CPETs

Everybody stops. Deaths are rare.

Ben Gerhardy, Respiratory AT. Sept 2019.

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Overview

- Why
- Exercise physiology 101
- Protocols
- Modality
- Clinical context
  - Indications
  - Normal
  - Examples

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Starters

- Who here has done/has supervises CPETS?
- Anyone want to volunteer their VO2max?

Oskar Svendson	Cyclist	97.5
Espen Bjerke	X-country skier	96
Greg LeMond	Cyclist	92.5
Killian Jornet	Ultrarunner	92
Cadel Evans	Cyclist	87
Chris Froome	Cyclist	84.6
Steve Prefontaine	Runner	84.4
Lance (PED) Armstrong	Cyclist	84
Joan Benoit (?highest F)	Runner	78.6

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Why

- Assessment of integrated cardiopulmonary capacity *under an increasing stress load*
- Resting cardiac/pulmonary function testing does *not* reliably reflect that of exercise
- Diagnostics, prognostics, assessment of treatment effect

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Back to the start

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Maximal Oxygen Intake as an Objective Measure of Cardio-Respiratory Performance[1]

HENRY LONGSTREET TAYLOR, ELSWORTH BUSKIRK[2, 3] AND AUSTIN HENSCHEL[3]. *From the Laboratory of Physiological Hygiene, University of Minnesota, Minneapolis, Minnesota*

1955

Opens with "During the Second World War…"

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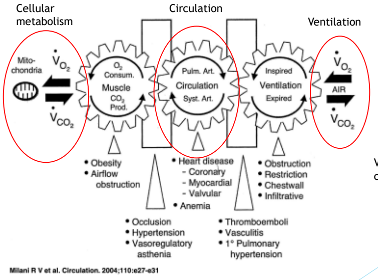

Ventilation-metabolism coupling

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Not a talk on V/Q, but…

- CO = HR x SV
  - HR = 70/min
  - SV = 70mL
  - CO = **4,900mL**/min (= Q)
- Ve = RR x Vt
  - But we are **more** interested in Va (Va = Vt – Vd)
  - RR = 15/min
  - Va = 500 – 150 = 350mL
  - Ve = 15 x 350 = **5,250mL**/min (= V)

In normal physiology: V≈Q

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Not a talk on cellular respiration, but…

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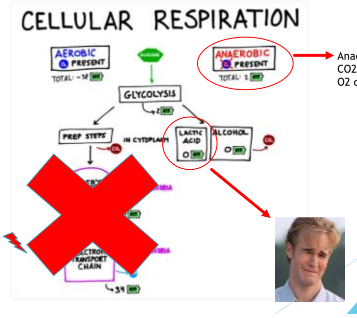

Anaerobic Threshold: CO2 production > O2 consumption

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Fick

- Oxygen uptake (VO2) = cardiac output . (arterial O2 – mixed venous O2)
  VO2 = (HR x SV) . (CaO2 – CvO2)
  VO2max = (HRmax . SVmax) . (CaO2max – CvO2max)
- 1 MET (metabolic equivalent) = resting O2 (VO2) uptake for an upright seated adult = 3.5mL/kg/min
- METs:
  - Sleeping = 0.9
  - Walking 5km/hr = 3.3
  - Going up 2 flights of stairs >4 mets
  - Light jogging = 7.0
  - Jogging 11km/hr = 11.2

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Exercise Intolerance

- Abnormally low VO2 max
- Physiologically (Fick):
  - Reduced HR
  - Reduced SV
  - Reduced CaO2
  - Increased CvO2

VO2max = (HRmax . SVmax) . (CaO2max - CvO2max)

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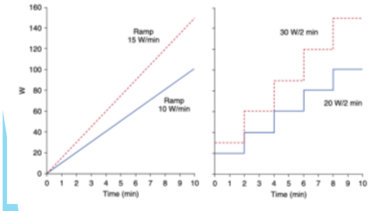
Protocols



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Protocols

Optimizing the exercise protocol for cardiopulmonary assessment

MARK J. BUCHFUHRER, JAMES E. HANSEN, TERRY E. ROBINSON, DARRYL Y. SUE, KARLMAN WASSERMAN, AND BRIAN J. WHIPP
Division of Respiratory Physiology and Medicine, Department of Medicine, Harbor-UCLA School of Medicine, Torrance, California 90509

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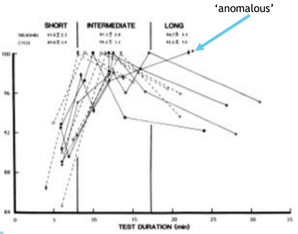
Protocols

This guy was called 'anomalous'



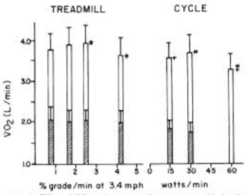


FIG. 2. Effects of different increments of power on anaerobic threshold (*hatched*) and maximal O_2 uptake ($\dot{V}O_2$) (*open bars*) for incremental treadmill at 3.4 mph (*left*) and cycle ergometry (*right*) on 5 subjects. Large SE reflect wide range of fitness levels of subjects. *†‡Pairs of tests significantly different at $P < 0.05$.

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Protocols: Incremental

- Increment too large: cardiac disease patients develop symptoms prior to VO2max
- Increment too small: cardiac failure patients can't reach VO2max
- Bruce protocol: unequal work increments giving nonlinear data

Clearly ramps are better…

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Protocols

Table 3. Hemodynamic and Gas Exchange Data (mean ± 1 SD) at Maximal Exercise for the Six Exercise Protocols

	Treadmill			Bicycle		
	Bruce	Balke	Ramp	25W	50W	Ramp
Heart rate (beats/min)	134 ± 25	131 ± 25	130 ± 24	124 ± 26	127 ± 33	128 ± 25
Systolic blood pressure (mm Hg)	171 ± 28	172 ± 25	179 ± 24	181 ± 25	185 ± 22	185 ± 24
Diastolic blood pressure (mm Hg)	86 ± 14	85 ± 13	85 ± 15	87 ± 23	88 ± 11	89 ± 13
Test duration (min)	6.6 ± 1.5	10.4 ± 3.4	9.1 ± 1.4	10.3 ± 2.2	7.1 ± 1.1	9.4 ± 0.8
Oxygen uptake (ml/kg per min)	22.3 ± 8†	21.1 ± 8	21.0 ± 8	17.7 ± 7*	18.1 ± 7	18.5 ± 7
Minute ventilation (liters/min, BTPS)	83.2 ± 30	72.8 ± 24	72.1 ± 27	68.6 ± 27	69.9 ± 23	71.9 ± 27
Carbon dioxide production (liters/min, STPD)	2.363 ± 1.0	2.018 ± 0.84	2.044 ± 0.94	1.910 ± 0.84	1.951 ± 0.75	1.930 ± 0.89
Respiratory exchange ratio	1.26 ± 0.15*	1.13 ± 0.1†	1.14 ± 0.12†	1.21 ± 1.2†	1.29 ± 0.14†	1.23 ± 0.12
Perceived exertion	19.0 ± 1	19.4 ± 1	19.5 ± 1	19.3 ± 1	19.0 ± 1	19.2 ± 2

*Significantly different from bicycle tests ($p < 0.05$); †Significantly different from other tests of the same mode ($p < 0.05$). 25 W = 25 W/2 min stage cycle ergometer test; 50 W = 50 W/2 min stage cycle ergometer test.

So maybe it just doesn't matter (unless you aren't male, in which case maybe it does)

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What keeps you up at night?

Is it best practice to determine protocols based on data from healthy male volunteers and apply those to sick patients?

Does it matter (as long as we are standardized)?

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Modality

	Bike	Treadmill
Exercise time	Higher (generally)	
Work (W)	Measurable	
VO2peak		Higher
AT		Higher
HR/BP/RR/RER/BORG	Equivocal(ish)	
Tolerability	Higher	
ECG Quality	Higher	
Procedural blood specimens	Easier	

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Specific Indications

- Cardiac
  - Heart transplant assessment
- Resp
  - Exercise-induced dyspnoea
- Other
  - Surgical survival
  - Exercise intolerance
  - Differentiating cardiac from respiratory causes of exercise intolerance
  - Medicolegal (impairment assessment)

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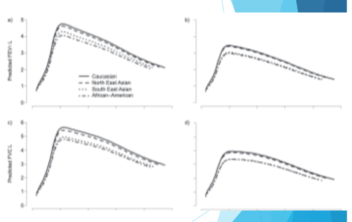
What is normal?

ERS TASK FORCE

Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations



- GLI: 97,759 participants; 33 countries

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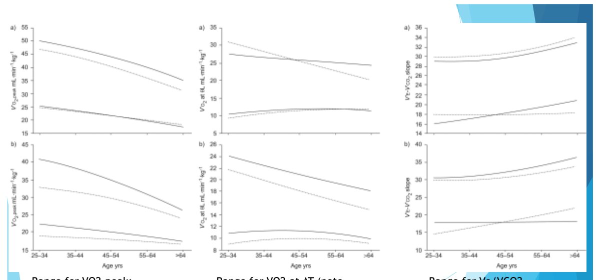

Range for VO2 peak:
A = males; B = females
Lines are 5th/95th centiles
Broken line: BMI >25; solid <25

Range for VO2 at AT (note different Y axis)

Range for Ve/VCO2

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Training effects

- Increase CaO2-CvO2 differential (CvO2 change)
  - Cellular
- Increased stroke volume
  - Rest + workload
- Increased Hct
- Lower resting HR

- Above = Increased VO2max

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Everybody stops

- Ventilatory
  - Muscle dysfunction
  - Gas exchange impairment
  - Ventilatory insufficiency
- Cardiovascular
  - Inadequate HR/SV
  - Circulatory anomaly
  - Haematological/Hb anomaly
- Peripheral
  - Neuromuscular dysfunction
  - Reduced mitochondrial/oxidative capacity of muscle
  - Malnutrition
- Other
  - Motivational
  - Perceptual
  - Soft

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Some Parameters – O2 Pulse

- VO2/heart rate (mL/beat)
- Oxygen consumption per cardiac cycle (heart beat)
- Initial rapid upstroke with slowing as exercise progresses
- Flattening/downward displacement:
  - Cardiac limitation (suggestion of) changes denominator
  - Reduced peripheral vascular perfusion changes numerator
  - Reduced O2 extraction changes numerator

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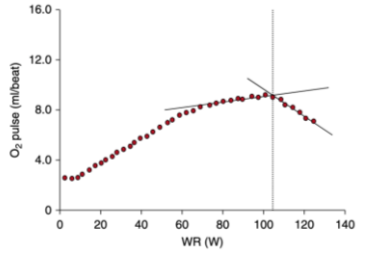

Down point reflecting a pathology (eg myocardial ischaemia)

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Some Parameters - VE/VCO2 slope

- Ventilation required to exhale 1L of CO2
  - Plotted against WR reflects **ventilatory efficiency** (higher = breathing more)
- PaCO2 ≅ VCO2 (related at least)
- Elevated VE/VCO2:
  - Hyperventilation (reduce PaCO2)
  - Higher Vd/Vt (deadspace)
- Reduced VE/VCO2:
  - Increased PaCO2 setpoint (alveolar hypoventilation)

Clinically:
- Primary hyperventilation syndrome
- V/Q mismatch
- CCF/Pul Htn (degree of elevation reflects disease severity)

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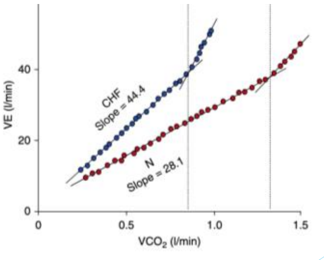

Normal = age dependant

Male: 0.12 x age + 21
Female: 0.08 x age + 25.2

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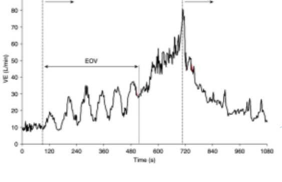
Some Parameters: Oscillatory Ventilation

- Ventilation is relatively linear to workload
- Oscillatory ventilation = cyclical hyperpnoea and hypopnea (Cheynne-Stokes similarity)



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Some Parameters: Oscillatory Ventilation

- Definition:
  - Variable
  - AHA: presence for at least 60% of exercise duration AND amplitude >15% of the average value of ventilation at rest
- Mechanisms (proposed):
  - Circulatory delay
  - Increased chemoreceptor sensitivity
  - Pulmonary congestion
- Clinically:
  - Translates to CCF (typically)
  - An independent, poor prognostic marker

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Importance of Effort

- Very very very very very
- Supervising clinician should be reporting clinician

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Interpretation

- This is NOT a CPET interpretation talk!

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Variables	Criteria of Normality
$\dot{V}O_2$max or $\dot{V}O_2$peak	> 84% predicted
Anaerobic threshold	> 40% $\dot{V}O_2$max predicted; wide range of normal (40–80%)
Heart rate (HR) Heart rate reserve (HRR)	HRmax > 90% age predicted HRR < 15 beats/min
Blood pressure	< 220/90
O_2 pulse ($\dot{V}O_2$/HR)	> 80%
Ventilatory reserve (VR)	MVV – $\dot{V}$Emax: > 11 L or $\dot{V}$Emax/MVV × 100: < 85%. Wide normal range: 72 ± 15%
Respiratory frequency (fR)	< 60 breaths/min
$\dot{V}E/\dot{V}CO_2$ (at AT)	< 34
VD/VT	< 0.28; < 0.30 for age > 40 years
Pa_{O2}	> 80 mm Hg
$P(A–a)O_2$	< 35 mm Hg

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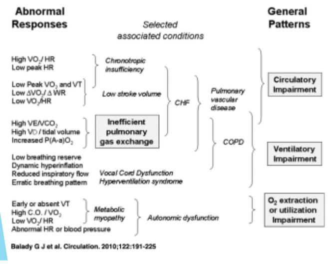
Simplified Pattern Approach



__Simply__

Cardiac limitation if:
VR >25% + HRR< 15% + failure to reach VO2

Resp limitation if:
HRR >15% + VR <25% + failure to reach VO2

Normal if achieve >84% predicted VO2peak without hitting the above

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Cardiac Limitation

- VO2max NOT reached (<84% predicted)
- Failure to increase CO appropriately
  - VO2/WR plot
- Predicted HR reached/HRR <15%
  - Consider dysrhythmias
- VE/VCO2 plot
- Oscillatory ventilation

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Ventilatory limitation

- VO2 max NOT reached
- MVV – Vemax >75% (wide error range)
- HRR >15%
- Consider high BORG for dyspnoea

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Metabolic/Neuromuscular considerations

- Hard! Mimic unfit/poor effort
- Anaerobic threshold
  - Myopathy variations
- ETCO2
- HRR >15%

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1 Slide on the AT

- VO2 point at which anaerobic glycolysis increases
- 3 criterion approach:
  - CO2 production >O2 consumption (excess VCO2 relative to VO2)
    - VCO2 against VO2 plot
  - Identification of hyperventilation relative to O2
    - VE/VCO2 and VE/VO2 against VO2 plot
  - Absence of hyperventilation at AT (identified from above)
    - EtCO2 and EtO2 against VO2 plot
    - Both rise after applying AT point
      - EtCO2 takes a few minutes to start to fall (resp compensation)

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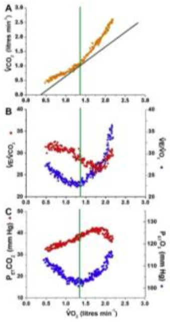

V-slope method

Increase in VE/VO2: CO2 increase is driving increased VE ("blowing off CO2") - so VE/VO2 rises

NO hyperventilation relative to increasing ETCO2: i.e. ETCO2 continues to rise after AT

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1.1 Slides on the RER

- Ratio of CO2 produced to O2 consumed (VCO2/VO2)
- Rest: RER (R) varies with diet
  - Fats = 0.7
  - Carbs = 1.0
  - 'Average' = 0.8
- RER >1.0 cannot be due to diet alone

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RER

- Glucose oxidation:
  - 6 O2 + C6H12O6 = 6 CO2 + 6 H2O + 38 ATP
  - 6 CO2/6 O2 = 1
- Fat oxidation:
  - 23 O2 + C16H32O2 = 16 CO2 + 16 H2O + 129 ATP (trust me on this one)
  - 16 CO2/23 O2 = 0.7

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Risk

- Death: 2-5/100,000
- Major cardiac event: 10-15/100,000

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No Way Jose!

TABLE 8. ABSOLUTE AND RELATIVE CONTRAINDICATIONS FOR CARDIOPULMONARY EXERCISE TESTING

Absolute	Relative
Acute myocardial infarction (3–5 days)	Left main coronary stenosis or its equivalent
Unstable angina	Moderate stenotic valvular heart disease
Uncontrolled arrhythmias causing symptoms or hemodynamic compromise	Severe untreated arterial hypertension at rest (> 200 mm Hg systolic, > 120 mm Hg diastolic)
Syncope	Tachyarrhythmias or bradyarrhythmias
Active endocarditis	High-degree atrioventricular block
Acute myocarditis or pericarditis	Hypertrophic cardiomyopathy
Symptomatic severe aortic stenosis	Significant pulmonary hypertension
Uncontrolled heart failure	Advanced or complicated pregnancy
Acute pulmonary embolus or pulmonary infarction	Electrolyte abnormalities BSL!
Thrombosis of lower extremities	Orthopedic impairment that compromises exercise performance
Suspected dissecting aneurysm	
Uncontrolled asthma	
Pulmonary edema	
Room air desaturation at rest < 85%*	
Respiratory failure	
Acute noncardiopulmonary disorder that may affect exercise performance or be aggravated by exercise (i.e. infection, renal failure, thyrotoxicosis)	
Mental impairment leading to inability to cooperate	

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When I say No

- Unstable cardiac disease (ischaemic, infective, electrical, some valvular)
- Acute PE/DVT
- Uncontrolled asthma
- Orthopaedic dysfunction

When I say Maybe

- Hypoxia
- Severe pul htn
- HOCM
- Poorly controlled DM

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And when your patients complain...

- Show them this
- https://www.youtube.com/watch?v=FbGgiiEfMcg

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