Effect of ultramarathon cycling on the heart rate in elite cyclists

G Neumayr, R Pfister, G Mitterbauer, A Maurer, H Hoertnagl

OBJECTIVES: To analyse the heart rate (HR) response and estimate the ultraendurance threshold—the optimum maintainable exercise intensity of ultraendurance cycling—in ultraendurance elite cyclists competing in the Race across the Alps.

METHODS: HR monitoring was performed in 10 male elite cyclists during the first Race across the Alps in 2001 (distance: 525 km; cumulative altitude difference: 12 600 m) to investigate the exercise intensity of a cycle ultramarathon and the cardiopulmonary strains involved. Four different exercise intensities were defined as percentages of maximal HR (HRmax) as follows: recovery HR (HRre), <70% of HRmax; moderate aerobic HR (HRma), 70–80%; intense aerobic HR (HRia), 80–90%; and high intensity HR (HRhi), >90%.

RESULTS: All athletes investigated finished the competition. The mean racing time was 27 hours and 25 minutes, and the average speed was 18.6 km/h. The mean HRmax was 186 beats/min, and the average value of measured HRs (HRaverage) was 126 beats/min resulting in a mean HRaverage/HRmax ratio of 0.68, which probably corresponds to the ultraendurance threshold. The athletes spent 53% (14 hours 32 minutes) of total race time within HRma, 25% (6 hours 51 minutes) within HRia, 19% (5 hours 13 minutes) within HRre, and only 3% (49 minutes) within HRhi, which shows the exercise intensity to be predominantly moderate (HRma + HRre = 78% or 21 hours 23 minutes). The HR response was influenced by the course profile as well as the duration. In all subjects, exercise intensity declined significantly during the race, as indicated by a decrease in HRaverage/HRmax of 23% from 0.86 at the start to 0.66 at the end.

CONCLUSIONS: A substantial decrease (10% every 10 hours) in the HR response is a general cardiovascular feature of ultramarathon cycling, suggesting that the ultraendurance threshold lies at about 70% of HRmax in elite ultramarathon cyclists.

Heart rate (HR) response to ultramarathon cycling has been little investigated. With the increasing popularity of ever more gruelling ultraendurance racing events, a clear delineation of exercise intensity becomes essential for both optimal competition preparation and reliable estimation of cardiovascular demands and hazards involved.

The intensity of a specific exercise can be estimated by the HR response. Therefore, the American College of Sports Medicine recommends certain percentages of HRmax—for example, 60–90%—as one method of prescribing exercise intensity. In ultraendurance competitions, the optimum maintainable intensity is the primary determinant of success. There is a critical exercise intensity, the ultraendurance threshold, at a relative degree below the athlete’s anaerobic threshold which guarantees achievement of the personal best ultramarathon time. The ultraendurance threshold is a new paradigm among threshold concepts which takes into account the unique considerations of ultraendurance events and can be identified by HR reading only. 

In general, information available on ultraendurance events is sparse and predominantly derived from the field of ultraendurance triathlon. HR data on marathon cycling are restricted to the experience of professionals competing in road races of the usual distances and recreational athletes participating in cycle touring events. Nothing is documented on the HR response of specialists involved in ultraendurance cycling lasting 24 hours and more. We therefore performed this study.

METHODS

Subjects

Ten volunteers from the 31 participants in the first Race across the Alps were the subjects of the study. The competitors were the world’s best ultramarathon cyclists, with former winners of the Race across America among them. They had no cardiovascular risk factors and heart diseases according to case history and clinical investigation. The subjects provided written informed consent in accordance with the guidelines established by the institutional ethics committee. Before the competition, they were instructed to maintain an adequate fluid intake ad libitum that was rich in carbohydrates. After the race, they recorded the amounts of fluid replacement. The athletes were weighed three times on electronic scales: immediately before and immediately and 24 hours after the race.

Characteristics of the race

The Race across the Alps is an extraordinary, very challenging ultraendurance cycling event held for the first time on 7 July 2001 in the Alps of Austria, Italy, and Switzerland. The course consists of a circuit including 11 mountain passes (fig 1). The distance is 509 km at an altitude above sea level of 300–2750 m, with a cumulative altitude difference of 12 200 m. The exercise volume of the race is unique, about threefold that of the hardest mountain stages in professional cycling. The race took place under varying weather conditions: extreme during the initial phase with persistent rain, cold temperatures, and snow on the first two mountain passes but with improvement during the course of the race. The temperatures ranged between −1°C and +20°C.

Abbreviations: cTn, cardiac troponin; HR, heart rate
HR monitoring

HRs were recorded, with intervals of 15 seconds, over the whole marathon using Polar Vantage NV telemeters (Polar Electro, Oy, Finland). All study participants were familiar with the use of HR monitors, as they usually trained under their control. The recorded data were analysed using a computer program (Polar Heart Rate Analysis Software 5.03; Polar Electro) that allows the user to select three reference HRs and to establish four levels of exercise intensity. The reference HRs were calculated by multiplying HRmax by the factors 0.7, 0.8, and 0.9. HRmax was obtained from the athletes by maximal incremental exercise testing performed before the race. The four exercise intensities were classified as follows: recovery heart rate (HRre), <70% of HRmax; moderate aerobic heart rate (HRma), 70–80%; intense aerobic heart rate (HR ia), 80–90%; high intensity heart rate (HR hi), >90%.

Biochemical markers

In addition to HR monitoring, selected biochemical markers (packed cell volume, and concentrations of haemoglobin, protein, and cardiac troponins (cTnI and cTnT)), were determined by standard methods as described previously. Blood specimens were taken by venepuncture from the antecubital vein the day before, immediately after, and one day after the competition and analysed on the same day. Venepuncture was performed with the subject lying down, at the same time in the morning on the day before and after the race. On the day of competition, it was performed in the afternoon immediately after the individual finishes. cTnI was measured by a two step sandwich microparticle enzyme immunoassay method (AxSYM Troponin I) on an AxSYM analyser (Abbott Diagnostika, Wiesbaden, Germany) with an upper reference limit of 0.5 μg/L, and cTnT by a third generation electrochemiluminescence immunoassay method (Troponin T Stat) on an Elecsys analyzer 2010 (Roche Diagnostics, Hoffmann-LaRoche Inc, Basel, Switzerland) with an upper reference limit of 0.1 ng/ml.

Statistical analysis

Results are expressed as mean (SD). The Mann-Whitney test was used to compare HR response, baseline characteristics, and race results between athletes with and without exercise induced cTn levels, and the Wilcoxon signed rank test for the changes in biochemical variables over the observation period. Regression analyses were computed to assess correlation between the variables by using the SPSS software package, version 9.0 (Chicago, Illinois, USA). Statistical significance was assumed at a level of p<0.05.

RESULTS

Baseline characteristics and biochemical markers

All 10 athletes successfully finished the ultramarathon. Most of them fulfilled their personal expectations. The mean racing time was 27 hours 25 minutes, and the average speed was

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177</td>
<td>5</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>71</td>
<td>7</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>22.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Training (km in 2001)</td>
<td>12000</td>
<td>6030</td>
</tr>
<tr>
<td>Weekly training (km)</td>
<td>490</td>
<td>110</td>
</tr>
<tr>
<td>Years of practice</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Race time</td>
<td>27 h 25 min</td>
<td>3 h 14 min</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>18.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Mass loss (kg)</td>
<td>−1.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Mass loss (%)</td>
<td>−2.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Fluid replacement (litres)</td>
<td>23.3</td>
<td>3.9</td>
</tr>
</tbody>
</table>

BMI, Body mass index.
Exercise intensity of a cycle ultramarathon

In a mean HR average/HRmax ratio of 0.68 for the total race workload was performed under aerobic conditions (HR required to maintain the cardiac output). This drift is augmented by dehydration\(^\text{12, 13}\) and reduced by fluid and carbohydrate replacement.\(^\text{14, 15}\) Over the time, power output declines, mainly as a result of altered substrate use.\(^\text{16}\) The ability to prevent or at least delay this decline through more balanced fuel utilisation is the critical objective of the ultraendurance threshold, the optimum performance intensity below the anaerobic threshold.\(^\text{17}\) The ultraendurance threshold for ultramarathon cycling has not yet been defined.

 Studies on the HR response to professional cycling have consistently shown that exercise intensity decreases as follows: time trials->high mountain stages>flat stages.\(^\text{12, 13, 15, 16}\) World class cyclists are capable of bearing intensities of 85–89% of HR\(_{\text{max}}\) during short distance (<40 km) and prologue (<10 km) time trials, and even 78–80% during long distance (>40 km) and uphill time trials.\(^\text{17}\) In the mountain stages of the Tour de France, the following distribution of HR ranges was found: 16% HR\(_{\text{re}}\), 33% HR\(_{\text{ma}}\), 36% HR\(_{\text{max}}\), and 15% HR\(_{\text{ia}}\). In contrast with cycling of the usual distances and durations, data on HR response in marathon or ultramarathon cycling are sparse. In a previous study, we showed the mean HR\(_{\text{average}}/HR_{\text{max}}\) to be 0.77 and to decline by 10% in recreational athletes who participated in a cycle touring event, the Ötztal Radmarathon.\(^\text{18}\) In one athlete who performed the Ötztal Radmarathon twice en blocque in a circuit of two identical laps—that is, a distance of 460 km and altitude difference of 11 000 m—HR\(_{\text{average}}/HR_{\text{max}}\) was found to be somewhat reduced (0.71), according to the prolonged race time of about 21 hours.\(^\text{19}\)

In this study we found a mean HR\(_{\text{average}}/HR_{\text{max}}\) of 0.68 in the world’s best ultraendurance cyclists in the absence of major dehydration. Potential systemic dehydration and plasma volume shifts making the plasma volume decline are confounding factors that influence the HR response. The athletes investigated have compromised to a successful fluid replacement strategy throughout the race, as indicated by their body masses remaining stable during the race and pronounced haemodilution after the race (tables 1 and 2). Similar data gained from recreational cyclists confirm that adequate fluid replacement is achieved by most athletes, even the less experienced, and is crucial for successful performance of ultraendurance events.\(^\text{18}\)

The finding of decreasing power output in long term cycling is in good accordance with data presented by O’Toole \textit{et al.},\(^\text{20}\) who suggested that, during prolonged cycling (more than six hours), a highly trained athlete may expect to exercise at an average intensity close to 80% HR\(_{\text{max}}\) but should also expect intensity to decline by 6–7% during the cycle ride. We observed an HR\(_{\text{average}}/HR_{\text{max}}\) of 0.86 during the first six hours, decreasing by 23% to 0.66 in the final period. The mean overall HR\(_{\text{average}}/HR_{\text{max}}\) ratio was calculated to be 0.68, which probably corresponds to the theoretical ultraendurance threshold. This gradual decrease in HR was uniform in all athletes and not related to the individual race time. The extent of decline was about 6% every six hours—similar to the value of 10% observed in recreational athletes during a cycle touring event lasting 10 hours.\(^\text{18}\)

### Table 2

<table>
<thead>
<tr>
<th>Selected biochemical variables measured in 10 competitors in the Race across the Alp</th>
<th>Before</th>
<th>After</th>
<th>24 h after</th>
</tr>
</thead>
<tbody>
<tr>
<td>cTnI (0–5 μg/l)</td>
<td>0/10</td>
<td>1/10 (1%)</td>
<td>0/10</td>
</tr>
<tr>
<td>PCV (0.40–0.52)</td>
<td>0.45 (0.02)</td>
<td>0.43 (0.02)</td>
<td>0.40 (0.02)</td>
</tr>
<tr>
<td>Hb (133–177 g/l)</td>
<td>151 (8.0)</td>
<td>146 (9.0)</td>
<td>133 (5.0)</td>
</tr>
<tr>
<td>%APV</td>
<td>-7.2%</td>
<td>-23.9%</td>
<td>-23.9%</td>
</tr>
<tr>
<td>Protein (48–82 g/l)</td>
<td>79.6 (3.5)</td>
<td>73.8 (4.0)</td>
<td>65.2 (2.0)</td>
</tr>
</tbody>
</table>

Unless otherwise indicated, values are mean (SD).

### Table 3

<table>
<thead>
<tr>
<th>Exercise intensity in percentage and absolute time (h/min) of total race time</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR(_{\text{average}}) (beats/min)</td>
<td>126</td>
<td>7</td>
</tr>
<tr>
<td>HR(<em>{\text{average}}/HR</em>{\text{max}}) (whole race)</td>
<td>0.68</td>
<td>3.5</td>
</tr>
<tr>
<td>HR(<em>{\text{average}}/HR</em>{\text{max}}) (first 6 h)</td>
<td>0.86</td>
<td>3.4</td>
</tr>
<tr>
<td>HR(<em>{\text{average}}/HR</em>{\text{max}}) (last 6 h)</td>
<td>0.66</td>
<td>3.5</td>
</tr>
<tr>
<td>HR decline from start to finish</td>
<td>23</td>
<td>3.5</td>
</tr>
<tr>
<td>HR(<em>{\text{re}}) (&lt;70% HR(</em>{\text{ma}}))</td>
<td>53%</td>
<td>13%</td>
</tr>
<tr>
<td>HR(<em>{\text{re}}) (70–80% HR(</em>{\text{ma}}))</td>
<td>25%</td>
<td>8%</td>
</tr>
<tr>
<td>HR(<em>{\text{re}}) (80–90% HR(</em>{\text{ma}}))</td>
<td>19%</td>
<td>6%</td>
</tr>
<tr>
<td>HR(<em>{\text{re}}) (&gt;90% HR(</em>{\text{ma}}))</td>
<td>3%</td>
<td>1%</td>
</tr>
</tbody>
</table>

HR, Heart rate.
of both investigations suggest that, during ultraendurance exercise, a decrease in the HR response is a general and very specific cardiovascular feature influenced by several factors, such as substrate depletion, fluid and electrolyte imbalances, altered muscle efficiency, thermoregulatory problems, cardiac fatigue, and psychological factors. In contrast with these individual variables, we consider environmental variables, such as weather conditions and altitude, to be of minor importance in the HR response as they are the same for all participants. Furthermore the HR response was certainly not biased by race tactics either. The Race across the Alps is an individual race. Drafting is forbidden and punished by disqualification. The clear majority of the workload was performed under aerobic conditions with HRmax + HRana + HRs together amounting to 97% (26 hours 36 minutes) of the total time. The rate of high intensity exercise was very small (HRS about 3% (49 minutes)). The observed distribution of exercise intensities characterises the energy supply in ultraendurance sports and shows once again aerobic metabolism to be the basis of the energy metabolism.

The interesting phenomenon of gradually decreasing HR during ultraendurance exercise indicates downregulation of the sympathetic system to protect the heart from serious damage. This assumption leads to the classical hypothesis by Nobel Laureate A V Hill in the 1920s that it is the heart, and not the skeletal muscle, that is at risk of anaerobiosis or ischaemia during exhausting exercise. This enduring hypothesis in exercise physiology holds that a limiting cardiorespiratory function determines maximal exercise performance and that there must be a “central governor” in either the heart or brain to limit heart work when myocardial ischaemia is developing or the oxygen delivery to the heart or brain to limit heart work when myocardial ischaemia is developing or the oxygen delivery to vital organs is threatened. Noakes and coworkers extended this central governor hypothesis to a new physiological model, proposing that this virtual governor regulates skeletal muscle recruitment during maximum exercise specifically to prevent progressive myocardial ischaemia which would precede the development of skeletal muscle anaerobiosis. As a result, cardiovascular function limits maximum exercise capacity, probably as a result of limiting myocardial oxygen delivery. This model is supported by the pharmacological finding of altered cardiac adrenergic chronotropic responsiveness after exhaustive exercise. In Hawaii Ironman triathletes, Douglas et al. found that, after strenuous long term strain, increasing intravascular boluses of isoproterenol were needed to raise resting HR >30 beats/ min. In the light of these results and according to Hill’s classical model, we interpret our finding of a gradual decline in HR during ultramarathon cycling as a downregulation phenomenon to protect the heart against capacity overload through long term exercise.

Nevertheless, we found some evidence of subclinical myocardial injury in one of the 10 athletes, indicated by a moderate and very temporary exercise induced increase in cTnI. The results of this study and previous work, however, provide no evidence that there may be an association between HR response and cTnI status after a race, indicating that factors other than duration and intensity cause this stress induced release of cardiac troponins in asymptomatic athletes after exceptional long term exercise.

The HR responses in this study show that the cardiovascular strains of ultramarathon cycling are moderate with respect to the intensity, but enormous with respect to the duration of the exercise. The cardiovascular response of ultramarathon cycling lasting about 24 hours is characterised by a pronounced decline in HR (10% every 10 hours), suggesting that the ultraendurance threshold lies just below 70% of HRmax.

**Take home message**

A pronounced decline in the HR response is a very specific cardiovascular feature of ultraendurance exercise. In ultramarathon cycling lasting more than 24 hours, the ultraendurance threshold lies just below 70% of HRmax.

**Authors’ affiliations**

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**REFERENCES**