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Conference Abstract

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The Effect of Rate of W′ Utilisation and Acute Fatigue on W′ Reconstitution

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1 Introduction

The critical power (CP) and *W′* concept has become more integrated within applied cycling performance science. Both parameters can be assessed in the laboratory and field and have become a useful tool for coaches and athletes (Leo et al. 2022; Moritani et al. 1981; Poole et al. 1988; Spragg, Leo, and Swart 2022). It is possible to mathematically model the depletion and recovery of *W′* during intermittent exercise (Skiba et al., 2012, Skiba and Clarke, 2021). Exercising at a work rate higher than CP causes a reduction in *W′* whereas when exercising at a work rate below CP there is an exponential reconstitution of *W′* (W'_{REC}) that is dependent on the recovery duration and a reconstitution time constant ($\tau_{W'}$). This is contingent on the difference between recovery power output and CP (D_{CP}) (Skiba et al., 2012; Skiba et al., 2013; Skiba et al., 2014).

There are generalised equations available for W'_{BAL} models that allow prediction of W'_{REC} (Bartram et al. 2018, 2022; Pugh et al. 2022; Skiba et al. 2012). However, for optimal use individualisation of W'_{BAL} is advised (Welburn et al. 2023) as W'_{REC} has been shown to correlate with athlete specific performance parameters such as VO_{2peak}, CP and LT_1. (Bartram et al. 2018, 2022; Caen et al. 2021; Pugh et al. 2022; Welburn et al. 2023). Recent work suggests that W'_{REC} is influenced by work rate (Caen et al. 2019) and slows with repeated exercise (Chorley et al. 2019). However, both factors are not currently accounted for in the W'_{BAL} model.

Durability (or fatigue resistance) is considered to be a key determinant of cycling performance (Muriel et al. 2022; Spragg et al. 2022). It appears that work rate has the greatest impact on durability (Leo et al. 2024; Spragg et al. 2024), therefore understanding the impact of work rate (i.e. the rate of *W′* utilisation) and acute fatigue on W'_{REC} could provide an important insight into the determinants of W'_{BAL} which would potentially allow improvements to the accuracy of the W'_{BAL} model. This study has two aims: assess the effect of (i) rate of W′ utilisation, and (ii) acute fatigue on W'_{REC} during intermittent exhaustive exercise.

2 Material and Methods

2.1 Participants

15 participants (11 males, 4 females; age: 22 [5] y, height; 1.76 [0.09] m, body mass; 71.13 [9.46] kg, $\dot{V}O_{2max}$; 60.90 [7.44] mL·min^{-1}·kg^{-1}, MAP; 381 [76] W, CP; 277 [57] W, W′ 24.89 [8.07] kJ, mean [SD]) were recruited for this laboratory-based investigation. Participants attended the laboratory on six separate occasions for the determination of $\dot{V}O_{2max}$, maximal aerobic power (MAP) and CP/W′. All tests were performed on an electronically braked ergometer (Excalibur Sport, Lode, Groningen, the Netherlands).

2.2 Methodology

All tests were performed on an electronically braked cycle ergometer (Excalibur Sport, Lode). Participants initially attended the laboratory on up to six separate occasions for the determination of LT_1, CP/ *W′*, $\dot{V}O_{2max}$, and MAP. During the first visit LT_1 (defined as baseline + 0.5 mMol·L^{-1}) was determined from submaximal step test (30 W every 4 minutes). After 30 minutes recovery $\dot{V}O_{2max}$ and MAP were determined from a maximal ramp protocol (25 W·min^{-1}). $\dot{V}O_{2max}$ and MAP were defined as the highest $\dot{V}O_2$ and power output for a 30-s and 60-s period during the test, respectively. Participants then performed a minimum of three constant load tests that were continued to exhaustion at a range of power outputs between 80-105% of MAP, the sequence of which were randomised. To enhance the accuracy of parameter estimates, when the standard error (SE) of CP was > 5% and W' > 10% an additional test was performed. The parameters of the power-duration relationship (CP and W') were calculated using the inverse linear model, the linear work-time model and the hyperbolic model. The equation associated with the lowest combined standard error for each participant was selected.

Participants subsequently performed two experimental trials, in a counter-balanced order. In both trials, participants completed intervals consisting of 40 sec on and 20 sec off. One trial was performed at a *W′* utilisation rate of 60 J·s^{-1} above CP [$WR_{60FRESH}$] and the other was performed at a *W′* utilisation rate of 120 J·s^{-1} above CP [$WR_{120FRESH}$]. These were based on unpublished work, in which we observed substantial variability in W'_{REC} during intermittent exercise where the work interval was performed at a work rate predicted to achieve exhaustion in 5 minutes (P_5). This resulted in range of work rates (i.e. rates of *W′* utilisation) between 40 to 180 J·s^{-1}, with clusters around 60 and 120 J·s^{-1}.

The number of repetitions were calculated to deplete ~75% of their W′. The recovery work rate between the interval efforts was at 100 W below CP (i.e. D_{CP} of 100 W). After the final interval participants then completed at an opened ended time to exhaustion (TTE) test at the same work rate. After a recovery period of ~60 min (involving cycling at 50% of LT_1), participants repeated the same interval protocol at the same W′ utilisation rate

[$WR_{60FATIGUED}$ & $WR_{120FATIGUED}$]. Total work done above CP ($W'_{totalTTE}$) was calculated for each open ended TTE. The W'_{BAL} model (Pugh et al. 2022) was used to calculate the depletion and reconstruction of W′ during both trials. An individual $\tau_{W'}$ was calculated for each exhaustive exercise under the assumption that at the point of task failure at the end of the TTE represents a W'_{BAL} of 0 kJ.

2.3 Statistical Analysis

A two-way repeated measures ANOVA was conducted assess differences in $W'_{totalTTE}$ with W′ utilisation rate (WR_{60} vs WR_{120}) and conditions (Fresh vs Fatigued) as the primary variables. Where significant main effects or an interaction was observed, Bonferroni-corrected post hoc t-tests were used to locate differences. Statistical significance was set at $P \leq 0.05$. Data are presented as mean ± standard deviation [SD] unless otherwise stated.

3 Results

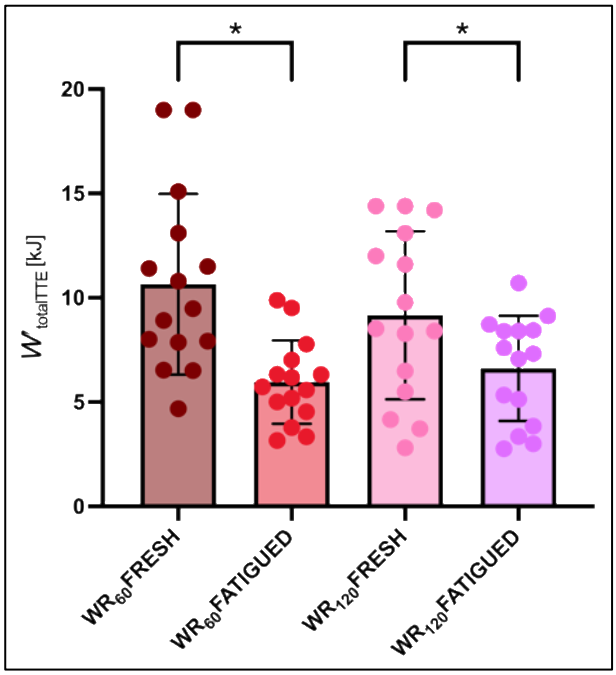

Figure1. $W'_{totalTTE}$ during the final open-ended TTE interval for the intermittent exercise trials [n=15].
*, significant difference ($P < 0.05$).

Figure 1 shows $W'_{totalTTE}$ during the final open-ended TTE interval for the intermittent exercise trials. There was a main effect for condition ($P < 0.001$, $\eta^2_p = 0.71$) and interaction (condition x W' utilisation rate; ($P = 0.047$, $\eta^2_p = 0.25$), but no main effect for W' utilisation rate ($P = 0.598$, $\eta^2_p = 0.021$). $W'_{totalTTE}$ was lower ($P < 0.001$, d = 1.39) in $WR_{60FATIGUED}$ compared to $WR_{60FRESH}$ and lower ($P = 0.03$, d = 0.76) in $WR_{120FATIGUED}$ compared to $WR_{120FRESH}$. The mean difference in the reduction in $W'_{totalTTE}$ between Fresh and Fatigue conditions was greater ($P = 0.046$, d = 0.71) in WR_{60} (-4.7 [0.8] kJ) compared to WR_{120} (-2.5 [0.7] kJ).

4 Discussion

These data suggest that acute fatigue reduces $W'_{totalTTE}$ during intermittent exhaustive exercise. The lower intensity (WR_{60}) also appears to have a greater effect on the reduction in total work done during the final TTE.

Although an individualised $\tau_{W'}$ was calculated for the fresh trials, it was not possible for the fatigued trials. This is because $W'_{totalTTE}$ was reduced, suggesting that W' does not reconstitute completely up to 1 hour after exhaustive intermittent exercise. This resulted physiological implausible $\tau_{W'}$ values when solving the W'_{BAL} model for 0 kJ at task failure in the fatigued trials (e.g. fresh $\tau_{W'}$: 425 sec vs fatigued $\tau_{W'}$: 4512 sec).

5 Practical Applications

These observations have important implications for future refinement of the W'_{BAL} model, particularly during fatiguing exercise where durability becomes critical. Moreover, these data suggest the potential requirement to include a 3rd parameter into the W'_{BAL} model (i.e., W'_{total}) to account for the deterioration in W'.

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References

Bartram, Jason C., Dominic Thewlis, David T. Martin, and Kevin I. Norton. 2018. "Accuracy of W′ Recovery Kinetics in High Performance Cyclists-Modeling Intermittent Work Capacity." International Journal of Sports Physiology and Performance 13(6):724–29. doi: 10.1123/IJSPP.2017-0034

Bartram, Jason C., Dominic Thewlis, David T. Martin, and Kevin I. Norton. 2022. "Validating an Adjustment to the Intermittent Critical Power Model for Elite Cyclists—Modeling W′ Balance During World Cup Team Pursuit Performances." International Journal of Sports Physiology and Performance 17(2):170–75. doi: 10.1123/ijspp.2020-0444

Caen, Kevin, Gil Bourgois, Charles Dauwe, Laura Blancquaert, Kobe Vermeire, Eline Lievens, J. O. Van Dorpe, Wim Derave, Jan G. Bourgois, Lauren Pringels, and Jan Boone. 2021. "W ′ Recovery Kinetics after Exhaustion: A Two-Phase Exponential Process Influenced by Aerobic Fitness." Medicine and Science in Sports and Exercise 53(9):1911–21. doi: 10.1249/MSS.0000000000002673

Caen, Kevin, Jan G. Bourgois, Gil Bourgois, Thibaux Van Der Stede, Kobe Vermeire, and Jan Boone. 2019. "The Reconstitution of W ′ Depends on Both Work and Recovery Characteristics." Medicine and Science in Sports and Exercise 51(8):1745–51. doi: 10.1249/MSS.0000000000001968

Chorley, Alan, Richard P. Bott, Simon Marwood, and Kevin L. Lamb. 2019. "Slowing the Reconstitution of W′ in Recovery with Repeated Bouts of Maximal Exercise." International Journal of Sports Physiology and Performance 14(2):149–55. doi: 10.1123/ijspp.2018-0256

Leo, Peter, Manuel Mateo-March, Andrea Giorgi, Xabier Muriel, Alejandro Javaloyes, David Barranco-Gil, Jesús G. Pallarés, Alejandro Lucia, Iñigo Mujika, and Pedro L. Valenzuela. 2024. "The Influence of High-Intensity Work on the Record Power Profile of Under-23, Pro Team, and World Tour Cyclists." International Journal of Sports Physiology and Performance 1–5. doi: 10.1123/ijspp.2023-0451

Leo, Peter, James Spragg, Tim Podlogar, Justin S. Lawley, and Iñigo Mujika. 2022. "Power Profiling and the Power-Duration Relationship in Cycling: A Narrative Review." European Journal of Applied Physiology 122(2):301–16. doi: 10.1007/s00421-021-04833-y

Moritani, Toshio, Akira Nac Ata, Hekrhrt A. Devries, and Masuo Muro. 1981. "Critical Power as a Measure of Physical Work Capacity and Anaerobic Threshold." Ergonomics 24(5):339–50. doi: 10.1080/00140138108924856

Muriel, Xabier, Manuel Mateo-March, Pedro L. Valenzuela, Mikel Zabala, Alejandro Lucia, Jesús G. Pallares, and David Barranco-Gil. 2022. "Durability and Repeatability of Professional Cyclists during a Grand Tour." European Journal of Sport Science 22(12):1797–1804. doi: 10.1080/17461391.2021.1987528

Poole, David C., Susan A. Ward, Gerald W. Gardner, and Brian J. Whipp. 1988. "Metabolic and Respiratory Profile of the Upper Limit for Prolonged Exercise in Man." Ergonomics 31(9):1265–79. doi: 10.1080/00140138808966766

Pugh, Charles F., C. Martyn Beaven, Richard A. Ferguson, Matthew W. Driller, Craig D. Palmer, and Carl D. Paton. 2022. "Critical Power, Work Capacity, and Recovery Characteristics of Team-Pursuit Cyclists." International Journal of Sports Physiology and Performance 17(11):1606–13. doi: 10.1123/ijspp.2021-0478

Skiba, Philip Friere, Weerapong Chidnok, Anni Vanhatalo, and Andrew M. Jones. 2012. "Modeling the Expenditure and Reconstitution of Work Capacity above Critical Power." Medicine and Science in Sports and Exercise 44(8):1526–32. doi: 10.1249/MSS.0b013e3182517a80

Spragg, James, Peter Leo, Andrea Giorgi, Borja Martinez Gonzalez, and Jeroen Swart. 2024. "The Intensity Rather than the Quantity of Prior Work the Subsequent Downward Shift in the Power Relationship in Professional Cyclists." European Journal of Sport Science. doi: 10.1002/ejsc.12077

Spragg, James, Peter Leo, and Jeroen Swart. 2022. "The Relationship between Training Characteristics and Durability in Professional Cyclists across a Competitive Season." European Journal of Sport Science 23(4):489–98. doi: 10.1080/17461391.2022.2049886

Welburn, J. Alex, J. Stephen Bailey, F. Charles Pugh, and A. Richard Ferguson. 2023. "Physiological Characteristics Associated with W′ and W′bal Used During Intermittent Exercise Task to Failure." Journal of Cycling Science 2(12):724–29. doi: 10.1123/IJSPP.2017-0034