FATIGUE DURING HIGH-INTENSITY EXERCISE: RELATIONSHIP TO THE CRITICAL POWER CONCEPT

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

The hyperbolic power-duration relationship for high-intensity exercise is defined by two parameters: an asymptote (critical power; CP) reflecting the highest sustainable rate of oxidative metabolism, and a curvature constant (W′), which indicates a fixed amount of work that can be completed above CP ($W_{>CP}$). According to the CP model of bioenergetics, constant work rate exercise above CP depletes the capacity-limited W′ with fatigue occurring when W′ is completely expended. The complete depletion of W′ has been reported to occur when $\dot{V}_{O2max}$ is attained and a critical degree of muscle metabolic perturbation (decline of finite anaerobic substrates and accumulation of fatigue-related metabolites) is reached. However, while the CP model is effective at predicting metabolic perturbation and the tolerable duration of severe-intensity constant work rate (CWR) exercise, it is unclear if metabolic perturbation and exercise performance can be explained by the CP model when different methods of work rate imposition are applied. Therefore, the purpose of this thesis was to: 1) investigate the efficacy of the CP concept to predict performance in exercise tests using different work rate forcing functions; and 2) explore whether the physiological bases for W′ are consistent across different methods of work rate imposition. In study 1, compared to severe-intensity CWR exercise, the tolerable duration of intermittent severe-intensity exercise with heavy- (S-H) moderate- (S-M) and light-intensity (S-L) ‘recovery’ intervals was increased by 47%, 100% and 219%, respectively. $W_{>CP}$ (W′) was significantly greater by 46%, 98%, and 220% for S-H, S-M and S-L, respectively, when compared to S-CWR, and the slopes for the increases in $\dot{V}_{O2}$ and iEMG were progressively lowered as the recovery work rate was reduced. In study 2, both the $\dot{V}_{O2max}$ and $W_{>CP}$ were similar across incremental cycling protocols that imposed a fixed ramp rate and cadence (4.33 ± 0.60 L·min^{-1}; 14.8 ± 9.2 kJ), a fixed ramp rate with cadence self-selected by the subjects (4.31 ± 0.62 L·min^{-1}; 15.0 ± 9.9 kJ) and a step

incremental test where subjects were instructed to select power output according to prescribed increments in ratings of perceived exertion (4.36 ± 0.59 $L \cdot min^{-1}$; 13.0 ± 8.4 kJ). In study 3, the $\dot{V}_{O2max}$ and $W_{>CP}$ were also not different across a 3 min all-out cycling test (4.10 ± 0.79 $L \cdot min^{-1}$; 16.5 ± 4.0 kJ), cycling at a constant work rate predicted to lead to exhaustion in 3 min until the limit of tolerance (4.20 ± 0.77 $L \cdot min^{-1}$; 16.6 ± 7.4 kJ) and a self-paced 3 min work-trial (4.14 ± 0.75 $L \cdot min^{-1}$; 15.3 ± 5.6 kJ). In study 4, after completing severe-intensity exercise (>CP) to exhaustion, muscle homeostasis ([PCr], pH, [ADP] and [P_i]) returned towards baseline and subjects were able to exercise for at least 10 min at a heavy-intensity work rate (<CP); however, when the work rate was lowered but remained in the severe-intensity domain (>CP), muscle metabolites ([PCr], pH, [ADP] and [P_i]) did not recover and exercise tolerance was severely limited (39 ± 31 s). Finally in study 5, during severe-intensity intermittent knee extension exercise, the tolerable duration of exercise was 304 ± 68 s when 18 s recovery was allowed and was increased by ~69% and ~179% when the intermittent recovery periods were extended to 30 s and 48 s, respectively. The increased exercise tolerance with longer recovery periods occurred in concert with increased $W_{>CP}$ (3.8 ± 1.0 kJ, 5.6 ± 1.8 kJ and 7.9 ± 3.1 kJ for the intermittent protocols with 18, 30 and 48 s of recovery, respectively) and a delayed attainment of critical intramuscular metabolite concentrations ([PCr], pH, [ADP] and [P_i]). Therefore, the results of this thesis demonstrate that fatigue during various high-intensity exercise protocols is influenced by the capacity to complete work above the CP (W′) and that W′ depletion is linked to the attainment of $\dot{V}_{O2max}$ and the attainment of critical levels of intramuscular [PCr], pH, [ADP] and [P_i]. These findings suggest that the CP model can be adapted to predict the degree of metabolic perturbation and exercise performance across a range of exercise settings in humans.

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Symbols and abbreviation

[ ]	concentration
Δ	difference
%Δ	% difference between GET and $\dot{V}_{O_2max}$
^{31}P-MRS	^{31}phosphorous nuclear magnetic resonance spectroscopy
ADP	adenosine diphosphate
ATP	adenosine triphosphate
Ca^{2+}	calcium
CI	confidence interval (e.g., 95% CI; CI_{95})
CO_2	carbon dioxide
CP	critical power (i.e., asymptote of the power/time hyperbola)
EMG	electromyogram
ET	endurance training
GET	gas exchange threshold
H^+	hydrogen ion/proton
HR	heart rate
iEMG	integrated electromyogram (μV·s)
K^+	potassium ion
MVC	maximal voluntary contraction
O_2	oxygen
P	power output
PCr	phosphocreatine (or creatine phosphate)
P_i	inorganic phosphate
T_{lim} / T_e	limit of tolerance/ time-to-exhaustion
$\dot{V}_{CO_2}$	carbon dioxide output

$\dot{V}_E$	pulmonary ventilation (expired)
$\dot{V}O_2$	pulmonary oxygen uptake
$\dot{V}O_{2max}$	maximum oxygen uptake
$\dot{V}O_{2peak}$	peak oxygen uptake
W	watt
W′	curvature constant of the hyperbolic power-duration relationship
WR	work rate

Declaration

The material contained within this thesis is original work conducted and written by the author. The following communications and publications are a direct consequence of this work.

Publications

Chidnok W, DiMenna FJ, Bailey SJ, Vanhatalo A, Morton RH, Wilkerson DP, Jones AM. Exercise tolerance in intermittent cycling: application of the critical power concept. *Med Sci Sports Exerc.* 2012; 44: 966-76.

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Chidnok W, Fulford J, Bailey SJ, DiMenna FJ, Skiba PF, Vanhatalo A, Jones AM. Muscle metabolic determinants of exercise tolerance following exhaustion: relationship to the 'critical power'. *J Appl Physiol,* 2013; [Epub ahead of print].

Conference communications

Chidnok W, DiMenna FJ, Bailey SJ, Vanhatalo A, Wilkerson DP, Jones AM (2011). Effect of 'recovery' intensity on oxygen uptake and exercise tolerance during severe intermittent cycling (Abstract). *BASES Annual Student Conference, University of Chester, UK.*

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