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Original research

Maximal rate of increase in heart rate during the rest-exercise transition tracks reductions in exercise performance when training load is increased

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ABSTRACT

Objectives: Heart rate kinetics are faster in well-trained athletes at exercise onset, indicating sensitivity to training status, but whether they track performance changes due to changes in training load is unknown.
Design: Randomised, counterbalanced, cross-over.
Methods: 17 cyclists completed two weeks of light and two weeks of heavy training. The day after each training period heart rate was recorded during 5 min cycling at 100 W to determine the maximal rate of heart rate increase. Participants then performed a 5 min cycle time-trial after which heart rate recovery was determined.
Results: Work during 5 min cycle time-trial decreased 3.5% ($P < 0.04$) in participants ($n = 8$) who increased training load (completed light training then heavy training) and, although maximal rate of heart rate increase did not change ($P = 0.27$), within-individual changes in work were correlated with changes in maximal rate of heart rate increase ($r = 0.87$, $P = 0.005$). Work during 5 min cycle time-trial increased 6.5% ($P < 0.001$) in 9 participants who decreased training load (completed heavy training then light training) and maximal rate of heart rate increase increased 28% ($P = 0.002$) but the changes in maximal work were not related to changes in rate of heart rate increase ($r = 0.32$, $P = 0.40$). Heart rate recovery tended to track changes in 5 min cycle time-trial work following increases and decreases in training load ($r = 0.65$–0.75, $P = 0.03$–0.08).
Conclusions: Maximal rate of heart rate increases during cycling at 100 W tracks reductions in exercise performance when training load is increased, but not performance improvements when training loads are reduced. Maximal rate of heart rate increase may be a useful adjunct to heart rate recovery for tracking changes in exercise performance.

1. Introduction

Prolonged strenuous exercise training can induce fatigue but can also promote adaptations that contribute to performance improvement. These adaptations occur during the recovery periods between training.[1] Thus, to achieve optimal adaptation and performance improvement, adequate recovery is necessary between training sessions. If recovery is inadequate, performance can be impaired acutely and, if continued, may result in overreaching or overtraining.[2]

Since the autonomic nervous system is interlinked with many physiological systems, it has been proposed that changes in its responsiveness may provide information about the ability to tolerate and adapt to different training loads.[3] Cardiac autonomic tone has been monitored using measures of heart rate (HR), HR variability (HRV) and HR recovery (HRR).[3] These parameters are modulated by efferent sympathetic and parasympathetic nerve activity and change in response to changes in training load,[4–6] although Buchheit et al.,[7,8] recently indicated that HRR is more strongly related to changes in training load than HRV.

HR increases at exercise onset, with the rate of increase being faster in well-trained compared with untrained individuals.[9] The faster HR increase in trained individuals may contribute to improved exercise performance through a more rapid increase in oxygen delivery to active muscle reducing peripheral muscle fatigue.[10] While the effects of changes in training load on HRV and HRR have been studied extensively, effects on the rate of increase in HR at the onset of exercise have not been investigated.

The aim of this study was to evaluate the effect of changes in training load on the maximal rate of increase in HR (rHRI)

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at the onset of a bout of standardised light exercise, in order to determine whether the rate of increase might provide information regarding how an athlete is responding to changes in training load. We hypothesised that reductions in exercise performance due to fatigue induced by a large increase in training load would be associated with a slower rHRI. We further hypothesised that improvements in exercise performance when training load is reduced, due to recovery and/or adaptation, would be associated with a faster rHRI.

2. Methods

Twenty-five male cyclists were recruited from cycling clubs in Adelaide, South Australia. The study was approved by the Human Research Ethics Committee of the University of South Australia and all volunteers provided written informed consent prior to participating.

A randomised, counter-balanced, cross-over design was used. During an initial habituation session participants were familiarised with the requirements of the study and had their peak HR assessed during a maximal 5 min cycling time-trial. Participants then undertook two weeks of heavy training (HT) designed to induce a state of fatigue, or two weeks of light training (LT). The training programmes were based on percentages of peak HR assessed during the habituation visit. The order of training was randomised such that some participants completed HT first and the others completed LT first, before switching to the alternate training programme for the subsequent two weeks. At the end of each two-week training period, on the day following the last training session, participants undertook testing. During testing rHRI was determined during the rest-exercise transition in response to 5 min of cycling at a power output of 100 W. This was followed by a short duration performance test (5TT) in which participants were asked to perform as much work (kJ) as possible over a time period of 5 min.

Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Seca, Hamburg, Germany). Body mass was measured to the nearest 0.1 kg using an electronic digital scale (Tanita Ultimate Scale, Tanita Corp., Tokyo, Japan).

All exercise testing was performed on an electronically braked cycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, Netherlands). For the 100 W exercise bout participants were seated on the ergometer prior to commencing exercise. At a predetermined point between 4 and 6 min after being seated participants commenced pedalling for 5 min at a power output of 100 W. Participants were unaware of when they would be instructed to begin the test to avoid an anticipatory increase in HR.[11] The pre-exercise HR was averaged during the 30 s prior to commencing pedalling and the steady-state HR was taken as the mean HR during the final 30 s of exercise. For 5TT, participants were instructed to perform as much work as possible in 5 min. The total work done was recorded as the measure of performance.

HR was recorded at 1 s intervals during the rest period prior to the 100 W exercise bout and throughout all exercise testing using a personal heart rate monitor (RS800CX, Polar Electro Oy, Kempele, Finland). HR was also recorded at 15 s intervals during all training sessions.

HR data during the 30 s preceding the commencement of the 100 W exercise bout and during the 5 min of exercise were fitted to a 4-component sigmoidal curve using the Solver function in Microsoft Excel (Microsoft Office Excel 2007, Microsoft Corporation, Washington, USA), according to the following equation:

$$y = a + \left(\frac{b}{1 + e^{c(x-d)}}\right) \quad (1)$$

Table 1
Training programme.

Light training	Heavy training
Warm-up	*Warm-up*
70–90 beats/min × 1 min	70–90 beats/min × 1 min
85–100 beats/min × 1 min	85–100 beats/min × 1 min
100–120 beats/min × 1 min	100–120 beats/min × 1 min
115–130 beats/min × 1 min	115–130 beats/min × 1 min
130–145 beats/min × 1 min	130–145 beats/min × 1 min
	<69% HRmax × 5 min
Training	*Training*
69–81% HRmax × 5.5 min	69–81% HRmax × 8.5 min
82–87% HRmax × 3 min	82–87% HRmax × 8 min
88–94% HRmax × 2.5 min	88–94% HRmax × 7.5 min
>94% HRmax × 2 min	>94% HRmax × 3 min
88–94% HRmax × 2.5 min	Repeat 4 times
82–87% HRmax × 3 min	
69–81% HRmax × 5.5 min	
Cool-down	*Cool-down*
<69% HRmax × 4 min	<69% HRmax × 6 min

HRmax, maximum heart rate determined during a 5 min maximal cycling time-trial during a familiarisation session.

where a is the lower HR plateau; b is the range of HR response; c is a curvature parameter, d is the HR50 (i.e. time at which half of the range in HR response was attained).

The rHRI was determined from the first derivative of this curve using Eq. (2):

$$\text{rHRI(beats/min/s)} = \frac{bxc}{4} \quad (2)$$

HRR was determined as the absolute decrease in HR (recorded as 1 s averages) during the 60 s following the end of the maximal cycling test, assessed with the participant supine (i.e. difference in HR at the end of 5TT and 60 s later).

Test–retest reliability for work done during 5TT and for rHRI and HRR was determined in 13 athletes not involved in the study who undertook two testing sessions separated by one week. The coefficient of variation was 1.2% for the work done during 5TT, 6.3% for rHRI and 7.1% for HRR.

All training was conducted on the participants' own bicycles with the rear wheel attached to a stationary trainer (Fluid Bicycles, Sydney, Australia). Training intensities were based on percentages of the maximum HR determined during a 5 min maximal cycle time-trial at each participant's familiarisation visit. LT required participants to undertake two weeks of cycling exercise for 34 min per day, with only 21% of the training performed above 88% of maximum HR. It was intended that LT should not result in participants experiencing any significant fatigue by the end of the training period. HT required participants to undertake two weeks of cycling exercise for 128 min per day, with 33% of the training being performed above 88% of maximum HR, and was intended to induce substantial fatigue from which they would not recover by testing on the day following the final training session. Compliance with training was determined by assessing the time spent in each training zone from the HR recordings during each training session expressed as a percentage of the prescribed time to be spent in each training zone. Details of the training programme are provided in Table 1.

Statistical analysis was performed using IBM SPSS Statistics 21 (IBM Corporation, Armonk, NY). Statistical significance was set at $P < 0.05$. Normality of data distribution was confirmed using the Shapiro–Wilk test prior to analysis. Means of outcome measures after HT and LT were compared using paired t-tests. Relationships between variables were assessed using Pearson's correlation coefficient. All data are presented as mean ± standard deviation (SD).