

Slowing the Reconstitution of W' in Recovery With Repeated Bouts of Maximal Exercise

Alan Chorley, Richard P. Bott, Simon Marwood, and Kevin L. Lamb

Purpose: This study examined the partial reconstitution of the work capacity above critical power (W') following successive bouts of maximal exercise using a new repeated ramp test, against which the fit of an existing W' balance (W'_{bal}) prediction model was tested. **Methods:** Twenty active adults, consisting of trained cyclists ($n=9$; age 43 [15] y, $\dot{V}O_{2\text{max}}$ 61.9 [8.5] mL·kg⁻¹·min⁻¹) and untrained cyclists ($n=11$; age 36 [15] y, $\dot{V}O_{2\text{max}}$ 52.4 [5.8] mL·kg⁻¹·min⁻¹) performed 2 tests 2 to 4 d apart, consisting of 3 incremental ramps (20 W·min⁻¹) to exhaustion interspersed with 2-min recoveries. **Results:** Intratrial differences between recoveries demonstrated significant reductions in the amount of W' reconstituted for the group and both subsets ($P < .05$). The observed minimal detectable changes of 475 J (first recovery) and 368 J (second recovery) can be used to monitor changes in the rate of W' reconstitution in individual trained cyclists. Intertrial relative reliability of W' reconstitution was evaluated by intraclass correlation coefficients for the group ($\geq .859$) and the trained ($\geq .940$) and untrained ($\geq .768$) subsets. Absolute reliability was evaluated with typical error (TE) and coefficient of variation (CV) for the group (TE \leq 559 J, CV \leq 9.2%), trained (TE \leq 301 J, CV \leq 4.7%), and untrained (TE \leq 720 J, CV \leq 12.4%). **Conclusions:** The reconstitution of W' is subject to a fatiguing effect hitherto unaccounted for in W'_{bal} prediction models. Furthermore, the W'_{bal} model did not provide a good fit for the repeated ramp test, which itself proved to be a reliable test protocol.

Keywords: critical power, modeling, testing, fatigue

Cycle races are often characterized by the ability of competitors to perform repeated surges of severe intensity efforts (“attacks”) interspersed with short recovery periods. The critical power (CP) model first introduced by Monod and Scherrer¹ offers an objective physiological framework for the work performed during these surges, which could lead to a better understanding of for how hard and how long a cyclist could attack.

The intensity of exercise can be classified into discernible domains,² with CP marking the boundary between the *heavy* and *severe* exercise domains.³ Below CP energy is derived predominantly from sustainable aerobic pathways,^{4,5} while work above CP requires a greater anaerobic contribution, drawing on a finite capacity of work known as W' . The precise physiological underpinnings of W' remain elusive; initially thought to be a finite amount of energy drawn from oxygen stores within the muscle, phosphates, and anaerobic glycolysis,⁶ but later shown to be related to the accumulation of fatiguing metabolites such as adenosine diphosphate, inorganic phosphate, and hydrogen ions within the muscle.⁷ The magnitude of W' has also been shown to be affected by oxygen availability⁸ dispelling the notion of it solely reflecting anaerobic capacity. Furthermore, the magnitude of W' has been correlated with muscle size⁹ and the development of the $\dot{V}O_{2\text{max}}$ slow component in the “headroom” between CP and maximal oxygen uptake ($\dot{V}O_{2\text{max}}$).^{10,11}

Despite W' appearing to be the product of a complex energetic system, the contribution of W' in determining exercise performance above CP is highly predictable. W' is expended at a rate proportional to the power output above CP. When CP and W' are known,

the limited duration of work (T_{lim}) at a power output (P) above CP can be predicted by the hyperbolic relationship described by Equation 1.

$$T_{\text{lim}} = W' / (P - \text{CP}) \quad (1)$$

Once depleted, W' has been shown to begin reconstitution only when power output falls below CP,¹² with recovery being curvilinear in nature.⁷ The reconstitution of W' has been shown to be slower than that of $\dot{V}O_{2\text{max}}$ recovery and faster than that of blood lactate (BLA).⁷ Further investigations¹³ have linked the reconstitution of W' with the recovery of muscle phosphocreatine concentration (PCr) establishing that, like W' , recovery of these metabolic factors initiates at intensities below CP. However, the kinetics of PCr recovery differed from that of W' ,¹⁴ indicating an associative link rather than a dependency, and that PCr recovery is only a part of a complex system of W' reconstitution.

Skiba et al¹⁵ suggested an exponential W' reconstitution model, based on an intermittent exercise protocol (Equation 2) for the remaining balance of W' (W'_{bal}) during exercise and recovery, where $t - u$ is the recovery duration.

$$W'_{\text{bal}} = W' - \int_0^t (W'_{\text{exp}}) (e^{-(t-u)/\tau_{W'}}) \quad (2)$$

Skiba et al¹⁵ evidenced that the rate of W' reconstitution increased as the difference between recovery power output and CP increased, deriving an average value for the time constant of W' reconstitution ($\tau_{W'}$) based on the difference between recovery power output and CP (D_{CP}) (Equation 3).

$$\tau_{W'} = 546e^{(-0.01D_{\text{CP}})} + 316 \quad (3)$$

Although the W'_{bal} model has been validated in subsequent studies,¹⁶ faster recovery kinetics have been observed in elite cyclists

Chorley, Bott, and Lamb are with the Dept of Sport and Exercise Sciences, University of Chester, Chester, United Kingdom. Marwood is with the School of Health Sciences, Liverpool Hope University, Liverpool, United Kingdom. Chorley (a.chorley@chester.ac.uk) is corresponding author.

resulting in the proposition of different relationship between D_{CP} and the W' reconstitution time constant (Equation 4).¹⁷

$$\tau_{W'} = 2287.2 \times D_{CP}^{-0.688} \quad (4)$$

The W'_{bal} model¹³ was derived from regression analysis, the only individualized independent variable being CP, with $\tau_{W'}$ assigned an average value based on D_{CP} . However, notable variations in $\tau_{W'}$ between individuals with similar CP have been observed.¹⁸ Furthermore, the only known points are the initial W' at the outset and defining $W' = 0$ J at the limit of tolerance of intermittent exercise. Hence, an additional possible limitation of the W'_{bal} model is that it assumes that the reconstitution of W' will be constant following repeated bouts of $>CP$ exercise. Therefore, the primary aim of the present study was to examine whether repeated bouts of maximal exercise, thus fully depleting W' , affect the rate of reconstitution of W' . A secondary aim of the present study was to assess the reliability of a repeated ramp test (RRT) to quantify an individual's reconstitution of W' and to assess the validity of the W'_{bal} model against this protocol.

Methods

Subjects

With institutional ethics approval, 20 healthy adults (male = 19 and female = 1; age: 39 [15] y, stature: 177.6 [6.0] cm, body mass: 74.3 [8.9] kg, $\dot{V}O_{2max}$: 56.7 [8.5] mL·kg⁻¹·min⁻¹) volunteered to take part in the study after providing written informed consent. The subjects included active noncyclists (untrained) (n = 11; age: 36 [15] y, stature: 178.8 [4.3] cm, body mass: 77.8 [8.1] kg, $\dot{V}O_{2max}$: 52.4 [5.8] mL·kg⁻¹·min⁻¹) and trained cyclists (n = 9; age: 43 [15] y, stature: 176.1 [7.6] cm, body mass: 70.6 [8.8] kg, $\dot{V}O_{2max}$: 61.9 [8.5] mL·kg⁻¹·min⁻¹).

Design

Following a repeated-measures design, subjects visited an air-conditioned laboratory on 3 occasions 2 to 4 days apart at similar times of day. Subjects were instructed to avoid strenuous exercise and alcohol in the previous 24 hours, caffeine in the preceding 4 hours, and to have eaten similar meals at least 3 hours prior. The first visit included familiarization and baseline testing, while subsequent visits were comprised of the RRT. All testing was conducted on an electronically braked cycle ergometer (Lode Excalibur Sport; Lode BV, Groningen, The Netherlands). Pulmonary gas exchange was measured breath by breath throughout each test using an online gas analysis system (Quark CPET; COSMED, Rome, Italy), calibrated prior to each test with gases of known concentrations and volumes. BLA was measured via capillary fingertip samples with a portable analyzer (Lactate Pro II; Arkay, Kyoto, Japan). All ramp phases increased at a rate of 20 W·min⁻¹.

Methodology

Baseline Tests. A single baseline test was used to establish parameters to be used in subsequent trials and act as a familiarization. The ergometer was adjusted for individual comfort and pedal type, and replicated in later visits. For CP determination, the ergometer was switched into “linear mode” requiring the configuration of the “linear factor” (Equation 5) and was based on a predicted CP and preferred cadence during this phase. These were established from subjects' own training data (where available), else

CP was predicted as 3× body mass (in kilograms)¹⁹ and defaulting to a cadence of 80 r·min⁻¹.²⁰

$$\text{Linear factor} = \text{power/cadence}^2 \quad (5)$$

The protocol commenced with a 5-minute warm-up at 100 W at a self-selected cadence, which then transitioned into a ramp until the limit of tolerance, despite very strong verbal encouragement. Power output was then stepped down to a constant work rate 30 W above estimated CP to ensure full depletion of W' as it has been shown that subjects can continue to cycle at a power output below their maximum power output but still above their CP for a short period.¹³ When cadence dropped to 50 r·min⁻¹ despite continued encouragement, the subjects were encouraged to cycle all out for 2 minutes to allow determination of CP from the final 30 seconds of this phase.²⁰ To avoid pacing, time to completion of this phase was withheld from subjects.²¹ Then followed 2 minutes of recovery at 50 W,²² before a further ramp commenced at 30 W above estimated CP, together with a step-down following intolerance again at 30 W above CP until cadence dropped to 50 r·min⁻¹. The protocol then ended with 5 minutes at 50 W (see Figure 1 for the power profile of the baseline test).

Experimental Trials. The RRT commenced with a 5-minute warm-up at 100 W, which then transitioned into a ramp. On reaching the limit of tolerance, power output was stepped down to a level 30 W above the CP determined during baseline testing, until the limit of tolerance, after which a 2-minute recovery at 50 W allowed a partial reconstitution of W' . Two further ramps to assess the amount of W' reconstituted then followed. The second and third ramps commenced at 30 W above measured CP, until the limit of tolerance before a step-down to the power output at 30 W above CP. A further 2-minute recovery period at 50 W preceded the final ramp (see Figure 2 for the power profile of the experimental trial). The protocol again finished with 5 minutes at 50 W. All reconstitution ramps commenced at 30 W above CP to minimize the impact of interday variability of CP on the measurement of W' . BLA were obtained at the start of each recovery phase and at the end of the cooldown. Three subjects failed to complete the third ramp successfully, and their data for this final ramp have been excluded from the results.

Data Processing. Breath-by-breath gas analysis was examined and errant breaths removed.²³ Data were reduced to second-by-second intervals by linear interpolation and time aligned to power output using Microsoft Excel 2016 (Microsoft Corp, Redmond, WA). $\dot{V}O_{2max}$ was deemed to be the maximum mean $\dot{V}O_2$ recorded over a 30-second period across all tests.²⁴ Localized $\dot{V}O_{2peak}$ measurements during each ramp were calculated as the mean $\dot{V}O_2$ over the last 10 seconds of each ramp phase. Power output during the all-out phase of the baseline test was split into 30-second time “bins” and CP was recorded as the mean power output during the final 30-second time bin. W' was calculated as the work done above CP during the initial ramp and step-down phases. Similarly, the amount of W' reconstituted during each recovery was calculated as the amount of work done above CP during the subsequent ramp and step-down phase.

Statistical Analysis

Descriptive statistics (mean [SD]) were calculated for all the dependent variables, and their distributions were confirmed as normal via the Shapiro–Wilk statistic. One-way repeated-measures analysis of variance was performed to identify within-test

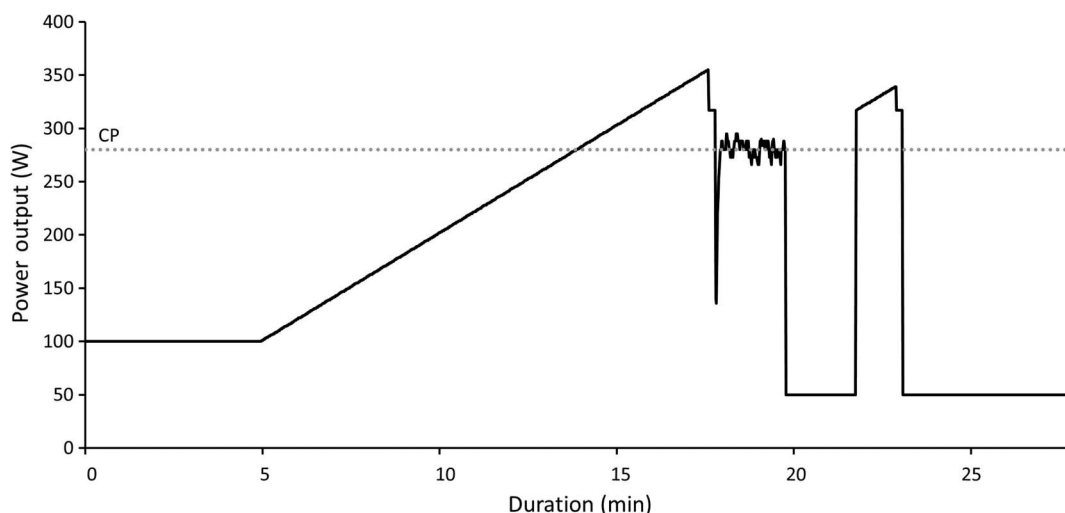


Figure 1 — A typical profile of power output during the baseline test protocol. The 100-W warm-up was followed by the ramp at a rate of $20 \text{ W}\cdot\text{min}^{-1}$ and the step-down to 30 W above estimated critical power. Actual critical power was determined from the 2-minute all-out phase. The 2-minute recovery at 50 W and second ramp, step-down, and final 5-minute recovery at 50 W served as a familiarization for the subsequent test protocols.

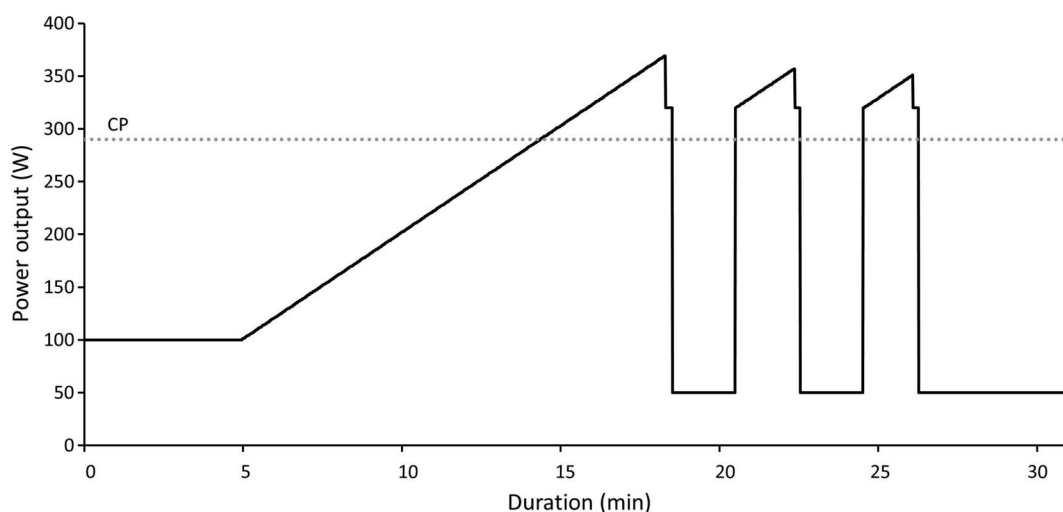


Figure 2 — A typical profile of power output during the repeated-ramp-test protocol. The 5-minute 100-W warm-up was followed by the ramp to the limit of tolerance and step-down to exhaust W' . All ramp rates were $20 \text{ W}\cdot\text{min}^{-1}$. The W' reconstitution ramps started at 30 W above CP; all step-downs were also at 30 W above CP. Recovery periods between ramps were 2 minutes at 50 W, and the final cooldown lasted 5 minutes at 50 W. W' and the amount of W' reconstituted composed the area contained within each ramp and step-down and CP. CP indicates critical power.

differences of power output in the 30-second time bins of the final 90 seconds of the baseline test all-out phase. Two-way repeated-measures analysis of variance was performed to assess the interaction between the repeated trials ($\times 2$) and the reconstitution ramp phases ($\times 2$) on the dependent variables (W' reconstituted, $\dot{V}O_{2\text{peak}}$, and BLA). Paired sample t tests were used to compare mean W' reconstitution between the repeated trials and between phases within tests. W' reconstitution measurements (within-subject errors) were explored and found to be homoscedastic. Mixed model intraclass correlation coefficients ($\text{ICCs}_{3,1}$), typical errors (TEs; SD of the differences/ $\sqrt{2}$), and coefficients of variation (CVs) together with 90% confidence intervals were calculated to quantify the reproducibility of W' and its reconstitution. To assist

interpretation in the form of an analytical goal, the minimal detectable change in performance required with 84% confidence²⁵ is expressed in terms of additional work above CP and the difference in time to exhaustion it would equate to. The W'_{bal} model was assessed by enumerating Equations 2 and 3 on a per-second basis using the measurement of CP from the baseline tests and W' and the power output profiles from the final test sessions. Paired sample t tests were then used to assess the fit of the model against actual measurements of W' at the points of exhaustion and after recovery periods. Analyses were also performed on the subsets of trained and untrained cyclists. Statistical significance was set at $P < .05$ throughout. Analysis was performed using SPSS v.23 (IBM Corp, Armonk, NY).

Results

Baseline Tests

There was no difference between mean power outputs in the 30-second time bins covering the final 90 seconds of the all-out phase ($P = .86$), as such CP for each subject was determined as the mean power output during the final 30 seconds. Mean CP was 259.6 (45.9) W (whole group), 276.3 (46.8) W (trained subset), and 245.9 (42.4) W (untrained subset). Mean values of W' , peak ramp power, and $\dot{V}O_2$ peak, respectively, were 9168 (3460) J, 334.7 (51.0) W, and 55.1 (9.3) mL·kg⁻¹·min⁻¹ (group); 9813 (2278) J, 356 (51) W, and 60.9 (9.2) mL·kg⁻¹·min⁻¹ (trained); and 8639 (4231) J, 317 (46) W, and 50.4 (6.4) mL·kg⁻¹·min⁻¹ (untrained).

Assessments of W' Reconstitution

Intratrial differences between the 2 reconstitution phases of the RRT are shown in Table 1. All groupings demonstrated a significantly reduced amount of W' reconstituted in the final recovery period ($P < .05$). Figure 3 shows both the group and subset means and individual values of the intratrial W' reconstitution. In addition, significant differences in W' reconstitution between the 2 recovery phases for the whole group ($P < .01$), cyclists ($P = .01$), and non-cyclists ($P = .04$) during trial 1 were observed, and for the group ($P < .01$) and trained cyclists ($P = .01$), only during trial 2.

RRT Reliability

The initial ramp phase of the RRT to deplete W' demonstrated excellent intertrial reliability (ICC = .922) for the determination of W' for the group. Furthermore, the reconstitution of W' measured in the subsequent ramps had high intertrial ICCs (see Table 2), with the greatest reliability being demonstrated by trained cyclists. This superior reliability is also reflected by the TE and CV values for the intertrial phases; CV < 5% for both W' reconstitution measurements. Paired sample t tests revealed no systematic changes in W' ($P > .05$) between the trials for the initial W' depletion phase or the first W' reconstitution for the group overall or subsets. When compared with the first trial, the second trial resulted in significant increases in the final W' reconstitution for the group and both subsets ($P < .05$).

A significant trial × ramp interaction was observed for reconstituted W' for the whole group ($P = .019$), corresponding to a smaller difference between the reconstitution ramps in the second

trial. However, no such effect was evident within either of the 2 subsets, and no other significant interactions or main effects were found for the measures of $\dot{V}O_2$ peak or BLA for the group or subsets ($P > .05$). Mean values of $\dot{V}O_2$ peak and BLA at the end of the reconstitution ramp phases, respectively, were 50.9 (8.0) mL·kg⁻¹·min⁻¹, 16.6 (3.0) mM·L⁻¹ (group); 55.0 (7.3) mL·kg⁻¹·min⁻¹, 16.8 (3.0) mM·L⁻¹ (trained); and 47.4 (6.9) mL·kg⁻¹·min⁻¹, 16.4 (3.1) mM·L⁻¹ (untrained).

Accuracy of the W'_{bal} Model

The predicted values of remaining W' from the W'_{bal} model (Equations 2 and 3) were compared with those of recorded

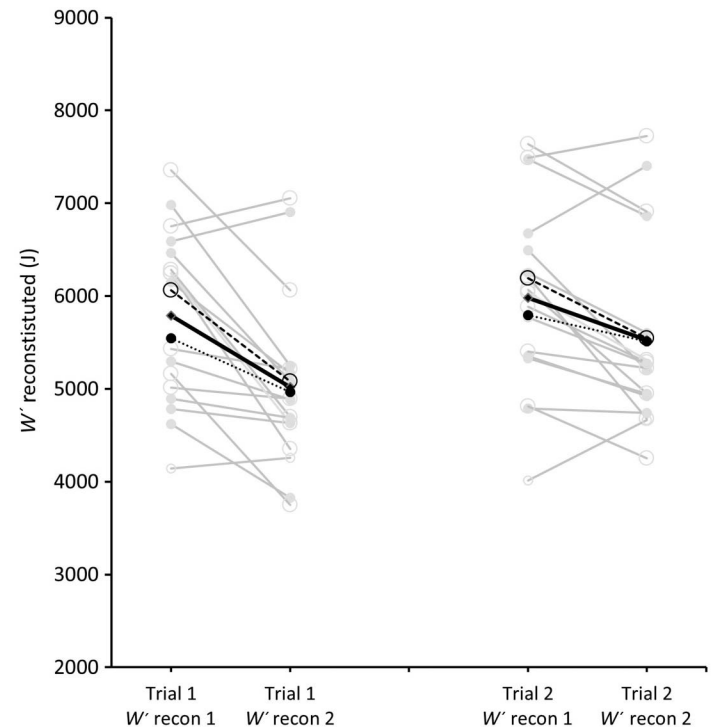


Figure 3 — Within-test differences in the amount of W' reconstituted following each 2-minute recovery period for each group. Mean differences in dark; individual changes shaded (trained cyclists, open circles; untrained cyclists, solid circles).

Table 1 Intratrial Differences in the Expenditure of W' Following the Reconstitution During the First and Second 2-Minute Recovery Periods

Group	Recovery 1: W' reconstituted, J, Mean (SD)	Recovery 2: W' reconstituted, J, Mean (SD)	Difference, J, Mean (SD)	ICC	TE, J	CV, % (90% CI)
Trial 1						
All	5789 (934)	5020 (919)	-769 (765)	.665	541	10.0 (7.8, 14.1)
Trained	6061 (807)	5081 (1040)	-980 (833)	.570	589	10.3 (7.5, 19.0)
Untrained	5547 (1017)	4965 (858)	-582 (692)	.772	489	9.3 (6.7, 15.9)
Trial 2						
All	5982 (1000)	5527 (1036)	-455 (606)	.860	429	7.4 (5.8, 10.6)
Trained	6193 (959)	5543 (1172)	-650 (537)	.856	380	6.3 (4.6, 11.6)
Untrained	5794 (1054)	5513 (972)	-282 (641)	.881	453	8.0 (5.8, 13.8)

Abbreviations: CI, confidence interval; CV, coefficient of variation; ICC, intraclass correlation coefficient; TE, typical error. Note: Results include a reduced sample size, where comparisons include the second reconstitution due to 3 cases of unsuccessful completion.

measurements (trial 2) at the local maxima W' reconstituted at the end of each recovery phase, and at subsequent full depletion at exhaustion (when $W'=0$). The predicted values significantly ($P < .01$) overestimated the measured values of remaining W' after the initial W' depletion and significantly underestimated the W' reconstituted by the end of the both recovery periods ($P < .01$). Although the model also overestimated the balance of W' at the end of the subsequent depletion phases by 605 (1170) J and 246 (2405) J, respectively, these converging differences were not significant. Figure 4 shows the recorded measurements of W' for a typical subject in comparison with the predicted values of W' using the W'_{bal} model.¹⁵

Discussion

The principal finding of the study was that the reconstitution of W' slowed following the repeated maximal intensity bouts

representing a fatiguing effect not accounted for in the current W'_{bal} models. Intratrial differences between successive ramps demonstrated a significant reduction in W' reconstitution during the second recovery period. This reduction was attenuated slightly in the second trial, although there were no accompanying physiological differences between any of the measurements of $\dot{V}O_{2peak}$ or BLA.

The complete depletion of W' results in the same intramuscular environment for each individual regardless of the preceding exercise^{5,26}; however, PCr reconstitution kinetics slow as intermittent exercise continues.²⁶ Although it was suggested that the slowing PCr reconstitution could affect W' reconstitution, this could not be confirmed due to the intermittent exercise protocol and the inability to measure intermediate values of W' .²⁶ By contrast, the present study clearly shows a reduction in W' reconstitution as exercise continued with repeated severe intensity bouts to the limit of tolerance and recovery periods, despite each

Table 2 Reliability Measures Between Trial 1 and Trial 2 for the Expenditure of W' Following the Reconstitution During the 2-Minute Recovery Periods

Group	Trial 1: W' reconstituted, J, Mean (SD)	Trial 2: W' reconstituted, J, Mean (SD)	Difference, J, Mean (SD)	ICC	TE, J	CV, % (90% CI)	Minimal detectable change, J	Detectable change as time difference @ 100 W above CP, s
First reconstitution								
All	6021 (1158)	6079 (1051)	58 (791)	.859	559	9.2 (7.3, 12.7)	732	7.3
Trained	6277 (994)	6409 (1106)	132 (426)	.958	301	4.7 (3.4, 8.1)	475	4.8
Untrained	5811 (1285)	5809 (970)	-2 (1018)	.768	720	12.4 (9.2, 19.7)	1068	10.7
Second reconstitution								
All	5020 (919)	5527 (1036)	507 (447)	.885	316	6.0 (4.7, 8.5)	425	4.3
Trained	5081 (1040)	5543 (1172)	461 (317)	.940	224	4.2 (3.0, 7.6)	368	3.7
Untrained	4965 (858)	5513 (972)	548 (555)	.827	392	7.5 (5.4, 12.8)	618	6.2

Abbreviations: CI, confidence interval; CV, coefficient of variation; ICC, intraclass correlation coefficient; TE, typical error. Note: Results include a reduced sample size, where comparisons include the second reconstitution due to 3 cases of unsuccessful completion. Detectable change is the change in the amount of W' reconstituted needed to be 84% confident that the test has detected a performance change between trials. It is also expressed as the change in the time to exhaustion if the athlete cycled at 100 W above critical power.

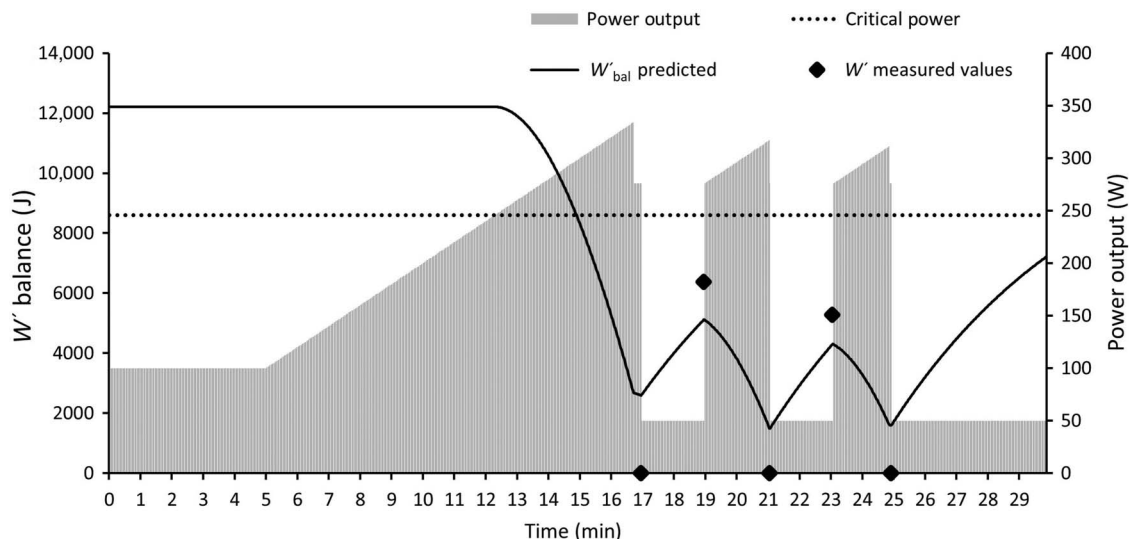


Figure 4 — Comparison of predicted W'_{bal} with the measured values of W' at limits of tolerance and at the end of the reconstitution periods for subject #12.

2-minute recovery period starting with complete W' depletion. Although W' and its reconstitution are not dependent on a single factor,^{15,26} this apparent fatiguing effect could be explained by the slowing of PCr reconstitution. Neither the W'_{bal} model¹⁵ nor the modification,¹⁷ incorporate any variables that could account for the fatiguing effect evidenced in the present study. Enhancements to a W'_{bal} model should therefore look to account for a fatiguing effect that slows W' reconstitution with repeated bouts of severe intensity exercise, to extend its validity beyond intermittent exercise protocols.

The RRT demonstrated good relative reliability for the measurement of W' reconstitution over both recovery periods with ICCs $> .85$ for the whole group. Further examination demonstrated excellent reliability for both reconstitution phases in the trained subset (ICCs $> .94$). These high values of relative reliability are comparable to those of current tests commonly used for assessing W' , such as the 3-minute all-out test²⁷ and the ramp-sprint test,²⁰ demonstrating the suitability of the RRT for discriminating between individuals, both trained and untrained. The measures of absolute reliability (TE and CV) showed greater susceptibility to training status. The trained subset yielded CVs of $<5\%$ in both W' reconstitution measurements, whereas the untrained subset demonstrated greater variability between trials with a CV of 12.4% for the first W' reconstitution, improving to 7.5% in the second. Therefore, intervention or longitudinal studies relying on measures of absolute reliability should look to use trained cyclists. Again, there are notable differences between the minimal detectable change for the trained and untrained subsets; hence, this protocol should only be used in this context for the assessment of trained individuals. The test sensitivity in the trained sample suggests a detectable change corresponding to an increased time to W' exhaustion of approximate 4 seconds when riding at 100 W above CP.

W' is a notoriously difficult parameter to measure, with TE and CV of measurement protocols based around the 3-minute all-out test typically in the region of 1.81 to 1.90 kJ and 12.0% to 39.4%, respectively.^{28,29} In the present study, the reconstitution of W' demonstrated greater interday reliability than that of W' itself (W' group: TE = 1421 J, CV = 13.1%) with the final reconstitution having the smallest TE and CV for the group and both subsets. This improved reliability corresponded to a reduction in the duration of time spent working above CP during each of the ramp phases, suggesting that the variation in CP is compounded over time in the variability of the W' measurements. Indeed, a mere ± 4 W interday variation in CP could account for all of the variation in W' reconstitution observed in the trained cyclists in the present study. W' reconstitution, and by extension W' itself, could be a much more reliable physiological quantity than otherwise thought.

The application of the W'_{bal} model¹⁵ was tested against measured values in the current study at each point of exhaustion (ie, when $W' = 0$ J) and at the end of each 2-minute recovery period. To allow for a single equation, the prediction model incorporates an element of W' reconstitution while work is being performed above CP, contradicting the findings that W' is only reconstituted when power output falls below CP.¹² Consequently, the prediction model overestimated W' at each point, where the limit of tolerance was encountered by up to ≈ 1.8 kJ, yet underestimated the W' reconstituted at the end of each recovery period by up to ≈ 2.0 kJ. There was also a wide degree of variation between subjects in the difference between W' reconstitution and their predicted values, further suggesting that the generalized equation for $\tau_{W'}$ requires individual adjustment. The differences between the

predicted and measured values converged as exercise progressed, as might be expected from a model derived from a continuous intermittent exercise protocol and fitted to a single point of exhaustion. Similar results have been observed when fitting the W'_{bal} model to a varied intensity intermittent exercise protocol,¹⁸ whereby actual exhaustion occurred before the prediction model. Although the prediction model has been shown to be valid for some protocols with a single point of exhaustion,^{16,30} it would appear not to fit the protocol of the present study. A derivation of the W'_{bal} model³¹ (Skiba2) separates the depletion and reconstitution phases of the W'_{bal} model during intermittent exercise, thus modeling W' reconstitution only when power output falls below CP. The Skiba2 model also allows $\tau_{W'}$ to be modified continuously throughout a session potentially making it more applicable to a wider range of protocols than the W'_{bal} model. However, like the W'_{bal} model, the Skiba2 model in its current form still derives $\tau_{W'}$ solely from the difference between an individual's CP and their power output during recovery. Although the Skiba2 model was validated against intermittent single-leg extension exercise, further validation of the model is required against sport-specific exercise.

Practical Applications

Despite the importance of W' reconstitution in athletic performance, this is the first study to examine the reconstitution of W' following repeated bouts of exercise that fully deplete W' . Hence, athletes and coaches should be aware that while useful, current W'_{bal} models do not account for any progressive slowing of W' reconstitution as exercise continues, which is a target for the improvement of present models of W' reconstitution.

The RRT provides a reliable test protocol with which to investigate W' reconstitution and practitioners can use utilize the minimal detectable change to determine real changes in athlete performance. However, future studies should ideally seek trained participants for longitudinal studies, where measures of absolute reliability are appropriate such as training intervention studies.

Conclusions

This study evidenced that the rate of W' reconstitution slowed in the second recovery period indicating that the reconstitution process is subject to fatigue, a factor not accounted for in the current W'_{bal} prediction model. The RRT protocol provided reliable measures of W' reconstitution, particularly in the trained population, providing a framework for further investigations.

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