Modeling Intermittent Cycling Performance in Hypoxia using the Critical Power Concept

Nathan Townsend[1,2], Samantha Shearman[1], Phillip Skiba[3], Dan Dwyer[1]

[1]*Centre for Exercise & Sport Science, Deakin University, Geelong, Australia*
[2]*Athlete Health and Performance Centre, Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar*
[3]*Dept. of Sports Medicine, Advocate Lutheran General Hospital, Park Ridge IL, USA*

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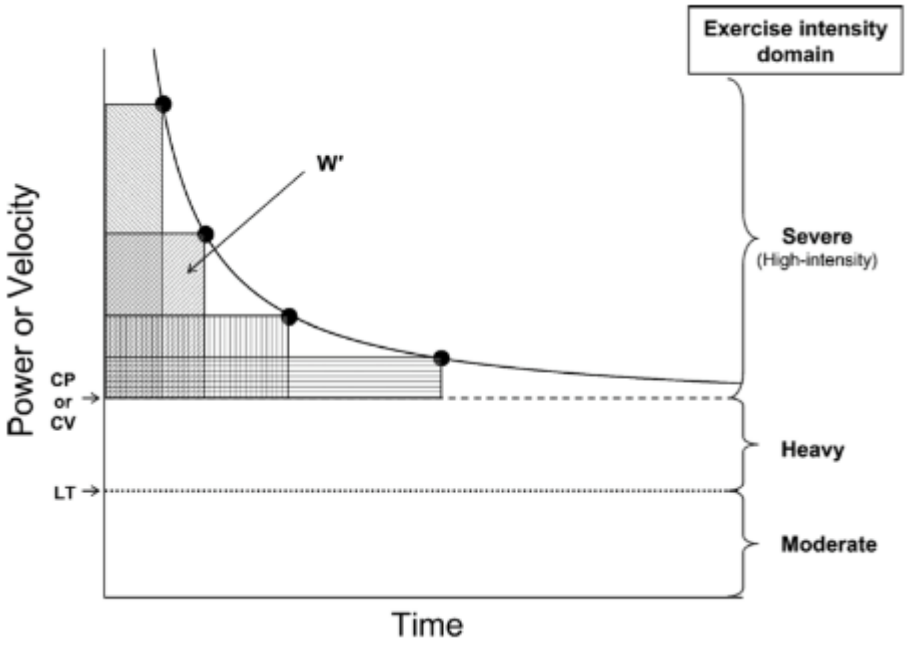
Critical Power Concept

Definitions

- *Critical Power:* the highest work rate that can be sustained without a progressively increasing non-aerobic contribution (Morton, 2006).

- *W':* the total amount of work that can be performed above critical power until the limit of tolerance (Jones et al., 2008).

$$P(t) = W' / time + CP$$



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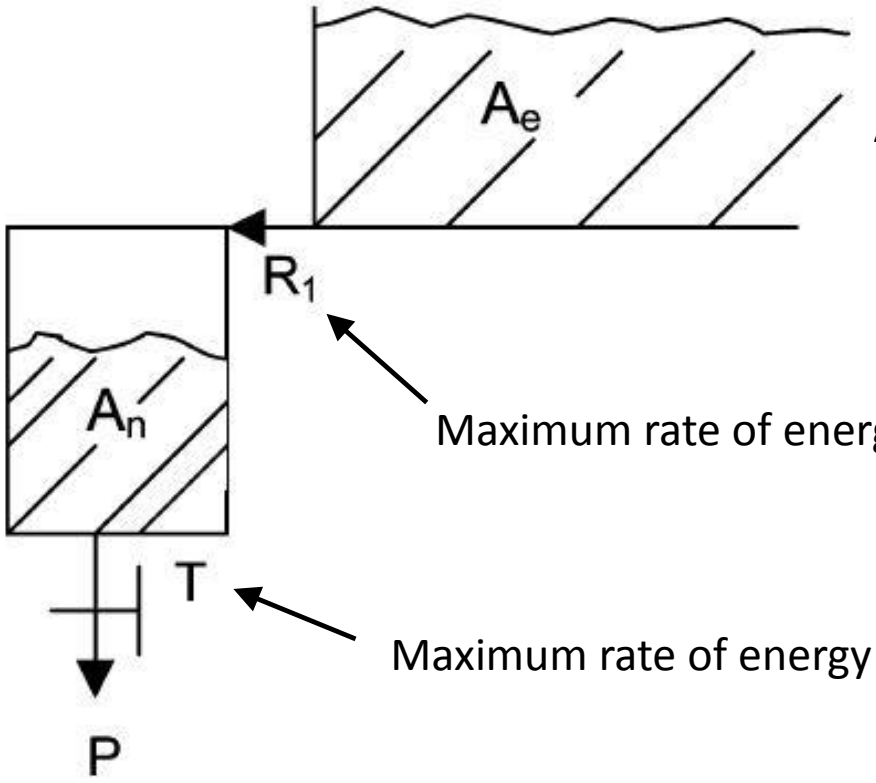
Critical Power Concept:
Morton's 2-Parameter Hydraulic Model



Aerobic metabolism

Volume of tank A_n = W'

Maximum rate of energy flow R_1 = critical power

Maximum rate of energy flow T >> R_1

Fig. 1 The CP concept as a hydraulic model

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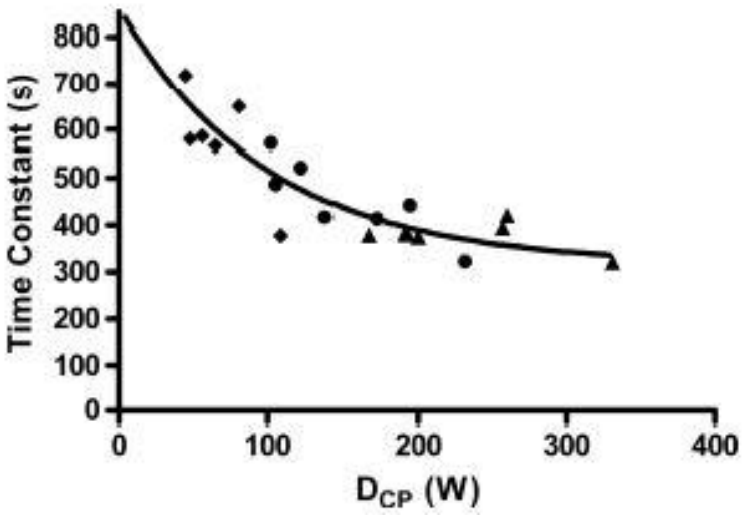
The "Work-Balance" (W'_{BAL}) Model (Skiba et al., 2012)

$$W'_{BAL} = W' - \int_0^t (W'_{exp})\,(e^{-(t-u)/\tau_{W'}})$$

$$\tau_{W'} = 546 \cdot e^{(-0.1 \cdot D_{CP})} + 316$$

W' = total work above critical power
W'_{BAL} = balance of W' remaining at any given time (t)
W'_{exp} = work expended during interval where P > CP
t – u = time interval during which P > CP
$\tau_{W'}$ = recovery time constant for W'_{bal}
D_{CP} = difference between CP and recovery power



Assumptions

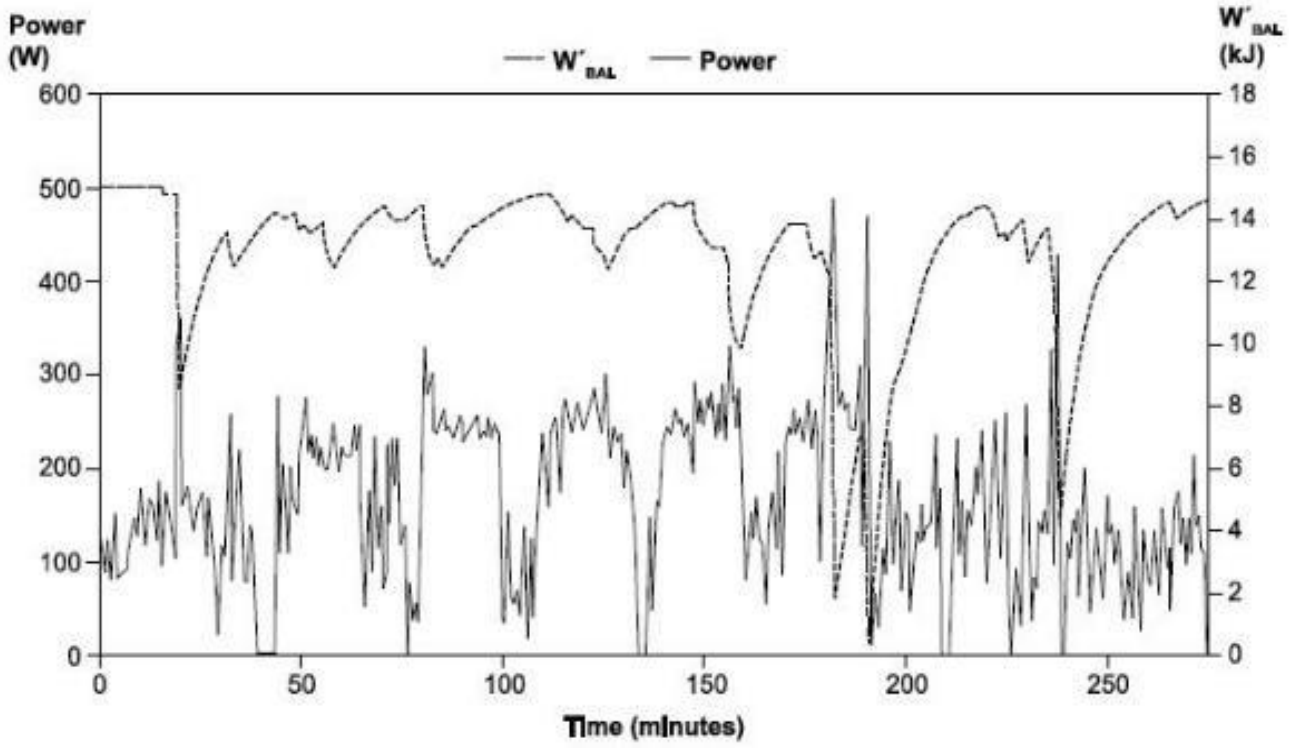
1. Expenditure of W' occurs when P > CP
2. Reconstitution of W' occurs when P < CP
3. Reconstitution of W' follows a predictable exponential time course

Skiba et al., 2014

Field Validation of Work-Balance Model

(Skiba et al., 2014)

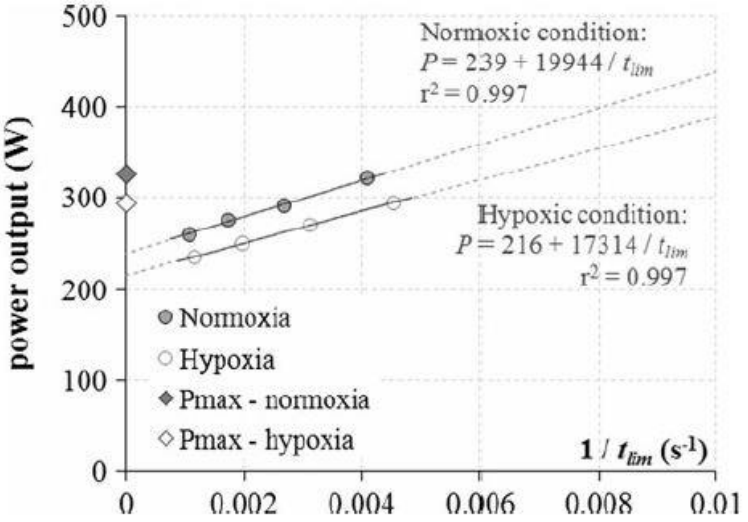
- Receiver-operator characteristic analysis (sensitivity vs specificity)
- Threshold value of W'_{BAL} = **1.5 kJ** to distinguish between "fatigued / non-fatigued"



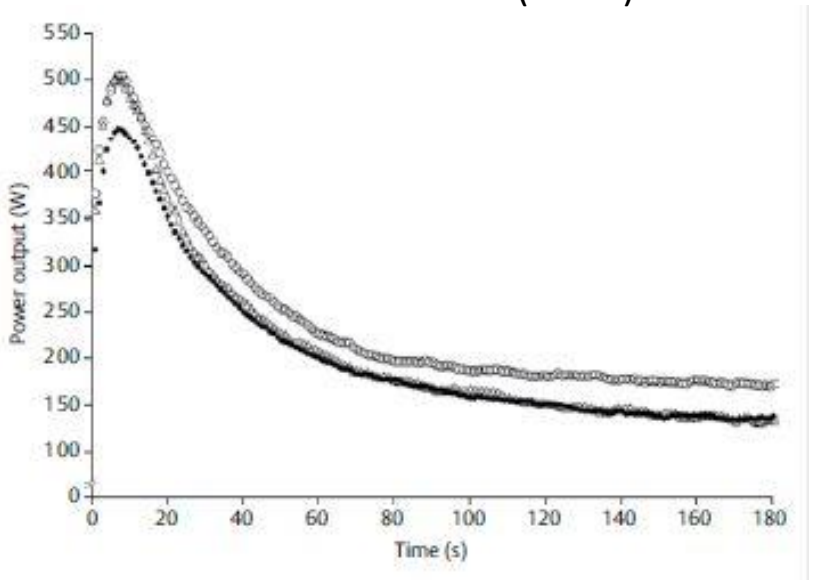
Effect of Hypoxia on CP + W’

- CP significantly reduced
- No sig. differences to mean W’, but wide variability related to ΔCP

2 parameter linear model



3 min “all out” test (3AOT)



Influence of moderate hypoxia on tolerance to high-intensity exercise

J. Dekerle · P. Mucci · H. Carter

Eur J Appl Physiol (2012) 112:327–335

Influence of Hypoxia on the Power-duration Relationship during High-intensity Exercise

L. Parker Simpson, A. M. Jones, P. F. Skiba, A. Vanhatalo, D. Wilkerson (IJSM, 2015)

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Aims & Hypotheses

- **Primary research aim:**

  To examine the effect of hypoxia on the efficacy of the W'_{BAL} model during high-intensity intermittent cycling

- **Hypotheses:**

  1. No difference in W'_{BAL} model results between normoxia and hypoxia when CP + W' is measured under same environmental conditions

  2. W'_{BAL} overestimated if normoxic CP + W' used to model performance in hypoxia

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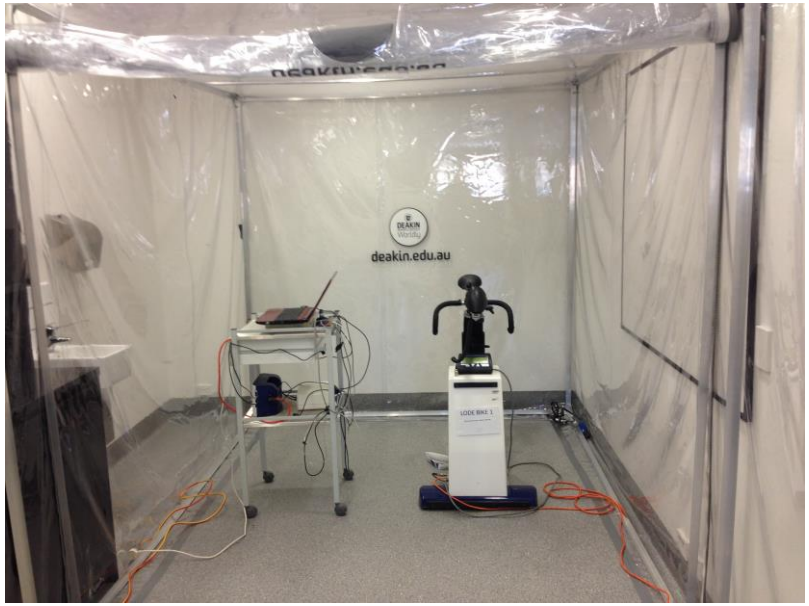
Methods

Subjects

- N = 11 trained, male cyclists
- Age: 27 ± 6.6 yr
- Height: 179 ± 7.5 cm
- Weight: 78.0 ± 7.1 kg
- VO_{2max}: 4.79 ± 0.56 $L.min^{-1}$



Conditions

- Normoxia (FiO_2 = 0.2093)
- Hypoxia (FiO_2 = 0.155 ≈ 2450m)

Design

- Counter-balanced, randomized, single blinded

Statistics

- Student's t-tests

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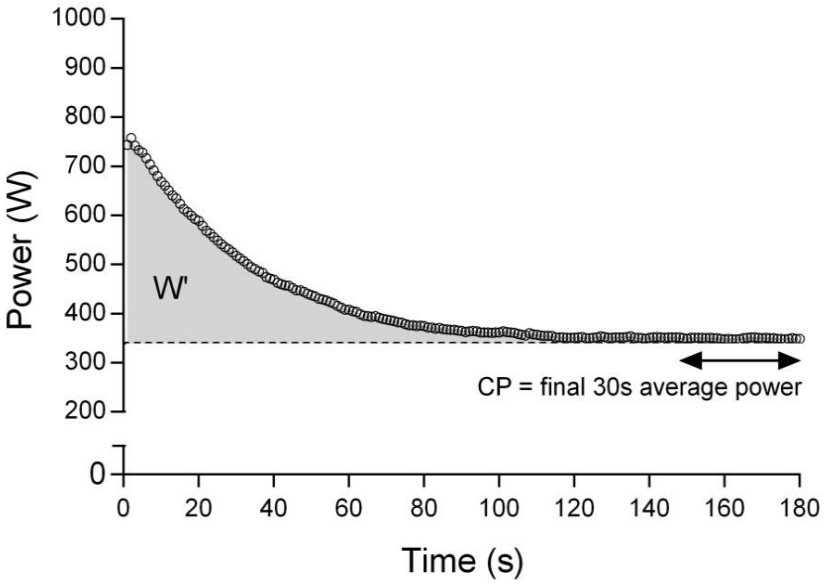
Methods

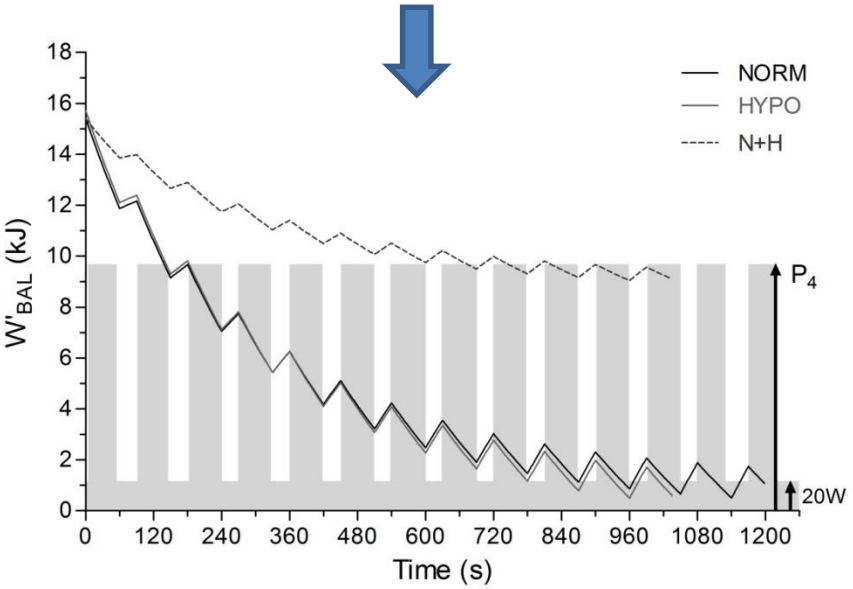
Procedures

1. VO_{2max} & 3min all-out test (3AOT) famil.
2. VO_{2max} → 30min recovery → 3min AOT *
   - VO_{2max} (30 $W.min^{-1}$ ramp)
   - CP + W'
3. *Repeat lab visit 2*
4. Intermittent TTe test (60s / 30s @ 4MMP)
5. *Repeat lab visit 4*



Analysis

- CP + W' results from 3AOT → W'_{BAL} model
- CP + W' in NORM → W'_{BAL} model in HYPO (N+H)
- W'_{BAL} at task failure: W'_{BALtf}
- Minimum W'_{BAL} : W'_{BALmin}



*Constantini et al., 2014

Results: VO_{2max} and 3min All Out Test

VO_{2max} ramp

NORM

VO_{2max} : 4.79 ± 0.56 L.min^{-1}

HYPO

VO_{2max} : 3.93 ± 0.47 L.min^{-1} *

18% decrease in VO_{2max}

3 min AOT

NORM

VO_{2pk} : 4.83 ± 0.57 L.min^{-1}

CP : 353 ± 46 W

W': 12.6 ± 4.1 kJ

HYPO

VO_{2pk} : 3.85 ± 0.48 L.min^{-1} *

CP: 319 ± 49 W *

W': 13.3 ± 5.3

10% decrease in CP

*Significantly different to NORM ($P < 0.001$)

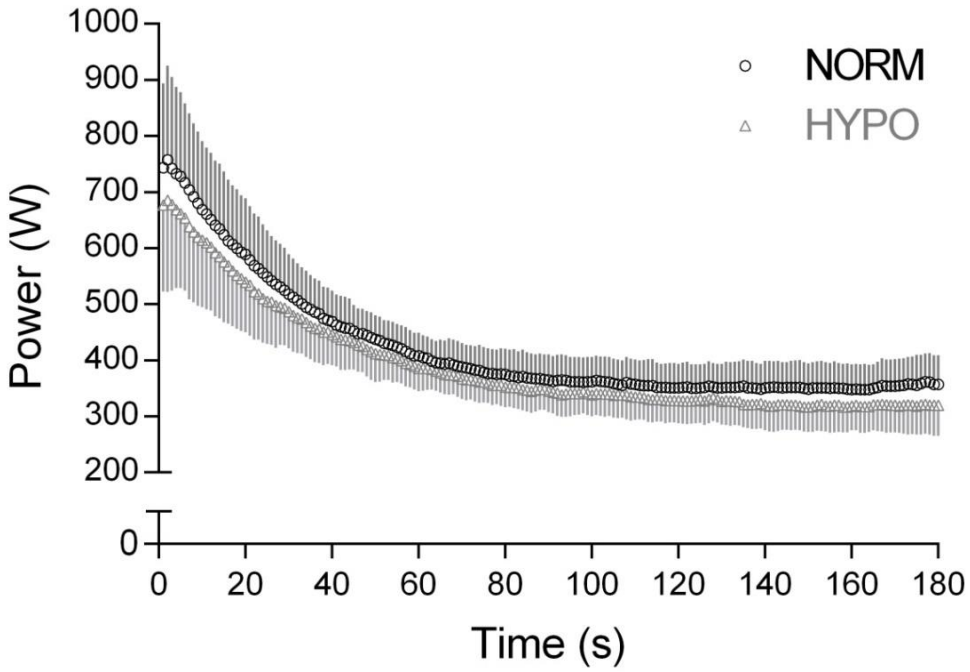


Figure 1: Mean (SD) power (W) during 3AOT in normoxia and hypoxia

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Results: Work-Balance Model

Table 1: W'_{BAL} model results for the intermittent test. Mean ± SD

	NORM	HYPO	N + H
$Time_{tf}$ (s)	1057 ± 261	860 ± 173*	-
$Work_{tot}$ (kJ)	287 ± 69	219 ± 51*	-
$\tau_{W'}$ (s)	337 ± 9	347 ± 12*	-
W'_{BALtf} (kJ)	2.0 ± 0.9	1.5 ± 0.8	8.4 ± 3.2#
W'_{BALmin} (kJ)	1.7 ± 0.9‡	1.3 ± 0.8	8.3 ± 3.2#
$Work_{tot}$ >CP (kJ)	35.0 ± 14.5	32.8 ± 17.4	12.2 ± 9.1#

* significantly different to NORM ($P < 0.01$)
# significantly different to HYPO ($P < 0.001$)
‡ significantly different to W'_{BALtf} ($P < 0.05$)

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Results: Work-Balance Model

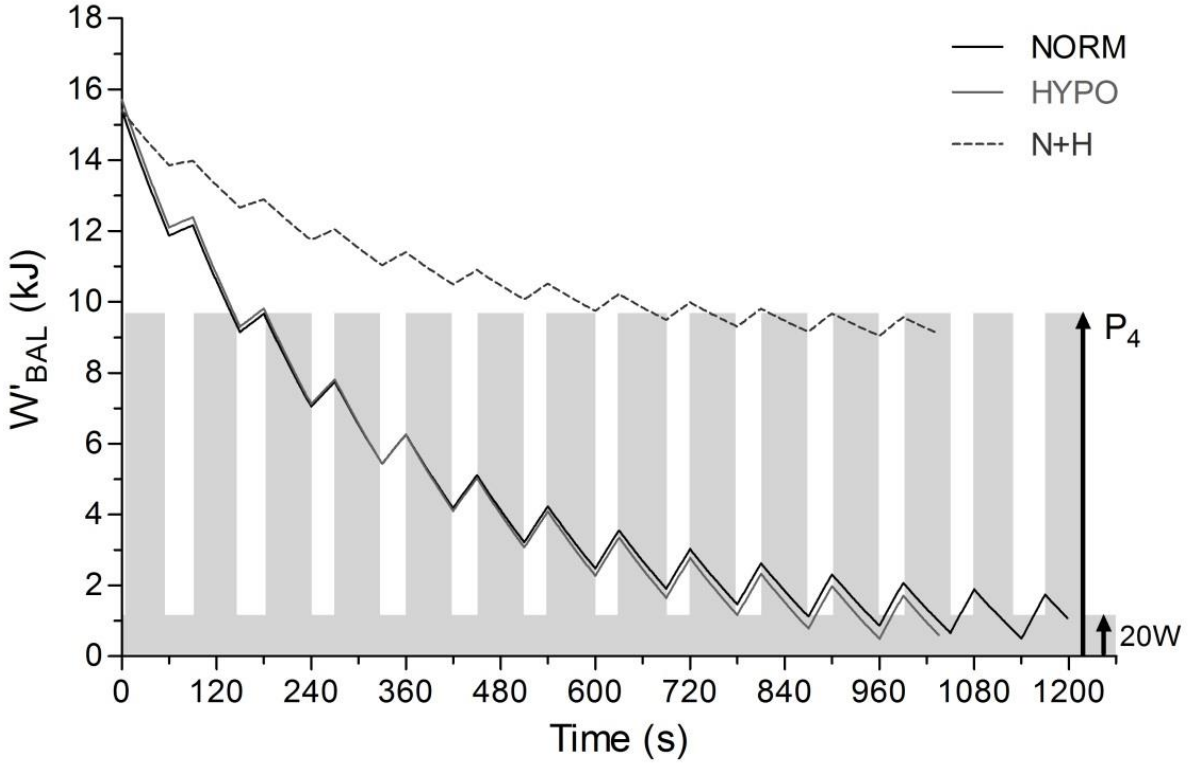


Figure 2: Modeled W'_{BAL} depletion and reconstitution for one subject in NORM, HYPO, and in hypoxia using normoxia derived model inputs (N+H). Light grey bars indicate work and recovery intervals. P4 indicates the power output predicted to result in exhaustion in 4 min. Note the recovery power output (20 W) remained the same across each condition

Results: Work-Balance Model (modified)

- Modified CP defined as minimum 30 s rolling average power in 3AOT

NORM

- EP = 353 ± 46 W ; W' = 12.6 ± 4.1 kJ
- CP = 347 ± 45 W* ; W' = 13.4 ± 3.9 kJ* ($P < 0.05$)

Table 2: Modified W'_{BAL} model results for the intermittent test. Mean ± SD

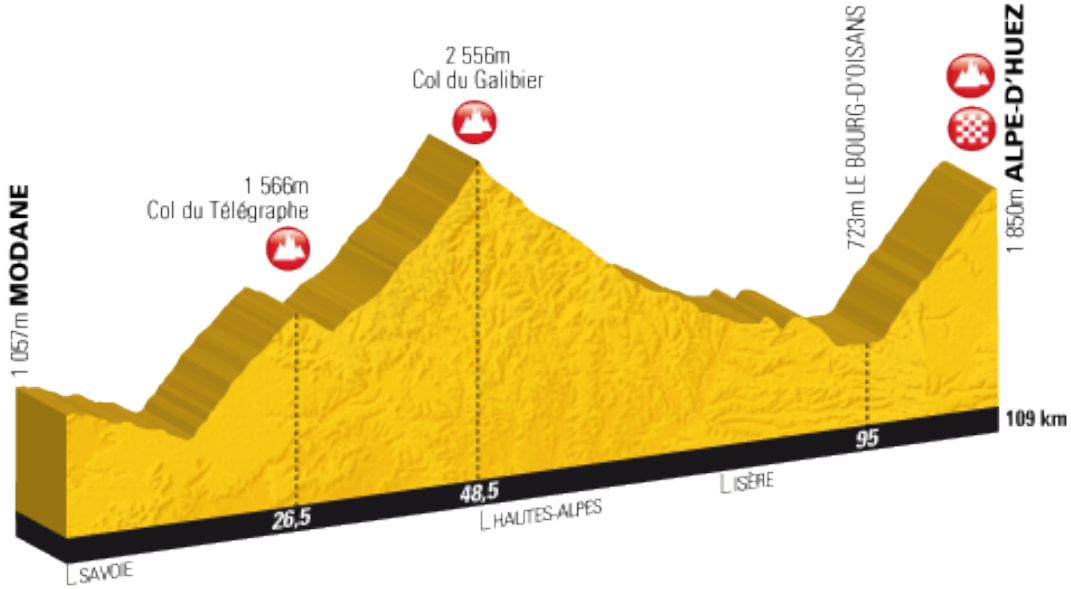
	NORM		HYPO		N + H	
	EP	CP	EP	CP	EP	CP
$Time_{tf}$ (s)	1057 ± 261	-	860 ± 173*	-	-	-
$Work_{tot}$ (kJ)	286.8 ± 69.1	-	219.0 ± 50.5*	-	-	-
$\tau_{W'}$ (s)	337 ± 9	339 ± 9†	347 ± 12*	346 ± 12*	-	-
W'_{BALtf} (kJ)	2.0 ± 0.9	1.5 ± 0.9†	1.5 ± 0.8	1.4 ± 0.7	8.4 ± 3.2#	7.9 ± 3.4†#
W'_{BALmin} (kJ)	1.7 ± 0.9‡	1.1 ± 0.9†‡	1.3 ± 0.8	1.2 ± 0.6	8.3 ± 3.2#	7.8 ± 3.4†#
$Work_{tot}$ >CP (kJ)	35.0 ± 14.5	39.0 ± 13.9†	32.8 ± 17.4	34.2 ± 15.8	12.2 ± 9.1#	15.5 ± 9.1†#

* significantly different to NORM ($P < 0.01$). # significantly different to HYPO ($P < 0.001$).
† significantly different to EP ($P < 0.05$). ‡ significantly different to W'_{BALtf} ($P < 0.05$)

Summary and Conclusions

- The W'_{BAL} model behaves similarly in hypoxia (≈2450m) and normoxia only when CP + W' are tested under the same environmental conditions as performance

- An overestimation of CP (with little change to W') leads to underestimation of time constant → overestimation of W'_{BAL} at the point of task failure
  - W' depletes more slowly when P > CP
  - W' recovers faster when P < CP



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Thank You

Results: Pearson Correlation

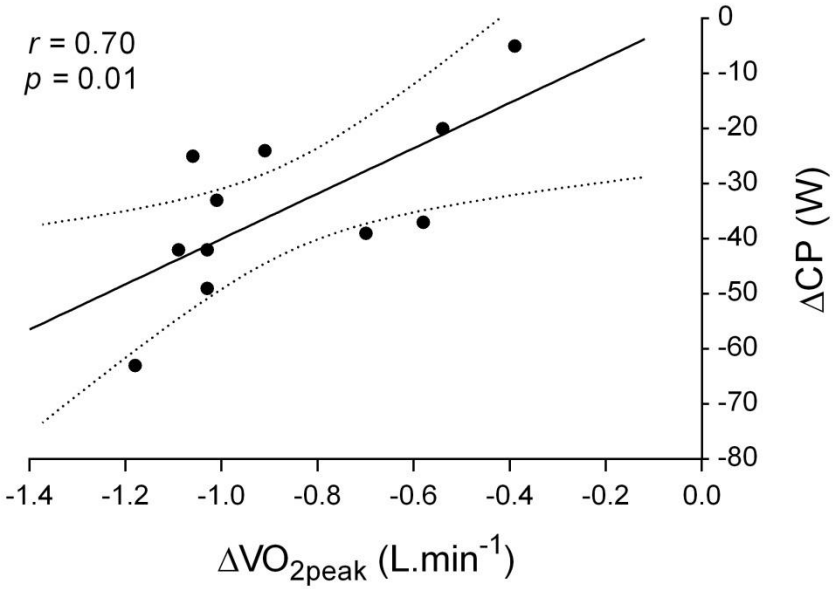

Figure 2: Linear regression between ΔCP (W) and ramp test ΔVO_{2peak} ($L \cdot min^{-1}$), where Δ denotes HYPO – NORM. Dotted lines indicate 95% confidence intervals.

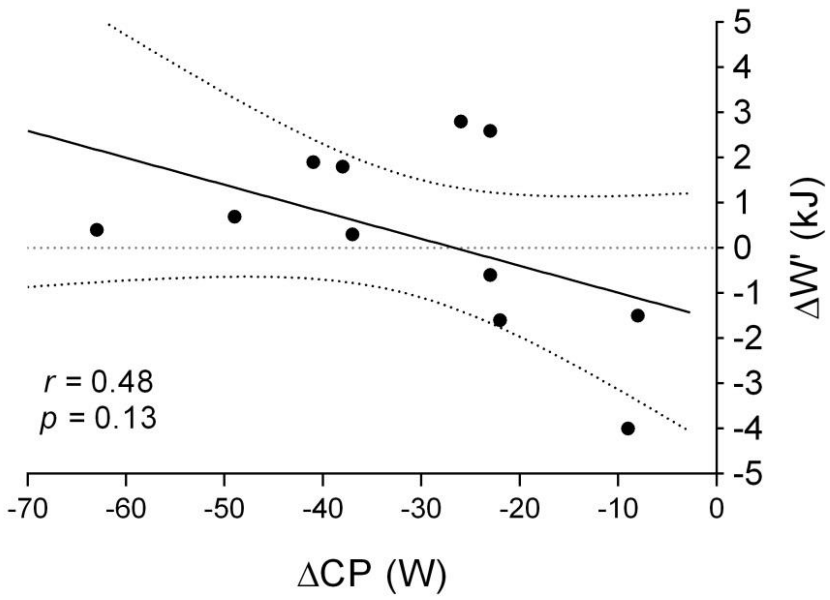

Figure 3: Linear regression between ΔCP and ΔW', where Δ denotes HYPO - NORM. Dotted lines indicate 95% confidence intervals.

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