



Universität
Basel

CPET in athletes



CPX International Inc.
formerly ISEIRE Inc.



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Disclosures

Nothing to declare regarding the presentation.

Key reasons why athletes are interested in CPET

- Maximal Oxygen Uptake ($\dot{V}O_2\text{max}$) - the upper limit of aerobic capacity
- Individual Anaerobic Threshold (IAT) - determines sustainable race pace
- Exercise Economy - optimizing technique and material
- Training Personalization - target specific areas of intensity
- Performance Monitoring - track progress over time
- Health Screening

You can do whatever you like if what you are measuring is related to performance in competition or is likely to be useful in training guidance.

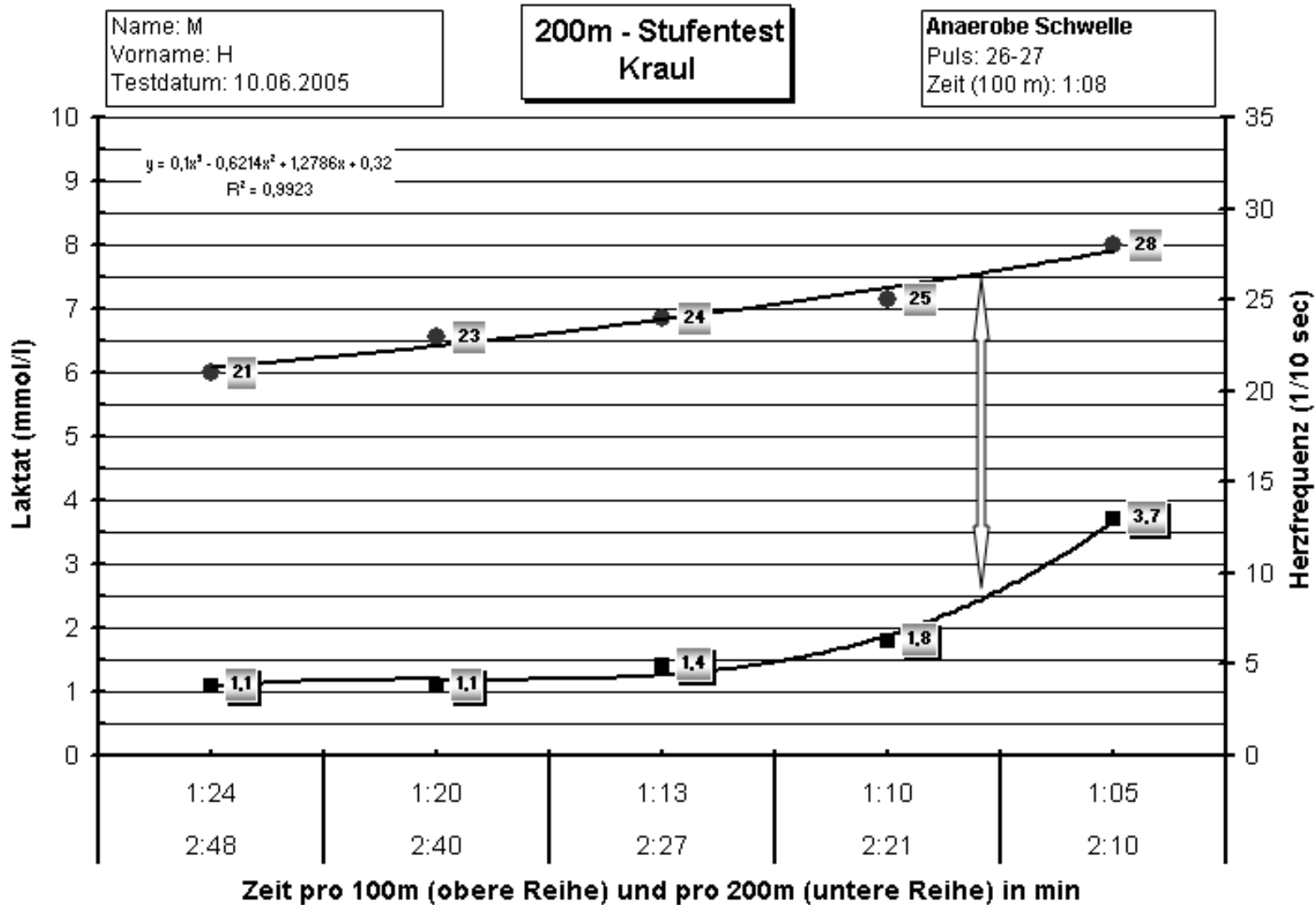
Prerequisite

Valid and reliable measurements at baseline and follow-up

- Definition of exhaustion criteria
- Daytime variation
- Verification test
- etc

Analysis methods for predicting competitive performance in swimming

- Step tests (Pansold, Simon, AIS etc)
- Step test: arms, legs
- Swimming channel: $\dot{V}O_2$ max measurement (direct, post-breathing)
- Swimming speed against resistance
- Turn and start analyses
- Strength measurement: biobank, strength analysis
- Heart rate variability measurement, salivary cortisol, urine catecholamine concentration, etc.
- Methods: modelling, neural network



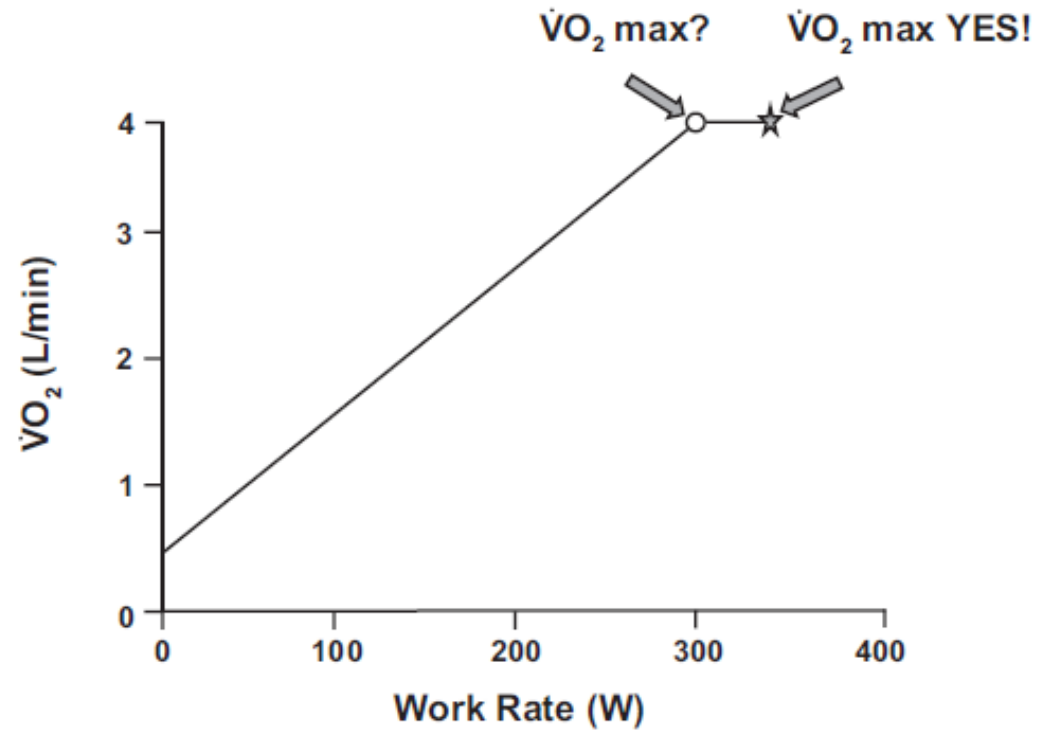
Multivariate linear regression with IPS-Score of respective length

	50 m	100 m	200 m	≥400 m
Age (years)		0.34**	0.26*	
Height (cm)			0.26*	
Resting HR (1/min)			-0.26*	-0.54**
Tendency to infection				0.41*
ESR (mm/2h)		-0.26*		
Creatine kinase (U/l)	0.37*	0.31*	0.29*	
Magnesium (mmol/l)	-0.49**			
IAS, endurance (IPSscore)		0.46**	0.48**	0.42*
ANT, sprint (IPS score)		0.51**	0.48**	0.35

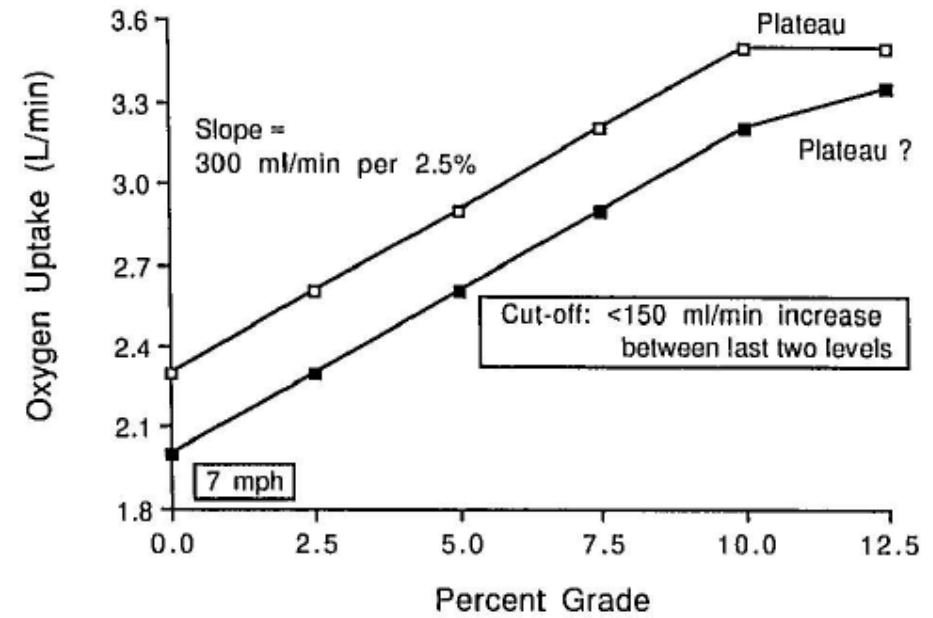
Unpublished data

Exhaustion criteria

$\dot{V}O_2$ -plateau

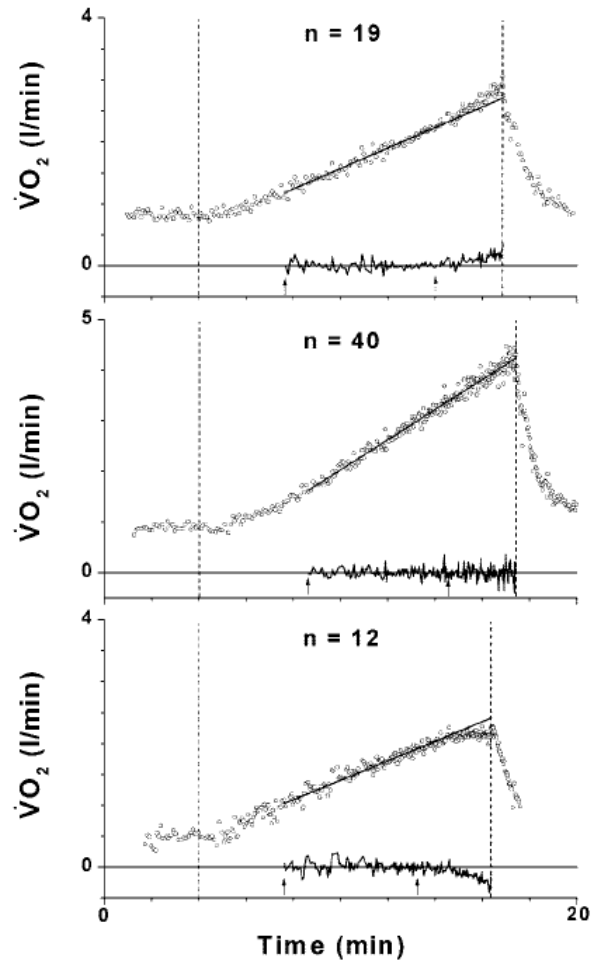


Poole and Jones J Appl Physiol (1985). 2017 Apr 1;122(4):997-1002

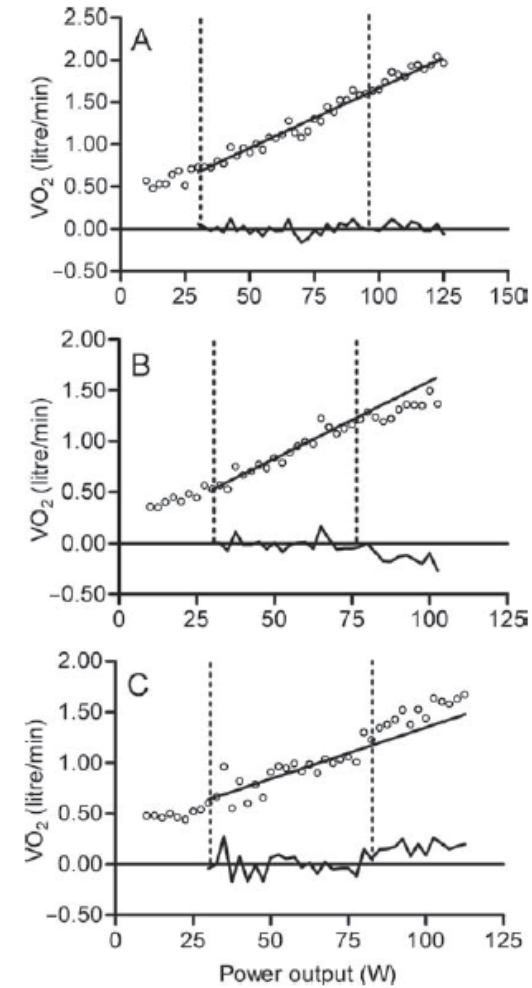


Howley et al. Med Sci Sports Exerc. 1995 Sep;27(9):1292-301.

$\dot{V}O_2$ -plateau only in 30-50% of tested people



Day et al J Appl Physiol (1985). 2003 Nov;95(5):1901-7



Barker et al Br J Sports Med. 2011 May;45(6):498-503

Factors influencing the $\dot{V}O_2$ -plateau incidence

Which factors influence whether or not a $\dot{V}O_{2\max}$ plateau occurs?

1.Motivation:	NO
2.Anthropometric data:	NO
3.Aerobic fitness:	NO
4.Anaerobic power:	NO
5.Type of exercise:	NO
6.Anaerobic capacity:	YES
$\dot{V}O_2$ -uptake kinetic:	YES

Typical CPET in cycling athlete

23 years
180 cm
64 kg
 $\dot{V}O_{2\max}$ 78 ml/kg/min

VT1 and VT2 clearly detectable

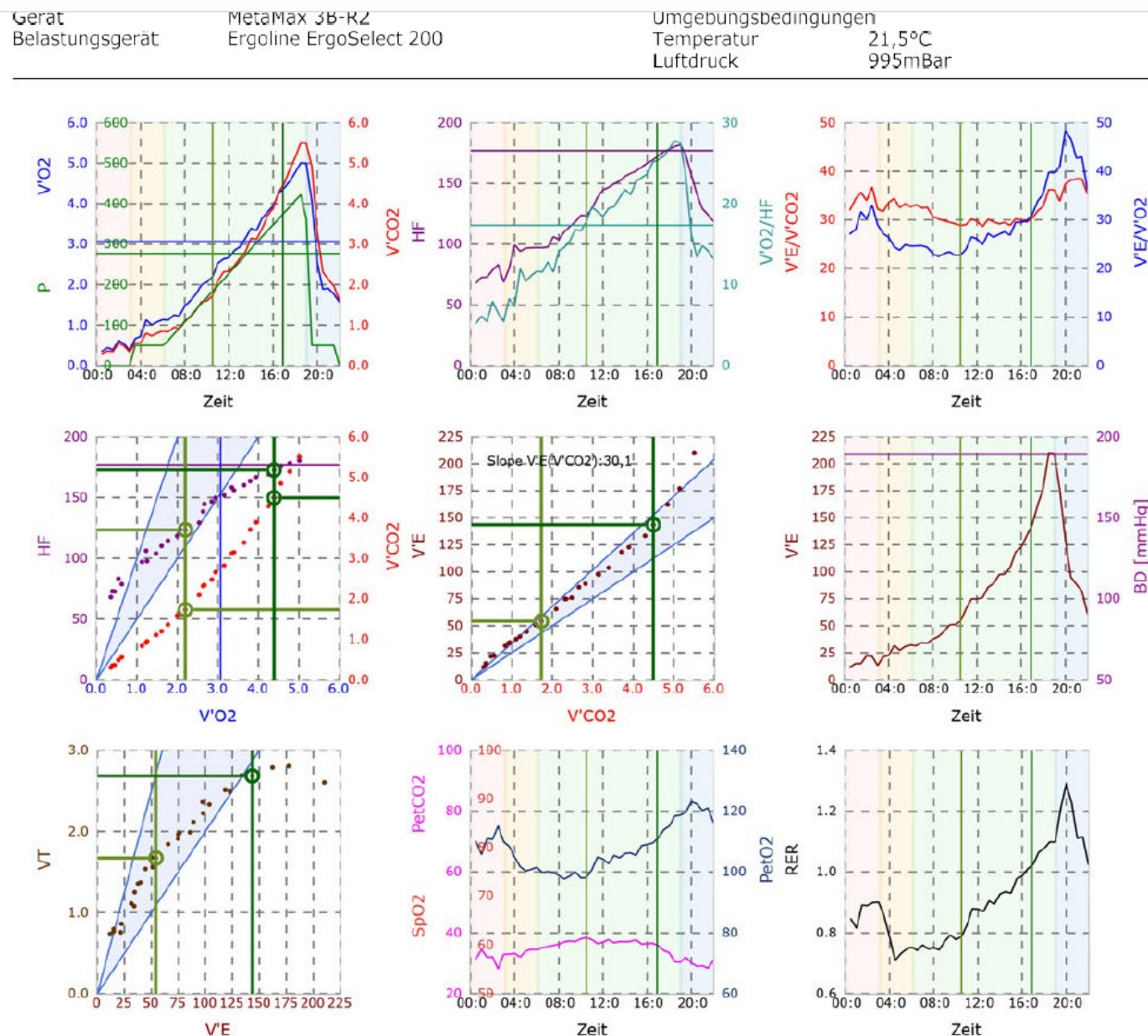
Exhaustion criteria:

$\dot{V}O_{2\max}$ plateau
RER > 1.13

Max heart rate (HR):

APMHR = 210-age

APMHR = 208-0.7*age



New Data-based Cutoffs for Maximal Exercise Criteria across the Lifespan

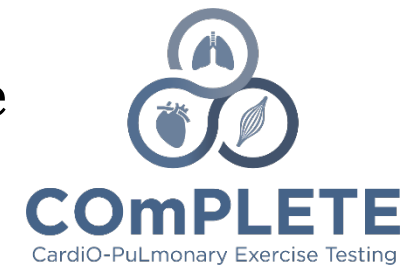


TABLE 1. Descriptive characteristics of the study population separated by sex

	<i>n</i>	Male	<i>n</i>	Female
Participants, <i>n</i> (%)		274 (52)		252 (48)
Age (yr)	274	53.5 ± 19.8 (20–91)	252	54.3 ± 19.4 (20–89)
Height (cm)	274	177.0 ± 7.3 (156.0–196.5)	252	165.6 ± 7.1 (149.0–186.0)
Body mass (kg)	274	76.6 ± 9.7 (51–104)	252	62.6 ± 8.8 (43–90)
BMI (kg·m ⁻²)	274	24.4 ± 2.5 (19.0–30.0)	252	22.8 ± 2.7 (17–30)
Rest systolic BP, mm Hg	274	130 ± 12 (95–159)	252	124 ± 15 (87–160)
Rest diastolic BP, mm Hg	274	79 ± 9 (57–100)	252	76 ± 9 (48–97)
HR at rest (bpm)	272	60 ± 10 (38–129)	247	62 ± 10 (44–104)
Smoking status, <i>n</i> (%)				
Never smoked (%)	274	220 (80.3)	252	200 (79.4)
Ex-smokers >10 yr (%)	274	54 (19.7)	252	52 (20.6)
Medication, <i>n</i> (%)				
Antihypertensives (%)	274	27 (9.9)	252	19 (7.5)
Beta blockers (%)	274	7 (2.6)	252	5 (1.9)
Performance				
P _{max} (W)	274	246 ± 82 (75–468)	252	157 ± 58 (45–299)
$\dot{V}O_{2max}$ absolute (L·min ⁻¹)	274	2.91 ± 0.80 (1.26–4.86)	252	1.88 ± 0.56 (0.70–3.55)
$\dot{V}O_{2max}$ relative (mL·kg ⁻¹ ·min ⁻¹)	274	38.3 ± 10.5 (16.4–65.1)	252	31.3 ± 8.6 (13.0–53.5)
Exhaustion criteria				
RER _{max}	274	1.17 ± 0.08 (0.93–1.41)	252	1.17 ± 0.08 (0.93–1.47)
HR _{max} (bpm)	265	171 ± 22 (96–210)	242	167 ± 20 (97–203)
RPE _{max}	234	19.3 ± 0.9 (15–20)	219	19.0 ± 1.2 (15–20)
BL _{max} (mmol·L ⁻¹)	241	8.6 ± 2.9 (2.4–16.2)	214	7.1 ± 2.6 (1.7–13.7)

Data are presented as mean ± standard deviation (minimum, maximum) if not stated otherwise.
 BMI, body mass index; BP, blood pressure; P_{max}, maximal power.

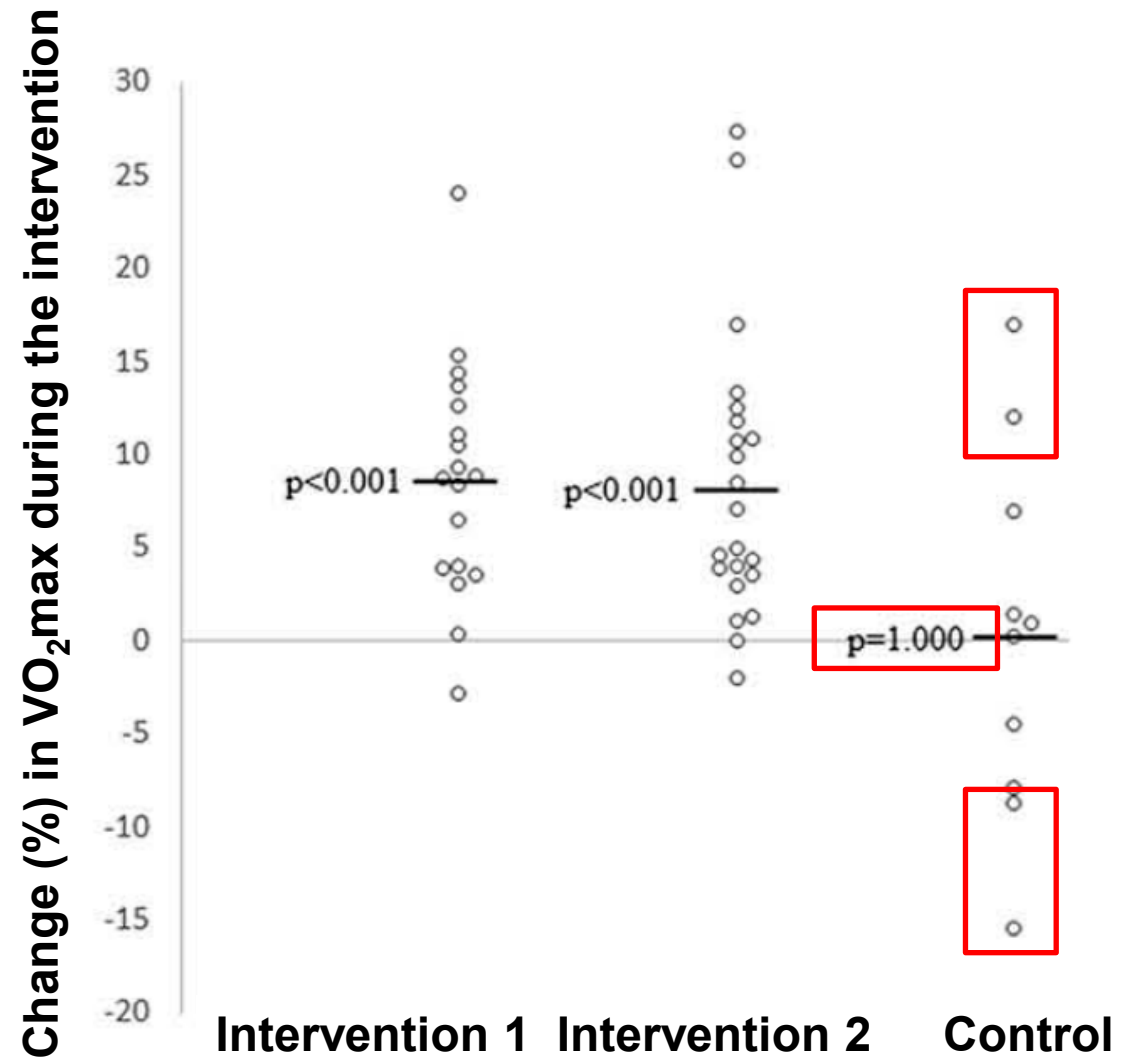
Secondary exhaustion criteria for healthy untrained individuals

Age group	RERmax	APMHR 210-age	APMHR 208-0.7*age
20-39 years	1.13	96%	93%
40-59 years	1.10	99%	92%
60-69 years	1.06	99%	89%



Diurnal variation and day to day variability

Variability of peak $\dot{V}O_2$ values

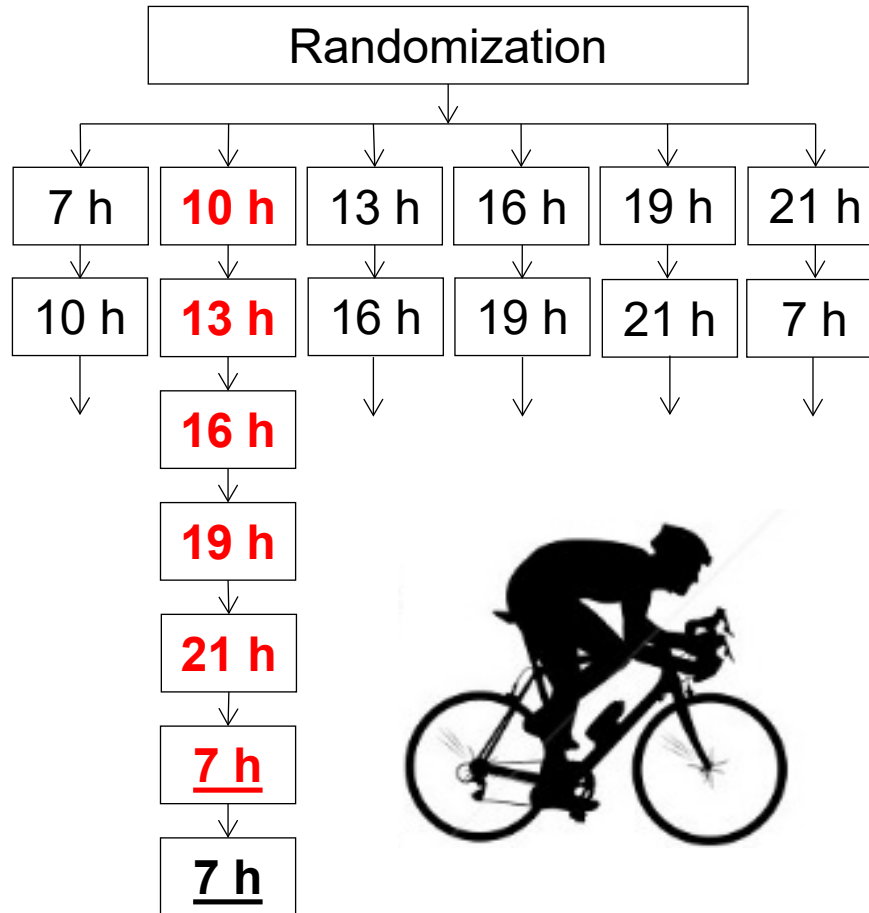


Diurnal variation in percentage of peak $\dot{V}O_2\text{max}$

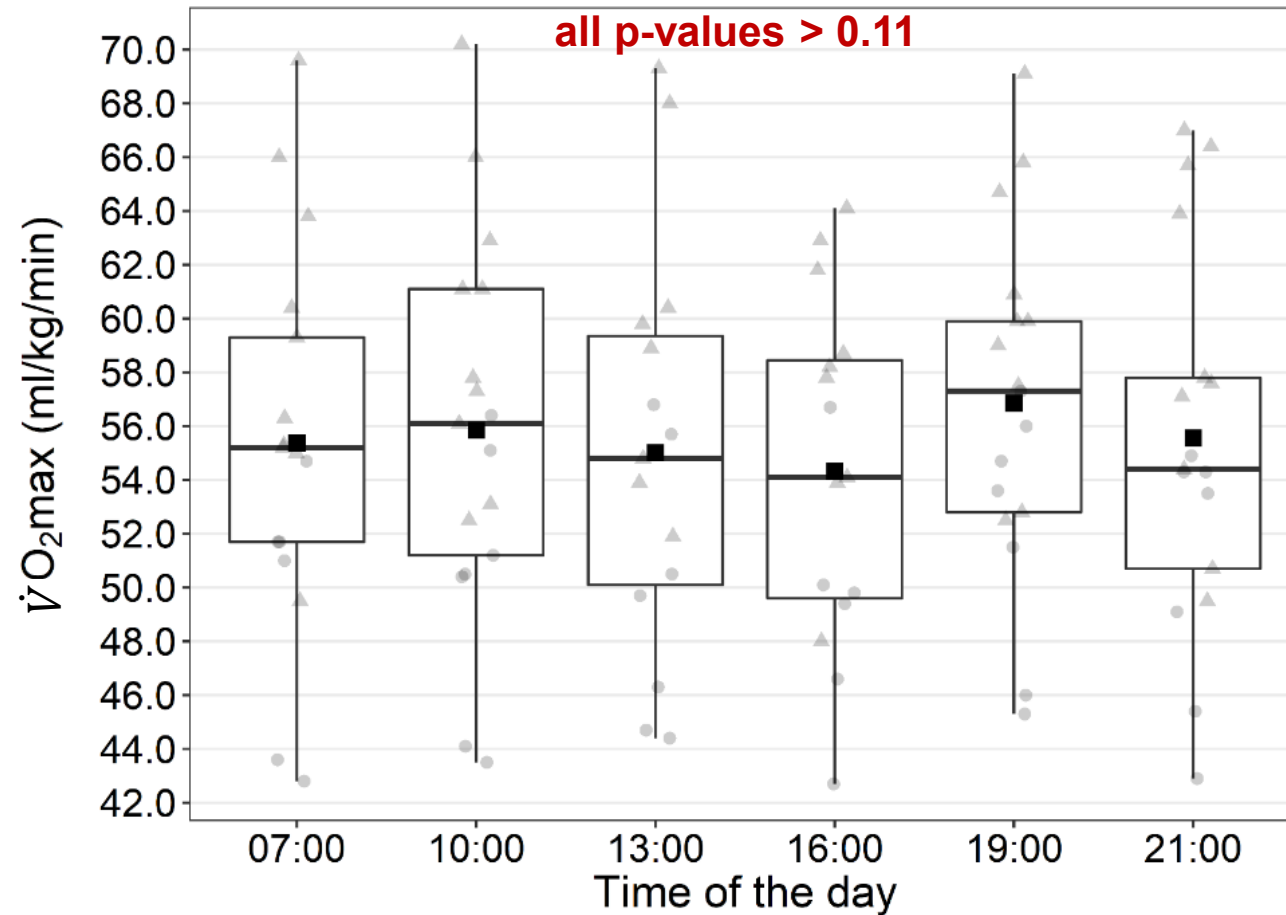


18 – 35 years

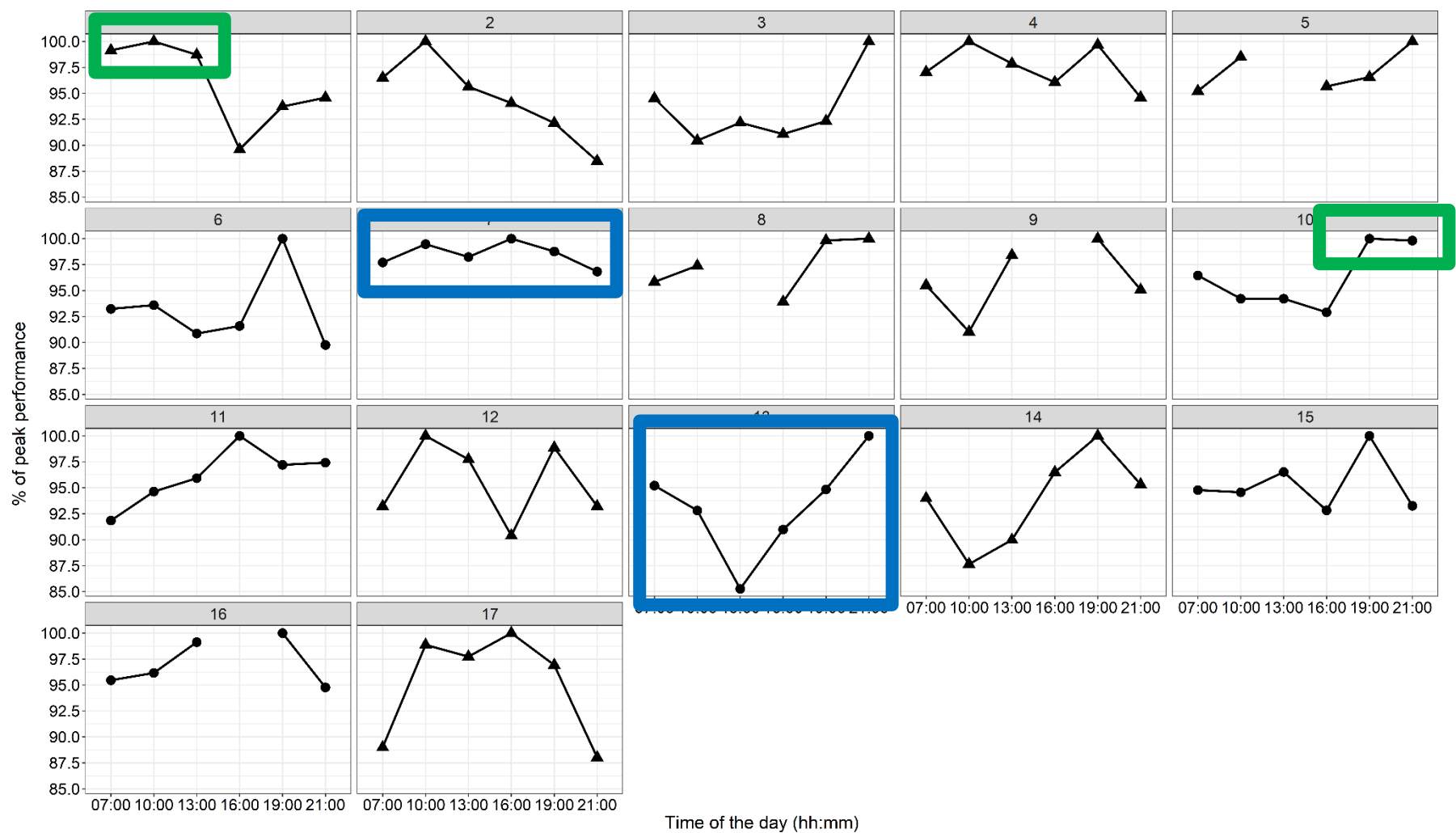
$\dot{V}O_{2\text{max}} > 90.$ percentile



Diurnal variation of peak $\dot{V}O_2\text{max}$.

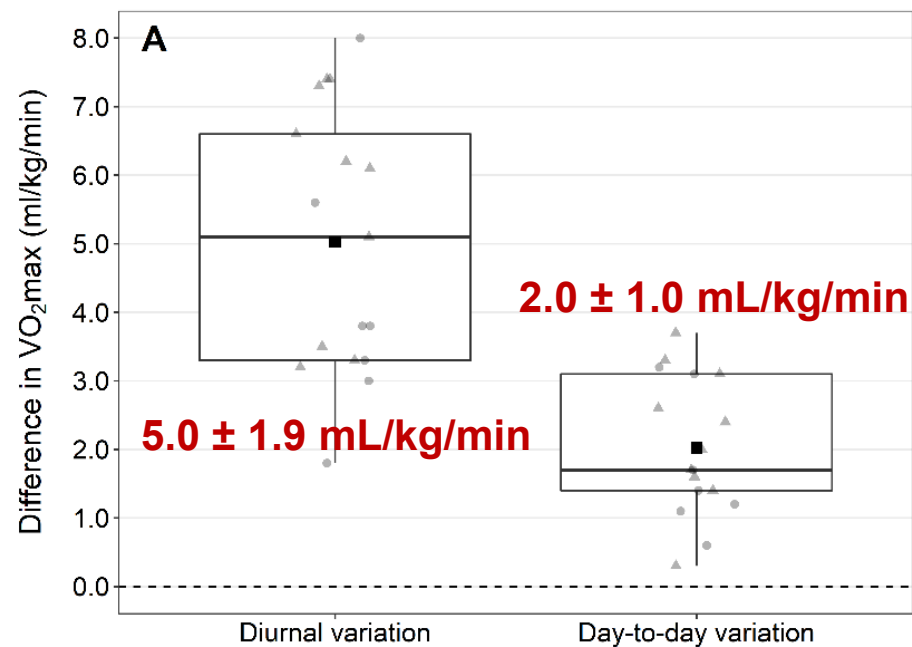


Diurnal variation in percentage of $\dot{V}O_2\text{max}$



Diurnal variation in percentage of peak $\dot{V}O_2\text{max}$.

Diurnal variation in percentage of $\dot{V}O_2\text{max}$

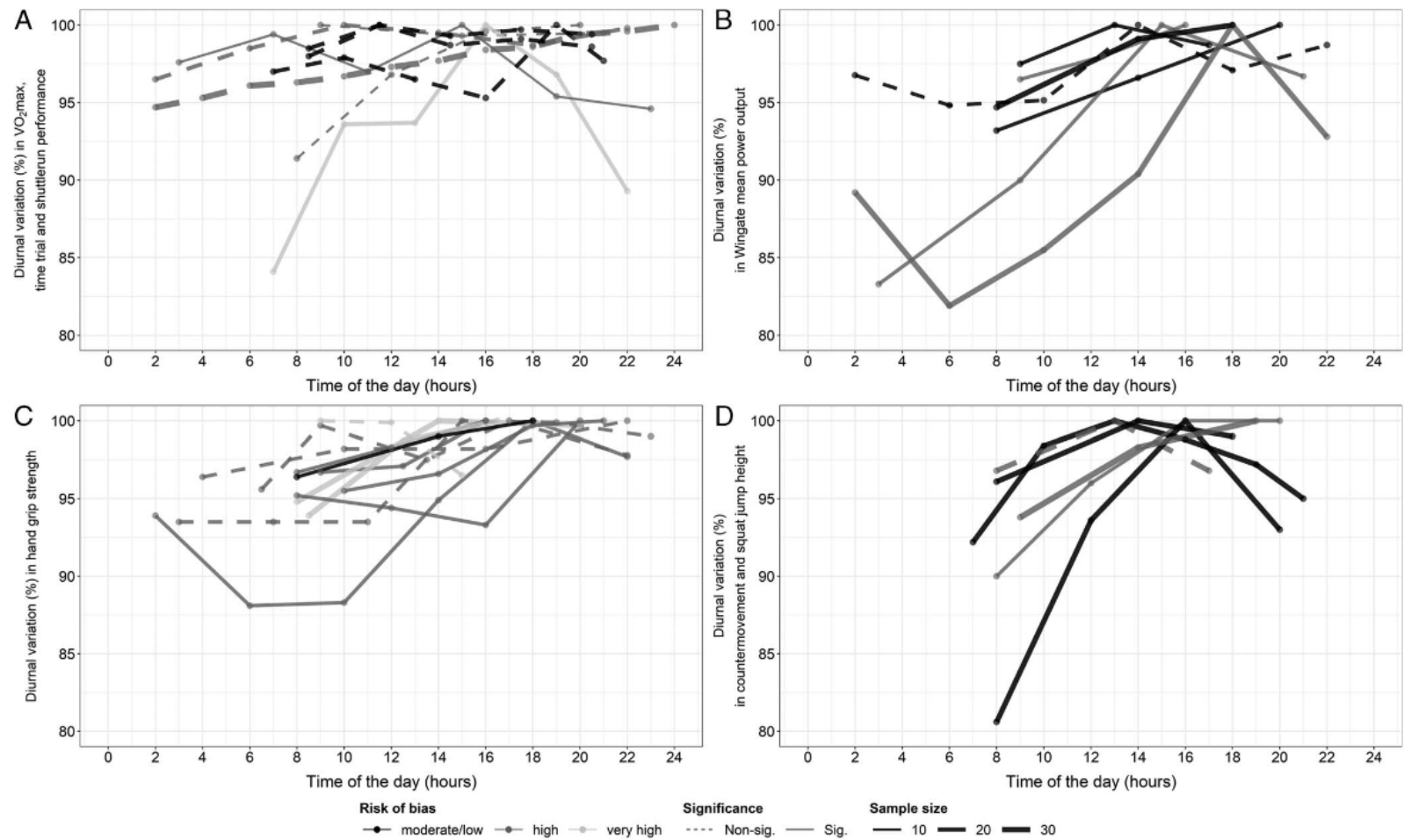


	Day 1	Day 2	ICC (95% CI)
Peak work-			0.99
load (W)	355 ± 57	356 ± 58	(0.97; >0.99)
Peak $\dot{V}O_2$	$4.01 \pm$	$3.99 \pm$	0.98
(L/min)	0.71	0.76	(0.93; >0.99)

Diurnal variations in maximal physical performance reported in the individual studies for

endurance
exercise tests

Handgrip
strength test

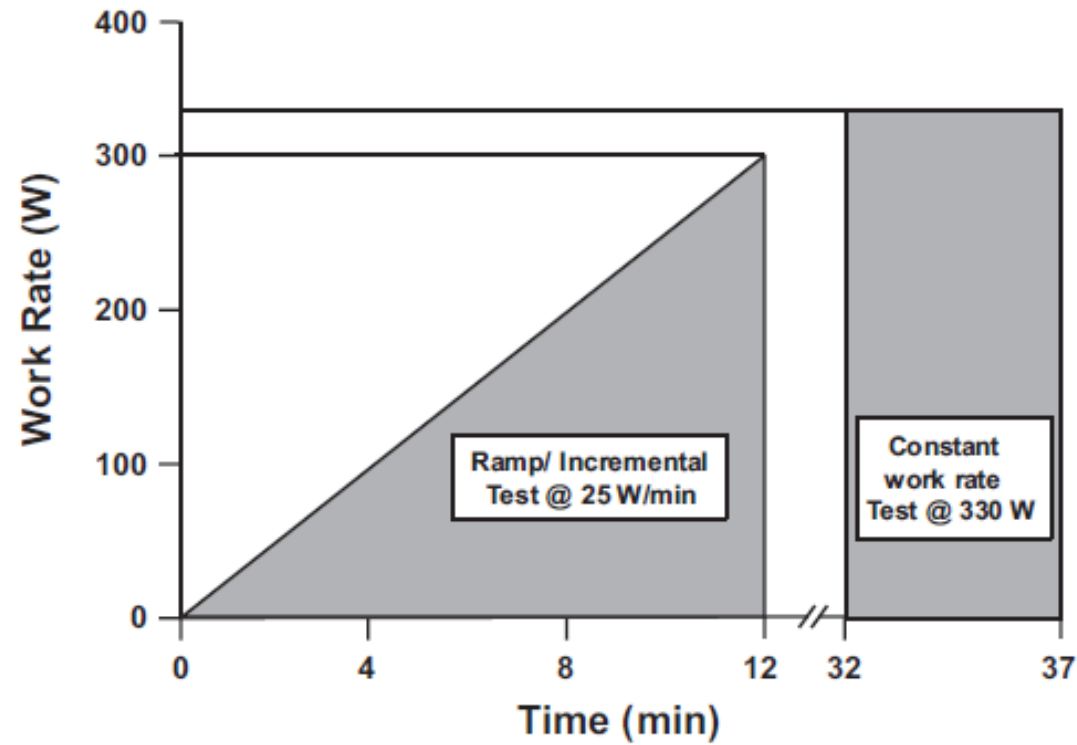


30-s Wingate test

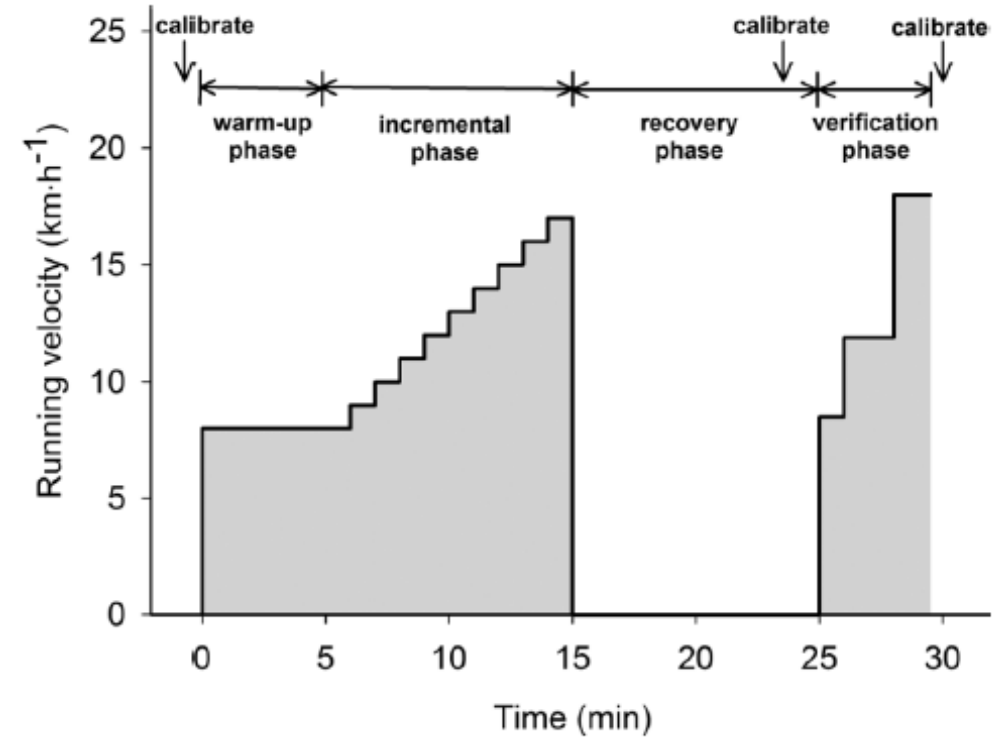
Jump height

Verification Test – sense or nonsense ?

Verification tests



Poole and Jones J Appl Physiol (1985). 2017 Apr 1;122(4):997-1002



Midgley et al. Appl Physiol Nutr Metab. 2009 Apr;34(2):115-23

Verification protocols

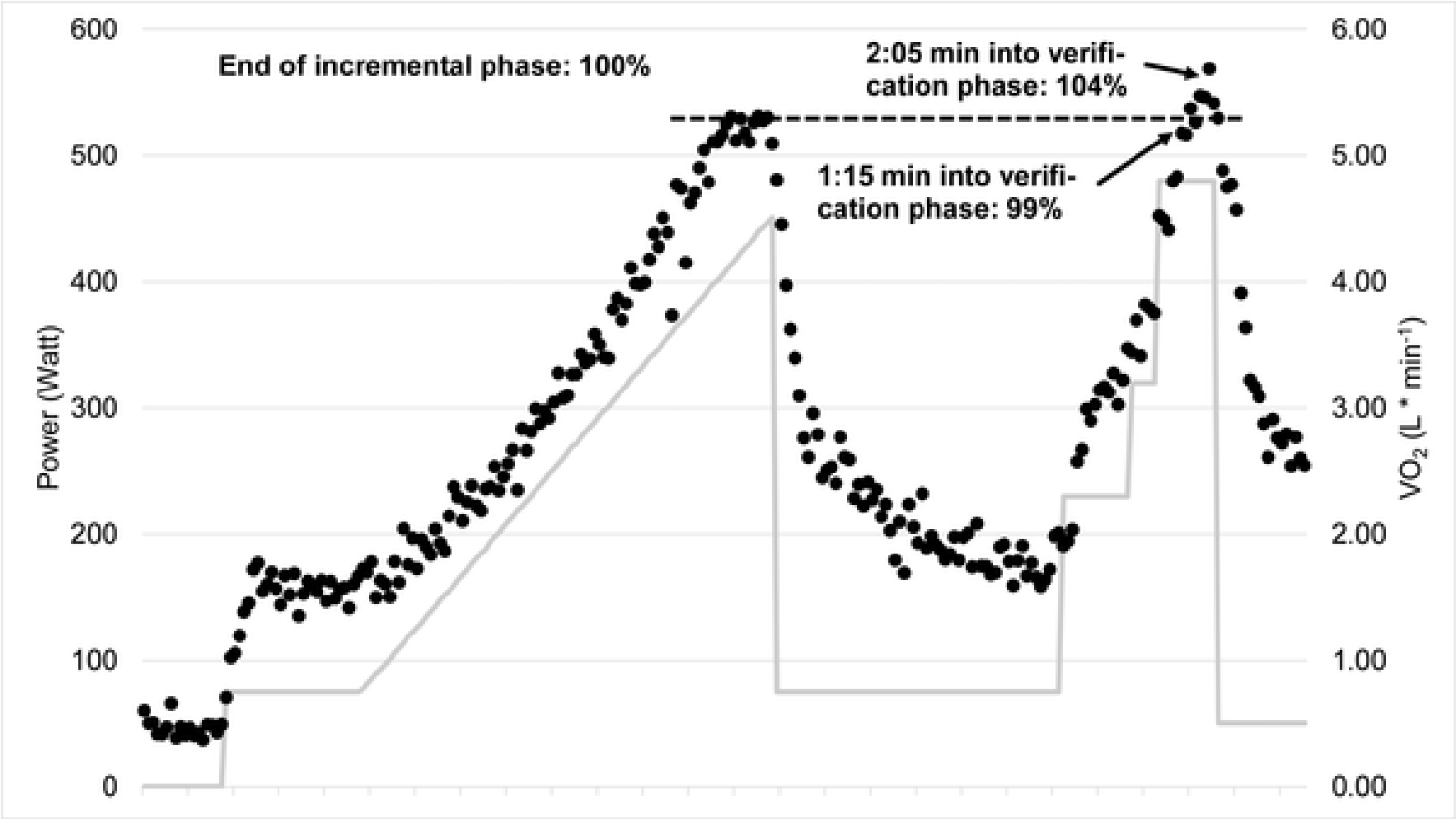
Study	Subjects	$\dot{V}O_2$ ramp	$\dot{V}O_2$ verification	TTE (min)
Midgley et al. (2009)	Cyclists (N=10)	4.05 ± 0.47 (l/min)	3.96 ± 0.38 (l/min)	1.7
Murias et al. (2018)	Untrained (n=45)	40.6 ± 11.4 (ml/min/kg)	40.9 ± 10.9 (ml/min/kg)	1.7 ± 0.4
Sansum et al. (2019)	Untrained (N=128)	m: 2.48 ± 0.73 f: 1.96 ± 0.31 (l/min)	2.36 ± 0.72 1.89 ± 0.34 (l/min)	1.6 ± 0.42 1.7 ± 0.33
Astorino et al. (2009)	Untrained (n=15)	2.37 ± 0.69 (l/min)	2.29 ± 0.75 (l/min)	4.2 ± 2.0

Verification protocols

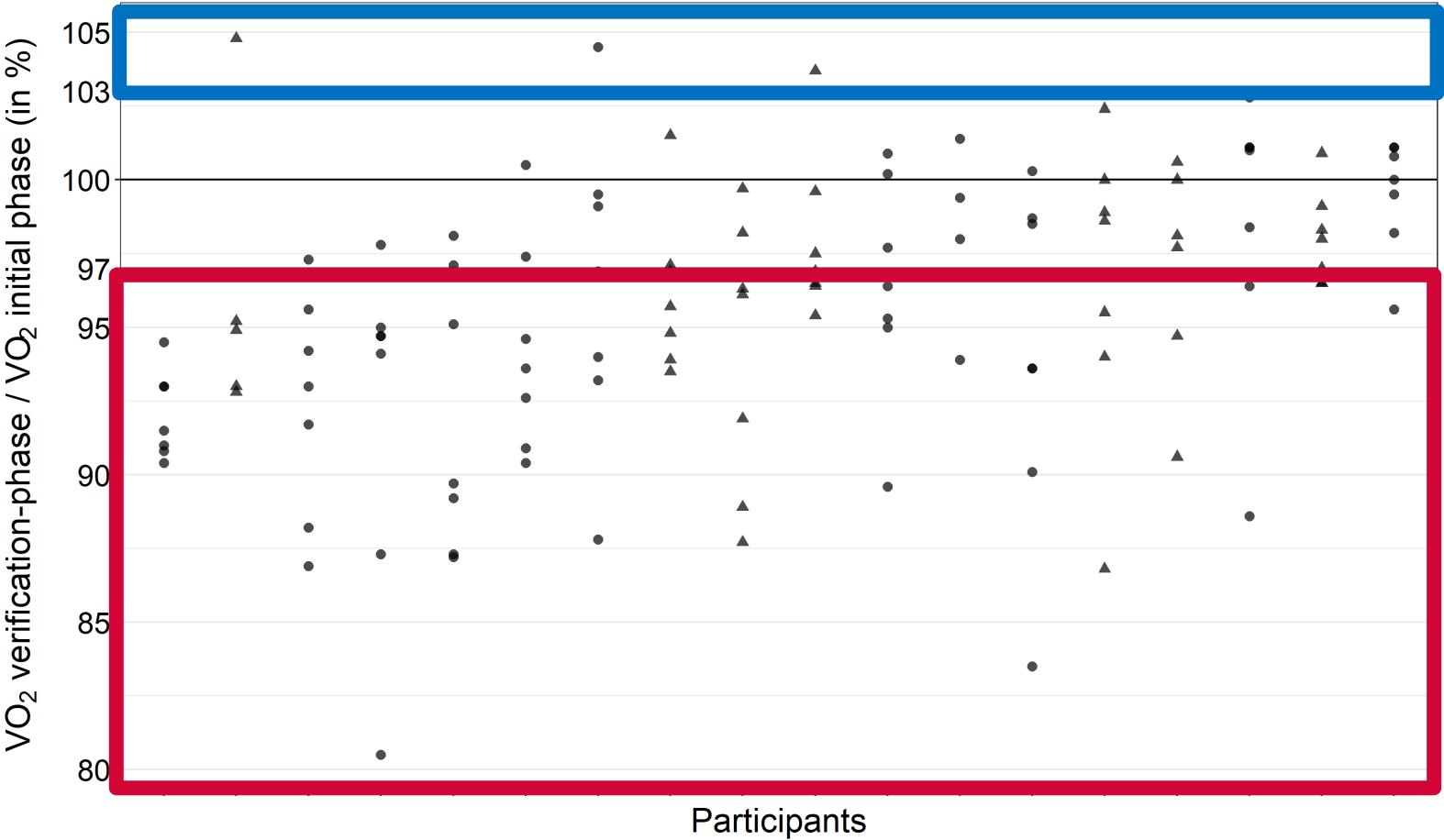
Study	Recovery	Verification	$\dot{V}O_2$ verified
Poole et al. (2009)	1 day +	3:00 20 W, stepwise increase to 105% Pmax	8 out of 8
Midgley et al. (2009)	10 min	2:00 50% Pmax, 1:00 70% Pmax, Pmax + 30 W	9 out of 10
Wagner et al. (2021)	10 min active	2:00: 50% Pmax, 1:00 70% Pmax, 105% Pmax	47 out of 126

Mean time to exhaustion during the verification phase was 1:15 ±0:20 minutes.

$\dot{V}O_2$ and work rate profile during a supra-peak power verification-bout in an individual, which was able to sustain the verification bout long enough to disprove the achievement of $\dot{V}O_{2max}$ in the incremental test.



Ratio of $\dot{V}O_2$ max achieved during the verification-phase divided by $\dot{V}O_2$ max from the initial phase of the exercise test.



verification- $\dot{V}O_2 > 103\%$

no $\dot{V}O_2$ -plateau and verification-
 $\dot{V}O_2$ of 97–103% of $\dot{V}O_2$ peak

No added value:
 $\dot{V}O_2$ - plateau present, irrespective
of verification- $\dot{V}O_2$, or no $\dot{V}O_2$ -
plateau was present and
verification- $\dot{V}O_2 < 97\%$ of $\dot{V}O_2$ peak
from initial phase of CPET.

Expressed as a percentage for all
tests performed by the participants.
Circles = males; triangles = females.

Added value of verification protocols

Different szenarios of test & verification test:

1. $\dot{V}O_2$ -plateau	& verification- $\dot{V}O_2 < 97\%$	no added value
2. $\dot{V}O_2$ -plateau	& verification- $\dot{V}O_2$ 97% - 103%	no added value
3. $\dot{V}O_2$ -plateau	& verification- $\dot{V}O_2 > 103\%$	no added value
4. no $\dot{V}O_2$ -plateau	& verification- $\dot{V}O_2 < 97\%$	no added value
5. no $\dot{V}O_2$ -plateau	& verification- $\dot{V}O_2$ 97% - 103 %	uncertain value
6. no $\dot{V}O_2$ -plateau	& verification- $\dot{V}O_2 > 103\%$	added value

Results:

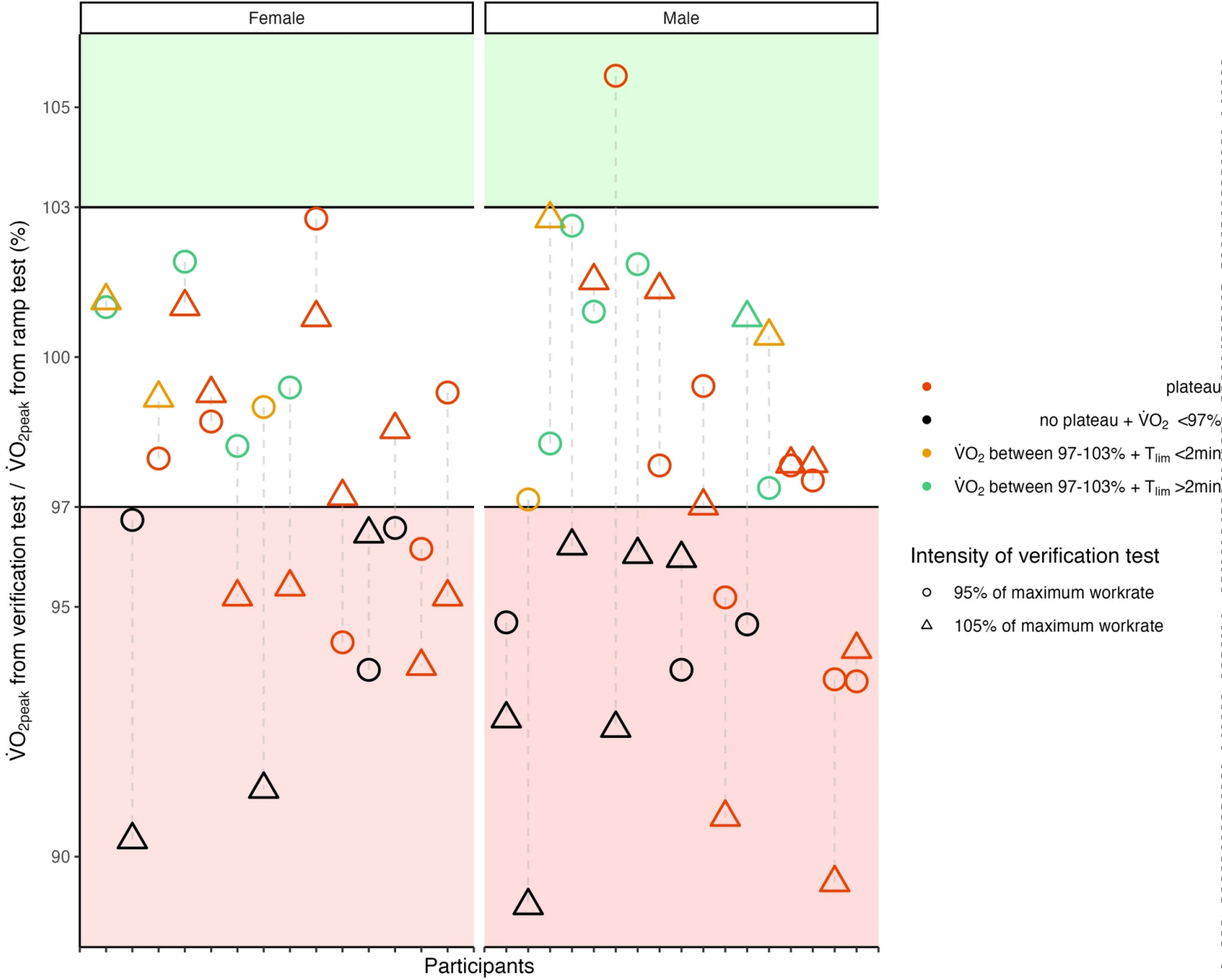
No added value: 66%

Uncertain value: 32%

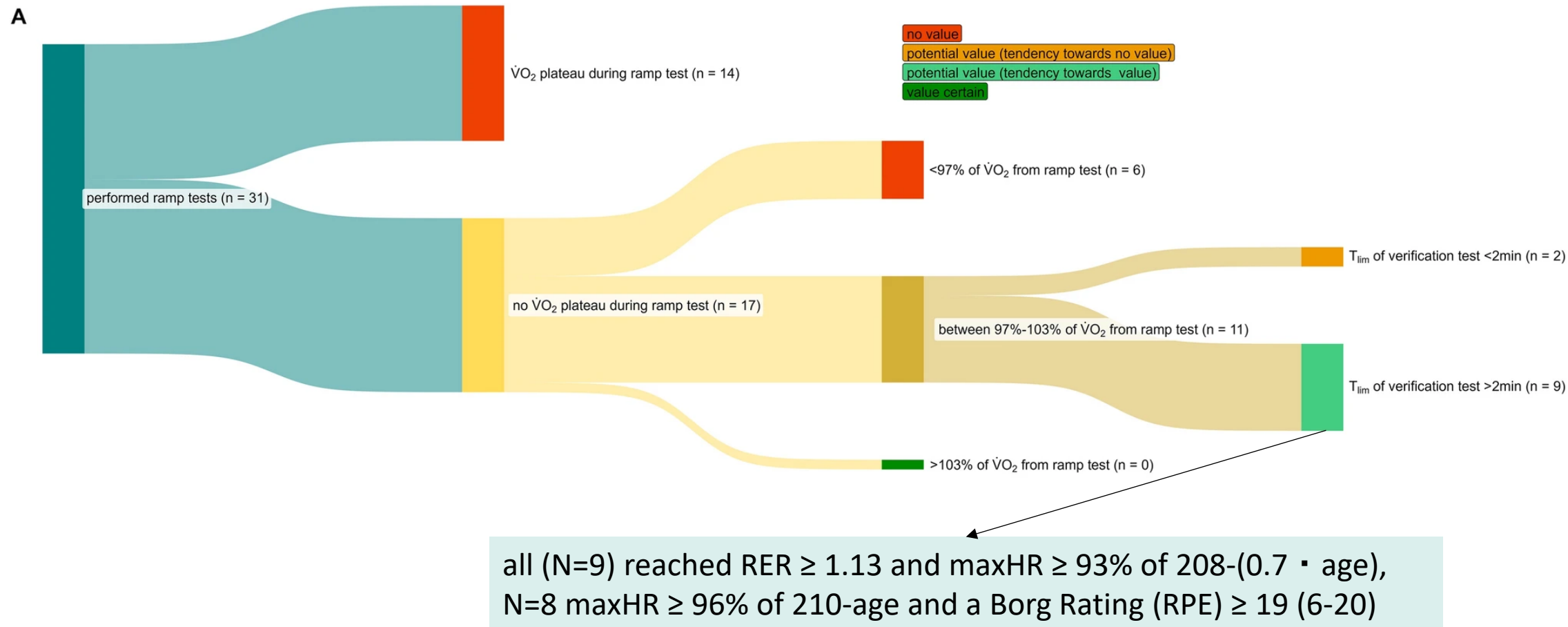
Added value: 2%

Ratio of verification $\dot{V}O_{2peak}$ divided by $\dot{V}O_{2peak}$ achieved in preliminary ramp test.

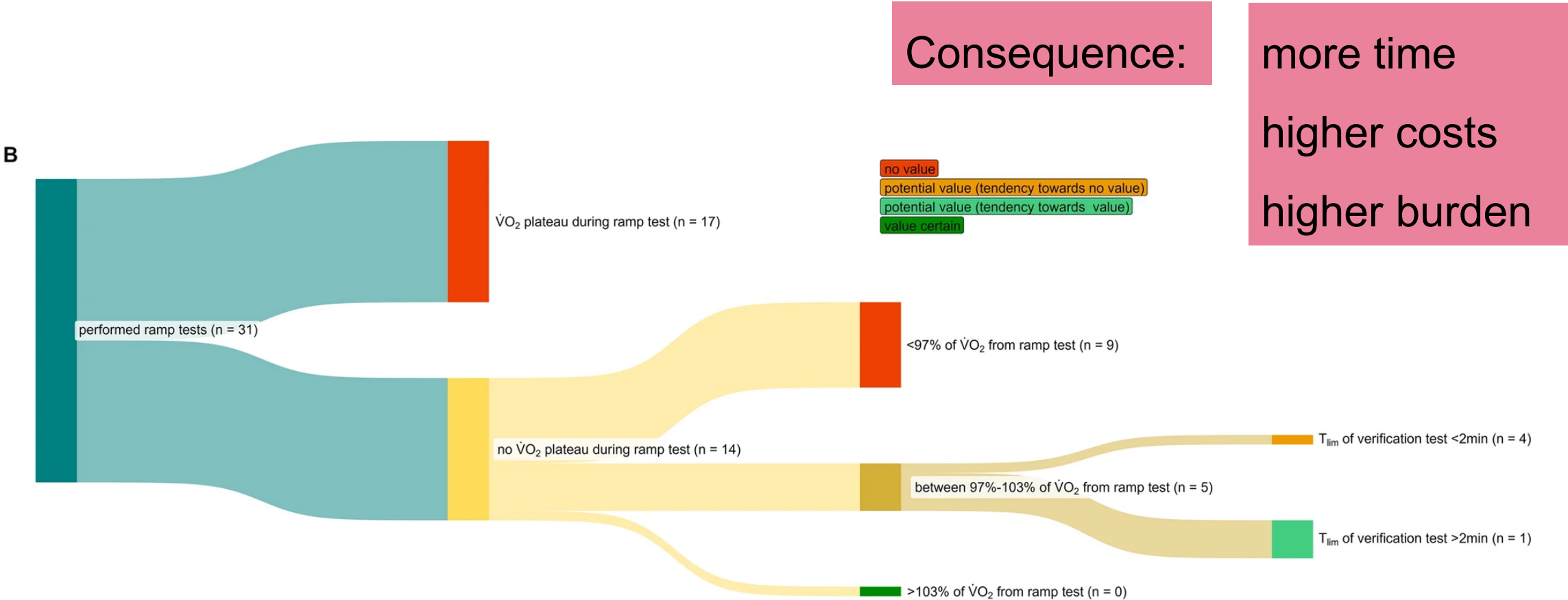
Presented as a percentage for all tests conducted by participants. T_{lim} time to the limit of exercise tolerance, $\dot{V}O_{2peak}$ highest oxygen uptake



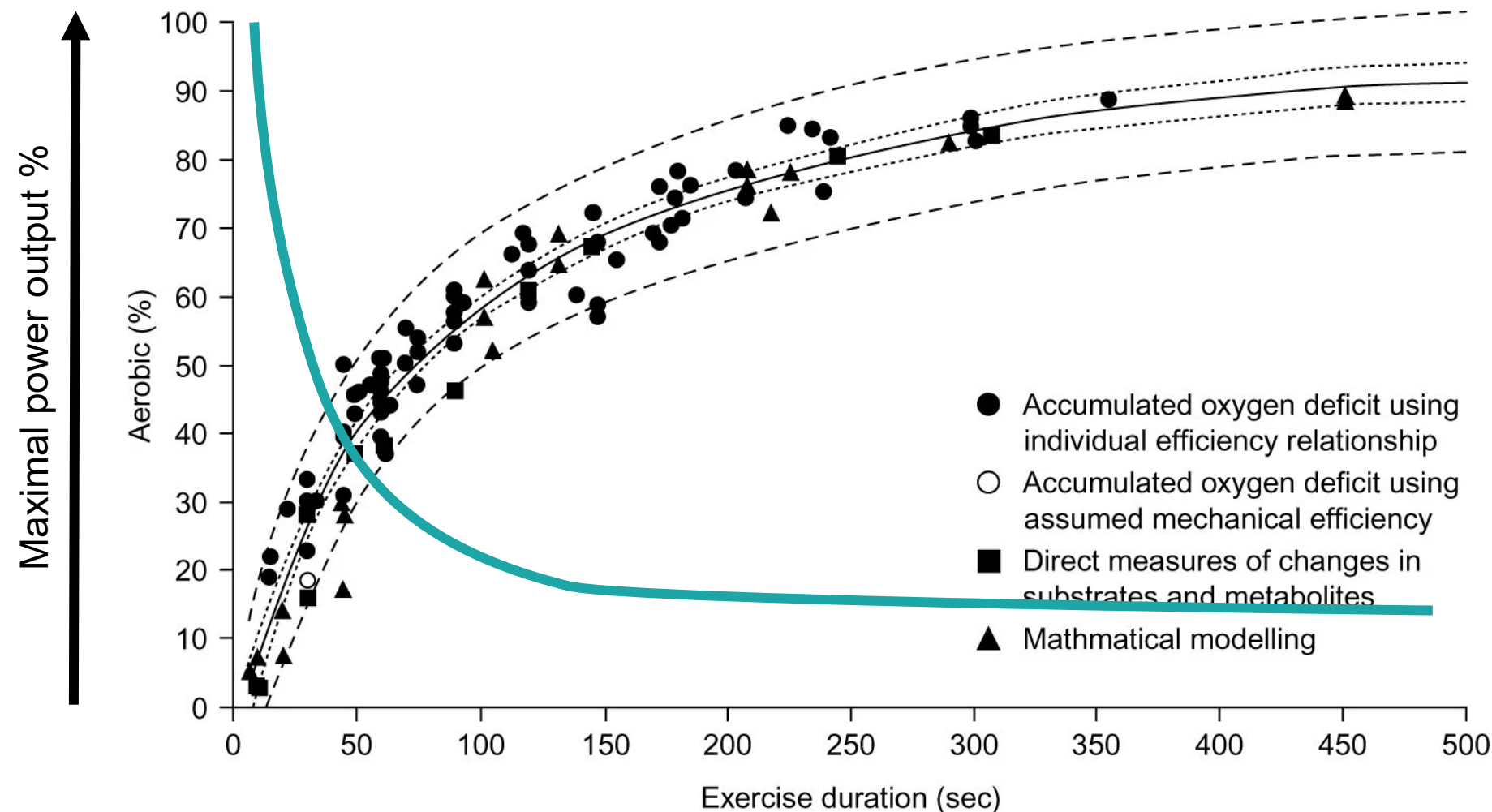
Classification of all sub-peak 95% verification phases performed into no added value, potential added value, and certain added value



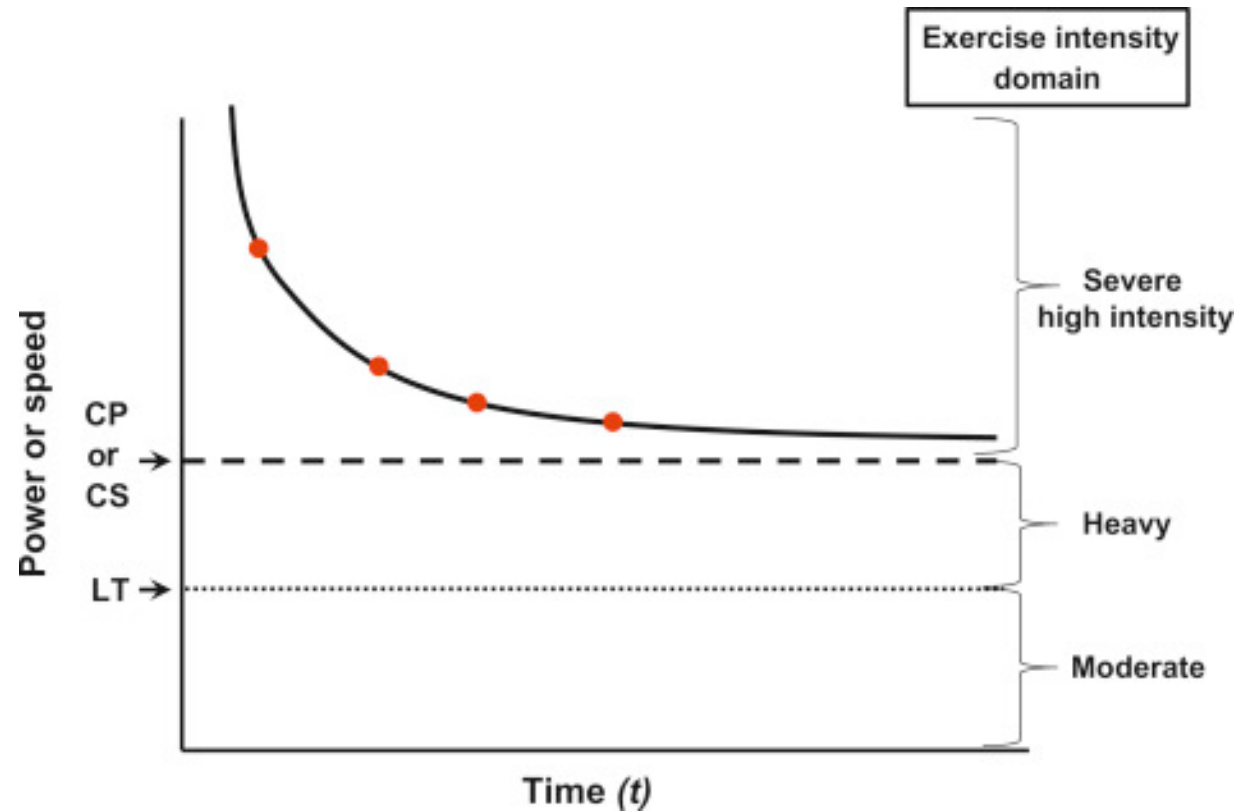
Classification of all supra-peak 105% verification phases performed into no added value, potential added value, and certain added value



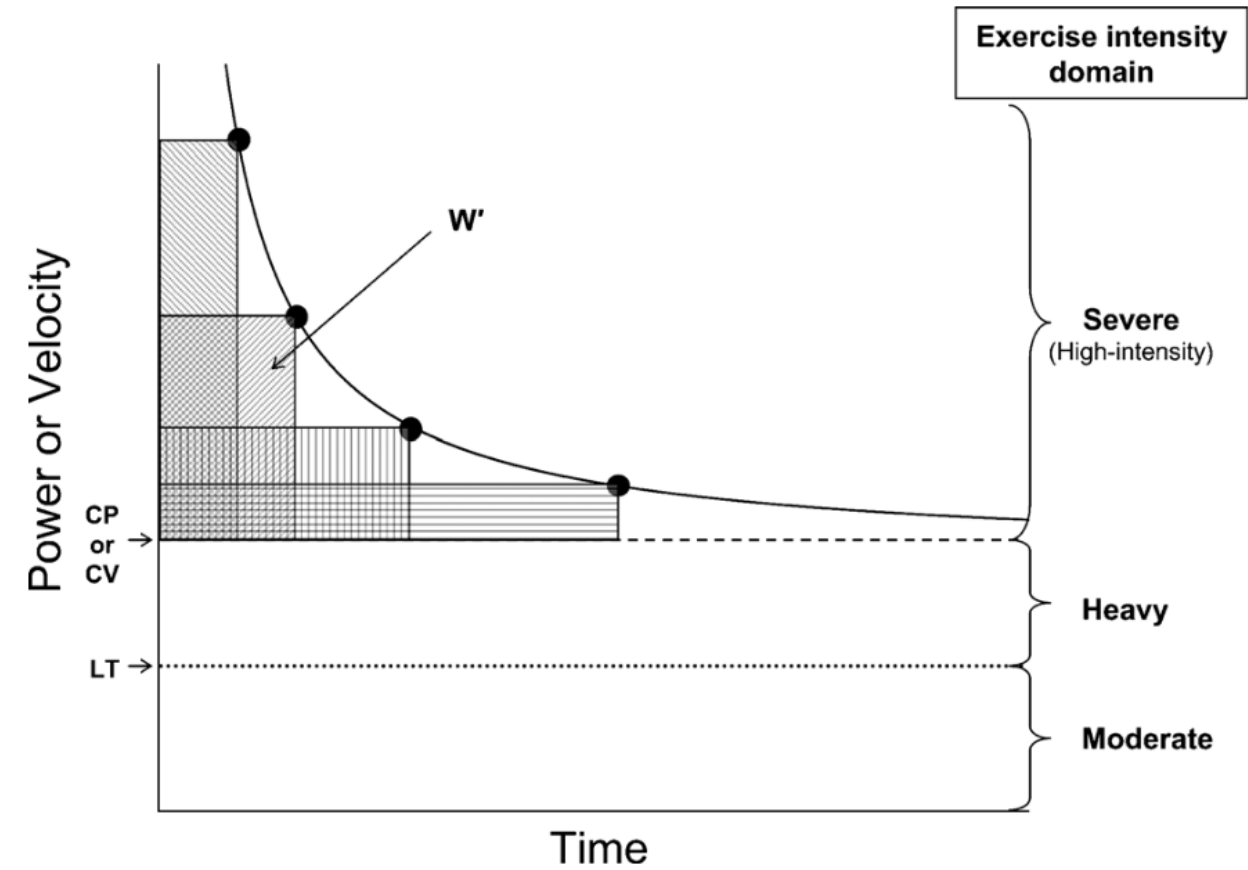
Energy System Interaction and Relative Contribution During Maximal Exercise

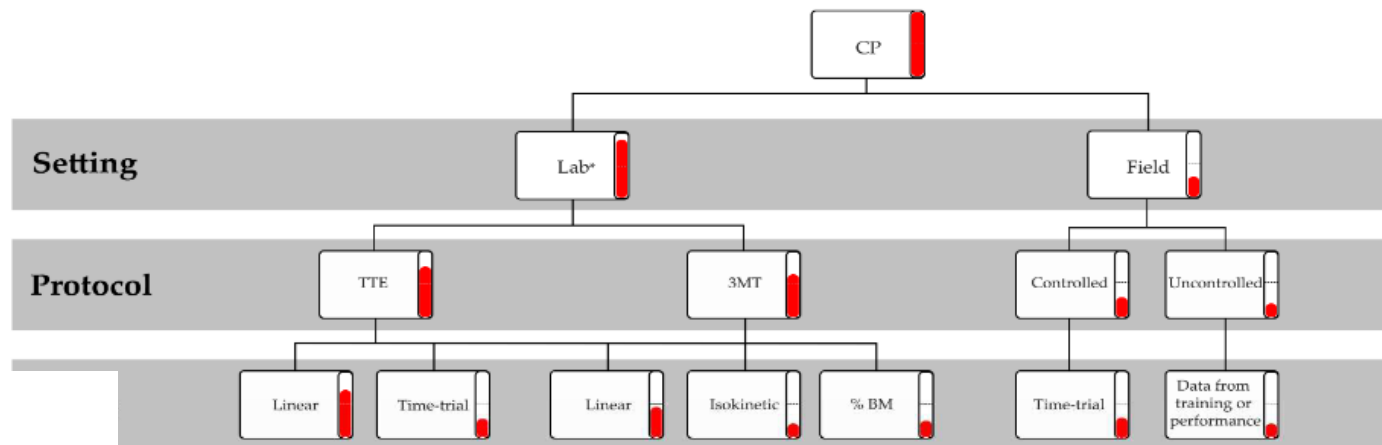
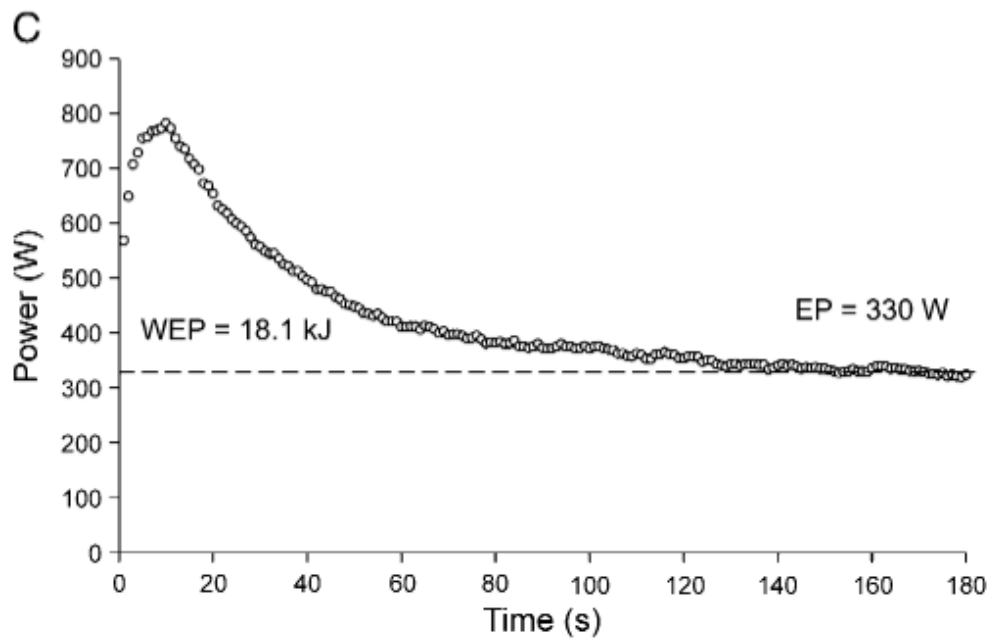


Critical power



W' = composed in part of anaerobic energy sources and expressed in kilojoules)





Y test *	Y *	N *	Y (N [5])	N	N	N	N
/time	70 %, 80 % Δ^* and 100 %, 105 % $\dot{V}O_{2peak}$ [13, 14] 80 %, 100% and 105 % MAP* or $p\dot{V}O_{2max}^*$ [19, 20, 23, 25, 28, 29, 30] 85 %, 100 % and 105 % MAP [24] 80 %, 95 % and 100 % $\dot{P}O_{peak}^*$, generate even TTE* between five trials [21] 70 % Δ, 98 % or 110 % P_{max}^* [27] $p^* = (W^*/\dot{I}lim^*) + CP^*$ [18] - fixed 70 [13, 14] - fixed 100 [27] - pref. fixed [18-21, 24, 28, 23, 25, 29, 30]	3, 7, 12 min [24] 3, 12 min [22] 3, 5, 12 min [24] - based on the TTE [30] 1, 4, 10 min [32]	- power/cadence2 [8, 13-15, 17, 18, 28, 29] - free gears * [16]	- maintained max. power (resistance provided by SRM) [20] - max. effort [28]	3.5 %, 4.5 % [13] 3 %, 4 %, 5 % [15] - PA-R * % BM* series of computation [18]	3, 7, 12 min [19, 23] 1, 4, 10 min [26] 2, 7, 12 min [26] 2, 6, 12 min [27] 2, 5, 12 min [31] <i>all done with max. effort</i>	- data from three highest PO values (3, 7 and 12 min) of all training and racing [23] - using a cycling software platform (2, 5, 12 min) [31]
sts	5+1 [21] 4+1 [13, 14, 18] 3+1 [19, 20, 23-25, 27-30]	- self-selected [22] - self-pacing strategy [24, 30, 32]	as high as possible [8, 13-18, 28, 29]	fixed preferred [20, 28]	as high as possible [13, 15, 18]	- as high as possible [19, 23, 26, 27] 80-100 rpm* [31]	–
iel/	- linear-TW* [13, 14, 18-21, 27-30] 1/time* [14, 18-21, 23-25, 27, 29, 30] 2-hyp* [14, 21, 27] 3-hyp* [14, 21] - EXP* [14, 21]	3 [22, 24, 30, 32] 2 [22]	1 [16] 2 [8, 13-15, 17, 18, 28, 29]	1 [20, 28]	1 [13, 15, 21]	3 [19, 23, 26, 27, 31]	–
	- linear-TW* [13, 14, 18-21, 27-30] 1/time* [14, 18-21, 23-25, 27, 29, 30] 2-hyp* [14, 21, 27] 3-hyp* [14, 21] - EXP* [14, 21]	- Linear-TW [22, 30, 32] 1/time [22, 24, 30, 32] 2-hyp [32] 3-hyp [32]	$W^* = 150$ s ($P150^* - CP$) $CP = \text{mean power over } 30 \text{ s}$ [8, 13-18, 28, 29]	$W^* = 150$ s ($P150 - CP$) $CP = \text{mean power over } 30 \text{ s}$ [20, 28]	$W^* = 150$ s ($P150 - CP$) $CP = \text{mean power over } 30 \text{ s}$ [13, 15, 18]	- Linear-TW [23-25] 1/time [19, 23, 26, 27, 31] 2-hyp [26, 27]	1/time [23, 31]
	- Quinton Corval 400 [13] - Lode Excaltur Sport [14, 18, 27-29] - SRM (Schober Rad Messtechnik) [20] - Bike with a PowerTap (CycleOps) [19, 23, 25] - Bike mounted Cycus2 [24] - Velotron Dynafit Pro [14] - Cycle ergometer (CompuTrainer) [30]	- Bike mounted Cycus (RBM) [24] - Bike (PowerTap, CycleOps) [22] - Cycle ergometer (CompuTrainer) [30] - bike fitted to a smart trainer [32]	- Quinton Corval 400 [13] - Lode Excaltur Sport [8, 14, 15, 17, 18, 28, 29] - Bike CompuTrainer [16]	- SRM (Schober Rad Messtechnik) [20] - Lode Excaltur Sport [28]	- Monark (818) [13] - Lode Excaltur Sport [15, 18]	- Road bike with a PowerTap (CycleOps) [19, 23] - Bike with SRM power meter [26, 27]	- Road bike with a PowerTap (CycleOps) [23] - Bike with crank system (SRAM Red) [31]

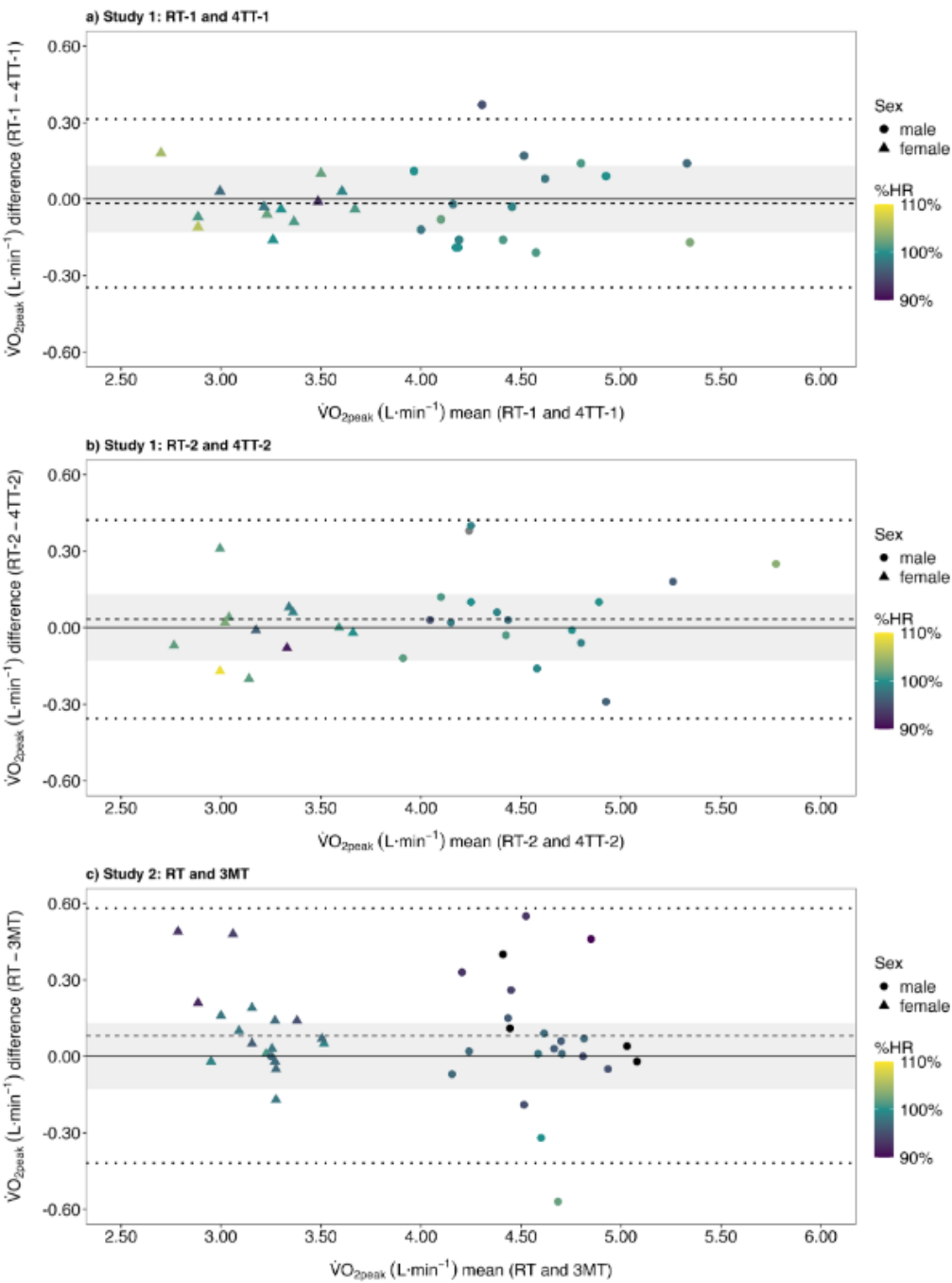
* preliminary = ramp or incremental test to exhaustion before the testing
 * Y = yes, N = no
 * $p\dot{V}O_{2max}$ = power at $\dot{V}O_{2max}$
 * MAP = maximal aerobic power
 * $\dot{P}O$ = power output
 * free gears = subjects change gears freely during 3MT
 * PA-R = physical activity rating
 * Lab = laboratory
 * TTE = time to exhaustion test
 * CP = critical power

* p = power values
 * W^* = work above critical power
 * $\dot{I}lim$ = time limit
 * linear-TW = linear total work model
 * 1/time = linear power model
 * 2-hyp = non-linear hyperbolic two parameter model
 * 3-hyp = non-linear hyperbolic three parameter model
 * EXP = exponential model
 * P150 = power over 150 seconds
 * rpm = revolutions per minute

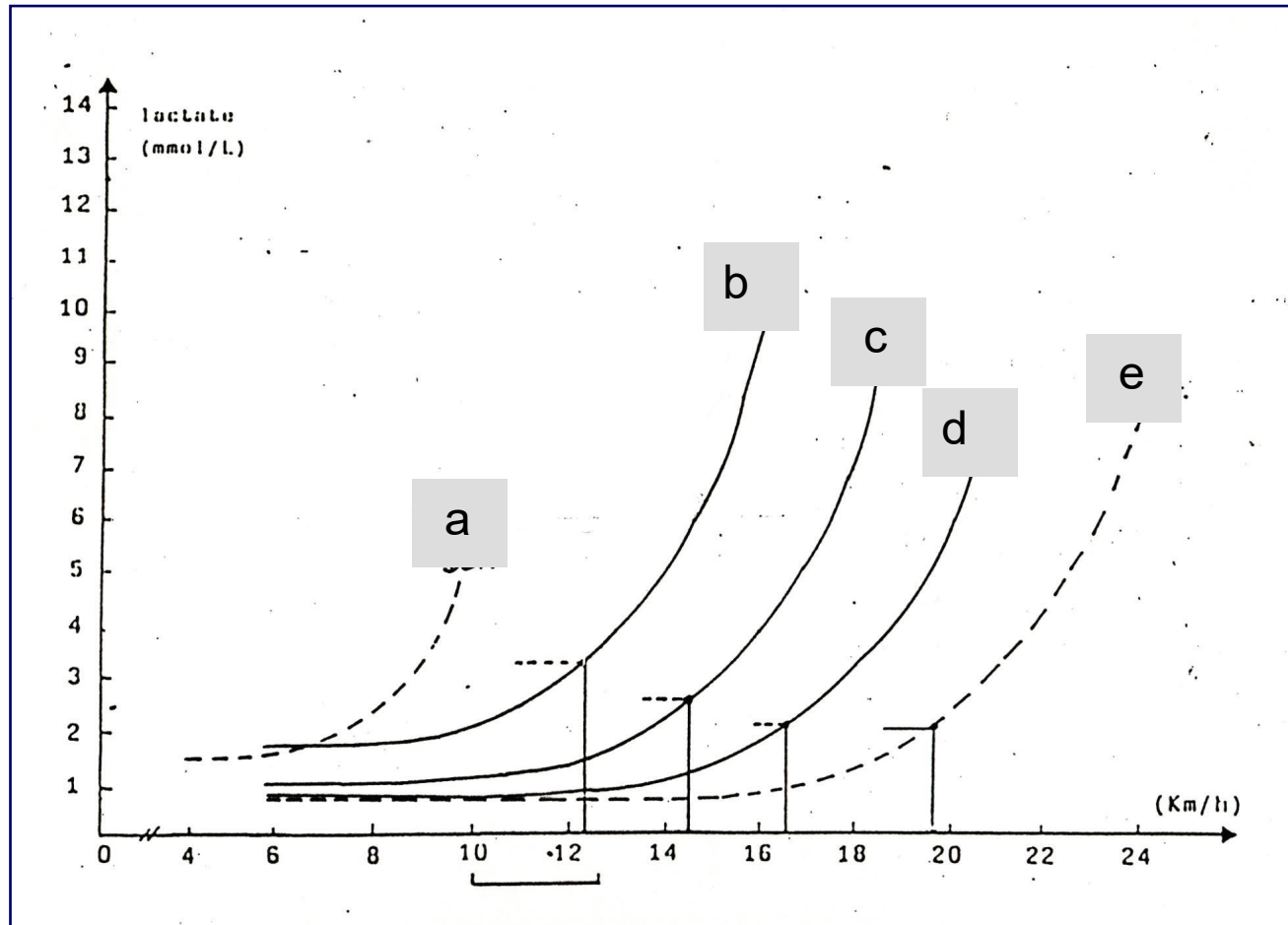
red column shows the frequency of usage of the method

Limited agreement of ramp $\dot{V}O_{2\text{max}}$ with 3min all-out and 4 min Time trial

Characteristics	Study 1 [#]		Study 2	
	Males <i>n</i> = 17	Females <i>n</i> = 13	Males <i>n</i> = 23	Females <i>n</i> = 17
Age (years)	23 ± 2 [21–28]	22 ± 2 [19–25]	30 ± 4 [24–39]	29 ± 4 [22–33]
Height (cm)	177 ± 5 [164–183]	165 ± 5 [157–179]	177 ± 6 [166–187]	166 ± 6 [158–175]
Body mass (kg)	70.5 ± 4.3 [63.1–79.6]	59.8 ± 7.8 [49.7–73.7]	87.0 ± 6.7 [73.1–101.7]	65.9 ± 5.0 [58.9–74.8]
Body fat content (%)	11.6 ± 4.0 [3.7–20.5]	21.0 ± 4.5 [15.7–27.7]	9.4 ± 3.1 [3.1–14.9]	9.9 ± 4.4 [3.4–18.7]
$\dot{V}O_{2\text{peak}}$ (mL·kg ⁻¹ ·min ⁻¹)	64.0 ± 5.7 [56.4–74.0]	55.6 ± 5.7 [51.4–64.8]	52.7 ± 3.5 [44.5–59.0]	49.4 ± 3.3 [44.1–58.3]



Step Test on Treadmill for Patient with HCM and Athletes



Comparison:

- a – hypertrophic cardiomyopathy
- b – tennis player („serve and volley“)
- c - tennis player („ash court“)
- d - 10 km runner
- e – marathon runner

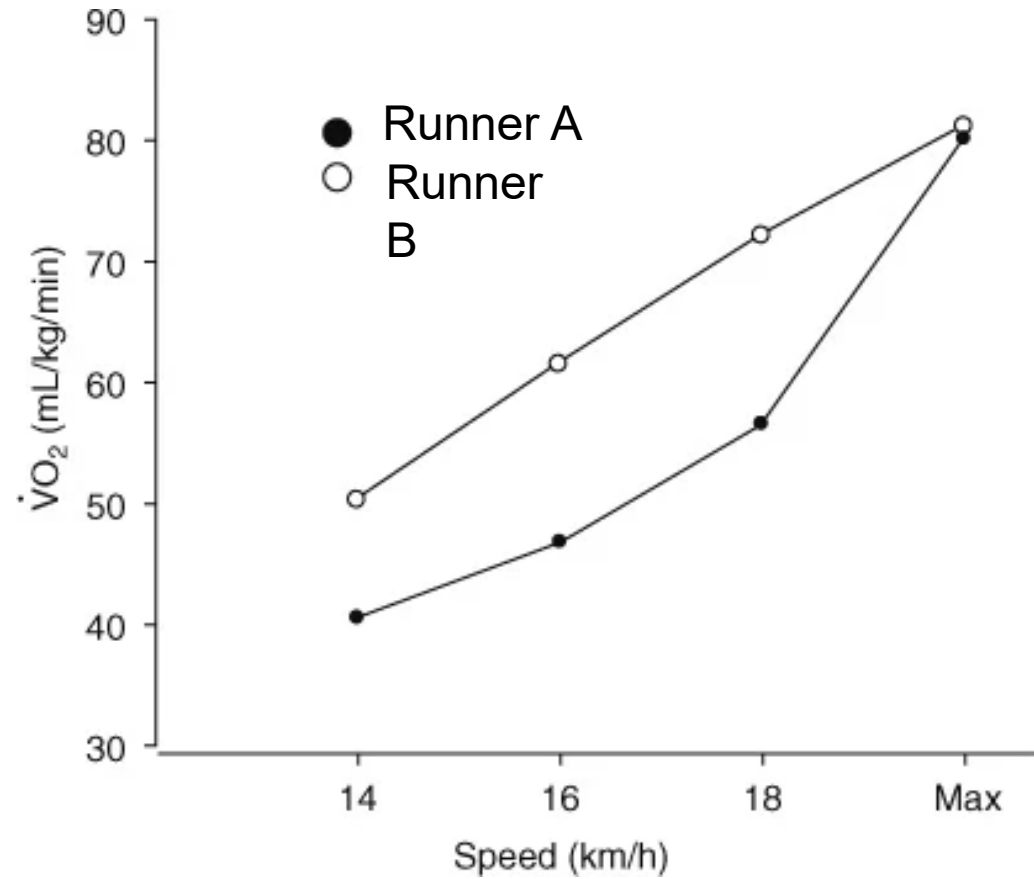
Running economy

Let's imagine...

Runner A

$\dot{V}O_{2\max}$ is
equal

Runner B



What is work economy and how is it measured?

Definition

Energy demand for given workload

Commonly measured as steady-state consumption of oxygen

Protocol

Different stages of speed or workload, long enough to reach steady-state

Duration

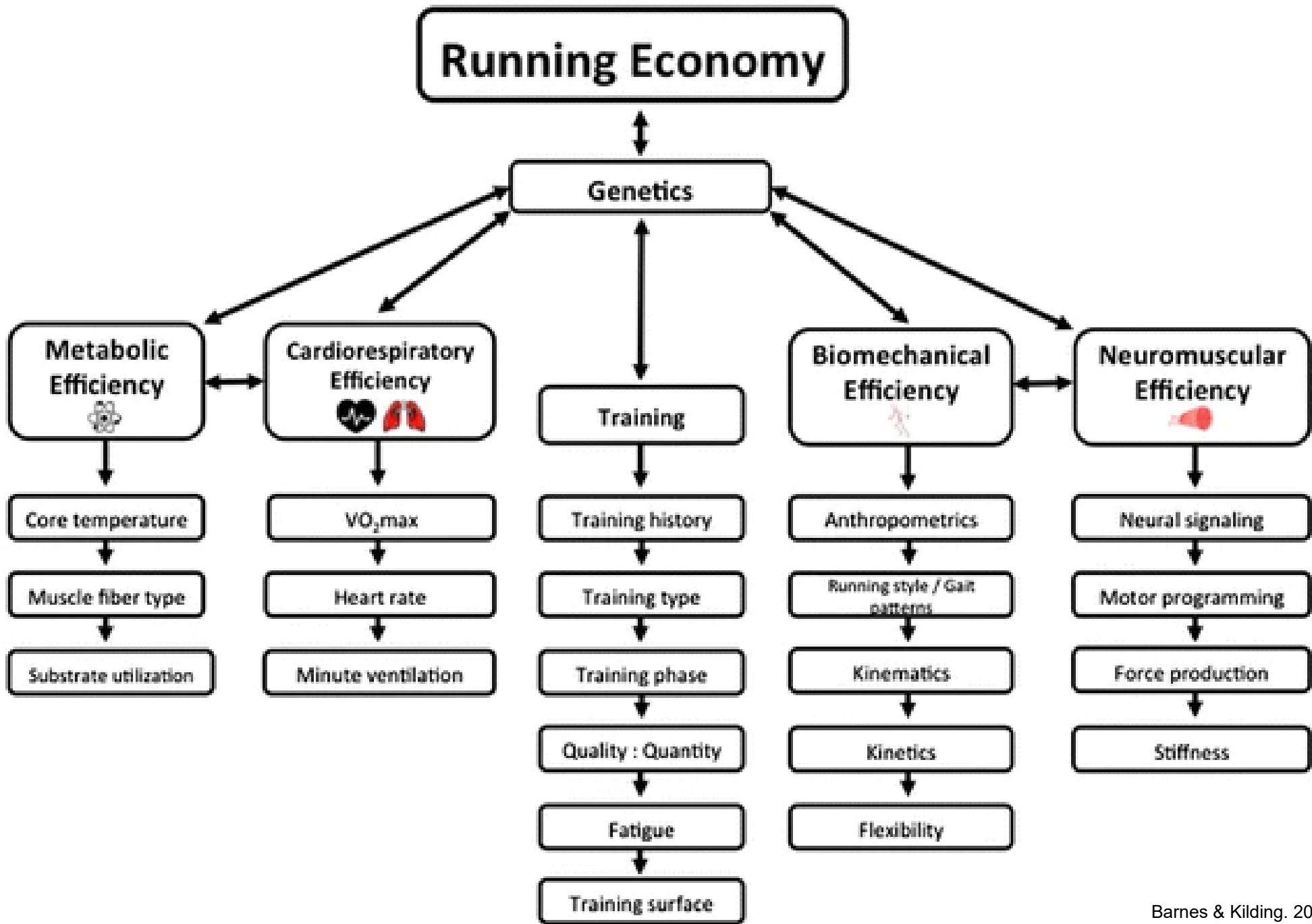
3-15 min if intensity is below ventilatory threshold 2

Slow component occurs with higher intensities

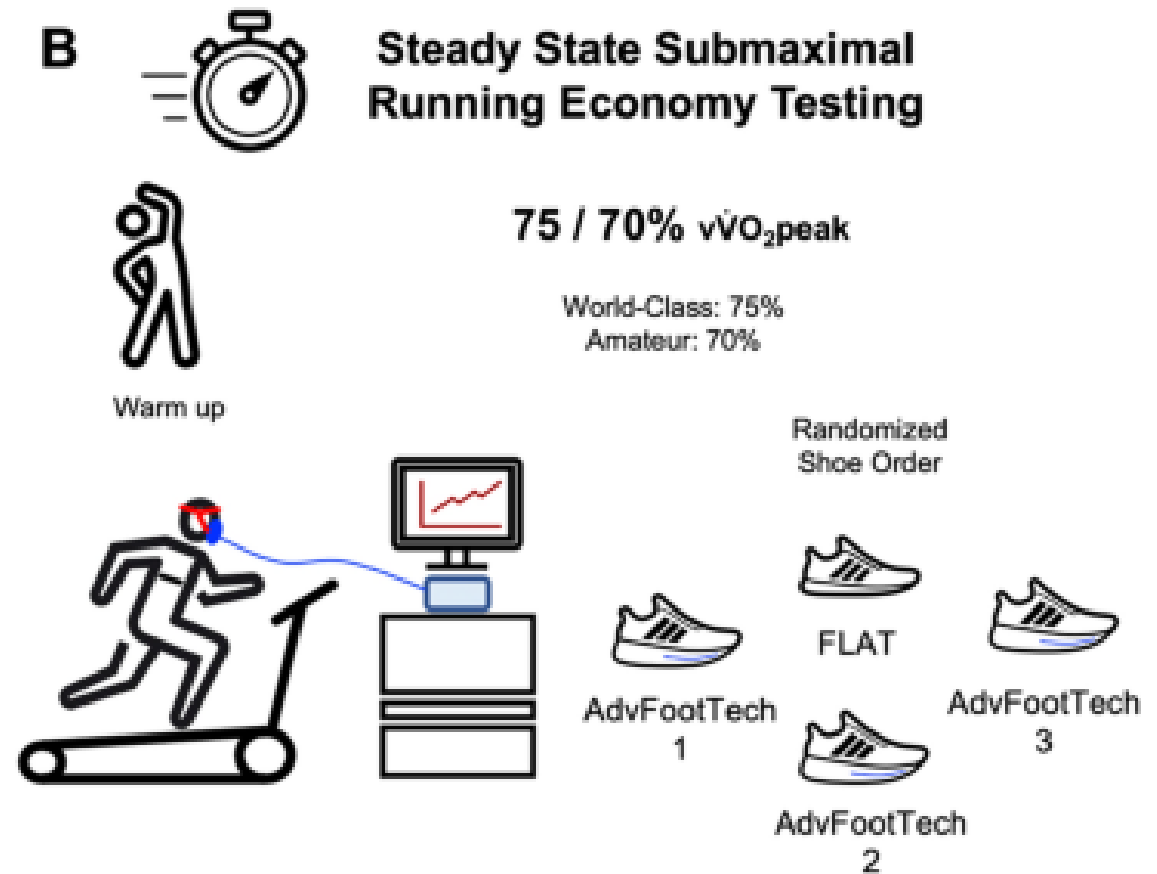
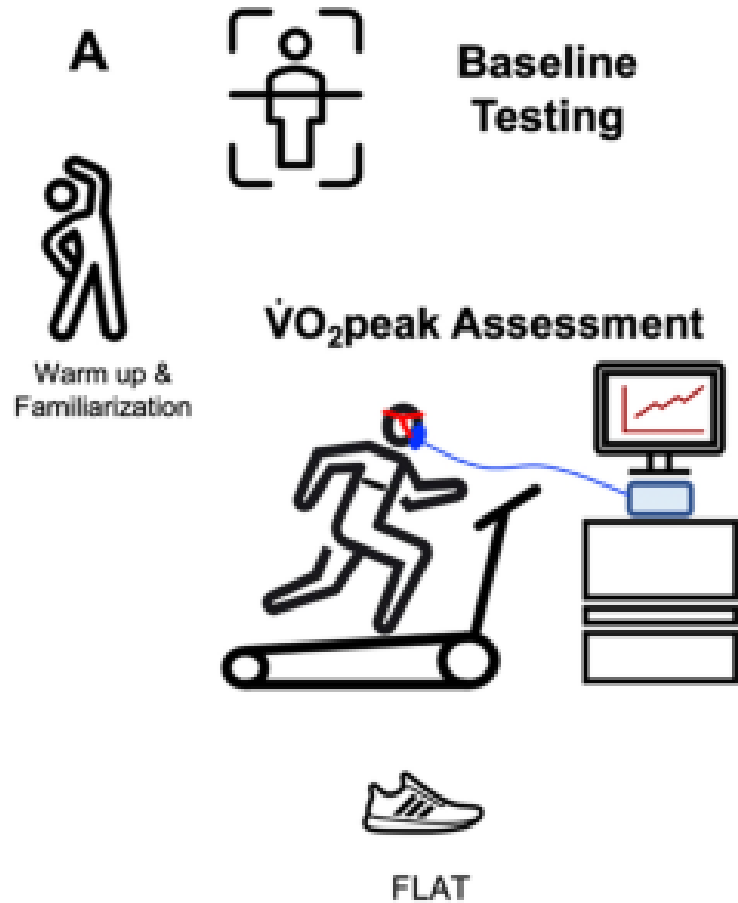
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Oxygen alone does not consider differences in substrate use

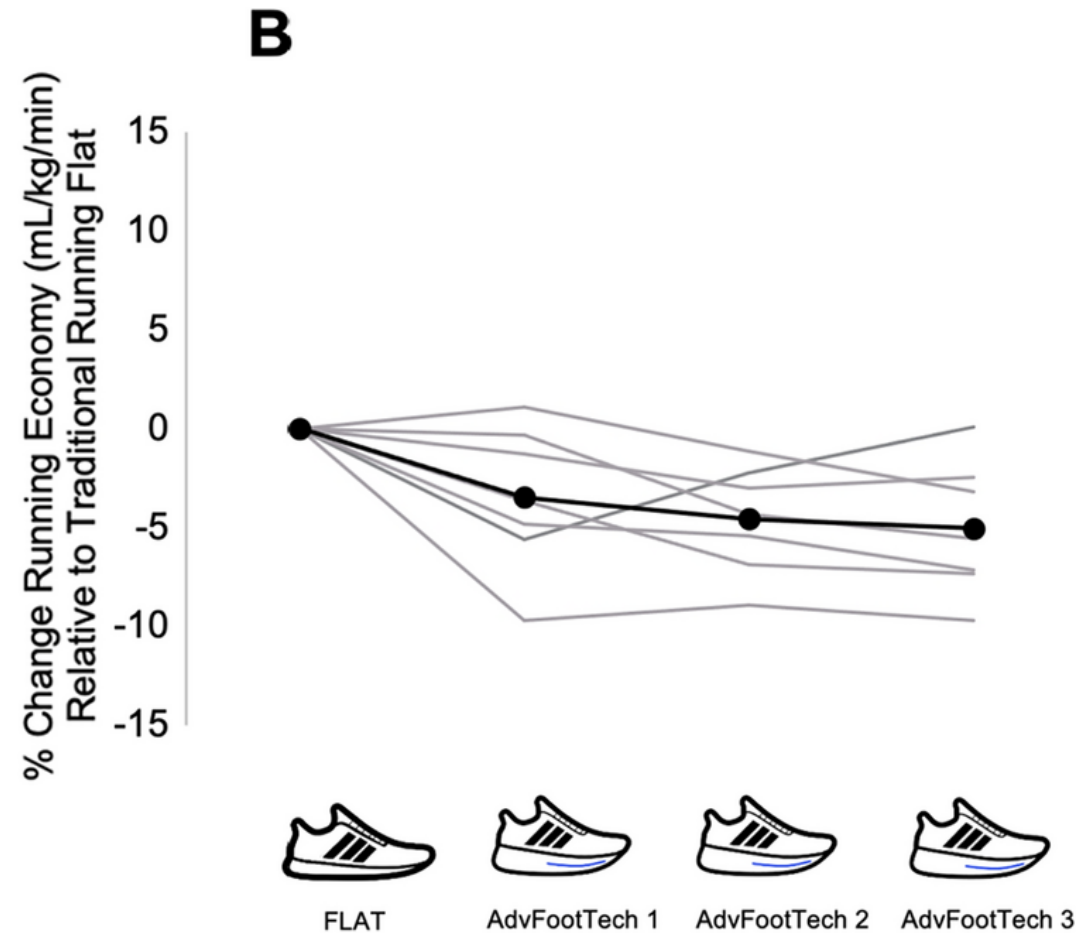
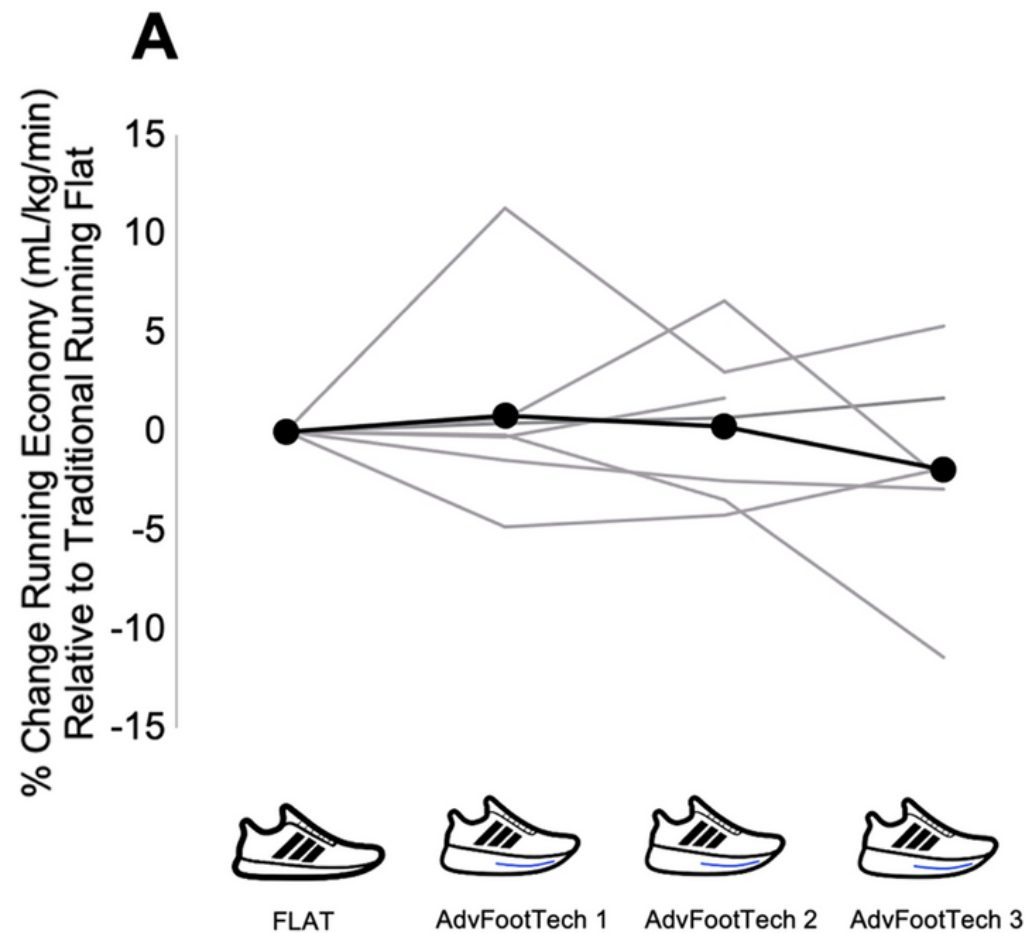
To be more accurate: **kcal/kg/min or kcal/kg/m**



How can equipment affect economy?



What factors affect work economy?



Take home messages

- Validity and reproducibility come first – standardise the test before you interpret the numbers
- Data-based exhaustion criteria ($\text{RER} \geq 1.13$, % APMHR) replace the plateau – but they stem from untrained cohorts and still await validation in athletes
- Time of day barely affects $\dot{V}\text{O}_{2\text{peak}}$ ($\text{ICC} \geq 0.98$) – it does affect VT1 and VT2, so keep follow-up tests at the same hour
- Verification phases add value in ~2% of tests, at the price of time, cost and additional strain – not a routine requirement
- $\dot{V}\text{O}_{2\text{max}}$ is only one of three determinants – report threshold and economy as well, and state the smallest change you can actually detect



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CPET in athletes



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