The longitudinal relationship among heart rate variability, training load, psychological state, and race performance in an elite middle-distance runner

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Headline

Heart rate variability (HRV) is an indirect index of autonomic nervous system homeostasis, and is used to assess changes in both negative and positive adaptation in athletes. It has been reported that coefficient variation (CV) of logarithm of the root mean square differences between adjacent normal R-R intervals (Ln RMSSD) is a sensitive response marker (1). In an earlier report, we showed that CV Ln RMSSD was small throughout a successful season of a graduate student middle distance runner (2).

Aim

We reported the runner's training load, psychological state, race performance, and HRV over the course of the following season. The present case study was unique due to the fact that we collected longitudinal data and enrolled the same subject who had already been reported on (2).

Athlete

A male national-level graduate student middle distance runner (age: 23 years, height: 175 cm, weight: 60 kg) started HRV recording from April 2018. The earlier report showed the previous year's data for a 23-week period from April 2018 to September 2018 (2). The subject updated his self-recorded times over a distance 800 m twice and 1500 m once during the previous year. Before the present study period, his personal best was 1:50:98 and 3:49:10 for the 800 m and 1500 m, respectively.

Design

This case study reported HRV, training load, psychological state, and race performance for 36 weeks from February 2019 to October 2019. The 36 weeks were divided into the first phase (1st-18th week) and second phase (19th-36th week) of the season. In the first phase, the most important competition was the Japan University Student Individual Championship (JUSIC, week 17). In the second phase, the most important competition was the Japan Student Athletics Championship Tournament (JSACT, week 31). Time standards were set for both competitions. In the previous year, the subject came seventh in JUSIC and was a semifinalist over 800 m in JSACT.

Methods

The details were provided in the earlier report (2). In brief, HRV was recorded with a Bluetooth chest-strap (H10 sensor, Polar Electro, Kempele, Finland) paired with a freely available smartphone application (Elite HRV, Asheville, North Carolina, USA). We used Ln RMSSD and CV Ln RMSDD as the HRV parameters. The subject's psychological state was assessed using the Hooper Questionnaire (3). The levels of stress, fatigue, sleep, and muscle soreness were recorded on a 7-point scale (where 1 indicated "very very good" and 7 indicated "very very bad"). The Hooper's score was quantified by summing the four scores. The Hooper questionnaire has been used in several case studies of endurance athletes (4,5). Training intensity was based on the distribution into five zones (zone1: easy and moderate continuous running, zone2: threshold intervals, zone3: harder aerobic intervals and anaerobic specific zones, zone4: fast repetition over shorter distances, hills or track training at 800-m and 1500-m pace, zone5: sprint and strides (6). The score for each zone was computed by multiplying the accumulated volume (minutes) in the zone by an intensity-weighted multiplier (1 for zone1, 2 for zone2, 3 for zone3, 4 for zone4, and 5 for zone5).

Statistical analyses

Weekly analysis was conducted for HRV, Hooper's score, and training load. Cohen's effect size was calculated to quantify the difference between the first and second phase. The effect size was classified as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), and very large (>2.0) (7). Pearson product moment correlation coefficients were used to quantify the relationship between weekly CV Ln RMSSD and training load and Hooper's score. An r-value between 0 and 0.3 was considered small, 0.31 and 0.49 as moderate, 0.5 and 0.69 as large, 0.7 and 0.89 as very large, and 0.90 and 1.00 as near perfect (7).

Results

Table 1 shows weekly HRV and training load values. Moderate difference was observed between the first and second phase for mean Ln RMSSD and CV Ln RMSSD. When examining the details of the weekly change more closely (Figure 1), it can be seen that the CV Ln RMSSD increased remarkably from the end of the first phase to the beginning of the second phase. Training load for the second phase was moderately lower compared to the first phase. The correlation between CV Ln RMSSD and Hooper's score was moderate ($r = 0.487$), whereas the correlation between CV Ln RMSSD and training load was small ($r = 0.219$). Table 2 shows the subject's race results. The subject updated his self-record for 800 m (1:50:20) and 1500 m (3:46:33) during the first phase. In addition, he came sixth in the main race over 1500 m (JUSIC). In the second phase, although the subject again recorded his best personal time over 800 m (1:50:11), he did not gain a

Table 1. Weekly value of HRV and training (mean ± SD)

	All seasons (1-36 weeks)	First phase (1-18 weeks)	Second phase (19-36 weeks)	Effect size
Mean Ln RMSSD (ms)	4.59 ± 0.14	4.53 ± 0.12	4.66 ± 0.13	1.08
CV Ln RMSSD (%)	5.9 ± 3.6	7.0 ± 3.9	4.7 ± 3.0	-0.64
Training Load (A.U.)	93.5 ± 37.0	105.2 ± 31.5	81.9 ± 37.0	-0.66

Table 2. Race Results

Week	800 m	1500 m	Race
9		3:51:99	Competition
10	1:51:72		Trial meet
13	1:51:47		Competition
13		3:46:33	Trial meet
15		3:53:20	Competition
15	1:51:86		Competition
17		3:54:02	Main race (preliminary stage)
17		3:53:04	Main race (final stage)
17	1:52:46		Main race (preliminary stage)
17	1:52:20		Main race (semi-final stage)
17	1:51:77		Main race (small final stage)
18	1:50:20		Trial meet
25		3:48:16	Trial meet
25	1:50:11		Trial meet
28	1:53:28		Competition (preliminary stage)
28	1:52:91		Competition (final stage)
28		3:53:50	Competition
31		3:56:45	Main race (preliminary stage)
31	1:52:80		Main race preliminary stage
36		3:50:27	Competition

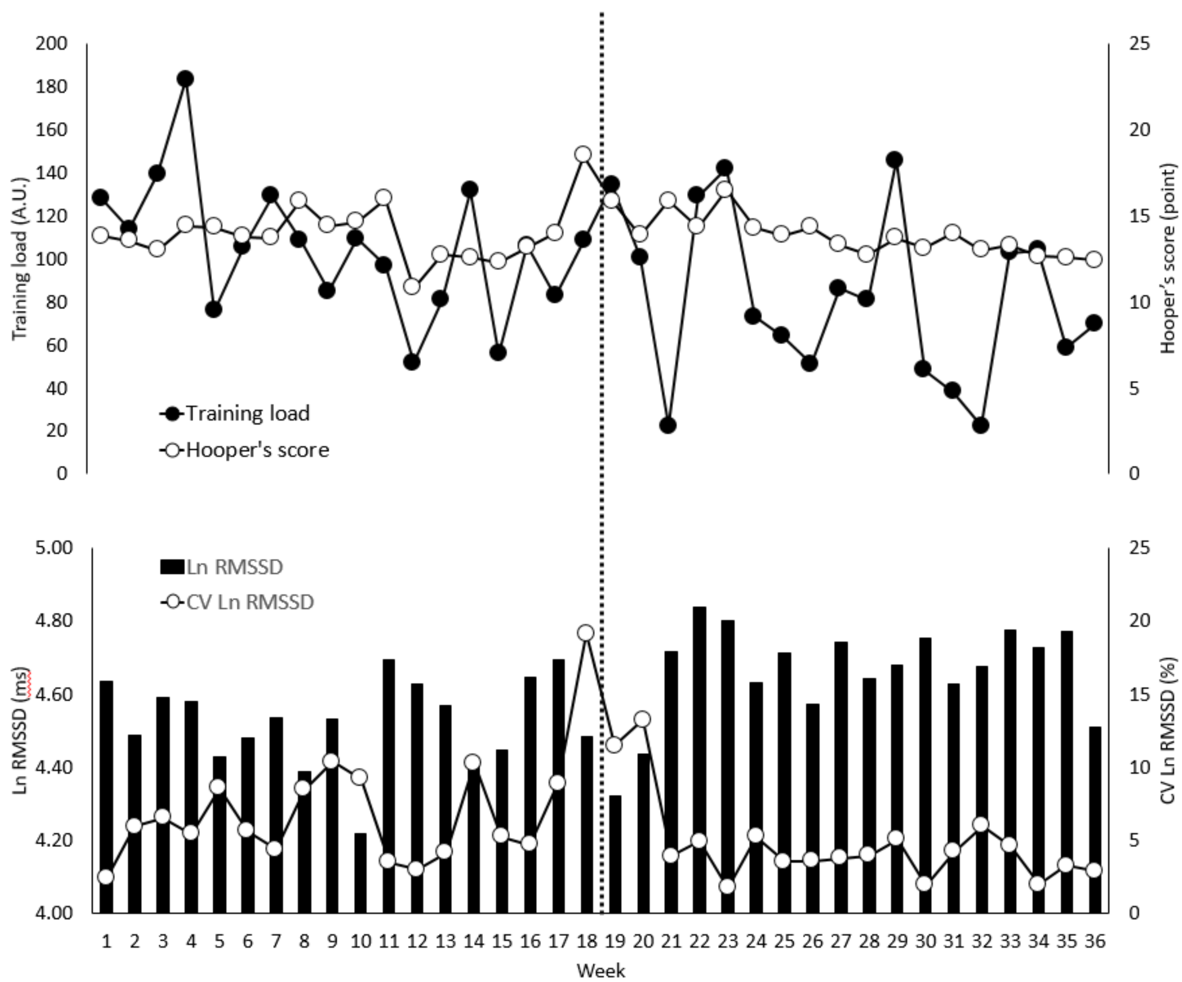

Fig. 1. Weekly changes in HRV and training load. The dotted lines indicate the boundary of the first and second phase of the season.

qualifying position in the preliminary stage of the main race (JSACT).

Discussion

The subject broke his personal record for two consecutive years. In particular, his time over 1500m was reduced by approximately three seconds in the first phase. On the other hand, his performance in the main race in the second phase was lower compared with the first phase and previous year (2). We demonstrated that the CV Ln RMSSD increased at the boundary of the first and second phase.

Previous studies (8-9) showed initial CV Ln RMSSD response was related to changes in aerobic fitness during off-season training. For example, Flat and Esco (8) suggested that a decrease in CV Ln RMSSD within the first three weeks of training is a favorable response. These previous results indicated that small fluctuations in Ln RMSSD were an important factor for producing training adaptation. In the present study, the CV Ln RMSSD increased remarkably at the boundary of the first and second phase. Indeed, the CV Ln RMSSD for the weeks 17 to 20 was higher than the highest value of the previous year (8.5%) (2). This result would appear to indicate that the subject could not increase aerobic fitness in the second phase of the season.

The relationship with CV Ln RMSSD was moderate based on the Hooper's score and was small for training load. The subject had several non-training stressors at the beginning of the second phase of the season such as an interim examination for his master's degree, presentation at an international conference, and air travel. Moreover, the subject participated in a relatively large number of races at the end of the first phase (Table 2). From the considerations cited above, we would have expected that life-style stressors, participation in many races, and insufficient recovery period would cause a large CV Ln RMSSD from the end of the first phase to the beginning of the second phase. In fact, the training load for the second phase was moderately lower compared to the first phase, suggesting that the subject did not have a training load large enough to induce adequate training stimulation.

Data obtained by several researchers were presented to show that increase in parasympathetic modulation has a positive effect on endurance performance (10-11). In order to clarify the longitudinal relationship between Ln RMSSD and middle-distance performance, we looked at Ln RMSSD during the previous season and current season. The weekly mean Ln RMSSD (4.59 ± 0.14 ms) in the current season was not higher than that in the previous season (4.63 ± 0.11 ms). Moreover, the mean Ln RMSSD in the first phase was lower than that in the second phase (4.53 ± 0.12 ms vs. 4.66 ± 0.13 ms, effect size = 1.08). Given the present result where the subject improved on his previous time over 1500 m by approximately three seconds, this finding was somewhat surprising. There may not be a causal relationship between parasympathetic modulation and middle-distance running performance at least for elite level middle distance runners. However, since there are few reports on long-term HRV changes for elite middle-distance runners, further studies are needed in order to clarify the relationship between middle-distance performance and HRV.

Practical Applications

- Conditioning based on both training and non-training (life-style) stressors are important for elite athletes. Since we assume that training load and the Hooper's score did not accurately reflect all the stressors, athletes and practitioners should always consider what could potentially be affecting HRV. The subject fine-tuned his training schedule when Ln RMSSD was low (2), but an increase in CV Ln RMSSD could not be prevented. Thus, the management of factors other than training load may be important for elite athletes.
- Increase in CV Ln RMSSD over a period of several weeks may be a predictor of improvement in middle-distance running performance being inhibited.

Limitations

- The result does not necessarily imply the existence of a cause–effect relationship. In particular, we could not determine whether the training load affected heart rate variability, or whether heart rate variability affected the training load.
- An athlete's HRV may be interpreted differently at different periods. A recent case study where the subject was an open-water world champion showed that parasympathetic activity was higher at the training camps, while sympathetic activity was high during taper (12). Because the subject of our report frequently participated in races, it was not possible to analyze by different period such as off-season, preparation taper, and competition.

Conflict of Interest

The present study forms part of a joint research project between the University of Tsukuba and KDDI Research. This study was funded by KDDI Research, Inc. FT is an employee of KDDI Research, Inc.

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