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The critical power concept in all-out isokinetic exercise

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ABSTRACT

The critical power concept has been applied to constant-load exhaustive exercise and recently validated for 3-min all-out exercise.
Objectives: To test the application of critical power to a 3-min all-out isokinetic cycling exercise.
Design: Single-group, experimental, comparative design.
Method: Nine participants performed a 3-min all-out isokinetic test and 4-5 constant-load exhaustive trials, at 60 and 100rpm, on an electrically-braked cycle. The linear P-t-1 relationship was modelled using a 2-parameter model (slope: critical power; intercept: Anaerobic Work Capacity). End power and accumulated work done above EP were calculated from the 3-min tests.
Results: No significant difference and a significant correlation was found between end power and critical power (60rpm: 259±40W vs. 245±38W, P>0.05; r=0.85, P<0.01; 100rpm: 227±57W vs. 212±44W, P>0.05; r=0.86, P<0.01). The Bias±95% limits of agreement were 14±42W at 60rpm and 15±57W at 100rpm. Work done above EP (60rpm: 14.7±3.0kJ; 100rpm: 17.3±3.1kJ) was not significantly different to the anaerobic work capacity (60rpm: 16.2±3.2kJ; 100rpm: 20.6±6.4kJ; P>0.05) but with only a significant correlation at 60rpm (r=-0.71, P<0.05).
Conclusions: The 2-parameter model underpinning the critical power construct can be applied to a 3-min all-out isokinetic test. End power does not differ and correlates with critical power. However, a further insight into levels of agreement leads to some scepticism concerning the use of the two variables interchangeably. The great intra-subject differences between work done above EP and the intercept of the P-t-1 relationship should also be considered.

1. Introduction

The extensive study of the hyperbolic power (P)–endurance time (t) relationship Eq. (1) has led to the development of several mathematical models, thereby providing a framework in which to understand more fully human endurance.[1] The 2-parameter model is routinely applied in cycle ergometry[1-3] offering estimates of curvature (W': Anaerobic Work Capacity) and asymptote (CP: critical power). CP is a theoretical construct whose mathematical definition refers as to an external/mechanical power output (in watts) that can be maintained indefinitely (CP). The aerobic nature of CP has been experimentally demonstrated.[1,4,5] CP is strongly determined by maximal oxygen uptake[5] and associated with muscular aerobic power.[6] The construct of CP was recently defined as the highest rate of energy transduction (oxidative ATP production, $\dot{V}O_2$) that can be sustained without continuously drawing on the energy store W'.[1]

$$t = \frac{W'}{P - \mathrm{CP}} \quad (1)$$

A mathematical equivalent of the P–t relationship represents total mechanical work done (W) as a function of t Eq. (2) and provides a good illustration of the two compartments of the 2-parameter CP model.[2] While the aerobic compartment ($\mathrm{CP}\cdot t$) is rate- but not capacity-limited, the second compartment is of finite amount (W') and would dictate the termination of open-end exercise.[2] Indeed, supra-CP exercise performed to exhaustion has been shown to end at full completion of W'.[7] The anaerobic nature of W' has been evidenced.[4,8] CP is a non-invasive, cost effective and accessible way of studying pacing strategies,[9,10] measuring aerobic endurance,[1,11] monitoring interventions effects,[8,12] defining training intensity domains[13] and predicting performance.[14]

$$W = \mathrm{CP} \cdot t + W' \quad (2)$$

Renewed interest in the CP construct has followed recent studies successfully applying the 2-parameter model to a 3-min all-out test.[6] The exhaustion of W' while power output remains above

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CP ($P-\text{CP}>0$) was shown to be complete when power output plateaued towards the end of the exercise.[6] According to the 2-parameter model, the external power output would then equal CP (Eq. (2): when $W'=0$, $W/t=\text{CP}$). An all-out test of 3 min was indeed shown to be long enough for CP to be sustained in the last 30 s of a 3-min all-out exercise (defined as End Power: EP).[6,11] Additionally, the work accumulated above EP (WEP) was not different from W' determined from the traditionally CP protocol.[6] Systematic and proportional changes in both CP and EP following a 4-week interval training intervention were later reported.[12] Interestingly, this is the only study published to date that has addressed the construct validity of EP as a surrogate for CP, using aerobic training as an intervention. Subsequent studies used CP and EP interchangeably and a single test is nowadays implemented instead of the traditional multi-test protocol for estimation of CP.[9,10,15]

$$P=\text{CP}+\frac{W'}{t} \tag{3}$$

The present study has been designed to test the construct validity of EP using an intervention (cadence) known to affect both EP[15] and CP.[16–18] The traditional iso-inertial 3-min test only allows for cadence to be slightly and not widely manipulated, leading to a non-systematic effect on EP.[15] Therefore in this study, an isokinetic mode was preferred so that a wide range of cadence could be used (60 vs. 100 rpm). This 60–100 rpm range had previously been successful in affecting CP.[19] If the CP construct can be applied to an iso-inertial 3-min test, so it should to a 3-min isokinetic test. Prior investigations of isokinetic exercise demonstrated that an '*isokinetic*' EP failed to reach CP after 90 s of all-out effort leading to the conclusion that 90 s was not long enough for W' to be fully utilised (∼111% of CP).[20,21]

The main purpose of the present study was to test the application of the CP construct to isokinetic all-out exercise of longer duration. In an isokinetic mode, the control of muscular contraction velocity enforces a change in the force component of mechanical power output only, as fatigue develops over time.[22] Peak power is known to be pedalling frequency dependent[22]; little is known about the deleterious effect of fatigue on the power output profiles of a 3-min all-out isokinetic exercise performed at widely different pedalling frequencies. Two pedalling frequencies were implemented in this study (60 vs. 100 rpm).

For the CP concept to be applicable to exercise of all-out nature, the following requirements are to be met: (*a*) the total work done during the all-out test (TWD) should be explained by Eq. (2) (i.e. TWD equals W' plus 180 (s) time CP); (*b*) the duration of the test should be long enough to fully deplete W' at which point, a power output plateau would be expected.[6] Consequently, (*c*) the amount of work accumulated above CP (WCP) should equal W' determined with the traditional protocol. The aim of the present study was to determine whether the three requirements above are fulfilled during isokinetic all-out exercise. It was further hypothesised that *isokinetic* EP would not differ significantly from CP determined with the traditional protocol, thus at both 60 and 100 rpm. To test for the interchangeability of the second parameter of the 2-parameter model, WEP and W' were also compared with a lack of significant difference and good levels of agreement as a research hypothesis.

2. Methods

Nine active men volunteered to take part in this study (age 21 ± 2 years; $\dot{V}O_{2max}$ 4.2 ± 0.8 L min^{-1}; body mass 73.0 ± 11.2 kg). All participants were briefed as to the benefits and risks of participation and gave their written informed consent to participate in the study, which was approved by the University Ethics Committee. All were familiarised with the laboratory testing procedures. Participants were instructed to arrive at the laboratory at the same time of day, in a rested and fully hydrated state, at least 3 h postprandial, and to avoid strenuous exercise in the 48 h preceding a test session. All were free of cardiac, metabolic or respiratory diseases.

The tests were performed on an electrically-braked cycle (Schoberer Rad Messtechnik with 8 strain gauges, SRM, Germany), the zero offset calibration procedure being performed on the SRM Powermeter before each test. Seat and handlebar heights were kept constant over the sessions for each participant. The laboratory temperature was set at 20 °C with 40–50% relative humidity. Heart rate was monitored every second using a telemetric heart rate monitor (Accurex+, Polar Electro Oy, Kempele, Finland). During the incremental tests and 3-min all-out tests, pulmonary gas exchange was measured continuously using a breath-by-breath open-circuit system (Ergocard®, Medisoft, Dinant, Belgium).

Participants visited the laboratory for the following stages of experimentation. Stage 1 involved the determination of lactate threshold (LT) and peak oxygen uptake (*peak* $\dot{V}O_2$). Stage 2 involved four to five constant-load tests to exhaustion to determine CP and W'. Stage 3 required for the participant to perform a 3-min all-out test for the measure of EP and WEP. Each participant performed stage 2 and 3 twice: once at 60 and once 100 rpm; Following Stage 1, all tests could be randomly assigned. They were preceded by 5 min of warm-up at 80% of LT followed by 1 min of unloaded baseline pedalling with the participants required to get close to the cadence of the test in the 15-s prior the beginning of the test. Familiarisations to the constant-load test and all-out isokinetic tests were performed following recovery from the incremental protocol. Participants were instructed to remain seated during each test and strong verbal encouragements were provided. The study was completed within four weeks for all participants with a minimum of 48 h before the 3-min tests and 24 h before the constant-load tests.[23]

For the LT test, the initial power output was 50 W for 5 min and then increased by 25 W every 3 min. The incremental test was stopped when the LT was surpassed or when capillary blood lactate concentration ($[\text{La}]_B$) rose above 4 mmol L^{-1}. An examination of the $[\text{La}]_B$–power output relationship was used to determine LT. The highest work rate attained that was not associated with an elevation in $[\text{La}]_B$ above baseline (resting) levels (less than 1 mmol L^{-1}), as determined by two observers, was designated as the work rate associated with LT.[14] After a rest period of 30 min, the participants performed a fast ramp test to exhaustion. The test began with an initial 5 min of cycling at 25 W below their previously determined LT and increased subsequently by 5 W every 12 s to the limit of tolerance. The protocol was terminated when a drop of more than 10 rpm of their self-selected cadence occurred for more than 5 s despite strong verbal encouragement. Maximum power (P_{max}) was derived from the SRM data logger as the highest power averaged over 30 s. The highest 30-s average of the second per second $\dot{V}O_2$ data was recorded as *peak* $\dot{V}O_2$.

For the series of constant-load exhaustive tests, the power output was chosen to elicit exhaustion in 3–15 min. During these testing sessions, participants were not informed of the imposed work rate, their performance times or heart rate. The only variable known to the subjects was cadence. The time to exhaustion was identified when the participant could no longer increase their cadence to the pre-set level after a fall by 5 rpm for more than 5 s for the second time during the test and despite strong verbal encouragement. CP and W' were estimated as the power intercept and slope of the least-squares linear regression of P vs. t^{-1} model (Fig. 1, panel B[24]; and Eq. (3)). The relationship was modelled using four points with an additional test subsequently performed and added to the modelling if the standard errors in the estimates were greater than 5 and 15% for CP and W′, respectively.

Fifteen seconds before the commencement of the 3-min all-out effort, the subject accelerated the flywheel to the required cadence