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Original research

Monitoring athletic training status using the maximal rate of heart rate increase

Clint R. Bellenger[a,*], Rebecca L. Thomson[a], Peter R.C. Howe[b], Laura Karavirta[c], Jonathan D. Buckley[a]

[a] *Alliance for Research in Exercise, Nutrition and Activity (ARENA), Sansom Institute for Health Research, University of South Australia, Australia*
[b] *Clinical Nutrition Research Centre, University of Newcastle, Australia*
[c] *Polar Electro Oy, Finland*

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ABSTRACT

Objectives: Reductions in maximal rate of heart rate increase (rHRI) correlate with performance reductions when training load is increased. This study evaluated whether rHRI tracked performance changes across a range of training states.
Design: Prospective intervention.
Methods: rHRI was assessed during five min of cycling at 100 W (rHRI_{cyc}) and running at 8 km/h (rHRI_{run}) in 13 male triathletes following two weeks of light-training (LT), two weeks of heavy-training (HT) and a two-day recovery period (RP). A five min cycling time-trial assessed performance and peak oxygen consumption ($\dot{V}O_{2\text{peak}}$).
Results: Performance likely decreased following HT (Effect size ± 90% confidence interval = -0.18 ± 0.09), then very likely increased following RP (0.32 ± 0.14). rHRI_{cyc} very likely decreased (-0.48 ± 0.24), and rHRI_{run} possibly decreased (-0.33 ± 0.48), following HT. Changes in both measures were unclear following RP. Steady-state HR was almost certainly lower (-0.81 ± 0.31) during rHRI_{cyc} than rHRI_{run}. A large correlation was found between reductions in performance and rHRI_{run} ($r \pm 90\%$; CI = 0.65 ± 0.34) from LT to HT, but was unclear for rHRI_{cyc}. Trivial within-subject correlations were found between rHRI and performance, but the strength of relationship between rHRI_{run} and performance was largely associated with $\dot{V}O_{2\text{peak}}$ following LT ($r = -0.58 \pm 0.38$).
Conclusions: Performance reductions were most sensitively tracked by rHRI_{run} following HT. This may be due to rHRI_{run} being assessed at a higher intensity than rHRI_{cyc}, inferred from a higher steady-state HR and supported by a stronger within-subject relationship between rHRI_{run} and performance in individuals with a lower $\dot{V}O_{2\text{peak}}$, in whom the same exercise intensity would represent a greater physiological stress. rHRI assessed at relatively high exercise intensities may better track performance changes.

1. Introduction

Well-trained athletes require high training stress to achieve sufficient stimulus for the physiological adaptations that allow for improvements in athletic performance.[1] High training stress in association with inadequate recovery periods can lead to the accumulation of training-induced fatigue that may result in functional overreaching (FO), non-functional overreaching (NFO) or overtraining (OT).[2] Unfortunately, a subtle difference exists between training an athlete to the point of FO, considered to be a desired state of training since it produces short-term performance decrements followed by supercompensatory performance improvements, and pushing them into NFO or OT, considered undesirable states since they result in long-term performance decrements without supercompensatory performance improvements.[2]

A simple and accurate marker of training status would be a valuable tool, allowing for recognition of training-induced fatigue, or the level of recovery/adaptation achieved, and facilitating adjustments in training load to optimise athletic performance at important time-points.[3–5] Presently, no such marker exists.[2]

Recent research has investigated the potential for changes in autonomic nervous system (ANS) function to infer training status.[3,6,7] Since the ANS interacts with many physiological systems,[8] examining its responsiveness to changes in training load

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[*] Corresponding author.
E-mail address: clint.bellenger@mymail.unisa.edu.au (C.R. Bellenger).

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may indicate the ability to adapt to an exercise stimulus.[4] Specifically, research has focussed on inferring training status through autonomic heart rate (HR) regulation as it provides a simple, non-invasive measure of ANS function.[9] Commonly used measures of autonomic HR regulation include resting HR, submaximal HR, maximum HR, HR variability (HRV) and HR Recovery (HRR).[4,10]

Assessing HR kinetics at the onset of exercise as a marker of autonomic HR regulation has not been well investigated. Since these kinetics are controlled by the parasympathetic and sympathetic divisions of the ANS,[11,12] and the balance of parasympathetic and sympathetic activity is altered following changes in training load,[13–15] training-induced changes in HR kinetics at the onset of exercise may be capable of inferring training status. Cross-sectional researched showed that the half-time for the increase in HR at the onset of exercise (i.e. the time taken for HR to reach one half of the difference between steady-state HR and pre-exercise HR) was shorter in athletes compared with untrained individuals, and was correlated with maximal oxygen consumption.[16] More recently, maximal rate of HR increase (rHRI) during the rest-to-exercise transition at the onset of submaximal cycling exercise was slowed in acutely fatigued[17] and overreached[18] cyclists, and this rHRI slowing was correlated with fatigue-induced reductions in exercise performance.

While these results suggest rHRI may be able to track changes in training status, it has presently been shown to track fatigue-induced reductions in performance,[18] and it is thus unknown whether rHRI can track performance across a range of training states, including following recovery and/or adaptations leading to performance improvement. Consequently, this study aimed to evaluate relationships between rHRI and performance following fatigue and recovery. Additionally, rHRI has been evaluated in cycle ergometry only, which limits its applicability in sports involving running. Therefore, this study also aimed to establish if changes in rHRI assessed during running were also correlated with changes in performance following changes in training load.

2. Methods

Seventeen male triathletes were recruited from clubs in Adelaide, South Australia. The University of South Australia's Human Research Ethics Committee granted approval and volunteers provided written informed consent prior to participating.

Pre-study familiarisation allowed participants to be habituated with the requirements of the study and testing procedures, and determine their peak HR during a maximal 5 min cycling time-trial (5TT), which was subsequently used to prescribe training intensities. Participants then undertook the training intervention and were tested after two weeks of light training (LT; baseline), two weeks of heavy training (HT; overreached state) and a two day recovery period (RP; recovered state). Testing occurred the day after completion of each period's final training session, and assessed body mass, rHRI during submaximal cycling (rHRI_{cyc}) and running (rHRI_{run}) tests, peak oxygen consumption ($\dot{V}O_{2\text{peak}}$) and exercise performance.

rHRI_{cyc} and rHRI_{run} were determined during the rest-exercise transition in response to 5 min of exercise at a power output of 100 W, and a velocity of 8 km/h, respectively. An intensity of 100 W was chosen in an effort to minimally exacerbate the presence of fatigue, and has previously tracked fatigue-induced reductions in exercise performance.[17,18] Similarly, a running velocity of 8 km/h was chosen as an intensity unlikely to exacerbate fatigue that could be performed at the start of any warm-up. Exercise onset occurred at random to avoid an anticipatory rise in HR[19] and the order in which these assessments occurred was randomised at baseline, and held constant at subsequent visits. Pre-exercise HR (mean HR during the 30 s prior to commencing exercise), and steady-state HR (mean HR during the final 60 s of exercise) were also calculated. Change in exercise HR was the difference between these variables.

rHRI testing was followed by a 5TT, with total work done expressed in absolute (kJ) and relative to body mass (kJ/kg) terms recorded as the measure of cycling performance. Indirect calorimetry sampled at 10 s intervals assessed $\dot{V}O_{2\text{peak}}$ during 5TT (TrueOne gas analysis system, ParvoMedics, Utah, USA), classified as the mean of the two highest consecutive readings.

Exercise testing was performed on an electronically-braked cycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, Netherlands), and a motorised treadmill (Model 645, Quinton Instrument Co., Washington, USA). HR was recorded at 1 s intervals during testing visits, and 15 s intervals during training sessions using a personal HR monitor (RS800CX, Polar Electro Oy, Kempele, Finland). Body mass was measured to the nearest 0.1 kg using an electronic digital scale (Tanita Ultimate Scale, Tanita, Tokyo, Japan).

rHRI was the first derivative maximum of a 4-component sigmoidal curve fit to the HR data for 30 s preceding exercise and during the subsequent five min of steady-state exercise, as previously described.[18] Test–retest reliability for rHRI_{cyc} and 5TT was determined as 6.3% (%CV) and 1.2% respectively.[18] Test–retest reliability for rHRI_{run} was 6.0% (%CV) as determined from six of the present study's participants.

Training was conducted on each participant's bicycle attached to a stationary trainer. LT required 32 min of cycling per day, with 22% of the training performed above 88% of peak HR, such that it would allow participants to be rested and recovered from any pre-study training prior to completing HT. HT required 124 min of cycling per day, with 34% of the training performed above 88% of peak HR, and was intended to induce substantial fatigue from which participants would not recover by testing on the day following the final training session. Training was ceased during the two day recovery period. Training program details have been provided previously.[18] Weekly training load during each period was quantified using Training Impulse (TRIMP) (duration in minutes multiplied by % of peak HR).[20]

Magnitude-based inference statistics[21] were preferred since they indicate the magnitude of an effect, which may be more relevant to practical detection of FOR, NFO or OT than statistically significant effects. Data are presented as mean ± standard deviation, and as percentage change and effect size (ES) with 90% confidence intervals. Data were log transformed before analysis to reduce bias arising from non-uniformity of error,[21] but presented in natural form for ease of interpretation. Changes in variables after LT, HT and RP were analysed using a modified statistical spreadsheet,[22] which calculates ES between time-points of interest using pooled standard deviation.[23] Threshold values for ES statistics were ≤ 0.2 (trivial), >0.2 (small), >0.6 (moderate), >1.2 (large), >2.0 (very large), and >4.0 (extremely large).[21] Probabilities to establish whether the true (unknown) differences were lower, similar, or higher than the smallest worthwhile change (calculated from each variable's CV) were also determined. Chances of higher or lower differences were evaluated qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99%, very likely; and >99%, almost certain. If the chance of higher or lower differences was >5%, the true difference was unclear. Within-subject correlations between rHRI and performance across the three testing time-points were evaluated using univariate analysis of covariance as described by Bland and Altman.[24] Relationships between changes in variables pre- and post-HT were assessed using Pearson's correlation to compare the present study's findings to those of Nelson et al.[18] Relationships between variables were also performed using Pearson's correlation and presented as *r* value with 90% confidence intervals, where *r* values were evaluated as follows: 0.0–0.1,