Heart rate variability during the first week of an altitude training camp is representative of individual training adaptation at the end of the camp in elite triathletes.

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Headline

Training camps at altitude aim at improving performance by spending time in a hypoxic environment, which typically increases red blood cells and improves oxygen carrying capacity. Despite these clear pathways, athletes often respond differently and not always positively (1, 2, 3). Measurement of morning resting heart rate (HR) and heart rate variability (HRV) can provide a non-invasive assessment of how an athlete is responding to stressors such as altitude. However, little data is available in the context of individual responses and adaptation to altitude in elite triathletes.

Aim

The purpose of this study was to determine whether changes in resting HR and HRV during the beginning of a 3-week training camp at altitude would be representative of training adaptation at the end of the training camp in elite triathletes. In particular, we hypothesized that a favorable adaptation profile in terms of resting physiology would be reflected by a smaller or absent increase in resting HR, a smaller or absent reduction in HRV and smaller or absent variation in HRV when going from sea level to altitude (4). Our rationale was based on the idea that a lower perturbation in homeostasis is typically representative of a positive response to a stressor and associated with improved performance outcomes in other sports (4, 5). In this work, due to a lack of performance data, we have relied on submaximal HR data to determine responders and non-responders to an altitude camp, as covered in detail in the Methods section.

Methods

Athletes. Four elite triathletes (2 male and 2 female) spent 23 days in Namibia at 1655 meters of altitude for two consecutive years in January 2019 and January 2020. All triathletes had been National Champions (at either junior, under 23 and / or Elite level) and provided written consent form. The study was approved by The Scientific and Ethical Review Board of the Faculty of Behavioral & Movement Sciences, Vrije Universiteit Amsterdam.

Design. This study used a longitudinal observational design. Resting HR and HRV (rMSSD) were measured daily using the validated HRV4Training app (6), which allows for measurements of HR and HRV (rMSSD) using either the phone camera, or an external sensor. Triathletes were instructed to take measurements daily upon waking, while lying in bed and breathing naturally (self-paced). Training data (GPS, HR) were acquired during workouts.

Methodology. Athletes were grouped into responders and non-responders to the training camp at altitude based on the relationship between HR and speed at submaximal intensity (velocity to HR ratio) at the end of the training camp (7, 8). In particular, responders were athletes whose velocity to HR ratio at the end of the camp reached sea level values. Our rationale for this methodology was the following. In an acute exposure to a hypoxic environment, a higher cardiac output is shown at any workload (9). However, after acclimatization, the relationship between HR and workload re-normalizes to sea level values (10). Thus, in our study, we considered responders the athletes who were able to positively adapt within the duration of the camp. Running data were used to determine the velocity to HR ratio, which was used to indicate training adaptation (see Figure 1). The velocity to HR ratio was averaged each week, prior to using the concept of the smallest worthwhile change (SWC), computed as 30% of the standard deviation in the ratio between velocity and HR, for an individual athlete, to determine responders vs. non-responders. We used 30% of the standard deviation as typically recommended in the literature when analyzing within-individual data (11).

Statistics

Differences between the time window before the camp (14 days) and the beginning of the training camp (10 days) were computed for rMSSD, heart rate and the coefficient of variation of rMSSD (CV rMSSD). Thus, each athlete was characterized by her or his individual response to the training camp. Individual responses (N = 7) were grouped into non-responders (N = 3, athletes that did not adapt during the training camp) and responders (N = 4). We used unpaired two-sided Wilcox tests to determine 95% confidence intervals and effect sizes (we report the estimate between 0 and 1, and magnitude as small, moderate or large).

Results

Figure 2 shows an example of daily HR, rMSSD collected for one athlete before and during the training camp at altitude. Figure 3 shows boxplots of the resting HR, rMSSD, and CV rMSSD for the responders and non-responders. Resting HR was more elevated during the first week of the training camp for non-responders (+4.6 ± 1.56 bpm) compared to responders (+0.5 ± 1.2 bpm, Wilcox test: 95% CI [-7.54, -2.10], effect size = 0.81, large). The CV rMSSD also increased by a greater extent for non-responders (+11 ± 6 %) than for responders (-3 ± 3%, Wilcox test: 95% CI [-0.21, -0.03], effect size = 0.80, large). The difference in rMSSD between pre-camp values and the first week of the camp was lower for non-responders (-11 ± 10 ms) compared to responders (+6 ± 29 ms, Wilcox test: 95%

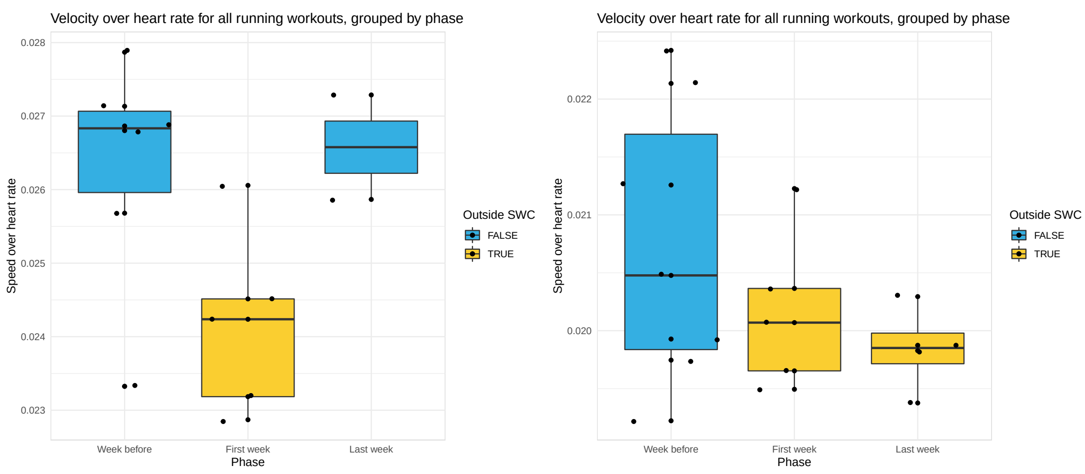

Fig. 1. An example of submaximal heart rate data (the velocity to heart rate ratio) for two athletes. The athlete on the left was part of the responder group, as the velocity to heart rate ratio is within the SWC during the last week of the camp. The athlete on the right was assigned to the non-responder group, as the velocity to heart rate ratio remained suppressed, even at the end of the camp. TRUE means that in a given week, the velocity to heart rate ratio was within the SWC of the week before the camp, at sea level. FALSE means that the velocity to heart rate ratio in a given week was outside of the SWC of the week before the camp.

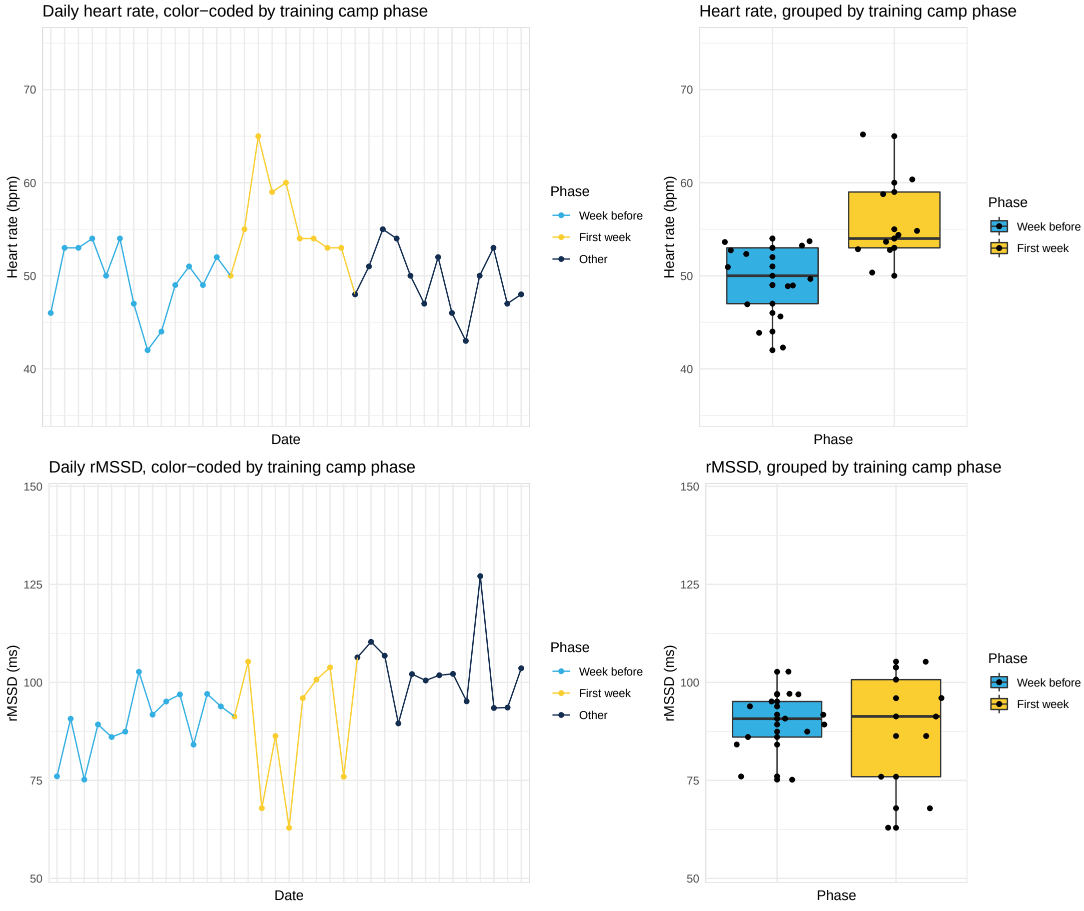

Fig. 2. Example of daily resting HR and HRV (rMSSD) for one athlete, as well as boxplots of the same parameters during the two periods of interest: before the camp and during the beginning of the camp. Resting HR increases during the first days of the camp, and then lowers to values similar to the athlete's values before the camp. Similarly, rMSSD reduces during the first days of the camp, despite normalizing quickly for this athlete, as illustrated by the boxplots showing little difference between the two periods. rMSSD spreads over a broader range, and jumps between higher and lower values, as also shown by a wider boxplot. This behavior is captured by a higher coefficient of variation (CV), or higher day to day variability despite a similar average rMSSD over a period of ten days.

CI [-12.77, 70.51], effect size = 0.27, small). The same athletes responded positively (or negatively) to successive camps.

Discussion

The main finding of this study was that elite triathletes who responded positively to a three-week training camp at altitude

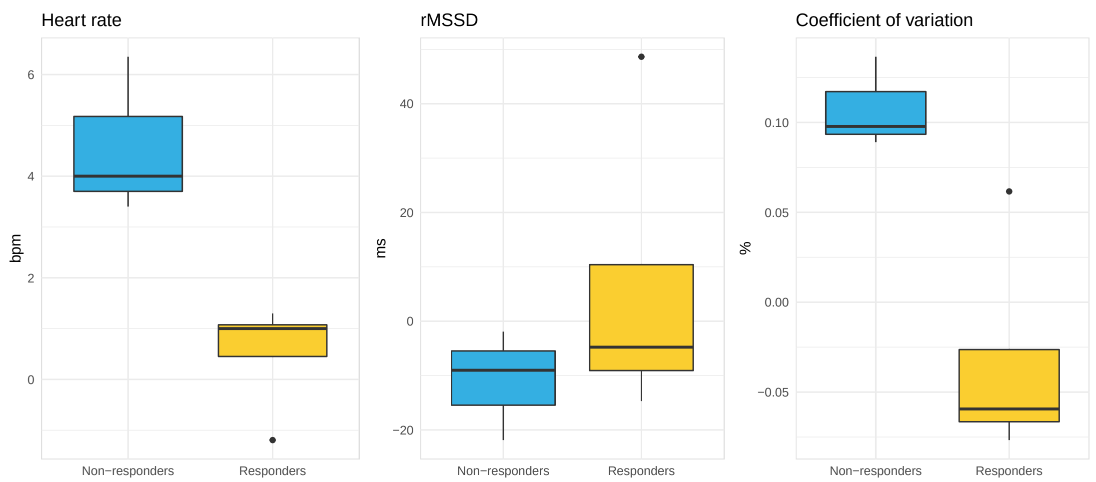

Fig. 3. Boxplots of the differences in resting HR, rMSSD and CV rMSSD between the period prior to the camp and the beginning of the camp in the two groups (responders and non-responders). The figure shows how responders have a more favorable physiological profile (lower increase in resting HR, lower CV).

(based on the speed to heart rate ratio) showed a more favorable physiological response during the beginning of the training camp. In particular, responders showed a lower increase in resting HR when going from sea level to altitude compared to non-responders. Additionally, responders showed a smaller reduction in HRV and no increase in the CV rMSSD when going from sea level to altitude. These findings suggest that exacerbated responses in cardiac activity at rest during the first week of a training camp at altitude might be indicative of difficulties in adapting to the altitude training stress.

It is clear both to the experienced coach and the scientist that athletes respond differently to the stimuli provided, and not all benefit in the same way from a given stimulus. Some athletes might adapt to the novel stimulus and improve, while others might struggle or require more time to adapt (1, 2). We speculate that a better response to the altitude training camp may be due to a relatively lower physiological stress being encountered (or perceived by the athlete), resulting in a more stable HRV profile (i.e. a lower CV). Flatt argued that a lower CV possibly indicates a reduced perturbation in homeostasis, and therefore athletes showing increased CV might benefit from a reduced training load (4). In another study, Flatt and colleagues reported a strong relationship between the degree of change in the CV and the fitness level measured in a performance test; that is, players showing a larger decrease in the CV during the first 2 weeks of the training camp experienced greater performance improvements post-training camp (4). In our study, we could make similar assumptions. In particular, the altitude challenge was evident in all athletes during the first days of the training camp, both in resting and workout data, with typical responses such as elevated HR while running and at rest. However, the data suggests that the degree of the disruption in homeostasis was greater for certain athletes, and that these athletes were the ones that eventually did not appear to adapt (well) to the training camp.

Practical Applications

- Practitioners could use morning measurements of resting HR and HRV during the first week of a training camp, and in particular assess the degree of the increase in resting HR or in the CV rMSSD as signs that are potentially predictive of positive or negative adaptation later on.
- Once athletes showing a poor response (higher increase in HR, CV rMSSD) have been identified, various strategies could be employed, either in terms of training load manipulation or by modifying other parameters.

Limitation

- Small sample size.
- The use of real-life field-based to determine adaptation to the training camp according to submaximal data and the velocity to HR ratio instead of laboratory or performance tests.

Conflit of interest

Marco Altini is the developper of the App used for data collection.

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