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Original research

Improved heart rate recovery despite reduced exercise performance following heavy training: A within-subject analysis

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ABSTRACT

Objectives: The recovery of heart rate (HRR) after exercise is a potential indicator of fitness which has been shown to respond to changes in training. This study investigated the within-individual association between HRR and exercise performance following three different training loads.
Design: 11 male cyclists/triathletes were tested after two weeks of light training, two weeks of heavy training and two days of rest.
Methods: Exercise performance was measured using a 5-min maximal cycling time-trial. HRR was measured over 60 s during supine recovery.
Results: Exercise performance decreased 2.2 ± 2.5% following heavy training compared with post-light training ($p = 0.01$), and then increased 4.0 ± 4.2% following rest ($p = 0.004$). Most HRR indices indicated a more rapid recovery of heart rate (HR) following heavy training, and reverted to post light training levels following two days of rest. HRR indices did not differ between post-light training and after the rest period ($p > 0.6$). There were inverse within-subject relationships between indices of HRR and performance ($r = -0.6$, $p \leq 0.004$). Peak HR decreased 3.2 ± 5.1 bpm following heavy training ($p = 0.06$) and significantly increased 4.9 ± 4.3 bpm following recovery ($p = 0.004$). There was a moderate within-subject relationship between peak HR and exercise performance ($r = 0.7$, $p \leq 0.001$). Controlling for peak HR reduced the relationships between HRR and performance ($r = -0.4$–0.5, $p < 0.05$).
Conclusions: This study demonstrated that HRR tracks short-term changes in exercise performance within-individuals, such that increases in HRR are associated with poorer exercise performance following heavy training. Peak HR can be compromised under conditions of fatigue, and needs to be taken into account in HRR analyses.

1. Introduction

Exercise training promotes adaptations that contribute to performance improvements, but to achieve optimal performance adequate recovery is necessary between training sessions. If recovery is inadequate, fatigue can impair exercise performance acutely or over days or weeks (i.e. overreaching), and if sustained over longer time periods overtraining may develop.[1] One of the most widely used methods for assessing how an athlete is recovering involves monitoring changes in cardiac autonomic regulation through the measurement of HR.

Heart rate recovery (HRR) is the rate at which heart rate (HR) decreases following the cessation of exercise. It is a non-invasive marker of autonomic control of the heart and is the result of a coordinated interaction between sympathetic withdrawal and parasympathetic re-activation.[2,3] Cross sectional studies have shown faster HRR in well-trained and aerobically fit participants compared with untrained participants.[4–7] Similarly, longitudinal studies and a recent review[8] have shown faster HRR following aerobic training programs aimed at improving or maintaining performance in previously untrained[9,10] and trained participants.[11–13] We recently found an increase in HRR following a training program that fatigued participants and led to reductions in performance.[14]

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This along with studies reporting other measures of autonomic function suggest there is a lack of consistency in how markers respond to different training loads,[15–17] and we hypothesize that HRR may increase following both fatigue and adaptation conditions.

Several studies have also shown relationships between improvements in exercise performance and changes in HRR,[11,12,18] suggesting that HRR could be used to monitor training-induced changes in performance. Low to moderate correlations have been observed in previous studies with young team sports athletes.[11,18] A strong positive correlation was found by Lamberts et al.[12] between the improvement in time taken to complete a 40 km time-trial and increases in HRR (greater decrease in HR) following four weeks of high intensity training in well-trained cyclists ($r = 0.97$, $p < 0.0001$). While these studies have shown relationships between changes in HRR and exercise performance, the strength and direction of the relationships are quite variable. Large between-individual variation in autonomic nervous system regulation is observed in response to the same training load and the associations between performance and autonomic nervous system activity seem highly individual. These previous studies have also only assessed participants before and after a single training period aimed at improving performance and there have not been studies that have assessed participants after different training periods, especially those designed to overreach participants. Therefore, the primary purpose of this study was to investigate the use of HRR to monitor changes in performance following a period of overreaching and recovery. The study aimed to investigate the within-individual changes between HRR and exercise performance following three training periods of different intensity and volume so the participants were assessed in three different training states: normal (rested) state, an overreached state and a recovered state.

2. Methods

Seventeen well-trained male cyclists or triathletes were recruited from local sporting clubs in Adelaide, South Australia. Participants were self-reported as healthy and injury-free. The study was approved by the University of South Australia's Human Research Ethics Committee and all participants provided informed written consent before participating.

Participants were familiarized with study requirements and equipment during a habituation session. Participants presented for testing at 2 h fasted and 24 h free from caffeine and alcohol. Participants were tested one day after three different training programs: 2 week of light training (normal state), 2 week of heavy training (overreached state) and 2 d of rest (recovered state) (Fig. 1). Testing comprised of a 5 min maximal cycling time-trial followed immediately by assessment of HRR whilst supine.

Both training programs consisted of 14 daily training sessions, and five HR based training zones presented as percentages of peak HR (HR_{peak}) were used to prescribe the training intensity. Participants undertook training on their own bicycles attached to wind-trainers. The overall prescribed training load increased 300% between light and heavy training; the volume of training increased dramatically from 32 min per day to 124 min per day, and the percentage of time spent above high intensity (88% HR_{peak}) increased from 22% to 34%. During the two days of rest participants did not undertake any exercise.

All exercise testing was performed on an electronically braked cycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, The Netherlands). HR was recorded at 1 s intervals throughout all exercise testing and at 15 s intervals during all training sessions using a personal heart rate 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 Corp, Tokyo, Japan).

Exercise performance was measured during a 5 min maximal cycling time-trial and was classified as both the absolute amount of work completed during the time-trial (kJ) and the amount of work completed relative to body weight (kJ/kg body weight). In our laboratory the coefficient of variation for test-retest reliability for this test is 1.2%.[14] HR_{peak} was the maximum HR value recorded during the time-trial and HR_{end} was the mean HR value over the last 5 s of the time-trial. Oxygen consumption was assessed by indirect calorimetry (TrueOne gas analysis system, ParvoMedics, Utah, USA) calibrated to manufacturer's specifications during the time-trial after light training. Peak oxygen consumption (VO_{2peak}) was classified as the mean of the two highest consecutive readings and was expressed relative to body mass (ml/kg/min).

Several indices of HRR were determined. $\Delta 60$ was the absolute difference between HR_{end} and mean HR recorded over 5 s after 60 s of supine recovery (HR_{60}).[19] $\Delta 60_{1mEnd}$ was the difference between the mean HR value over the last 1 min of the time-trial and the mean HR recorded over a 5 s period that occurred 60 s after the test.[20] $\Delta 60_{peak}$ was the difference between the HR_{peak} from the time-trial and the mean HR over a 5 s period that occurred 60 s after the test. T30 (in s) was the negative reciprocal of the slope of the regression line between the natural logarithm of the HR and time from the first 30 s after exercise.[6] $T30_{min}$ (in s) was the smallest time constant (−1/steepest slope) using the negative reciprocal of the slope of the regression line between the natural logarithm of the HR and using all possible data sets of 30 s duration within the first min after exercise.[20]

All data were analyzed using SPSS Statistics 21 (IBM Corporation, Armonk, NY) with significance of $p < 0.05$. Data are presented as mean ± standard deviation. Means of outcome measures after light training, heavy training and the rest period were compared using one-way repeated measures analysis of variance. Within-subject correlations between HRR and exercise performance across the three testing time-points were evaluated using univariate analysis of covariance.[21] Pearson's correlations were used to assess relationships between changes in variables across two testing periods. For some analyses only relative performance has been reported as results were similar for both absolute and relative performance.

3. Results

Four participants did not complete the study due to injury or illness, or were unable to tolerate the heavy training. Eleven of the 13 participants who completed the required testing and training had complete HRR data due to technical issues with HR data collection (Age, 32.5 ± 10.1 y; body mass, 77.5 ± 9.7 kg). Compliance with achieving the prescribed training duration and intensity zones was 97.2 ± 8.3% and 86.5 ± 24.3%, respectively for light training and 92.4 ± 8.7% and 68.5 ± 37.8%, respectively for heavy training.

Relative exercise performance on the time-trial decreased −2.2 ± 2.5% after heavy training compared with after light training and then increased 4.0 ± 4.2% after rest (Table 1). HRR indices were greater and faster following heavy training, and then decreased/slowed following rest, except for T30 which did not change significantly (Table 1). HR_{peak} tended to decrease 3.2 ± 5.1 beats following heavy training ($p = 0.06$) and significantly increased 4.8 ± 4.3 beats following rest (Table 1). The HR at the end of exercise was significantly lower at the post heavy training assessment compared with the post light and post rest assessments (Table 1). There was no difference for all variables between assessments after light training and rest (performance, $p > 0.09$; HRR, $p > 0.6$; HR measures, $p > 0.4$).