Heart Rate Variability Reflects Training Load and Psychophysiological Status in Young Elite Gymnasts

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Abstract

Sartor, F, Vailati, E, Valsecchi, V, Vailati, F, La Torre, A. Heart rate variability reflects training load and psychophysiological status in young elite gymnasts. *J Strength Cond Res* 27(10): 2782–2790, 2013—In gymnastics, monitoring of the training load and assessment of the psychophysiological status of elite athletes is important for training planning and to avoid overtraining, consequently reducing the risk of injures. The aim of this study was to examine whether heart rate variability (HRV) is a valuable tool to determine training load and psychophysiological status in young elite gymnasts. Six young male elite gymnasts took part in a 10-week observational study. During this period, beat-to-beat heart rate intervals were measured every training day in weeks 1, 3, 5, 7, and 9. Balance, agility, upper limb maximal strength, lower limb explosive, and elastic power were monitored during weeks 2, 4, 6, 8, and 10. Training load of each training session of all 10 weeks was assessed by session rating of perceived exertion (RPE) and psychophysiological status by Foster's index. Morning supine HRV (HF% and LF%/HF%) correlated with the training load of the previous day ($r = 0.232$, $r = -0.279$, $p < 0.05$). Morning supine to sitting HRV difference (mean R wave to R wave interval (RR), mean heart rate, HF%, $SD1$) correlated with session RPE of the previous day ($r = -0.320$, $r = 0.301$, $p < 0.01$; $r = 0.265$, $r = -0.270$, $p < 0.05$) but not with Foster's index. Training day/reference day HRV difference (mean RR, $SD1$) showed the best correlations with session RPE of the previous day ($r = -0.384$, $r = -0.332$, $p < 0.01$) and Foster's index ($r = -0.227$, $r = -0.260$, $p < 0.05$). In conclusion, HRV, and in particular training day/reference day mean RR difference or $SD1$ difference, could be useful in monitoring training load and psychophysiological status in young male elite gymnasts.

Key Words HRV, gymnastics, session RPE

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Introduction

Training load determination is crucial for training planning and periodization (12,14) and this is true also in gymnastics (1). In particular, because gymnasts are used to deal with high training loads from childhood (1). Training load, monotony, and strain were found to be involved in 84% of illnesses of athletes (13). The rate of injuries in gymnastics is high and it is proportional to the level of the gymnasts; the higher the level, the more injuries occur (29). Moreover, some injuries are difficult to treat because of the intensity of training and competitions (17). The high rate of injuries might be associated to the so-called overtraining syndrome (16). This syndrome occurs when the performance is reduced, despite excessive training loads and it is accompanied by low quality of recovery and prolonged fatigue (21). Overtrained athletes have been observed to have severe psychophysiological complaints (3). Although it is believed that overtraining occurs in gymnastics (9), research in this field is still rather scarce. The above mentioned scientific evidence seems to support a need for training load estimation and overall psychophysiological status in high-level gymnasts.

Training load can be estimated using a training session rating (0–10 Borg scale) of perceived exertion (RPE) (14). The validity of the use of session RPE in team gymnastics has been recently documented (31). Foster and Lehmann (15) have developed a 7-item questionnaire, which uses straightforward language, well understandable by athletes, that assesses their psychophysiological status. Although these 2 tools are very useful to quantify the training input and its effects, they are limited because they are based on subjective ratings and self-reports.

Heart rate (HR) monitors are widely used among sportsmen, in particular, in endurance sports. These monitors give easy access to physiological information, such as HR and heart rate variability (HRV). Heart rate is often used to assess training intensity (e.g., training impulse, training zones) (22) and to estimate aerobic power (e.g., maximal HR, HR recovery) (28). Heart rate variability response depends on the training status of athletes and the training stimuli (39). These applications are not generally used in gymnastics, and also because wearing a chest belt throughout a gymnastics session may be inconvenient. However, HRV measured outside training sessions could result in useful applications for this discipline. Heart rate variability, and in particular the frequency bands, carries information about the responsiveness of the autonomic nervous system (38). Indeed, HRV at rest is mainly influenced by fluctuations in the parasympathetic tone (10). Heart rate variability has been shown to reflect autonomic imbalance in overtrained athletes (35,36,44,45). However, others did not confirm these findings (20). Whether HRV can be used as a marker of overtraining is still under debate (2). However, in a meta-analysis, it has been shown that HRV could be considered a valid marker of autonomic balance in short-term fatigue (6). In fact, a reduction in the high-frequency (HF) component and an increase in the low-frequency (LF) component of the power spectrum of the HRV have been shown to relate with fatigue (40,41). Recently, HRV has been shown to correlate with training load in runners (37).

For these reasons, HRV is a good candidate to reflect training load and psychophysiological status in gymnasts. The objective of this study was to evaluate the use of HRV statistical measures as markers of training load and psychophysiological status in gymnastics. We hypothesized that short-term HRV measured in the morning just after waking up should reflect session RPE of the previous day and Foster's index. This is because of HRV's correlation with autonomic nervous system responsiveness (34). An HRV-based marker would be objective, practical, and rather easy to integrate in the training routine.

Methods

Experimental Approach to the Problem

To test our research hypothesis, we have designed an observational study, where elite gymnasts were followed for 10 weeks. We have selected several dependent variables, session RPE, Foster index, HRV, and a battery of performance tests to observe the effect of the independent variable, training load, on the gymnasts.

Subjects

All gymnasts ($n = 6$) consented to take part in this observational study (Table 1). Four of 6 gymnasts took part in international events (European Artistic Gymnastic Championship) in 2011 and 2012, where 2 of 4 classified among the first 12 athletes. The gymnasts underwent 2 sessions of anthropometric evaluations. One at the beginning of the study, and the other one at the end of the 10 weeks, anthropometric results are presented in Table 1. These 2 sessions were conducted the same time of the day. Gymnasts were asked to wear only their underwear (no socks) to measure their height and weight. Three skinfolds (pectoral, abdominal, and quadricipital) were measured 3 times as described by Graves et al (18). Body density and fat percentage were estimated using Jackson-Pollock's (23) and Brozek's (7) equations. Biceps, waist, and quadriceps circumferences were also measured 3 times (18) (Table 1).

The Italian Gymnastic Federation's Committee approved the research protocol of this study, which was in conformity with the Declaration of Helsinki. All gymnasts belonging to the national Italian junior male selection were informed of this study. They participated on a voluntary basis after enough time was given to them and to their parents for reading the participant information sheet, asking clarification, and signing the informed consent.

Procedures

Training Sessions. Mondays, Tuesdays, Thursdays, and Fridays were composed of a morning session (3 hours), including 15 minutes of warm-up, 20 minutes of physical conditioning, 30 minutes of trampoline and tumbling, and the rest of the time the gymnasts worked on the 6 pieces of gymnastics equipment. Wednesdays (3 hours) was composed of morning sessions consisting of 10 minutes of warm-up, 30 minutes of specific physical conditioning, and the rest of the time was for acrobatic training, work on 4 pieces of gymnastics equipment and specific technical work on dismounts. Saturdays morning sessions (3 hours) comprised 30 minutes of physical conditioning, 2 hours of basic exercises on the 6 pieces of gymnastics equipment, and the rest of the time for generic physical conditioning. Afternoon sessions (3 hours) included 30 minutes of specific physical conditioning and work on the 6 pieces of gymnastics equipment for the rest of the time. Gymnasts never trained on Sundays.

Heart Rate Variability Monitoring. All gymnasts were provided with a beat-to-beat HR monitor (Polar, RS800CX; Polar Electro, Kempele, Finland). They were familiarized with the use of this equipment and thoroughly instructed on how to conduct this test. A mock-up session was organized where each gymnast carried out this test himself in front of the researcher and the quality of the data was assessed. The HRV tests took place in the morning. After emptying their bladders (26), gymnasts wore the chest belt and the HR monitor and lay down in the supine position. A metronome (DM-10; Metronome, Soundsation, Porto Recanati, Italy) was set so that the subject would perform 12 paced breaths per minute. Gymnasts were instructed to have the light dimmed and silence. Because athletes shared the same room in pairs, they could assist each other. After recording the beat-to-beat intervals for 6 minutes in this position, an acoustic cue reminded the gymnasts to move to a sitting position. They were asked to continue breathing 12 times per minute in the sitting position for an additional 6 minutes. A second acoustic cue indicated the end of the HRV testing session. The HRV tests were conducted every day, from Monday to Saturday, every other week (weeks 1, 3, 5, 7, and 9). It was

TABLE 1. Gymnasts' characteristics ($n = 6$).

	Beginning of observation period	End of observation period	p
Age (y)	16 ± 2		
Height (m)	1.54 ± 0.09	1.57 ± 0.10	0.031*†
Weight (kg)	46.0 ± 10.8	47.2 ± 9.9	0.149
Body mass index	19.2 ± 2.4	19.07 ± 2.0	0.844*
Thigh skinfold (mm)	7.50 ± 1.92	8.02 ± 1.97	0.241
Pectoral skinfold (mm)	4.91 ± 0.61	4.21 ± 0.45	0.049†
Abdominal skinfold (mm)	6.78 ± 1.19	6.81 ± 1.17	0.944
Jackson-Pollock's body density estimation	1.09 ± 0.00	1.09 ± 0.00	
Brozek's body fat % estimation	5.07 ± 0.84	5.02 ± 0.89	
Biceps circumference (cm)	27.7 ± 3.5	28.2 ± 3.1	0.028†
Waist circumference (cm)	67.5 ± 4.4	69.4 ± 4.5	0.063*‡
Quadriceps circumference (cm)	42.8 ± 3.9	43.8 ± 4.1	0.177

*Data were not normally distributed, Wilcoxon signed rank test was used.
†$p < 0.05$.
‡$p < 0.10$.

decided not to test every single morning for 10 weeks to increase gymnasts compliance. Data were processed by using Kubios HRV software (version 2.0; Department of Physics, University of Kuopio, Kuopio, Finland). Of the 6 minutes recorded in the supine and sitting positions, the first and last 30 seconds were discarded. Artifact correction was carried out using Kubios' artifact correction option; very low correction level was used as default and visual inspection showed noticeable changes in very few cases. Low-quality beat-to-beat data were discarded from the analysis. For the time domain, we have selected mean RR, which is the mean of the beat-to-beat HR intervals (milliseconds) and mean HR (beats per minutes). As recommended by Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (43), we show also the *SD* of all normal heart periods and the HRV triangular index, which is the integral of the RR interval histogram divided by the height of the histogram (42). Concerning the frequency domain analysis, Fast Fourier transform spectrum was used. Because a short-term recoding was considered, very LF band was excluded from the analysis. The LF and HF bands were defined from 0.04 to 0.15 Hz and from 0.15 to 0.4 Hz, respectively. LF% and HF% were calculated as follows: LF (ms^2)/total power (ms^2)·100% and HF (ms^2)/total power (ms^2)·100%, respectively. We also show the LF/HF ratio, which for some may be an index of sympathovagal balance (4). For the nonlinear HRV analysis, we show the *SD* of the Poincaré plot perpendicular to the line of identity (*SD*1) (42) because this was used by Kiviniemi et al (25) to modulate aerobic training.

Performance Tests. The weeks after the HRV evaluations (weeks 2, 4, 6, 8, and 10), gymnasts were asked to undergo a series of performance tests. These tests were conducted at the same time of the day and the same day of the week. The performance testing session always started with blood pressure assessment at rest in the sitting position. Blood pressure was measured by an automatic device (Omron M6; Omron Healthcare Europe, Hoofddorp, The Netherlands).

The performance tests were conducted in a random order and they included 1 repetition maximum bench press (interclass reliability, $r = 0.95$, and intraclass reliability, ICC = 0.98, $n = 10$), squat jump, counter movement jump (interclass reliability, $r = 0.99$, and intraclass correlation coefficient, ICC = 0.99, $n = 8$; for both jumps), standing on 1 foot blind (interclass reliability, $r = 0.66$, and intraclass reliability, ICC = 0.60, $n = 8$), and an agility *T* test (interclass reliability, $r = 0.71$, and intraclass reliability, ICC = 0.79, $n = 8$). The reliability of these tests was obtained from 2 familiarization trials conducted before the start of the observation period on the same 6 gymnasts involved in this study plus 2–4 female gymnasts, who eventually did not participate in the 10-weeks of observation period. The determination of 1 repetition maximum was done after Kraemer et al's description (27), in short 1 minute after a warm-up phase, gymnasts were asked to lift gradually increasing weights (3 minutes rest between weights) until the weight could no longer be lifted successfully. Vertical counter movement jump was performed as developed by Sargent (11) and squat jump as recommended by Bosco (5), gymnasts were asked to get ready to jump in a squatting position (knee angle around 90°) and jump with or without counter movement leaving a mark of the highest reachable point on the wall with the fingers of the right hand, the best of 3 jumps was considered for the analysis. Standing blind and the agility *T* test were carried out as previously described (24). Briefly, gymnasts were asked to stand with their dominant foot on the floor and nondominant foot on the medial face of the knee with

Table 2. Blood pressure and performance tests ($n = 6$).

	Week 2	Week 4	Week 6	Week 8	Week 10	*p*
Systolic blood pressure (mm Hg)	104 ± 8	102 ± 7	104 ± 6	101 ± 15	102 ± 7	0.299
Diastolic blood pressure (mm Hg)	61.8 ± 8.6	62.0 ± 5.8	62.2 ± 7.4	58.2 ± 9.1	59.2 ± 7.1	0.231
1 repetition maximum bench press (kg)	54.8 ± 14.7	49.2 ± 9.4	57.0 ± 7.8	48.6 ± 15.7	63.5 ± 14.7	0.116
Squat jump (cm)	246 ± 21	236 ± 30	246 ± 18	247 ± 20	245 ± 13	0.620
Counter movement jump (cm)	252 ± 23	240 ± 33	251 ± 19	254 ± 25	257 ± 23	0.362
Standing blind (s)	2.58 ± 0.85	3.52 ± 3.14	1.38 ± 0.45	3.18 ± 0.73	2.67 ± 0.98	0.178
Agility *T* test (s)	12.8 ± 0.53	11.9 ± 0.29	12.1 ± 0.99	14.2 ± 1.97	12.5 ± 0.42	0.063*

*Trend for a main effect of time.

their hands on the hips and eyes closed as long as they could. The agility *T* test consisted of running 5 m forward, then always facing forward run 2.5 m to the left, then 5 m right, followed by 2.5 m left, and finally run 5 m backward to the starting point, the best of 2 trials was considered.

Session RPE and Foster's Index. Gymnasts were asked to rate the perception of the effort that they put overall into the training session (14) using a 0–10 Borg scale. Because they always had 2 sessions per day, the average was taken. The training session duration was standard (3 hours). The gymnasts were asked to rate their RPE immediately after ending their training sessions. To keep track of gymnasts' physiological and psychological symptoms, the 7-item Foster's psychological complaint questionnaire was used (15). The Foster's index evaluates in comprehensible and straightforward language general complaints, mood, tiredness, wakefulness, lethargy, dynamicity, and muscle soreness on 0–10 scales. Athletes were asked to fill in this questionnaire in the morning before starting with the morning training session. Although session RPE and Foster's questionnaires were filled in every day for 10 weeks, some data are missing when athletes did not train, were competing, traveled, or for any other reasons they were not in their training routine.

Statistical Analyses. Statistical analysis was conducted using Sigma Stats (Sigma Plot 11; Systat Software, Erkrath, Germany). Unless otherwise mentioned, data are presented as means ± *SD*s. Anthropometric measures collected at the beginning and at the end of the study were analyzed by paired *T* tests. If normality was not satisfied, a Wilcoxon signed rank test was performed. The effect of time on blood pressure and

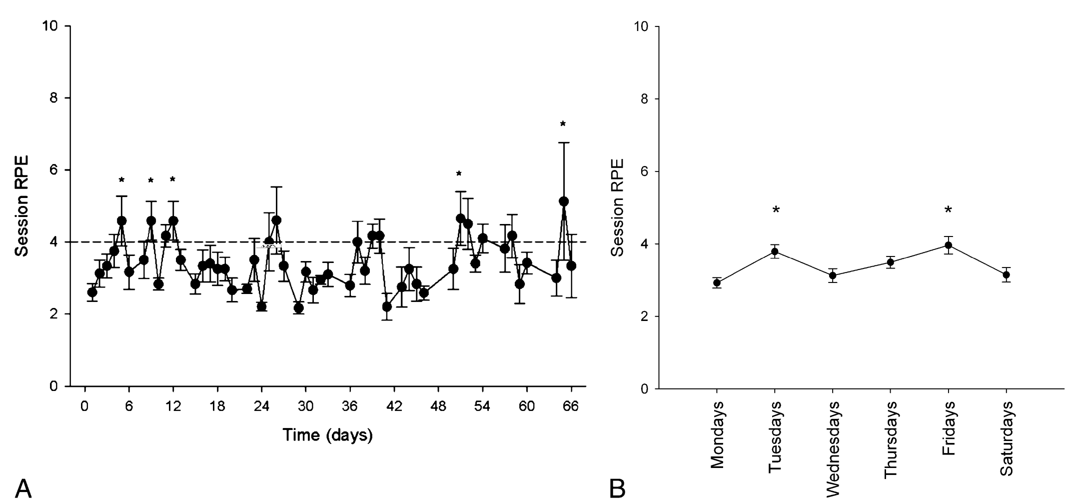

Figure 1. A) Daily average of session rating of perceived exertions (RPE) throughout a 10-week period in 6 elite male gymnasts. *Days with average session RPE significantly higher than in day 41. Dashed line (RPE = 4) corresponds to somewhat hard. B) Averages of each week day. *Averages of week days with average session RPE significantly higher than on Mondays. Data are presented as means ± *SEM*.

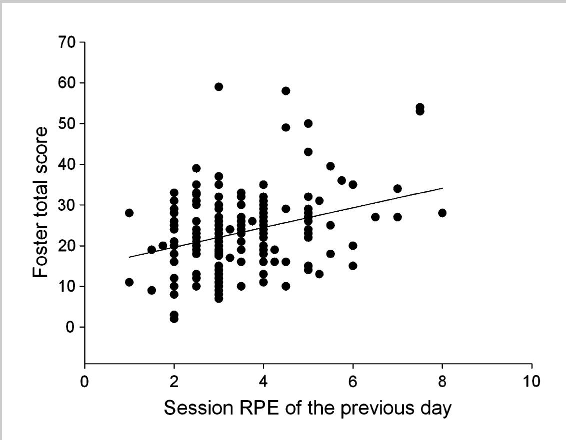

Figure 2. Pearson correlation between Foster total score (where 0 represents no psychophysiological complaints and 70 high complaints) and daily average of session rating of perceived exertion of the previous day ($r = 0.321$, $p < 0.001$, $n = 207$).

performance tests was statistically tested by using 1-way repeated measures analyses of variance (ANOVAs). One-way repeated measures ANOVAs were also employed to test session RPE, Foster's index, and selected HRV features for main effects of time. In case of a significant main effect of time, Tukey's test was used as post hoc test. Pearson correlation coefficients between HRV features and session RPE and Foster's index were also calculated. The significance level was set at 0.05. The probability value for trends was set at 0.10.

Results

Anthropometrics

Data related to gymnasts' anthropometrics are shown in Table 1. We found a small (3 cm) but significant increase in the stature of the gymnasts, whereas body weight did not change significantly. Pectoral skinfold thickness was significantly smaller (0.7 mm) after 10 weeks of observation period. Abdominal and quadricipital skinfold thicknesses did not show any significant change. We observed also a significant increase (0.5 cm) in biceps circumference and a trend toward an increase (1.9 cm) in waist circumference. Quadriceps circumference did not increase significantly.

Blood Pressure and Performance Tests

Blood pressure and strength, explosive power, balance, and agility were monitored every other week for 10 weeks. Data are shown in Table 2. There were no main effects of time for all parameters measured except for the agility *T* test where a trend was found.

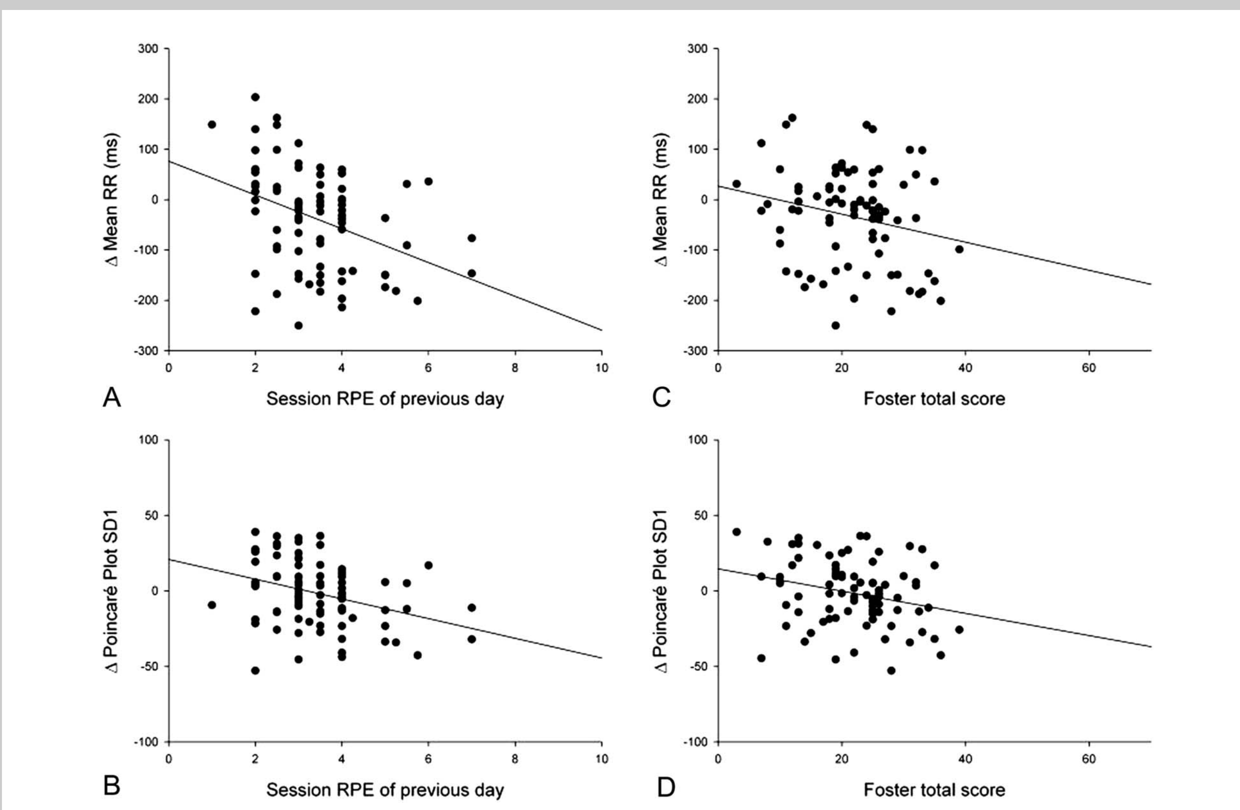

Figure 3. Pearson correlation between day/reference (Monday) difference in mean RR and Poincaré Plot *SD*1 versus daily average of session RPE of the previous day (A, B) and Foster total score (C, D) (see also Table 4).

TABLE 3. Correlations of the supine to sitting differences in heart rate variability (HRV) with training load and psychophysiological status.

Supine sitting difference (%)	Session RPE of the previous day ($n = 87$)	p	Foster total score ($n = 92$)	p
ΔMean RR	−0.320	0.003‡	−0.152	0.149
ΔMean heart rate	0.301	0.005‡	0.012	0.270
ΔSDNN	0.033	0.761	0.006	0.956
ΔHRV triangular index	0.180	0.095*	0.106	0.313
ΔLF%	0.015	0.893	−0.159	0.130
ΔHF%	−0.265	0.013†	−0.159	0.129
LF%/HF%	−0.060	0.581	0.037	0.724
ΔPoincaré plot *SD*1	−0.270	0.011†	0.007	0.948

*$p < 0.10$.
†$p < 0.05$.
‡$p < 0.01$.

Session RPE and Foster's Index

A significant main effect of time was found for session RPE over the 10 weeks of observation ($p < 0.001$). When followed up with Tukey test, we observed that session RPE of day 41 (Saturday) was significantly lower than days 5, 12 (Fridays, $p < 0.05$), 9, 51, and 65 (Tuesdays, $p < 0.05$) (Figure 1A). Foster's index showed a significant main effect of time ($p = 0.002$). Follow-up revealed that on day 11 (Thursday), Foster's index was significantly higher than on days 25, 36, and 46 (Monday, Thursday, and Monday, respectively, $p < 0.05$), and on day 52 (Wednesday). A strong significant positive correlation was found between Foster's index and session RPE of the previous day ($p < 0.001$) (Figure 2). Weekly training monotony was calculated dividing the average session RPE of the week by the *SD* of the session RPE of the same week. No significant main effect of time was observable ($p = 0.148$). When session RPE data were pooled for each week day (e.g., Mondays, Tuesdays, etc.), a significant main effect of time was found ($p = 0.003$), and Tukey post hoc test showed that average session RPE on Mondays was significant lower than on Tuesdays and Fridays (Figure 1B).

Heart Rate Variability

A main effect of time was observed in the mean RR ($p = 0.010$). Follow-up tests revealed differences between day 57 (Monday) and days 3 (Wednesday, $p = 0.006$) and 61 (Friday, $p = 0.039$). Mean HR also showed a main effect of time ($p = 0.031$), but when followed up, no significant differences were found. *SD* of all normal heart periods and HRV triangular index did not show a main effect of time ($p = 0.30$, $p = 0.435$, respectively). In the frequency domain, LF% ($p = 0.200$) and HF% ($p = 0.257$) also did not show a main effect of time.

TABLE 4. Correlations between the day/reference (Monday) difference in heart rate variability and training load and psychophysiological status.

Day HRV/reference HRV difference	Session RPE of the previous day ($n = 88$)	p	Foster total score ($n = 81$)	p
ΔMean RR	−0.384	<0.001§	−0.227	0.041†
ΔMean HR	0.349	<0.001§	0.168	0.133
ΔSDNN	−0.095	0.377	−0.033	0.769
ΔHRV triangular index	0.195	0.068*	0.126	0.261
ΔLF%	−0.352	<0.001§	−0.106	0.347
ΔHF%	−0.138	0.200	−0.204	0.068*
LF%/HF%	0.039	0.716	0.151	0.179
Δ Poincaré plot SD1	−0.332	0.002‡	−0.260	0.019†

*$p < 0.10$.
†$p < 0.05$.
‡$p < 0.01$.
§$p < 0.001$.

When considering the HRV measured in the supine position, session RPE of the previous day significantly correlated with HF% ($r = 0.232$, $p = 0.030$, $n = 88$) and LF%/HF% ($r = -0.279$, $p = 0.008$, $n = 88$). Foster's index showed trends toward correlations with *SD* of all normal heart periods ($r = -0.178$, $p = 0.089$, $n = 92$) and Poincaré *SD*1 ($r = -0.117$, $p = 0.091$, $n = 92$).

More convincing were the correlations between HRV supine sitting difference and session RPE of the previous day. Δmean RR ($p = 0.003$), Δmean HR ($p = 0.005$), ΔHF% ($p = 0.013$), and ΔPoincaré *SD*1 ($p = 0.011$) revealed significant correlations, whereas ΔHRV triangular index a trend for a correlation ($p = 0.095$). No correlations were found between HRV supine sitting difference and Foster's index (Table 3).

When Monday HRV was taken as reference and a given training day HRV minus reference HRV was correlated to session RPE of the previous day, we found that Δmean RR and ΔPoincaré *SD*1 correlated well with both session RPE of the previous day ($p < 0.001$, $p = 0.002$, respectively) and Foster's index ($p = 0.041$, $p = 0.019$, respectively). We also found that Δmean HR and ΔLF% significantly correlated with session RPE of the previous day ($p < 0.001$, both). Finally, we found a trend toward a significant relation between ΔHRV triangular index and session RPE of the previous day ($p = 0.068$) and ΔHF% and Foster's index ($p = 0.068$) (Table 4 and Figure 3).

Discussion

In this study, we observed that HRV reflects training load and psychophysiological status of young elite male gymnasts. It is important to notice that due to their young age (16 years), the athletes tested in this study were in a development phase. Indeed, we have found a small but significant increase in stature over the 10 weeks of observation. Although we did not find any significant changes in body weight, body composition of these young athletes seemed to be changed. In fact, in 10 weeks, we observed a lower subcutaneous adipose tissue in the pectoral region and an increase in biceps circumference, whereas there was a trend toward an increase in waist circumference. Considering that abdominal skinfold thickness did not increase, the greater waist circumference could be due to augmented abdominal muscle volume.

Interestingly, we did not find significant improvements in the performance tests. This outcome was surprising because gymnasts trained all qualities which we have tested: upper limb strength, lower limb explosive power and elastic power, balance, and agility. Because session RPE showed that the majority of the training sessions were below 4 (Figure 1), which corresponds to somewhat hard, and the mean value of 10 weeks Foster average score was 3.24, whereas the maximum Foster average score was 5.24 (5 corresponds to a moderate complaint), we exclude that this lack of improvement in the performance tests was due to overtraining. An explanation for the rather moderate RPE is that because the gymnasts were asked to rate the overall sense of effort perceived during the entire training session, the little effective work on the apparatuses and the high technical requirement may have reduced their ratings. Moreover, in this study, we have monitored HRV that is known to reflect autonomic imbalance, which is a characteristic feature of overtraining (2). By not having a control group, it is difficult to interpret the HRV data with respect to overtraining. However, we did not observe an increase in the LF or a decrease in the HF band over time which might make us further exclude that these gymnasts were overtrained.

Importantly, Foster total score strongly correlates with session RPE of the previous day (Figure 2), giving credit to the good quality, in terms of consistency, of our data set. In our study, morning HRV monitoring resulted as a useful tool to predict the previous day session RPE and the actual psychophysiological status. In detail, we found for morning supine HRV that the HF% was higher if the day before gymnasts had trained at a heavier training load and if the day before the load was higher, the LF/HF ratio was lower and vice versa. This estimated increased parasympathetic activity after a heavier day of training is consistent with the previous literature (30). However, some authors did not observe changes in HRV after the exercise training (2). This discrepancy may be due to the age of the populations studied. In fact, studies conducted in young individuals usually observe increases in HRV measures, but studies in older adults show no changes (2). Moreover, moderate aerobic training state results in a higher morning HF%, whereas this is unchanged in a high aerobic training state (8).

To test the autonomic responsiveness, we also looked at the differences in HRV from the supine position to the sitting position. This analysis has shown much more convincing correlations with the training load of the previous day. In particular, in the time domain, the supine to sitting difference (%) of mean RR and of mean HR correlated to session RPE of the previous day. Supine to sitting Δmean RR negatively correlated with the training load of the previous day, meaning that for heavier training loads, the day before sitting mean RR is greater than supine mean RR the morning after. The opposite occurs for mean HR where supine is greater than sitting after heavier training days. The negative correlation of supine to sitting ΔHF with the session RPE of the day before is consistent with what we found for HF% in the supine position. In fact, even higher HF in the sitting position than in the supine position was generally observed after a heavier training load the previous day. Higher HF is generally expected when supine than when sitting in a balanced autonomic nervous system (33).

Another way to analyze the HRV was to look at the difference between a given training day and a reference day. We have chosen the first Monday as a reference day because gymnasts never trained on Sundays. This is an approach very similar to the one used by Kiviniemi et al (25,26), where the authors modulated the training load considering HF or *SD*1 above or below the reference day. In our study, we found that the given day/reference day Δ*SD*1 had the highest correlation with Foster's index. Moreover, this parameter also correlates well with the training load of the previous day. Although our measuring conditions (supine) were different from the conditions described by Kiviniemi et al (2010) (standing), the negative correlation of a given day/reference day Δ*SD*1 and session RPE of the previous day that we have found is consistent with Kivinimei et al's idea to decrease the training stimulus when *SD*1 was attenuated (25). To us, it is coherent to use this parameter to modulate the training load of gymnasts. Furthermore, it has been shown that Poincaré plot can indicate fatigue after prolonged exercise (19) and could be also used to discriminate between trained and overtrained athletes (32). Also given day/reference day Δmean RR showed a good correlation with Foster's index and session RPE of the day before. Perhaps, this HRV measure could be also used to modulate the training load. Our study seems to confirm that HRV may clarify the relationships between psychological and physiological processes (4). A limitation of this study is the reduced sample size; this is because the Italian national youth selection is composed of a limited number of gymnasts. This study could in the future be extended to the female selection. As future direction to validate the practical value of these HRV markers, a larger trial involving training modulation according to the selected HRV marker should be performed. In conclusion, HRV reflects training load and psychophysiological status in young elite male gymnasts.

Practical Applications

Heart rate variability measures, such as mean beat-to-beat intervals and Poincaré plot *SD*1, could be used as markers of training load and psychophysiological status of male gymnasts. These measures could be easily extracted from commercially available HR monitors, which record RR intervals, and analyzed automatically by free software like the one used in this study. The use of HRV is an objective way for monitoring the training that might reduce the risk of overtraining.

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