Modeling the Expenditure and Recovery of Anaerobic Work Capacity in Cycling

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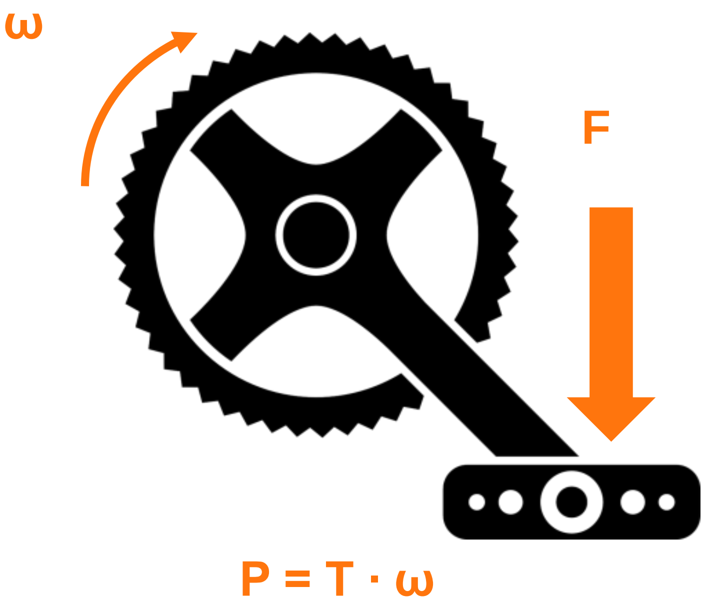
Motivation

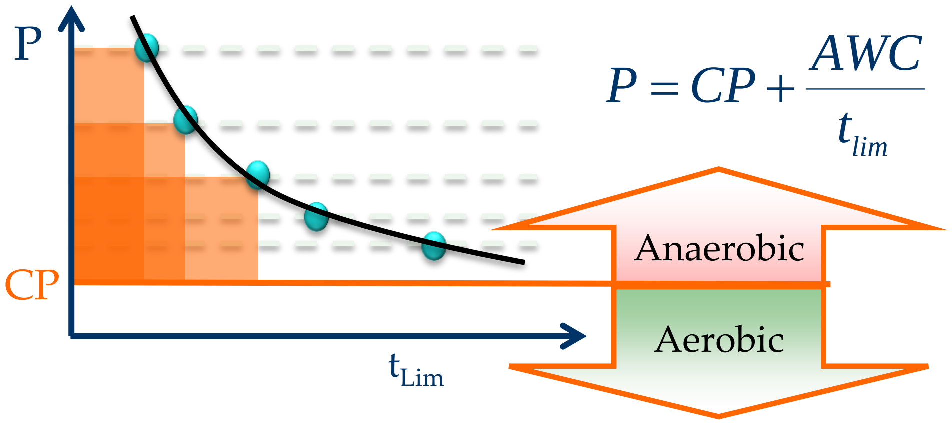
- Why is it important?
  - Optimize performance
    - Maximize recovery
    - Minimize fatigue



- How to optimize performance?
  - Determining “distance-to-empty”
  - Exhaust energy reserves at the point of crossing the finish line
  - Optimally fatiguing in training

- What is needed to model performance?
  - Critical Power (CP): The power which a human can generate “indefinitely” [1]
  - Anaerobic Work Capacity (AWC): Finite expendable anaerobic energy above CP [1]

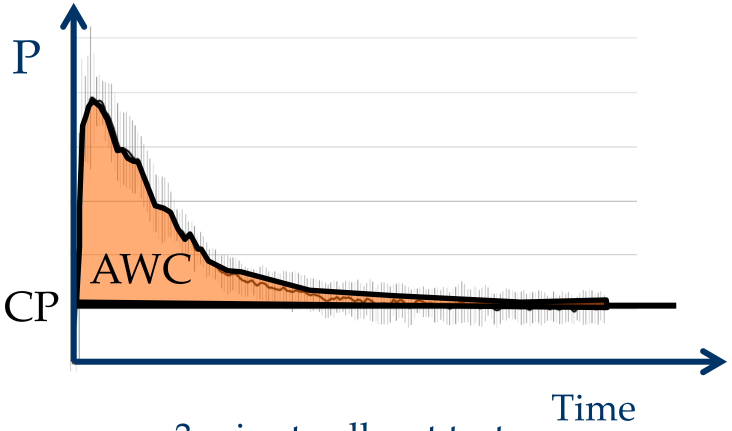
Existing models of CP and AWC



$$P = CP + \frac{AWC}{t_{lim}}$$

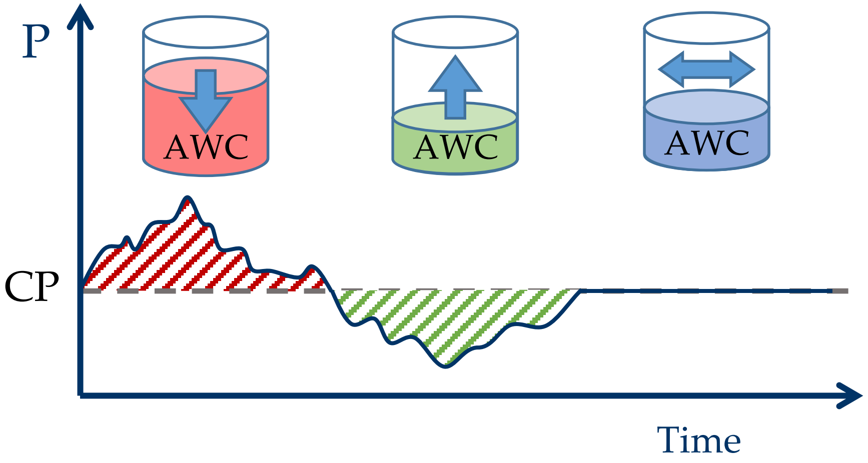
Time to exhaustion tests

Monod and Scherrer [1]



3 minute all-out test

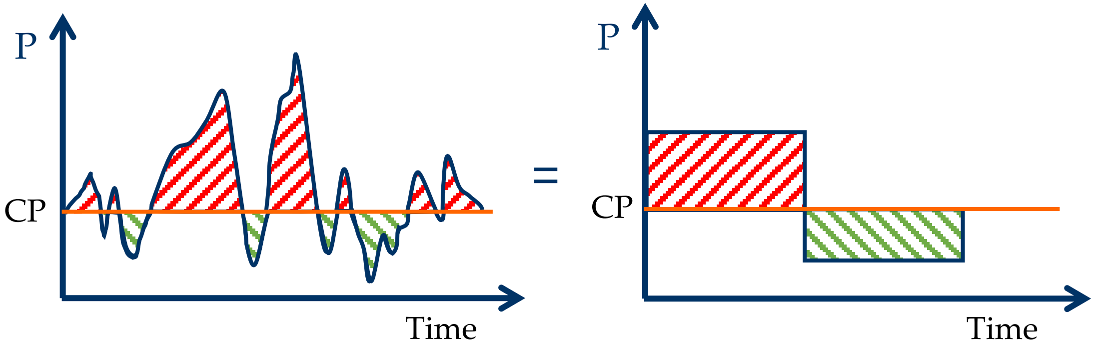
Vanhatalo and colleagues [2]



$$AWC_{bal} = AWC - \int_0^t (AWC_{exp}) \cdot e^{-\left(\frac{(t-u)}{\tau_{W'}}\right)} du$$

$$\tau_{W'} = 546 \cdot e^{(-0.01 D_{CP})} + 316$$

Skiba and colleagues [3]



Research objective

Research Objective	Modeling expenditure and recovery of AWC as related to CP.

RQ1

- For all recovery powers and durations, is the rate of recovery of AWC equal to the rate of expenditure? (Does recovery coefficient, Φ=1?)

RQ2

- What is the influence of recovery power (β) and recovery duration (Δt) on coefficient of recovery (Φ)?

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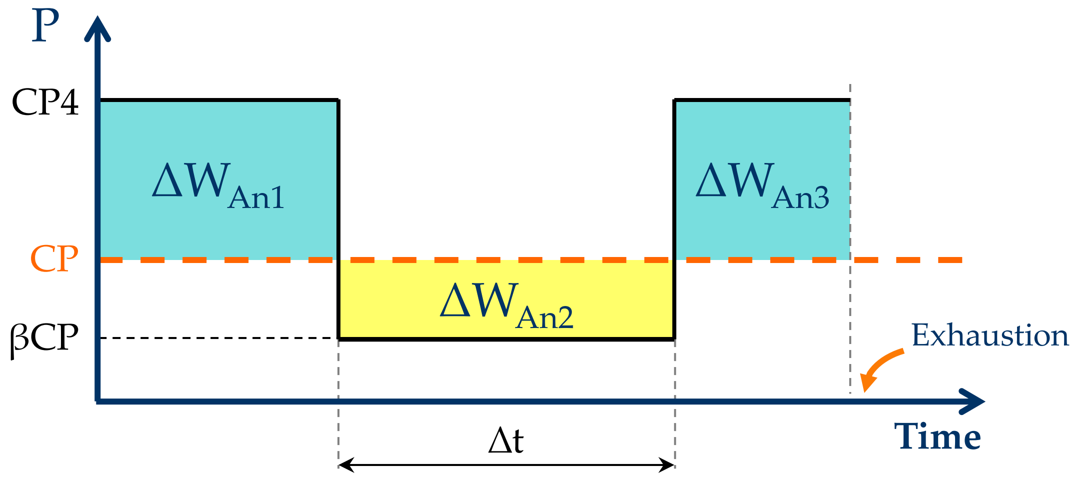
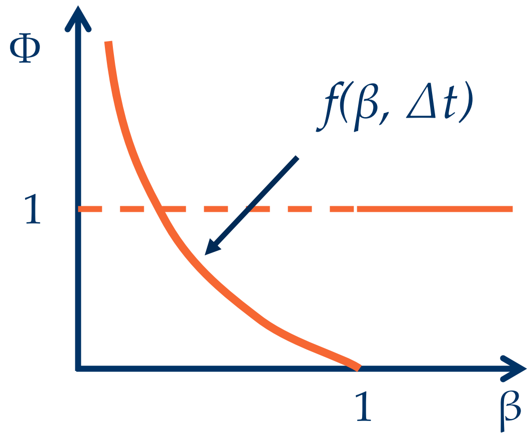
Experimental protocol and mathematical model



$$\Delta W_{An} = CP \cdot (\beta - 1) \cdot \Phi \cdot \Delta t$$

$$\beta = \frac{P}{CP}$$



$$\Phi = \frac{\sum Areas\ above\ CP - AWC}{Area\ below\ CP}$$

- Test protocol*
  - 3min all out test
    - CP and AWC
  - Determine CP4
  - Intermittent protocol
- Participants
  - 9, Age: 27.6 ± 6.3

β Options	Δt Options
50%	15 s
75%	30 s
100%	60 s

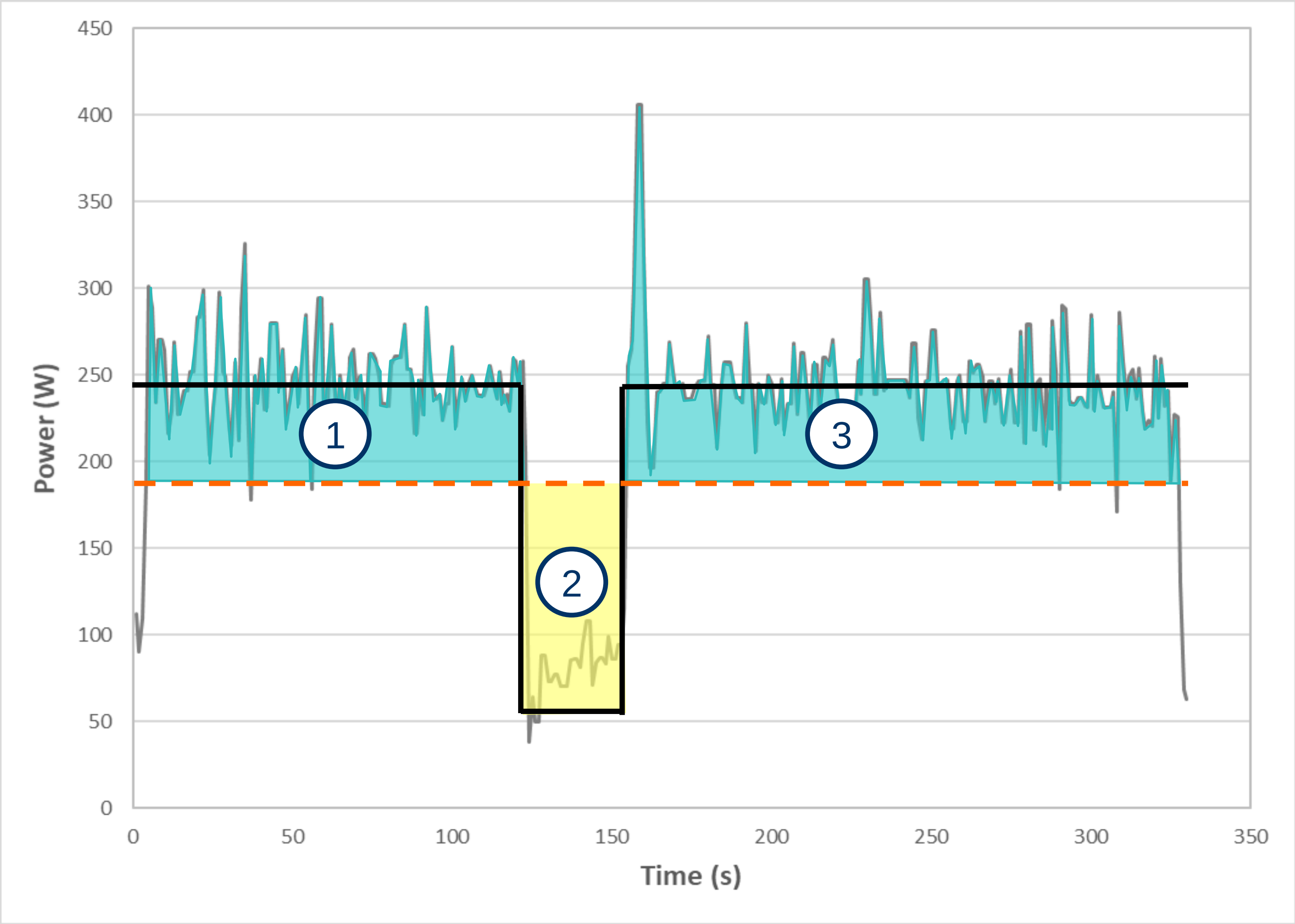
* Clemson University IRB Number: IRB2016-169

Example of results

- Subject: C10
  - CP: ~185 W
  - AWC: ~11300 J
- β = 50%
- Δt = 30 s

$$\Phi = \frac{\sum Areas\ above\ CP - AWC}{Area\ below\ CP}$$

23 valid Φs calculated



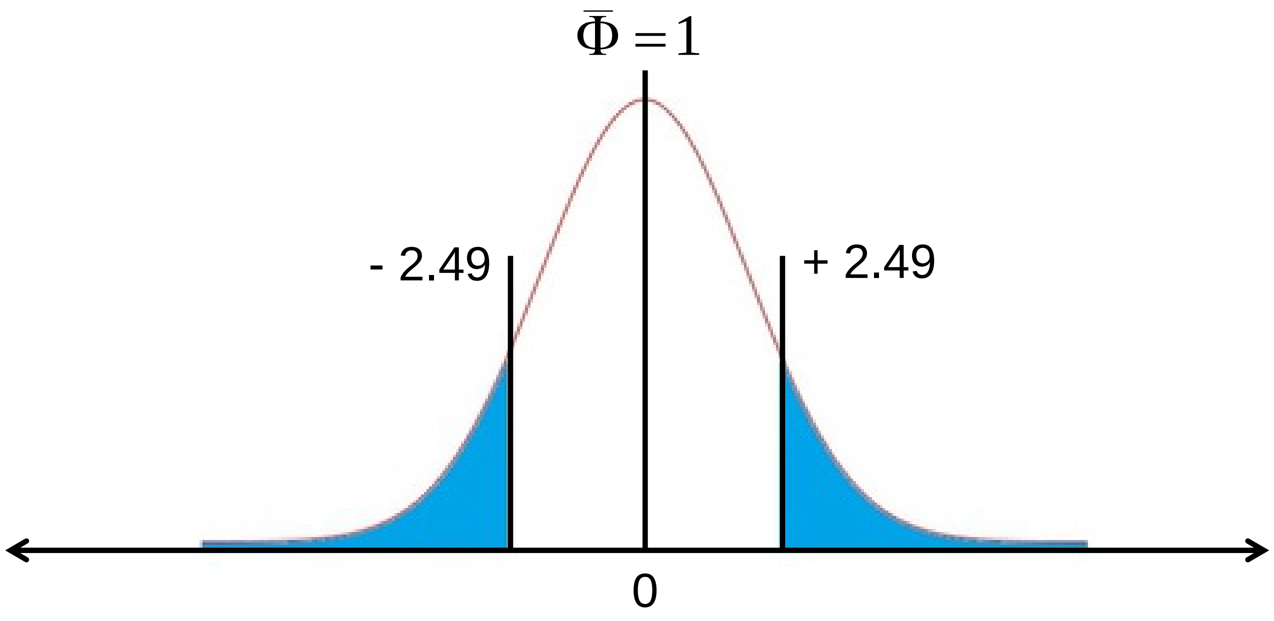
Analysis of Expenditure and Recovery results

Answering RQ1: Is the rate of recovery of AWC equal to the rate of expenditure?

H_0: The mean value of Φ, $\bar{\Phi} = 1$

H_a: The mean value of Φ, $\bar{\Phi} \neq 1$

- Significance, α = 0.05
- Two-tailed t-test results
- P = 0.029
- Reject the H_0



Recovery is not equivalent to expenditure.

Influence of β and Δt on Φ

- Answering RQ2: Is the magnitude of Φ influenced more by Δt or β?
- Analysis of Variance
- Significance, $\alpha = 0.05$

$$\Phi = -8.07 + 14.80 * \beta - 0.0180 * \Delta t$$

- R-squared = 0.50

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	90.621	45.311	9.64	0.001
β	1	87.556	87.556	18.62	< 0.001
Δt	1	1.977	1.977	0.42	0.524
Error	19	89.325	4.701		
Total	21	179.946			

β has a larger influence on Φ than t.

Optimal control

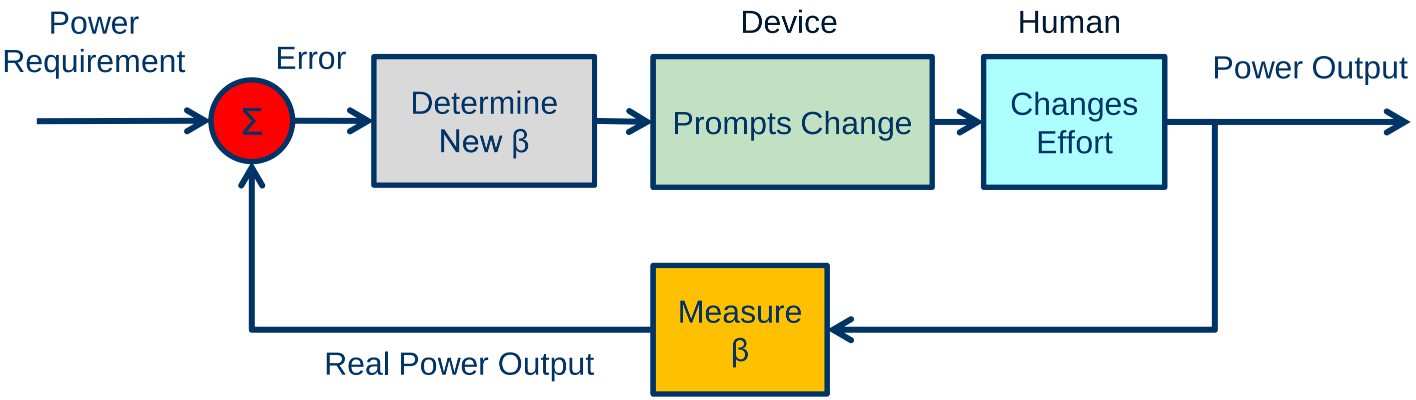
- Estimating Required Power [4]

$$P_{req} = f(v, a, m, w, A, G, C_{rr}, C_d, \rho, v_w)$$

Cyclist properties:
Velocity (v), Acceleration (a), Mass (m), Weight including bike (w), and Frontal area (A)

Environmental properties:
Gradient (G), Coefficient of rolling resistance (C_{rr}), Coefficient of drag (C_d), Density of air, and Wind velocity (v_w)

- What it would the control loop look like?



Closure

Conclusions

- Recovery of AWC is not proportional to expenditure
- Power-level of recovery significantly influences recovery
- The models need to be athlete specific rather than generic
- Develop human-in-the-loop feedback control system to optimize performance

Future/Current work

- Athlete specific model of expenditure and recovery
- Optimal control validation
- Study muscle oxygenation (SMO_2) and heart rate (HR) response
- Examine the effect of power (as $\%VO_{2max}$) on recovery coefficient Φ
- Investigate injury and fatigue in relation to AWC

References

[1] Monod, H., and J. Scherrer. "The Work Capacity Of A Synergic Muscular Group." Ergonomics 8.3 (1965): 329-38.

[2] Vanhatalo, A. "Determination of critical power using a 3-min all-out cycling test." Medicine and science in sports and exercise 39.3 (2007): 548.

[3] Skiba PF, Chidnok W, Vanhatalo A, Jones AM (2012) Modeling the Expenditure and Reconstitution of Work Capacity above Critical Power. Med Sci Sports Exerc 44:1526–1532. doi: 10.1249/MSS.0b013e3182517a80

[4] Burke ER, Pruitt AL (2003) Body positioning for cycling. In: Burke ER (ed) High-Tech Cycl., 2nd ed. Human Kinetics, pp 69–92

Thank you for your attention.

Questions?

Participant details

- 8M, 1F
  - Age: 27.6 ± 6.3
- Recreationally active
  - 2 runners
  - 2 cyclists
  - 4 weight training
  - 1 recreational triathlete

Group 1			Group 2		
Subject	**Critical Power (W) (Mean ± SD)**	**AWC (kJ)**	**Subject**	**Critical Power (W) (Mean ± SD)**	**AWC (kJ)**
C7	187 ± 5.6	10.62	C11	160 ± 13.6	10.25
C4	236 ± 6.6	10.46	C2	119 ± 14.7	6.00
C1	165 ± 8.2	14.70	C12	102 ± 23.8	8.56
C8	236 ± 10.8	12.40	C3	135 ± 17.7	7.18
C10	186 ± 11.5	11.31			
Average	202 ± 8.5	11.9		129 ± 17.5	8.00

%AWC recovered