Early History

“In running the oxygen requirement increases continuously as the speed increases, ....; the actual oxygen intake, however, reaches a maximum beyond which no effort can drive it. The oxygen intake may attain its maximum and remain constant merely because it cannot go any higher owing to the limitations of the circulatory and respiratory system.”


In performing his research, Hill used:

- 6-7 subjects
- limited running speeds
- discontinuous running protocols
- combined data from multiple subjects
What is \( \text{VO}_2\text{max} \)

\[ \text{VO}_2 \]

\text{Cardiorespiratory limitations}

\[ \text{Duration should be } \sim 8-10 \text{ min} \]

\text{Time or Intensity}

\text{Definitions:}

- The maximum rate oxygen can be taken in (pulmonary), transported (circulatory), and utilized (peripheral) for energy production.

- The maximal \textit{rate} at which the body can consume oxygen during exercise.

\text{Other “less correct” terms!}

- “aerobic power”
- “aerobic capacity”
- “maximal cardiorespiratory capacity”
"VO_{2\text{max}} represents the physiological ceiling for the ability of the oxygen transport system to deliver O_{2} to contracting muscles."

"… Oxygen consumption peaks and remains constant or drops slightly, even though work intensity continues to increase…. The best single measurement of cardiorespiratory endurance and aerobic fitness."
"… the maximal rate that the body can consume oxygen during exercise… detected as a plateau despite further increases in exercise intensity..."
Determinants of VO$_2$max

**CENTRAL**
- Cardiac Output (HR x SV)
- $\Delta A$-aPO$_2$
- SaO$_2$ [Hb]
- Oxygen delivery

**PERIPHERAL**
- Capillary density
- PO$_2$ gradients
- Fiber dimensions
- Muscle mass
- O$_2$ supply-demand relationships
- Peripheral Oxygen Diffusion

$$VO_2\text{max} = Q_{\text{max}} \times aV\text{O}_2\Delta_{\text{max}}$$

**Physiological and Psychological inputs before exercise:**
- Physiological state
- Expected distance/duration
- Previous experience/motivation/external competition

**Feedback during exercise:**
- Fuel reserves
- Rate of heat accumulation
- Hydration state
- Self-belief

**Continuous feedback from various body systems is integrated to regulate the exercise intensity by continuously modifying the number of motor units recruited in the exercising limbs**
For 34 subjects, breath-by-breath data with an 11 breath average, and based on $\Delta VO_2 \leq 50 \text{ mL/min}$ for $VO_2\text{max}$ and closest neighboring data point.

$VO_2$ plateau incidence = 86%

Background

- No universally recommended procedures for processing $VO_2$ data from breath-by-breath indirect calorimetry, or from time averaged systems.

- No standardized criteria or recommended methods for detecting either of a $VO_2$ plateau, the maximal rate of oxygen consumption ($VO_2\text{max}$), or a peak $VO_2$ in the absence of a $VO_2$ plateau ($VO_2\text{peak}$).

- Increasing use of breath-by-breath indirect calorimetry in education, research and professional practice

- The lack of any objective criteria to follow when processing decreases the validity of measurement.
Challenges

- How do researchers in exercise physiology currently collect and process data?
- How long should the protocol be?
- What type of protocol should be used?
- What causes the “noise” in breath-by-breath VO\textsubscript{2} data?
- Should this “noise” be reduced? If so, how?
- What is a VO\textsubscript{2} plateau?
- How can a VO\textsubscript{2} plateau be objectively determined?
- What is VO\textsubscript{2}max vs. VO\textsubscript{2}peak?
- How can VO\textsubscript{2}max and VO\textsubscript{2}peak be objectively determined?

What causes the “noise” in breath-by-breath VO\textsubscript{2} data?

\begin{align*}
\text{VO}_2 (\text{L/min}) & \quad 2.17 \pm 0.3 \text{ L/min, with a range of 1.4 – 3.3 L/min} \\
\text{VE STPD (L/min)} & \quad 10 - 70
\end{align*}
Variability 96% explained by a two-factor model of VE and FEO₂

Variability Remaining

VO₂max Issues
Should this “noise” be reduced?

**YES**

How should this “noise” be reduced?

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**Time Averaging**

- **a=bb**
- **c=30 s**
- **d=60 s**
- **e**

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**VO2max Issues**
Breath Averaging

Digital Filtering

VO2max Issues
Digital Filter Example

What is a VO$_2$ plateau?

VO$_2$ plateau at VO$_{\text{max}}$

Initial deviation from linearity

Linear regression
What is VO₂max or VO₂peak?

Data Example

treadmill running
Conclusions

- Clear rationale for processing breath-by-breath VO$_2$ data to decrease “noise”.
- Processing best done by digital filtering
- Still formulating and debating criteria and methods to quantify VO$_2$ plateau, VO$_2$max, VO$_2$peak
- In the absence of a VO$_2$ plateau, what are valid criteria to use to verify a “true” VO$_2$max?