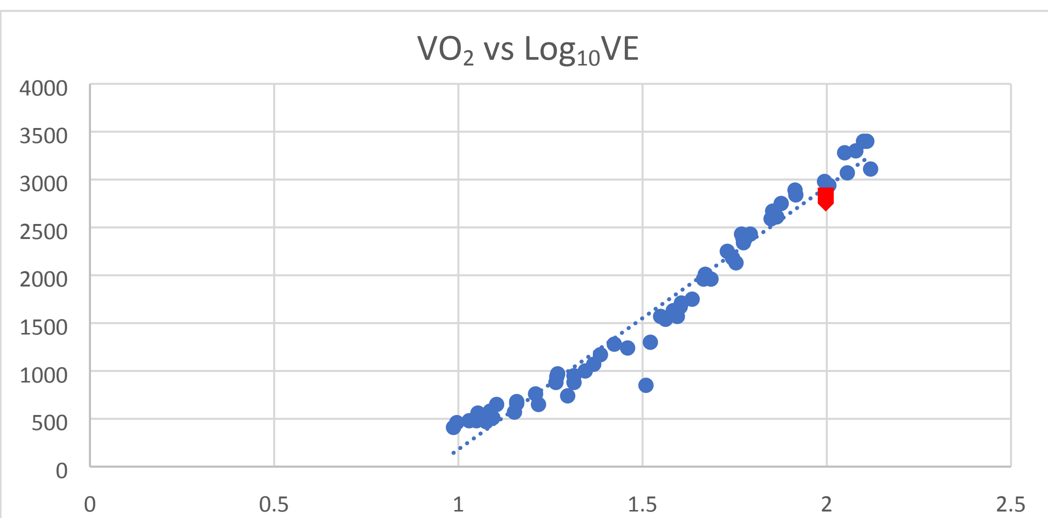


Figure.9. The Oxygen Uptake Efficiency Slope

Metabolism

The Respiratory Exchange Ratio (RER) is influenced by metabolically determined respiratory quotient and transient hyperventilation at maximal exercise and represents O_2 uptake at cellular level. There is an appropriate increase in the respiratory exchange ratio from 0.8 at rest to 1.37 during peak exercise and a maximum of 2.13 in recovery.

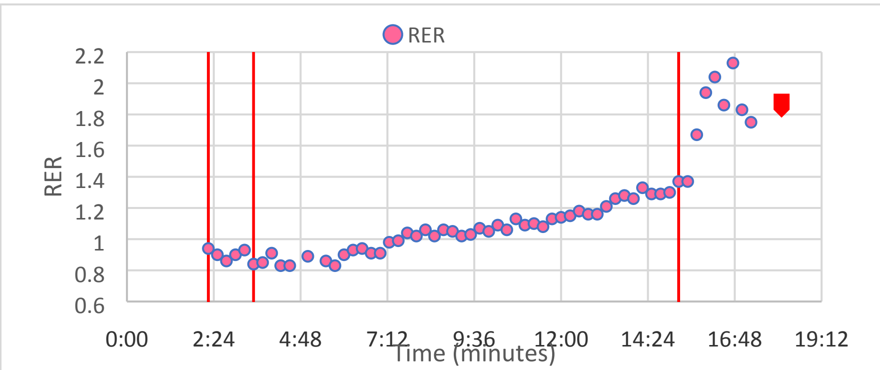


Figure.10. Panel-8: RER across the exercise time

Ventilation

The tidal volume (VT) increases steadily with increase in minute ventilation (fig.11). The red dashed line marks the participant's Maximum Voluntary Ventilation (MVV) calculated from his FEV1 (Kor, Ong, Earnest, & Wang, 2004). The distance between the highest VE (end of curve) and MVV, is the breathing reserve, which expressed as percentage of MVV is 38.49%. The VT at maximal exercise is less than inspiratory capacity and vital capacity, as expected in healthy individuals without ventilatory limitations.

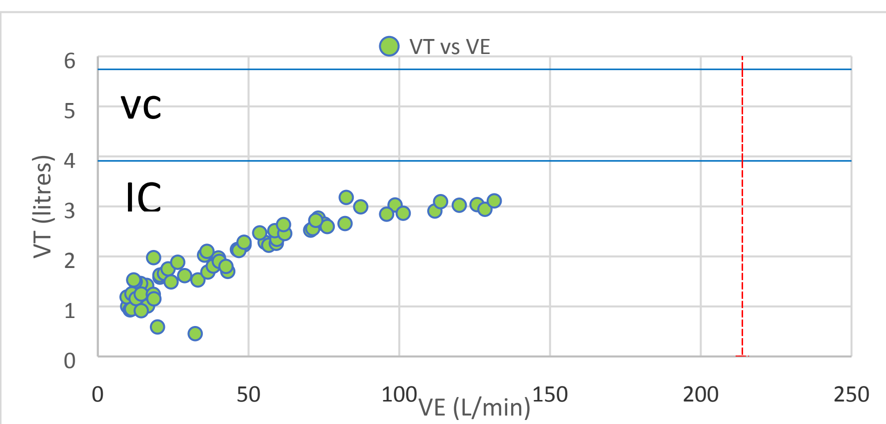


Figure.11: Tidal volume as function of minute ventilation (IC-Inspiratory capacity; VC- Vital capacity)

Table.3. Results of Spirometry

Variables	Values
FEV1	5.09
FVC	5.73
FEV1/FVC	89%
SVC	5.74
IC	3.91

Table.4. Universal CPET reporting proforma

Exercise Modality: Lower Extremity (Cycle) Ergometer		
Protocol: Ramp Protocol (Myers et al., 1991; Whipp, Davis, Torres, & Wasserman, 1981)		
Peak VO_2 (ml O_2.kg^{-1}.min^{-1}): 39.45 **Peak VO_2 (ml O_2.kg^{-1}.min^{-1}):** 47.56 (adjusted for FFM) **VO_2 at VT (ml O_2.kg^{-1}.min^{-1}):** 20.66	**Percent predicted peak VO_2:** 97.69% **Peak RER:** 1.37 (during exercise) : 2.13 (recovery)	**VE/VCO_2 Slope:** 23.71 **EOV** ☐ Yes ☑ No
$P_{ET}CO_2$(mmHg) **Resting:** * **Increase during exercise:** *	**VE/VO_2 at peak ET:** 39	**▲Q/▲VO_2:** *
VE/MVV: 0.61	**PEF (L/min): Pre ET** *	**Post ET** *
O_2 Pulse trajectory ☑ Continuous rise throughout ET ☐ Early and sustained plateau ☐ Decline		
▲VO_2/▲W trajectory ☑ Continuous rise throughout ET ☐ Early and sustained plateau ☐ Decline		
Resting HR (beats/min): 61 **Peak HR (beats/min)** : 174 **Percentage of age predicted maximal HR** : 92.06% **HRR at last min (beats):** 15	**Resting BP (mmHg):** * **Peak BP (mmHg):** * **Maximal Workload** **Cycle ergometer Watts:** 298	**Resting pulse oximeter (%):** * **Peak pulse oximeter (%):** *
ECG criteria ☑No arrythmias/ Ectopy/ ST segment changes ☐No arrythmias/ Ectopy/ ST segment changes: not exercise limiting ☐No arrythmias/ Ectopy/ ST segment changes: exercise limiting		**ECG description:** Normal response to exercise.
Subjective symptoms (primary termination criteria) ☑ RPE ☐ Angina ☐ Dyspnea		
Additional Notes:		
EOV: Exertional Oscillatory Ventilation; PEF: Peak Expiratory Flow; * values not measured.		

Discussion

The CPET provided wealth of information on the participant's physiological response to graded exercise. On comparing with the results with normative data (Table 4), we see that the participant has good exercise capacity for his age.

Table.4. Summary of Results compared to normative values

Variable	Measured values	Normative values for participants age category
Peak Work Rate (W)	298	225 ± 38 (Meyer et al., 1994)
Peak VO_2 (ml/min)	3400	2966 -6107 (Koch et al., 2009)*
VO_2- WR Slope	10.18	8.06 - 11.47 (Barron et al., 2015)
VAT (ml/min)	1800	1033-4143(Koch et al., 2009) *
VAT (% of VO_2 max)	52.94	50-65% (Wasserman et al., 2011)
Peak HR (beats /min)	174	177 ± 14 (Meyer et al., 1994)
Heart rate reserve (beats)	15 beats	<15 beats (Wasserman et al., 2011)
HR- VO_2 Slope	0.036	0.03 to 0.057 (Barron et al., 2015)*
O_2 pulse (ml 0_2/beat)	19.6	19.3 ± 3.5 (Meyer et al., 1994)
RER (at peak exercise)	1.37	1.11 ± 0.08 (Meyer et al., 1994)
VE- VCO2 slope	23.71	19.12-30.66 (Koch et al., 2009)*
OUES	2743.9	1783.5-3951.4 (Barron et al., 2015)
Minute Ventilation (L/min)	131.5	71.12-151.86(Koch et al., 2009) *
Breathing reserve (% of MVV)	38.49%	10-40% (Wasserman et al., 2011)
*values expressed as 5% to 95% reference range		

He exercised to a maximal work rate of 298 W and achieved a VO_{2peak} of 3.4 L/min (39.03ml/kg/min) which corresponds to 97.69% of his predicted maximum. The slope of VO_2 as a function of work rate reflects the increased amount of O_2 consumed per unit increase in work rate, VO_2- WR slope was 10.18 (Normative value: 8.1 to 11.6 (Barron et al., 2015; Koch et al., 2009). Even the HR-VO_2 slope was within normal limits, this implies that the stroke volume (SV) and cardiac output were maintained in pace with the increase in work rate. Towards the end of test, a clear plateau in the VO_2 curve is seen, i.e. there is no further increase in VO_2 with increase in work rate. Thus, peak VO_2 achieved by the participant is equal to VO2max (MAXIMAL oxygen uptake)(Wasserman et al., 2011). This confirms that the participant has no significant impairment in the cardiopulmonary system. His maximal workload was more than the normative range for his age, this could be a result of his regular exercise training indicating that his fitness levels and physiologic responses allows for normal maximal aerobic function.

Although the participant did not achieve his predicted maximum, a relatively small Heart rate reserve (HRR) at the end of test, further rules out any underlying undiagnosed CV disease (Wasserman et al., 2011), but HRR of just 15 beats at the end of test implies that his cardiovascular response will allow only a limited improvement in his exercise capacity with any further training. However, physical training is known to reduce the maximal heart rate by 3-7% (Londeree & Moeschberger, 1982), so with appropriate training, we can increase his HRR. This wider HRR can then be used to further improve his exercise performance. The O_2 pulse reflects SV and arterio-venous oxygen difference, the participant's O_2 pulse increases immediately with exercise and drops steeply in the recovery, to maintain the SV in response to the abrupt decrease in afterload when exercise stops. This confirms that the SV was maintained in pace with the changes in work rate.

The ventilatory threshold appears to occur around 160 W, corresponding to VO_2 of 1.8L/min (20.66ml/kg/min) i.e. 52.94% of $VO_{2\ max}$. Ventilatory equivalents for oxygen and carbon dioxide at VAT reflects the ventilation-perfusion matching of a normal individual. VAT is an important basis for exercise prescription in sports medicine. Endurance sports like football required a near maximal energy delivery from both aerobic and anerobic sources along with occasional bouts of high intensity work. When any activity is performed for prolonged time, the energy requirement is dominated by aerobic supply. In order to enhance the aerobic performance, a high volume training at VAT supplemented by short periods of high intensity interval training is important(Laursen, 2010). VAT is considered a better indicator of aerobic endurance than VO2max, as VAT may change without changes in VO_{2max}(Allen, Seals, Hurley, Ehsani, & Hagberg, 1985). The VAT for elite football players is around 57-63% of $VO_{2\ max}$. Hence appropriate exercise routine with 75% of total training volume performed at VO_2 close to or at VAT and 10-15% performed at higher levels, well above the VAT would help improve the participant's performance(Laursen, 2010). Since the participant has achieved his VO_2 max, improvement in exercise capacity should be checked as improvement in VAT when CPET is performed to monitor the effect of training. Prescribing exercise intensity based on VAT is reliable and effective, however determination of VAT may show within participant variation and hence a subsequent verification test or re-test would increase the reliability of results and improve the efficacy of exercise prescription(Mann, Lamberts, & Lambert, 2013). A major limitation of this report was incomplete data. A subsequent test performed under similar conditions with recording of systolic BP, blood saturation, end tidal oxygen and carbon dioxide tension, supplemented by arterial blood gas analysis can provide a better insight on cardiovascular response and improve the reliability of the results.

Finally, the data demonstrated a cardiac pattern of limitation which one expects to see in apparently healthy individuals. Limiting cardiac pattern is evident by the following:

- Presence of clear ventilatory threshold.
- Plateau in O2 pulse.
- RER clearly rises above 1.1
- Stopped exercise due to leg fatigue.
- Presence of large ventilatory reserve.
- Heart rate near predicted maximum.

Conclusion

The CPET reveals that the participant has optimal exercise capacity for his age and gender. He shows normal cardiovascular, pulmonary and metabolic response to exercise. Exercise intensity at VO_2 levels equal to his VAT along with short duration, high intensity interval training will help improve his endurance. Thus, to enhance his performance, one-third of his training volume should be around VO_2 of 20.66ml/kg/min that corresponds to HR that corresponds to HR zone of 139-146 beats/min. High intensity training at VO_2 around 33 ml/kg/min should also be included in the training for short duration. He has good ventilatory reserve and shows cardiac pattern of limitation as one expects to see in normal adults.

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