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Conference Abstract

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Beyond a Single Time Constant: Evaluating the Cross- Protocol Transferability of $\tau_{W'}$ in Cyclists

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Abstract

The quantification of W' reconstitution kinetics ($\tau_{W'}$) is central to W' balance (W'_{BAL}) modelling, yet whether an individualized $\tau_{W'}$ can be transferred across different intermittent exercise structures remains unclear. This study examined the cross-protocol transferability of a reference $\tau W'$ derived from a 60 s - 30 s high intensity interval training (HIIT) protocol. Six trained male cyclists completed baseline testing and four exhaustive HIIT protocols: 60 s–30 s HIIT, short HIIT (S-HIIT), long HIIT (L-HIIT), and decreasing power output HIIT (DPO-HIIT). The $\tau_{W'}$ required to yield W'_{BAL} = 0 kJ at task failure during 60 s - 30 s HIIT was defined as Ref-$\tau_{W'}$ and subsequently applied to the other protocols. End-exercise W'_{BAL} differed across protocols ($p<0.001$). Ref-$\tau_{W'}$ produced the smallest bias and root mean square error during S-HIIT (3.3 and 4.3 kJ), whereas larger errors were observed during L-HIIT (6.5 and 7.0 kJ) and DPO-HIIT (6.8 and 7.4 kJ). Protocol-specific $\tau_{W'}$ values also differed ($p<0.001$), with no differences between 60 s - 30 s and S-HIIT or between L-HIIT and DPO-HIIT. These findings indicate that $\tau_{W'}$ is protocol dependent and that a single individualised value may not accurately transfer across distinct HIIT structures. Transferability therefore appears greater between protocols with similar work and recovery characteristics.

Keywords

critical power, W' balance modelling, recovery kinetics, high-intensity interval training, time constant

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1 Introduction

The quantification of W' recovery kinetics ($\tau_{W'}$) remains a critical challenge in W' balance (W'_{BAL}) modelling (Welburn et al., 2026; Caen et al., 2021). While early models proposed generalised $\tau_{W'}$ values, recent consensus emphasises the necessity of individualisation to enhance predictive accuracy (Pugh et al., 2025; Bartram et al., 2017). However, a critical unresolved question is whether a single individualised $\tau_{W'}$ value functions as an intrinsic, static physiological constant for a given athlete, or if it is dynamically modulated by the specific characteristics of the exercise protocol (e.g., work-rest ratio, bout duration). From a practical standpoint, resolving this is crucial: while generalised equations are already known to produce large predictive errors for individual athletes, even an individualised $\tau_{W'}$ will fail to optimise real-time W'_{BAL} monitoring and pacing strategies if it cannot be reliably transferred across varying intermittent exercise modalities. That is, it remains unclear whether $\tau_{W'}$ is protocol dependent or transferable across disparate exercise modalities. Therefore, this study aimed to test the robustness and cross-protocol transferability of the individualised $\tau_{W'}$. We aim to determine if an individualised $\tau_{W'}$ derived from a standard intermittent protocol (60 s -30 s HIIT) can accurately predict task failure across disparate exercise modalities, including short HIIT (S-HIIT), long HIIT (L-HIIT) and decreasing power output HIIT (DPO-HIIT).

2 Material and Methods

2.1 Participants

Level 3-4 male cyclists (De Pauw et al., 2013) (n= 6), age; 27.6 ± 6.8 years, body mass; 70.7 ± 6.7 kg, CP; 284 ± 36 W (SEE: 1.9 ± 0.9 W), W'; 19.1 ± 2.1 kJ (SEE: 1.3 ± 0.5 kJ) and $\dot{V}O_{2max}$; 59.1 ± 4.7 mL·kg·min^{-1} participated in this study.

The study was conducted in accordance with the Declaration of Helsinki and received institutional ethics committee approval (Decision No: 24-11.1T/41; Date: 28 November 2024).

2.2 Design

A randomised repeated-measures design was used in this study. Participants completed 10 – 13 separate laboratory visits for the determination of gas exchange threshold (GET), peak work rate (WR_{peak}), maximal oxygen uptake ($\dot{V}O_{2max}$), critical power (CP), W', highest intensity permitting $\dot{V}O_{2max}$ attainment (I_{HIGH}) and four distinct HIIT modalities: 60 s - 30 s HIIT, S-HIIT, L-HIIT, DPO-HIIT. All tests were performed on an electronically braked ergometer (Lode Excalibur Sport).

2.3 Methodology

Participants first performed a 60-s - 30-s HIIT protocol Work: 94% WR_{peak}; Recovery (Rec): 50 W) to volitional exhaustion. The specific $\tau_{W'}$ value required to yield a W'_{BAL} of exactly 0 kJ at task failure was retrospectively calculated for each participant and designated as the reference time constant (Ref-$\tau_{W'}$). This Ref-$\tau_{W'}$ was subsequently applied to three distinct HIIT protocols performed to exhaustion: S-HIIT (15 × 44 s/44 s; Work: ~110% of WR_{peak}; Rec ~10% of WR_{peak}), L-HIIT (4 × 3 min/3 min; Work: ~89% of WR_{peak}; Rec ~25% of WR_{peak}), and DPO-HIIT (6 × 115 s/115 s; Work: starting at IHIGH and decreased by 4 equal steps to the CP + 10%; Rec ~25% of WR_{peak}).

2.4 Statistical Analysis

Model performance at exhaustion was assessed using Bias (mean of raw errors), and Root Mean Square Error (RMSE) to quantify the overall magnitude of the prediction error. Variables were analysed using one-way repeated-measures ANOVA with Bonferroni

post-hoc comparisons. Significance was accepted at $p<0.05$. Statistical analyses were performed using JASP (Version 0.98.1; JASP Team, 2026).

Partial eta squared (ηp^2) was reported as a measure of effect size. Effect sizes were interpreted as small ($\eta p^2 \geq 0.01$), medium ($\eta p^2 \geq 0.06$), and large ($\eta p^2 \geq 0.14$).

3 Results

End-exercise W'_{BAL} estimates at task failure differed significantly when Ref-$\tau_{W'}$ was applied across the distinct HIIT protocols ($F=27.70$; $p<0.001$; $\eta p^2=0.847$). The mean Ref-$\tau_{W'}$ values derived from the 60 s - 30 s HIIT protocol was 83±8 s. When this Ref-$\tau_{W'}$ value was applied, the lowest systematic bias and RMSE were observed in the S-HIIT protocol (Bias: 3.3 kJ; RMSE: 4.3 kJ). Conversely, application to the L-HIIT and DPO-HIIT protocols resulted in substantially larger prediction errors (Bias: 6.5 kJ and 7.0 kJ; RMSE: 6.8 kJ and 7.4 kJ, respectively) (Figure 1). Actual $\tau_{W'}$ values required to reach 0 J at task failure were different across protocols ($F=26.24$; $p<0.001$; $\eta p^2=0.840$) (Table 1). Post-hoc comparisons revealed no differences in the required $\tau_{W'}$ between the 60 s - 30 s and S-HIIT protocols ($p=0.095$) nor between the L-HIIT and DPO-HIIT protocols ($p=0.269$).

Table 1. Cross-Protocol W'_{BAL} Estimates and Protocol-Specific $\tau_{W'}$ Values.

HIT Protocol	ProtocolSpecific $\tau_{W'}$ (s)	Post-hoc comparisons
60 s - 30 s	83.8	a
S - HIIT	104.1	a
L - HIIT	216.8	b
DPO - HIIT	196.8	b

Values sharing the same letter are not significantly different; values with different letters indicate significant pairwise differences (Bonferroni-adjusted, $p < 0.05$)

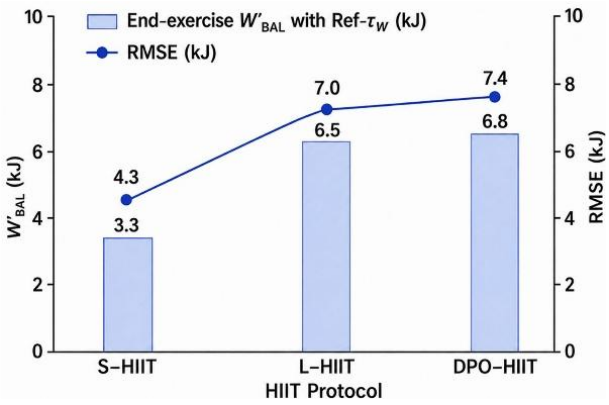

Figure 1. End-exercise W'_{BAL} and RMSE values following application of Ref-$\tau_{W'}$ across HIIT protocols.

4 Discussion

Preliminary findings suggest that speed of an athlete's recovery drastically slows down during long-interval workouts compared to short-interval workouts. Translated to bioenergetic modelling, these findings suggest that $\tau_{W'}$ is not a constant, universally transferable physiological trait, but rather a highly protocol-dependent variable. The inability of the Ref-$\tau_{W'}$ to accurately predict task failure in L-HIIT and DPO-HIIT underscores the limitations of using a single time constant across divergent HIIT structures. The required $\tau_{W'}$ values naturally grouped into two distinct clusters: short-interval (60 s - 30 s and S-HIIT) and long-interval (L-HIIT and DPO-HIIT) modalities. This clustering aligns seamlessly with recent bi-exponential models of W′ reconstitution (Caen et al., 2021; Chorley et al., 2022). Specifically, short-interval modalities are thought to rely predominantly on the fast phase of recovery, which is closely associated with rapid phosphocreatine (PCr) resynthesis. In contrast, the prolonged work bouts in long-interval modalities likely induce greater metabolic perturbation, presumably making the overall reconstitution highly dependent on the slow phase (associated with intracellular metabolite clearance), thereby substantially lengthening the required $\tau_{W'}$.

5 Practical Applications

From an applied perspective, coaches and practitioners should recognise that real-time W'_{BAL} monitoring and pacing strategies cannot rely on a single static recovery metric based solely on athlete characteristics. To optimise performance and prevent premature exhaustion, training prescriptions and algorithms must explicitly account for protocol characteristics, particularly the inherently slower recovery dynamics that occur during longer interval structures.

6 Conclusions

Consequently, contemporary W'_{BAL} models must evolve beyond treating CP, W', and $\tau_{W'}$ as unchanging constants and assumptions and incorporate dynamic scaling factors that account for the accumulated work duration and the progressive nature of exercise-induced metabolic stress.

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Conflicts of Interest: The authors declare no conflict of interest.

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