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ORIGINAL INVESTIGATION

Critical Power and W′ Recovery Characteristics of Team Pursuit Cyclists

Charles F. Pugh,[1,2] Martyn C. Beaven,[1] Richard A. Ferguson,[3] Matthew W. Driller,[4] Craig D. Palmer,[2] and Carl D. Paton[5]

[1]Te Huataki Waiora School of Health, University of Waikato, Hamilton, New Zealand; [2]Cycling New Zealand, Cambridge, New Zealand; [3]School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, United Kindom; [4]Sport and Exercise Science, School of Allied Health, Human Services and Sport, La Trobe University, Melbourne, VIC, Australia; [5]School of Health and Sport Science, The Eastern Institute of Technology, Napier, New Zealand

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***Purpose*:** Leading a 4-km team pursuit (TP) requires high-intensity efforts above critical power (CP) that depletes rider's finite work capacity (W′), whereas riders following in the aerodynamic draft may experience some recovery due to reduced power demands. This study aimed to determine how rider ability and CP and W′ measures impact TP performance and the extent to which W′ can reconstitute during recovery positions in a TP race. ***Methods*:** Three TP teams, each consisting of 4 males, completed individual performance tests to determine their CP and W′. Teams were classified based on their performance level as international (INT), national (NAT), or regional (REG). Each team performed a TP on an indoor velodrome (INT: 3:49.9; NAT: 3:56.7; and REG: 4:05.4; min:s). Ergometer-based TP simulations with an open-ended interval to exhaustion were performed to measure individual ability to reconstitute W′ at 25 to 100 W below CP. ***Results*:** The INT team possessed higher CP (407 [4] W) than both NAT (381 [13] W) and REG (376 [15] W) ($P < .05$), whereas W′ was similar between teams (INT: 27.2 [2.8] kJ; NAT: 29.3 [2.4] kJ; and REG: 28.8 [1.6] kJ; $P > .05$). The INT team expended 104% (5%) of their initial W′ during the TP and possessed faster rates of recovery than NAT and REG at 25 and 50 W below CP ($P < .05$). ***Conclusions*:** The CP and rate of W′ reconstitution have a greater impact on TP performance than W′ magnitude and can differentiate TP performance level.

***Keywords*:** intermittent exercise, track cycling, endurance physiology, W′ reconstitution, high performance

The men's team pursuit (TP) is a track cycling event in which 4 riders work together to complete 4 km in the fastest time possible. Team members rotate positions between leading the team and riding closely behind to share the work and permit recovery before their next lead effort. A TP team traveling at a speed of approximately 60 $km \cdot hr^{-1}$ requires the lead rider to produce 550 to 650 W,[1,2] while the mean team power output across all positions has been reported to be between 425 and 460 W.[1,2] Given the TP requirement for repeated high-intensity efforts, it is unsurprising that oxidative aerobic pathways contribute the majority (approximately 75%) of a TP's energy demands.[2,3] TP cyclists thus possess endurance-orientated characteristics such as superior power output at maximal and submaximal intensities.[4,5]

The maximum sustainable rate of oxidative metabolism and the corresponding power output has been termed the critical power (CP, in Watts), while the finite work capacity and thus tolerance to exercise above CP can be defined as the "work-prime" (W′, in Joules). Together, the CP and W′ are parameters that describe the power–duration relationship of cycling performance. Male TP cyclists competing at world cup level have been reported to have a CP of approximately 391 W, meaning a rider leading the TP will expend W′. A drafting rider has the opportunity to cycle at power outputs below CP,[6] however, it is yet to be fully established if meaningful recovery occurs during periods of below CP cycling in the TP.

Cycling at intensities below CP reduces a rider's metabolic demands,[7] and permits recovery.[8] Skiba et al[9,10] published a model for intermittent exercise that assumes W′ is expended when power > CP, and predicts the extent of W′ reconstitution[11] when power < CP. The rate of W′ reconstitution correlates with an individual's $\dot{V}O_2$max and CP[8] and depends on both the duration and intensity of work and relief periods.[12] Therefore, the rate of W′ reconstitution is activity specific and may represent an important metric for TP performance. Moreover, the rate of W′ reconstitution is reportedly faster in well-trained cyclists[4] compared with recreational participants.[10]

The balance between W′ expenditure and reconstitution (W'_{BAL}) predicts the remaining W′ at any point during intermittent exercise and indicates the proximity of individual riders to task failure. The W'_{BAL} model can be employed within the TP if the rate of W′ reconstitution is assessed in conditions that reflect the duration and intensity of the TP. While Skiba et al[9,10] determined recovery rates ranging from 50 to 300 W below CP, the protocol's work/relief characteristics do not reflect actual power demands of the TP. Bartram et al[4] developed a protocol to assess the rate of W′ reconstitution that is physiologically relevant to the TP and published generalized recovery rates at 50 to 200 W below CP in high-performance endurance track cyclists. Bartram et al[6] subsequently applied their population-specific recovery model to a TP team of similarly well-trained cyclists and concluded that while their recovery rates produced reasonable W'_{BAL} predictions, individually derived recovery models are necessary for optimal W'_{BAL} tracking. Furthermore, Bartram et al[6] reported the mean power during periods of W′ reconstitution was approximately 79 W below CP, yet the stochastic power demands of the TP suggest there are recovery periods within 50 W of CP. Therefore, while previous literature has investigated the importance of protocol design for determining the rate of W′ reconstitution and demonstrated that TP

Q3 Pugh (cp115@students.waikato.ac.nz) is corresponding author.

races feature periods below CP, the rate of W′ reconstitution may not yet have been assessed at sufficient intensities to model W'_{BAL} in a TP. Furthermore, the degree to which the rate of W′ reconstitution and periods spent below CP are performance determinants of the TP is unclear.

To our knowledge, there are currently no studies that have applied W'_{BAL} modeling to different levels of TP performance using individualized parameters. Therefore, the primary aim of this study was to compare the CP, W′, and rates of W′ reconstitution across 3 TP performance levels (international [INT], national [NAT], and regional [REG]). A secondary aim was to evaluate the association of recovery ability with the magnitude of recovery and end TP W'_{BAL} values. It was hypothesized that CP, W′, and rate of W′ reconstitution would differ between performance levels, and that W'_{BAL} values would be influenced by the recovery models employed.

Methods

Subjects

Twelve competitive male track cyclists participated in the study (age: 22 [3] y, height: 181 [4] cm, and body mass: 77.6 [5.9] kg). All cyclists had high-performance training histories, and 9 had previously competed in INT competitions at junior or senior World Championships. Participants were grouped by their current respective TP performance level as either INT (n = 4, age: 24 [3] y, height: 179 [4] cm, body mass: 74.2 [4.9] kg), NAT (n = 4, age: 21 [2] y, height: 184 [3] cm, body mass: 76.5 [3.6] kg), or REG (n = 4, age: 22 [3] y, height: 181 [3] cm, body mass: 82.1 [5.7] kg). All participants gave their written informed consent to complete the study, which was approved by the University of Waikato Human Research Ethics Committee and performed in accordance with the Declaration of Helsinki.

Experimental Design

In a cross-sectional design, participants performed 8 experimental trials over 4 weeks (Figure 1). Participants initially completed a cycling CP assessment protocol consisting of 3 time trials (TT) over 1-, 4-, and 10-minute durations to determine CP and W′. These test durations have been applied by high-performance Australian cyclists[4,6,13] and are consistent with recommendations by Poole.[14] Participants then performed a maximal effort TP within their respective teams on an international standard 250-m indoor velodrome. Finally, participants performed 4 high-intensity interval sessions to assess rate of W′ reconstitution at various TP relief intensities. Intervals were completed at individual TP lead power with the relief intensities being performed at 0, 25, 50, and 100 W below CP; the relief intensity at CP (0) was performed first, and the order of remaining trials was randomized. Prior to each testing session, participants were requested to not ingest any potential performance enhancing ergogenic aids (eg, sodium bicarbonate).

Performance Measures

Critical Power and W′. Field-based TTs were used to derive estimates of rider CP and W′. Performance tests of 1-, 4-, and 10-minute duration were conducted in a randomized order and separated by at least 24 hours. Participants performed a self-selected 20-minute warm-up before each trial and were instructed to produce their "greatest average power possible" for each TT. Trials began from a stationary start, and participants were required to remain seated and maintain a cadence of 100 to 120 RPM using self-selected gear ratios. Participant's personal bicycles were fitted with an SRM (Schoberer Rad Meßtechnik) crankset calibrated according to Wooles et al.[15]

Team Pursuit. Each team performed a TP in simulated competition conditions against similarly matched teams that did not participate in the study, starting on opposite sides of the track. Participants used their personal fixed-gear bicycles fitted with the power meters from field-based TTs. The first rider began from a starting gate, and a Tissot timing system (Corgémont) provided a finishing time for the third rider to complete 4 km. The mean power exerted when the rider was in the lead position was defined as the lead power.

W′ Reconstitution Trials. The reconstitution rate of W′ ($\tau_{W'}$) was estimated using data from 4 simulated TP races performed over 2 consecutive days (with 4-h rest between trials on the same day). These trials took place at an indoor venue, and the conditions were 20 °C to 24 °C, 30% to 45% relative humidity. Tests were performed on the same bicycles and power meters as the field-based TTs mounted on a stationary cycle ergometer (Wahoo KICKR version 5), calibrated according to the manufacturer's instructions. The ergometer's resistance was controlled via software (TrainerRoad) using an isokinetic function set to predefined power requirements. All trials were preceded by a standardized

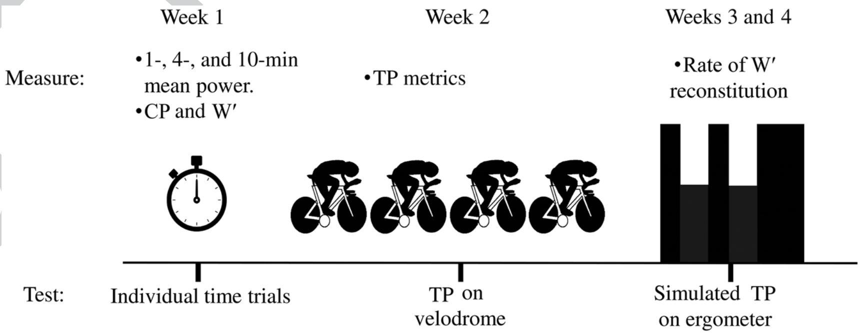

Figure 1 — Study timeline. The first week of the protocol prescribed performance tests to determine CP and W′. The second week included a 4-km TP. In the final 2 weeks, participants completed 4 ergometer-based interval sessions to determine the rate of W′ reconstitution at the intensities observed in the team pursuit. CP indicates critical power; TP, team pursuit; W′, work capacity above CP.

20-minute warm-up featuring a 10-minute ramp from 35% to 85% CP and 1.5-minute constant load cycling at 100% CP, followed by 15 seconds at the participant's TP lead power and finally 8.25 minutes at 35% CP.

The trial format featured two 30-second intervals at the participant's TP lead power interspersed by 60-second periods at each prescribed TP relief intensity below CP (D_{CP}). Relief conditions were CP (D_{CP} 0), 25 W below CP (D_{CP} 25), 50 W below CP (D_{CP} 50), and 100 W below CP (D_{CP} 100). Immediately following the second relief interval, participants performed a time to exhaustion interval at their TP lead power. Participants completed a familiarization trial of the D_{CP} 0 condition in the week preceding data collection. Participants were instructed to maintain a pedal cadence of 110 to 120 rpm.

Data Analysis

Power data were recorded at 1 Hz and downloaded to Golden Cheetah (version 3.5, open-source, https://www.goldencheetah.org/) before being processed in Excel (Redmond).

Three separate CP models were employed to determine the lowest standard error of the estimates for CP and W′:

Linear work–time model:

$$\text{Work} = (\text{CP} \cdot T) + W'. \tag{1}$$

Linear power–time model:

$$\text{P} = \frac{W'}{T} + \text{CP}. \tag{2}$$

Nonlinear power–time model:

$$T = \frac{W'}{(P - \text{CP})}, \tag{3}$$

where *Work* represents the cumulative mechanical energy output (Joules), and P represents the mean power output for a given duration (*T*, in seconds). The nonlinear power–time model produced lower standard error of the estimates than the linear work–time and linear power–time^{-1} models for CP (4 [2] W vs 7 [2] W and 10 [3] W, respectively) and was used to estimate CP and W′ for all participants.

Power data from each TP race were analyzed for mean power output, work performed above CP relative to the initial amount of the W′ (%), mean power output during lead efforts, and mean relief power output while in positions 2, 3, and 4.

Power data from W′ reconstitution trials and CP and W′ parameters were processed to estimate W'_{BAL} using the following formula:

$$W'_{\mathrm{BAL}} = \begin{cases} W'_{\mathrm{BAL},i-1} - ([P_i - \mathrm{CP}] \cdot \Delta u_i), & P_i > \mathrm{CP} \\ W'_0 - W'_{\mathrm{expended}} \cdot \left(e^{-\frac{\Delta u_i}{\mathrm{tau}}}\right), & P_i < \mathrm{CP} \end{cases}, \tag{4}$$

where i = the ith segment of the total time subdivided into n segments at 1 Hz (Δu), P_i = mean power output for segment i. Thus, W'_{BAL} is calculated sequentially and $W'_{\mathrm{BAL},I-1}$ represents a preceding estimation of W'_{BAL}. W'_{expended} is the quantity of depleted W′ at $i-1$ and is calculated as:

$$W'_{\mathrm{expended}} - W'_0 - W'_{\mathrm{BAL,i-1}}, \tag{5}$$

see Skiba and Clarke[16] for review. The W′ reconstitution time constant (tau, in seconds) is provided by the power function of D_{CP}–tau:

$$\text{Tau} = A \cdot {D_{\mathrm{CP}}}^{B}, \tag{6}$$

where *A* represents a scaling factor and *B* represents the rate of decay.

Previous literature demonstrates that there is a high-level of agreement for CP between laboratory and field testing yet W′ is environment specific.[17,18] Therefore, a parameter (W'_{ERG}) was calculated from the D_{CP} 0 trial to standardize the magnitude of W′ on a stationary ergometer when no recovery would occur. The participant's W'_{ERG} was defined as the final W'_{BAL} value of the D_{CP} 0 trial. A single tau value was set for each of D_{CP} 25, 50, and 100 W conditions and determined using Excel's iterative Solver function, which fit end W'_{BAL} values to W'_{ERG}. D_{CP}–tau power regressions were derived for each participant to predict tau at any intensity below CP.[4,10]

Power data from the TP were processed using the parameters of CP, W′, and individualized $\tau_{W'}$ to produce W'_{BAL} traces during TP races. To explore the effect of different D_{CP}–tau models on TP W'_{BAL} values, races were also processed using the equations from Skiba et al[10] and Bartram et al.[4]

Generalized D_{CP}–tau power functions were calculated for each team from mean $\tau_{W'}$ at D_{CP} 25, D_{CP} 50, and D_{CP} 100. Individualized equations cannot be reported because of an agreed-upon embargo with the national federation.

Statistical Analysis

Data were analyzed in SPSS (IBM) using 1-way analysis of variance between the 3 performance levels and dependent variables: CP; W′; 1-, 4-, 10-minute TT mean power output; TP mean power output; TP mean power output in all positions; TP W′ work done; and $\tau_{W'}$ at D_{CP} 25, D_{CP} 50, and D_{CP} 100. Post hoc analyses were performed to compare between groups with Tukey HSD test. The assumption of normality was verified using the Shapiro–Wilk test. A repeated-measures analysis of variance was performed to compare final TP W'_{BAL} predictions from individualized D_{CP}–tau models with previously published models.[4,10] Bivariate correlations (r) were performed between CP and D_{CP}–tau (D_{CP}: 25, 50, and 100) and the strength of r was determined using the following criteria: ≤.1, trivial; >.1 to .3, small; >.3 to .5, moderate; >.5 to .7, large; >.7 to .9, very large; and >.9 to 1.0, almost perfect.[19] Statistical significance was set at $P < .05$.

Results

CP and W′

The mean CP and W′ estimates and 1-, 4-, and 10-minute average power outputs are presented in Table 1. The INT team had a greater CP compared with NAT ($P = .047$) and REG teams ($P = .021$), whereas the INT team's W′ magnitude was not different from NAT ($P = .519$) or REG ($P = .667$) teams. The mean power output of the INT team's 1- and 4-minute TT was not different to NAT ($P = .900$, $P = .273$) and REG teams ($P = .793$, $P = .087$), respectively. In contrast, mean power output in the 10-minute TT was greater in the INT team than NAT ($P = .040$) and REG teams ($P = .020$).

Team Pursuit Races

Team pursuit data are presented in Table 2. The INT team produced a greater mean TP power output compared with REG ($P = .034$) but not NAT teams ($P = .072$). The INT team produced a greater mean power output while leading the TP than both NAT ($P = .016$) and REG teams ($P = .015$). No differences were observed between the

Table 1 Absolute CP and W′ Estimates and Performance Test Average Power Outputs for INT, NAT, and REG TP Performance Levels

	1 min, W	4 min, W	10 min, W	CP, W	CP SEE range, W	W′, kJ	W′ SEE range, kJ
INT	777 (42)	523 (13)	452 (6)[a,b]	407 (4)[a,b]	3–8	27.2 (2.8)	1.7–2.8
NAT	791 (26)	506 (8)	430 (9)	381 (13)	3–6	29.3 (2.4)	1.8–2.7
REG	798 (50)	498 (17)	424 (16)	376 (15)	2–5	28.8 (1.6)	1.0–2.9

Abbreviations: CP, critical power; INT, international; NAT, national; REG, regional; SEE, standard error of the estimate; TP, team pursuit; W′, work capacity above CP. Note: Values are presented as mean (SD), where applicable.

[a] A significant difference ($P < .05$) between INT and NAT squads. [b] A significant difference ($P < .05$) between INT and REG squads.

Table 2 Team Pursuit Data for INT, NAT, and REG Performance Levels

	INT	NAT	REG
Finishing time, min:s	3:49.9	3:56.7	4:05.4
Mean power, W	501 (26)[b]	471 (34)	463 (12)
Lead rider power, W	658 (13)[a,b]	609 (23)	613 (19)
Mean power at position 2, W	446 (31)	422 (53)	423 (50)
Mean power at position 3, W	405 (30)	372 (27)	370 (16)
Mean power at position 4, W	426 (21)	392 (35)	381 (19)

Abbreviations: INT, international; NAT, national; REG, regional. Note: Values are presented as mean (SD), where applicable.

[a] A significant difference ($P < .05$) between INT and NAT squads. [b] A significant difference ($P < .05$) between INT and REG squads.

INT team and NAT or REG teams for the mean power output of positions 2 ($P = .809$, $P = .813$), 3 ($P = .108$, $P = .088$), and 4 ($P = .294$, $P = .140$), respectively.

W′ Reconstitution

The mean relief intensity of the D_{CP} 0 trial was 6 W above CP, whereas the mean relief intensity of the D_{CP} 25, D_{CP} 50, and D_{CP} 100 trials were 20, 43, and 91 W below CP, respectively. The mean duration of W′ reconstitution trials for INT, NAT, and REG teams were 224 (13), 243 (11), and 216 (10) seconds, respectively. There were large, significant negative correlations between CP and $\tau_{W'}$ at D_{CP} 25 ($r = -.819$, $P = .001$) and D_{CP} 50 ($r = -.714$, $P = .009$), but no significant correlation at D_{CP} 100 ($r = -.510$, $P = .091$) (Figure 2). Individualized D_{CP}–tau data are presented in Table 3 along with the Bartram et al[4] and Skiba et al[10] D_{CP}–tau values for comparison of models. Generalized D_{CP}–tau functions for INT, NAT, and REG teams are presented in Figure 2. The mean standard error of A and B D_{CP}–tau parameters are 19% and 15% in the INT team, 20% and 12% in the NAT team, and 13% and 9% in the REG team, respectively. The INT team possessed lower tau values compared with NAT and REG teams at D_{CP} 25 ($P = .034$ and $P = .009$) and D_{CP} 50 ($P = .032$ and $P = .017$), respectively. There was no difference in $\tau_{W'}$ at D_{CP} 100 between the INT team and NAT ($P = .158$) or REG ($P = .119$) teams.

Team Pursuit W′$_{BAL}$

Figure 3 shows TP W′$_{BAL}$ traces using the individualized, Bartram,[4] and Skiba[10] D_{CP}–tau models, and Table 4 presents the final W′$_{BAL}$ values from all models. The W′ expended relative to its initial amount was similar in the INT (104% [5%]) to the NAT (75% [18%]; $P = .117$) and REG teams (99% [7%]; $P = .754$). Bartram D_{CP}–tau model produced similar final W′$_{BAL}$ values to individualized D_{CP}–tau models in the INT ($P = .333$) and NAT ($P = .295$) teams, but greater final W′$_{BAL}$ values in the REG team ($P = .006$). Skiba D_{CP}–tau function produced significantly lower final W′ values in the INT team ($P = .002$) but had no effect with the NAT ($P = .165$) and REG ($P = .267$) teams.

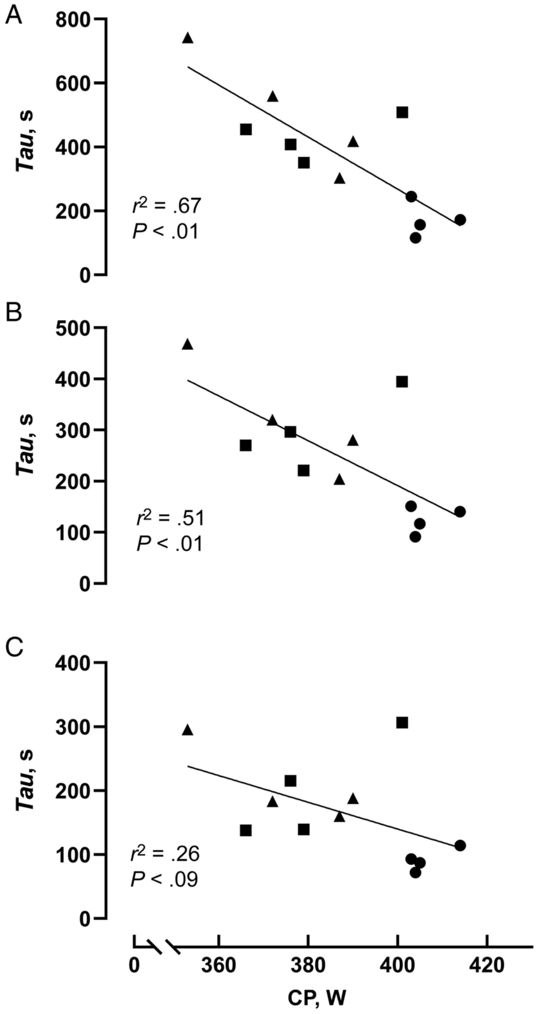

Figure 2 — Relationship of CP and rate of recovery in TP cyclists. (A) Rate of recovery 25 W below CP. (B) Rate of recovery 50 W below CP. (C) Rate of recovery 100 W below CP. •, International; ▲, national; ■, regional. CP indicates critical power; Tau, the time constant of W′ reconstitution; TP, team pursuit.

Table 3 The W′ Reconstitution Individualized Tau Data With the Bartram and Skiba 2 Relationships

	INT	NAT	REG	Bartram	$\text{Skiba}_{\text{INT}}$	$\text{Skiba}_{\text{NAT}}$	$\text{Skiba}_{\text{REG}}$
Tau equation	$789 \cdot D_{\text{CP}}^{-0.468}$	$1883 \cdot D_{\text{CP}}^{-0.487}$	$5184 \cdot D_{\text{CP}}^{-0.700}$	$2287 \cdot D_{\text{CP}}^{-0.688}$	W'/D_{CP}	W'/D_{CP}	W'/D_{CP}
Interval power, W	658 (13)	609 (23)	613 (19)				
W'_{ERG}, kJ	10.7 (1.8)	7.0 (3.6)	7.7 (1.5)				
W′ reconstitution time constant, s							
D_{CP} 25	176 (47)^{a,b}	393 (77)	546 (124)	250	1088 (110)	1173 (96)	1154 (62)
D_{CP} 50	125 (23)^{a,b}	279 (75)	335 (79)	155	544 (55)	586 (48)	577 (31)
D_{CP} 100	92 (15)	200 (69)	207 (53)	96	272 (28)	293 (24)	288 (15)

Abbreviations: CP, critical power; D_{CP}, difference between relief intensity and critical power; INT, international; NAT, national; REG, regional; Tau, W′ reconstitution time constant; W′, work capacity above critical power; W'_{ERG}, final W'_{BAL} value of the D_{CP} 0 trial. Note: Values are presented as mean (SD), where applicable. Generalized equations are reported instead of individualized equations because of an agreed-upon embargo with the national federation. Tau equations are presented in the format: $A.D_{\text{CP}}^{B}$, where A is a scaling factor and B is the rate of decay.

[a] A significant difference ($P < .05$) between INT and NAT squads. [b] A significant difference ($P < .05$) between INT and REG squads.

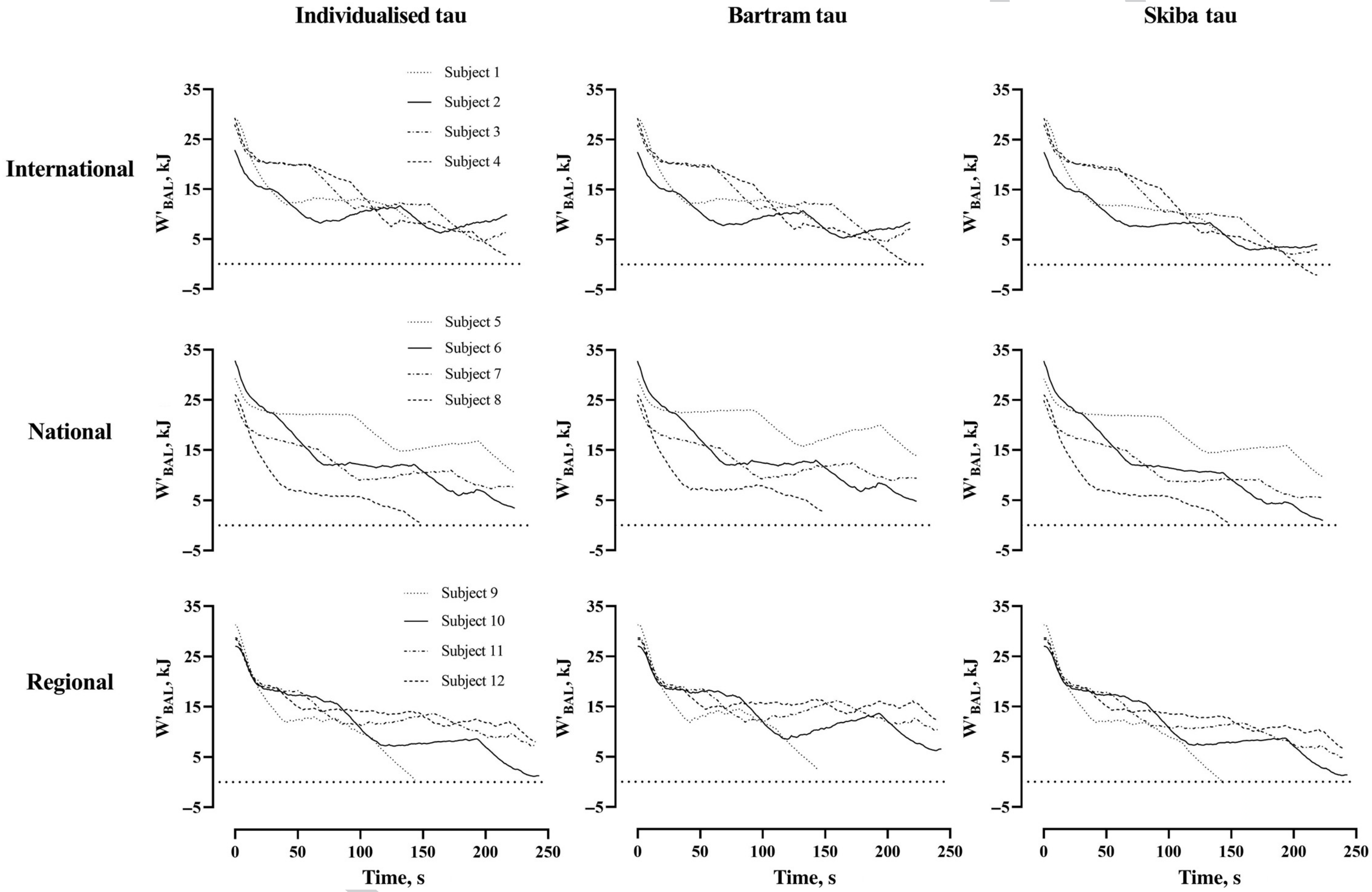

Figure 3 — Modeling W'_{BAL} during a TP using individualized, Bartram, and Skiba tau recovery rate models. Leading TP efforts can be identified by sharp reductions in W'_{BAL}. (A) International TP with individualized tau. (B) International TP with Bartram tau. (C) International TP with Skiba tau. (D) National TP with individualized tau. (E) National TP with Bartram tau. (F) National TP with Skiba tau. (G) Regional TP with individualized tau. (H) National TP with Bartram tau. (I) National TP with Skiba tau. Tau indicates the time constant of W′ reconstitution; TP, team pursuit; W'_{BAL}, remaining capacity to perform work above critical power.

Discussion

The main aim of this study was to determine how rider ability and individual CP and W′ measures impact TP performance and to what extent W′ can reconstitute during recovery positions in a TP race. The present data demonstrate that the INT TP team is distinguished from lower performing teams by enhanced CP and $\tau_{W'}$, but not W′ magnitude. In addition, while W'_{BAL} values were

Table 4 Comparison of the Individualized Recovery Rate Relationship on the W'_{BAL} Values of TP Races With the Bartram and Skiba Relationships

	INT	NAT	REG
End W'_{BAL}, kJ			
Individualized	6.8 (3.6)	6.4 (5.3)	4.3 (4.0)
Bartram	6.2 (4.1)	9.0 (6.0)	8.5 (3.4)[a]
Skiba 2	3.0 (3.7)[a]	5.3 (5.2)	2.9 (3.4)

Abbreviations: INT, international; NAT, national; REG, regional; TP, team pursuit; W'_{BAL}, balance between W' expenditure and reconstitution. Note: Values are presented as mean (SD).

[a] A significant difference to individualized recovery rate relationship ($P < .05$).

influenced by the employed D_{CP}–tau model, similar W'_{BAL} values were observed between the individualized, Skiba, and Bartram model forms with respect to performance level.

The main finding that CP and $\tau_{W'}$ were greatest in the INT TP team is not surprising given that high-performance pursuit cyclists have highly adapted aerobic physiological characteristics including an enhanced $\dot{V}O_2$max, proportion of type I muscle fibers, capillary density, mitochondrial content,[5] and $\dot{V}O_2$ uptake kinetics.[20] While CP,[21,22] and intense exercise performance[23] are known to be highly dependent on muscle capillary supply, the physiological underpinnings of $\tau_{W'}$ have yet to be established. An enhanced muscle capillary supply may facilitate the clearing of fatigue-inducing metabolites[23] and increase oxygen availability in the muscles,[3] both of which likely accelerates $\tau_{W'}$ as indicated by the relationship between muscle reoxygenation rate and $\tau_{W'}$.[7]

Leading a TP demands a power output greater than CP which results in expenditure of W' and contributes to the high levels of fatigue typical of TP events. Despite an approximately 50% reduction in aerodynamic drag,[24] the power requirements of drafting riders are still substantial, and there could be opportunities to ride below CP. Recovering in nonlead positions is critical as it reduces the metabolic requirements,[25] which can preserve W'. To our knowledge, the current study is the first to implement W'_{BAL} modeling in high-level TP teams using individualized estimates of CP, W', and $\tau_{W'}$ at TP relief intensities. The INT team recovered faster than the NAT and REG teams at D_{CP} 25 and D_{CP} 50, which indicates the importance of recovery at intensities just below CP to TP performance. Moreover, in the INT team, the overall expended quantity of W' was greater than its initial magnitude and indicates there were periods of meaningful recovery despite the high intensity. Models from Skiba et al[10] and Bartram et al[4] permit extrapolation of D_{CP}–tau to D_{CP} 25, yet overpredicted tau at D_{CP} 25 in the INT team of the present study (1138 s vs 250 s vs 176 s, respectively). This difference in D_{CP}–tau between the current INT team and published models emphasize the importance of individualized $\tau_{W'}$ testing for sports requiring maximal efforts with periods above and below CP.

The present study compared the individualized, Skiba et al[10] and Bartram et al[4] D_{CP}–tau relationships using TP W'_{BAL} values. Our findings suggest that $\tau_{W'}$ of the INT and NAT teams were similar to Bartram model, whereas, the NAT and REG teams were similar to Skiba model.[10] As Bartram's participants were high performing and Skiba's were recreational, these results indicate that published models may provide approximate estimates of $\tau_{W'}$ with respect to performance level. Indeed, we report significant correlations between CP and $\tau_{W'}$ at D_{CP} 25 and D_{CP} 50 (both $r^2 > .5$), which supports previous literature findings.[8] We observed that NAT-level cyclists possessed higher tau values compared with elite cyclists in Bartram et al[4] despite similar CP estimates. This observation supports previous literature and indicates that $\tau_{W'}$ is multifaceted and likely influenced by protocol design, CP, $\dot{V}O_2$max, and EPOC.[8,26]

As a consequence of a greater CP and faster W' reconstitution, the INT team were able to produce a higher lead rider power output than the NAT and REG teams, which likely contributed to the INT team finishing 7- and 15-second faster than NAT and REG teams, respectively. The power outputs generated by the INT team were greater than previously published data from INT competition[2] (mean power: 501 vs 461 W; lead power: 658 vs 581 W, respectively), while the approximately 25-second faster finishing time indicates a remarkable improvement in performance over the past approximately 20 years. Although the higher mean speed produced by the INT team in the present study partially explains the increase in power demand, the time disparity may also be attributed to developments in reduction of aerodynamic drag[27] or increased technical ability.

A TP team which achieves full W' depletion by the race's finish has been suggested to be optimal for performance.[4] However, a lower final W'_{BAL} value does not exclusively belong to an optimally paced team as poor strategic and technical decisions may reduce final W'_{BAL} values without a corresponding improvement in TP finishing time. The comparison data presented in Figure 3 and Table 4 demonstrate that final TP W'_{BAL} values were often greater than 0 kJ with no differences between performance levels and suggest that a TP team's ability to fully deplete W' was not a decisive TP performance factor. Yet, subject 1 withdrew from their race with a W'_{BAL} of approximately 9 kJ, and the NAT TP team finished with 25% of their W' remaining, which implies suboptimal pacing strategies and thus, faster performances are theoretically possible.

This study features the following limitations. Cardiometabolic data during CP and W' estimation trials were not obtained, which does not allow the verification of the attainment of $\dot{V}O_2$max. While the well-trained participants were likely to have attained $\dot{V}O_2$max during 4- and 10-minute performance tests, we cannot verify the 1-minute performance test elicited $\dot{V}O_2$max. However, test durations less than 90 seconds are adequate to determine maximal accumulated oxygen deficit,[28] and endurance training is reported to hasten $\dot{V}O_2$ uptake kinetics to permit attainment of $\dot{V}O_2$max in < 2 minutes.[29] Additionally, the 1-, 4-, 10-minute trial format is not considered the "gold-standard" CP protocol, which advocates test durations of 2 to 15 minutes. Yet, the test durations are within the recommendations by Poole[14] and are employed by the Australian high-performance track endurance program[4,6,13] and, anecdotally, in New Zealand's equivalent male track endurance program. Recent literature[30] indicates that W' reconstitution exhibits biexponential recovery kinetics unlike the monoexponential model applied in the present study. Presumably, an INT TP team's superior endurance capacity may lead to faster W' reconstitution in both the "slow" and "fast" phases. However, it could be speculated that a TP team would benefit most from enhanced "fast-phase" kinetics, given periods of below CP intensity are transient.

Practical Applications

This study utilized performance tests that are readily replicable in a practical setting and provided acceptable error to allow confidence in estimating CP and W'. The D_{CP}–tau models presented offer a generalized estimate of $\tau_{W'}$ from INT to REG performance levels and permit practitioners to implement approximate W'_{BAL} modeling in other TP cyclists. While improvements in CP and/or W′ may lead to enhanced TP performance, our data indicate that overall endurance capacity is the most important physiological factor of TP performance.

Conclusions

Field-based performance tests for CP, W′, and W′ reconstitution in INT, NAT, and REG TP cyclists revealed that the INT team is distinguished by an enhanced CP and faster W′ reconstitution at TP relief intensities. These findings suggest that CP and rate of recovery have a greater impact on TP performance than W′ magnitude and demonstrate the importance of high-intensity aerobic fitness to the TP.

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Queries

Q1. As per style, abbreviation is not allowed in article title. Please suggest whether "W′" can be changed to "work capacity."

Q2. Please note that there is a mismatch noticed in the author name between manuscript ("Martyn C. Beaven" and "Matthew W. Driller") and meta-page/data ("Christopher Martyn Beaven" and "Matt Driller"). We have followed the one given in manuscript. Please check and confirm.

Q3. Please ensure author information is listed correctly here and within the byline.

Q4. As per journal style, "mean ± SD" should be represented as "mean (SD)." Hence, the values are changed accordingly. Please check and confirm.

Q5. Please provide expansion for "RPM."

Q6. Please check and confirm "Skiba 2" in Tables 3 and 4.

Q7. Please provide expansion for "EPOC."