Heart Rate Variability Threshold Values for Early-Warning Nonfunctional Overreaching in Elite Female Wrestlers

Ye Tian,[1] Zi-hong He,[1] Jie-xiu Zhao,[1] Da-lang Tao,[2] Kui-yun Xu,[3] Conrad P. Earnest,[4] and Lars R. Mc Naughton[5]

[1]*Biology Center, China Institute of Sport Science, Beijing, China;* [2]*Combat and Weightlifting Administration Center of Anhui province, Hefei, China;* [3]*Elite Sports College, Beijing Sports University, Beijing, China;* [4]*Department for Sport, Health and Exercise Science, University of Bath, Bath, United Kingdom; and* [5]*Department of Sport and Physical Activity, Edge Hill University, Ormskirk, Lancashire, United Kingdom*

Abstract

Tian, Y, He, Z-H, Zhao, J-X, Tao, D-L, Xu, K-Y, Earnest, CP, and Mc Naughton, LR. Heart rate variability threshold values for early-warning nonfunctional overreaching in elite female wrestlers. *J Strength Cond Res* 27(6): 1511–1519, 2013—Functional overreaching (FOR) represents intense training followed by a brief reduction in performance and then a rapid recovery (<2 weeks) and performance supercompensation. Nonfunctional overreaching (NFOR) occurs when the reduced performance continues ≥3 weeks. Heart rate variability (HRV) is a promising tool for detecting NFOR. In this study, the authors examined HRV thresholds in 34 elite female wrestlers (mean ± *SD*: age 23 ± 3 years; height 165.6 ± 6 cm, weight 63 ± 8 kg) for FOR/NFOR during training before 11 major competitions. Supine HRV was analyzed weekly at the same time of day using time and frequency domain methods. The authors observed that the time domain index, square root of the mean of the sum of the squares of differences between adjacent R-to-R intervals (rMSSD, milliseconds), denoting parasympathetic tone, showed those responding normally to training (82.76 ms, 95% confidence interval 77.75–87.78) to be significantly different to those showing a decrease (45.97 ms, 95% confidence interval, 30.79–61.14) or hyper-responsiveness (160.44 ms, 95% confidence interval, 142.02–178.85; all, $p < 0.001$). Similar results were observed for mixed sympathetic and parasympathetic signal standard deviation of the NN intervals (ms): normal (65.39; 95% confidence interval, 62.49–68.29), decrease (40.07; 95% confidence interval, 29–51.14), and hyperresponse (115.00; 95% confidence interval, 105.46–124.54; all, $p < 0.001$) and synonymous frequency domain components. An examination of the 95% confidence interval shows a narrow band surrounding a normal response compared with broader bands accompanying adverse responses. Thus, severe perturbations both above and below normal responses lasting >2 weeks indicated an athlete's transition to NFOR and, hence, are useful for assessing possible overreaching/training.

Key Words parasympathetic modulation, fatigue, performance, pre-competition training

Introduction

Because athletes strive to improve their performance, they invariably increase the frequency, volume, and intensity of training. In doing so, they invariably experience fatigue. This fatigue ranges from short-term "normal" fatigue when recovery is achieved within hours or days to longer-lasting "abnormal" fatigue where recovery is prolonged (31). This latter aspect of recovery can be divided into a number of distinct duration phases, which include functional overreaching (FOR), nonfunctional overreaching (NFOR), and the overtraining syndrome (OTS) (32). Recovery accompanying the FOR state typically occurs within 2 weeks, is a vital part of training, and often used by athletes during a typical training cycle before a period of recovery. It is further hypothesized that FOR stimulates a supercompensation effect and, as a result, increases performance to a level higher than previously attained (10).

With regard to NFOR, however, recovery may take several weeks (i.e., > 3 weeks), eventually leading to the OTS (26). Subsequently, OTS may last months or years, during which time athletes are unable to sustain normal training and have significant decrements in performance, combined with physical and psychological health problems (32). For both athletes and coaches alike, monitoring pre-competition training is important for determining, and

Address correspondence to Dr. Ye Tian, tianye@ciss.cn.

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hence, trying to avoid the occurrence of NFOR or OTS. Autonomic nervous system (ANS) imbalance, as assessed through heart rate variability (HRV), has been proposed as a means of detecting the signs and symptoms of the overtraining (OT) state (22).

Heart rate variability indices are analyzed from the R-to-R intervals (aka, NN) of heart rate recordings have been used as indicators of ANS function (21,23,24,33), and provide a promising tool for detecting an overreaching/overtraining state (1,2). In the OT state, the frequency domain determined index, high frequency (HF), indicating parasympathetic activity, and total power (TP), denoting mixed sympathetic and parasympathetic activities, was shown to be higher in a junior female cross-country skier suggesting an ANS imbalance with extensive parasympathetic modulation (12). An increased low-frequency power (LF), a marker of increased cardiac sympathetic modulation, has also been reported in endurance athletes (35). In the overreached state, previous investigations have found shifts toward both sympathetic (16,29,37) and parasympathetic (30) predominance. A significant increase in low-frequency (LF) spectral power was seen in a mixture of cohorts such as young female endurance athletes (37) and junior rowers (16).

Contrary to the aforementioned observations, LF was either unchanged in elite canoeists (11) or significantly lower in elite runners (30) accompanying overtraining. However, it should be noted that the assessment of LF is of mixed opinions regarding its significance because some investigators interpret LF component as a marker of sympathetic modulation (especially when expressed in normalized units), whereas others view LF to be associated with both sympathetic and vagal influences. Significant and progressive decreases in HF and normalized high frequency power (HFnu) have also been shown in elite middle distance male runners (29) but not in their elite female counterparts after 6 weeks of training (36). Lastly, Earnest et al. (6) showed that continued exposure to prolonged periods of intense cycling exercise during a 3-week Grand Tour of Cycling (Vuelta a Espana) caused a severe reduction in HRV indices in riders serving as "domestiques" vs. those riders who were protected in an effort to "save" them for more important stages where they would contend for stage victories.

The data accumulated to date suggest that few definitive conclusions can be drawn regarding the use of HRV for the diagnoses of FOR/NFOR or OT. While it seems intuitive that a relative state of irrecoverable fatigue induced by training would suppress autonomic function, the literature suggests that some athletes may experience a hyper-reactive response. The primary aim of this study was to use a prospective longitudinal design to determine whether it is possible to predict NFOR using HRV parameters during training cycles leading up to international competition in elite female athletes participating in wrestling. We hypothesized that NFOR can be predicted and thus prevented by monitoring HRV parameters.

Methods

Experimental Approach to the Problem

Initially, we believed that HRV parameters might be valuable in monitoring elite wrestler' training to avoid NFOR. In a short 'pilot study' before the 2007 World Championship, we measured a number of HRV parameters, with meaningful results. On the basis of these results, we embarked on the continued acquisition of HRV preceding 10 international competitions using the criteria observed during this pilot study. At the same time, we also performed a number of case studies because some of the athletes had continuously participated in several competitions. Finally, we summarized the common features with the accumulation of the samples and the measurement data. Hence, the valuable markers and reference thresholds of HRV parameters were obtained for early-warning NFOR.

No later than 6 weeks before each tournament, HRV was measured for each athlete scheduled to participate in the international competitions during 2007, 2010, and 2011 (see Table 1). At the same time, we recorded each athlete's planned training load, the actual athlete's completion load, and the combative scoring capacity for each athlete. On the basis of previous research defining FOR/NFOR and competition analysis and suggestions from the experienced national coaches, the FOR and NFOR state were determined for each athlete (4,26).

Subjects

Thirty-four elite female wrestlers participated in the study. All were medal winners in national and international competitions and were training on the national team preparing for 11 international competitions during 2007, 2010, and 2011 (see Table 1). Athletes were numbered from A1 to A34 to indicate that they had participated in several competitions. The athletes were drawn from the following weight classes and with the following physical characteristics (age, height, weight, percent body fat; mean ± *SD*): 46 kg ($n = 1$, 18 years, 155 cm, 48 kg, 11.8%); 48 kg ($n = 6$, 22 ± 3 years, 158 ± 2 cm, 52 ± 3 kg, 11.55 ± 3.45%); 52 kg ($n = 1$, 18 years, 156 cm, 56 kg, 15.5%); 55 kg ($n = 9$, 22 ± 2 years, 163 ± 3 cm, 61 ± 3 kg, 12.7 ± 1.9%); 60 kg ($n = 1$, 19 years, 164 cm, 66 kg, 21.3%); 63 kg ($n = 8$, 24 ± 2 years; 170 ± 1 cm, 67 ± 1 kg, 15.1 ± 3.9%); 72 kg ($n = 8$, 24 ± 2 years, 173 ± 3 cm, 73 ± 3 kg, 20.2 ± 7.0%). Overall, the athletes $\dot{V}O_{2max}$ ranged from 46.5 to 52.4 $mL \cdot kg^{-1} \cdot min^{-1}$, and peak power output (as determined by a standard Wingate test) ranged from 7.8 to 8.1 $W \cdot kg^{-1} \cdot min^{-1}$. Body weight was measured according to the International Wrestling Federation's official regulations. Percent fat was calculated with skinfold thickness according to the formula of Brozek et al. (3). Written informed consent was obtained from each subject before the start of the study, which was approved by the local institutional ethics committee (China Institute of Sport Science, China). Subjects were informed about the procedures and aims of the study, and subjects gave their written consent to participate.

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Table 1. The subjects and the monitored period.*

Competitions	N1	Athletes participated in several competitions
2007 Senior World Championships	4	A14
2010 World Cup	14	A1, A2, A4, A5, A6, A7, A8, A9, A14, A15
2010 Asian Qualifying Tournament for the YOG	3	A13
2010 Youth Olympic Games	1	A13
2010 Junior Asian Championships	5	A3, A6, A10, A11
2010 Junior World Championships	5	A3, A4, A6, A10, A11
2010 Senior Asian Championships	7	A1, A2, A5, A8, A9, A12, A15
2010 Senior Combat Games	3	A7, A10,
2010 Senior World Championships	7	A1, A2, A4, A8, A12, A15
2010 16th Asian Games	4	A1, A4, A8,
2011 Senior World Championships	7	A1, A3, A4,

*Athletes were numbered from A1 to A34 to indicate that she had participated in several competitions.

Maximal Oxygen Consumption ($\dot{V}O_2$.max)

All subjects performed a graded treadmill (Erich Jaeger Treadmill E6, Hoechberg, Germany) test to determine maximal oxygen consumption ($\dot{V}O_2$.max) using a breath-by-breath monitoring system (Oxycon Champion, Jaeger, Germany). After a warm-up (15 min of self-controlled low-intensity running), the exercise test commenced at a speed of 8 $km \cdot h^{-1}$ followed by increases of 0.8 $km \cdot h^{-1} \cdot min^{-1}$ until 16 $km \cdot h^{-1}$; thereafter, the grade was increased in 1.0% increments each minute until the subject reached voluntary exhaustion. Heart rate values were collected continuously throughout the test using a Polar Vantage heart rate monitor (Polar, Kempele, Finland). The criteria for ($\dot{V}O_2$.max) attainment were respiratory exchange ratio $\geq$1.1 and a change in ($\dot{V}O_2$.max) in the last 30-second interval $\leq$5% or 100 $mL \cdot min^{-1}$. Fingertip blood samples for blood lactate analysis (YSI 1500; Yellow Springs Instruments, Yellow Springs, OH) were obtained 4 minutes after the end of the test.

30-Second Wingate Test

The Wingate test was performed using a cycle ergometer (Monark 894E Monark Exercise AB, Vansbro, Sweden). A warm-up preceded the test consisting of voluntary running on a treadmill followed by voluntary bicycle pedaling for 2–4 minutes against a light resistance. During the cycling warm-up, 2–3 short 4- to 8-second sprints were performed. After the warm-up, a 3- to 5-minute rest was allowed before beginning the Wingate test. To start the test, subjects accelerated their pedaling velocity against no resistance for 5 seconds to achieve maximal pedaling velocity. Then the resistance used for testing was added and the 30-second test began. During the entire 30 seconds of the test, the wrestlers pedaled as fast as possible against a resistance relative to body weight (0.080 $\times$ body weight) (40). Peak anaerobic power, anaerobic capacity, and fatigue index (peak power − minimum power/peak power) were calculated using the software supplied by the manufacturer (Monark 894E, version 2.2; Sweden).

Measurement of Heart Rate Variability and Training Load

Heart rate variability was measured weekly using the OmegaWave sport technology system (OmegaWave Technologies, LLC, Portland, OR, USA) as described in the manufacturer's reference manual and standardized guidelines for the measurement of HRV (17). The following time domain indices (in milliseconds) were analyzed and are assumed to represent ANS activity (24,33): the standard deviation of all normal RR (SDNN) and square root of the mean of the sum of the squares of differences between adjacent RR (rMSSD). Frequency domain parameters include total power (TP − ms^2), low-frequency power (LP − ms^2), high-frequency power (HP − ms^2), and low-to-high frequency ratio (LF:HF). Whereas the HF component is generally defined as a marker of vagal modulation, the LF component depends on both the sympathetic and parasympathetic nervous systems. The LF:HF ratio reflects the global sympathovagal balance and can be used as a measure of ANS balance (17).

Training loads varied on a weekly basis and were divided into high, medium, and light load with an adjusted week according to the individual training requirements. In the high-load week, the training was high-load training in the morning (9:00–12:00 AM) and afternoon (3:00–6:00 PM) on Monday, Tuesday, Thursday, and Friday with low-load training on the Wednesday and Saturday morning. In the medium-load week, the intensity and volume were either both reduced to half or only 1 was reduced to half. The light-load week comprised only 3 half-day low-load training, whereas in the adjusted week, athletes undertook recreational activities comprising basketball, football, and other team or individual activities at a low level. Hence, the measurements

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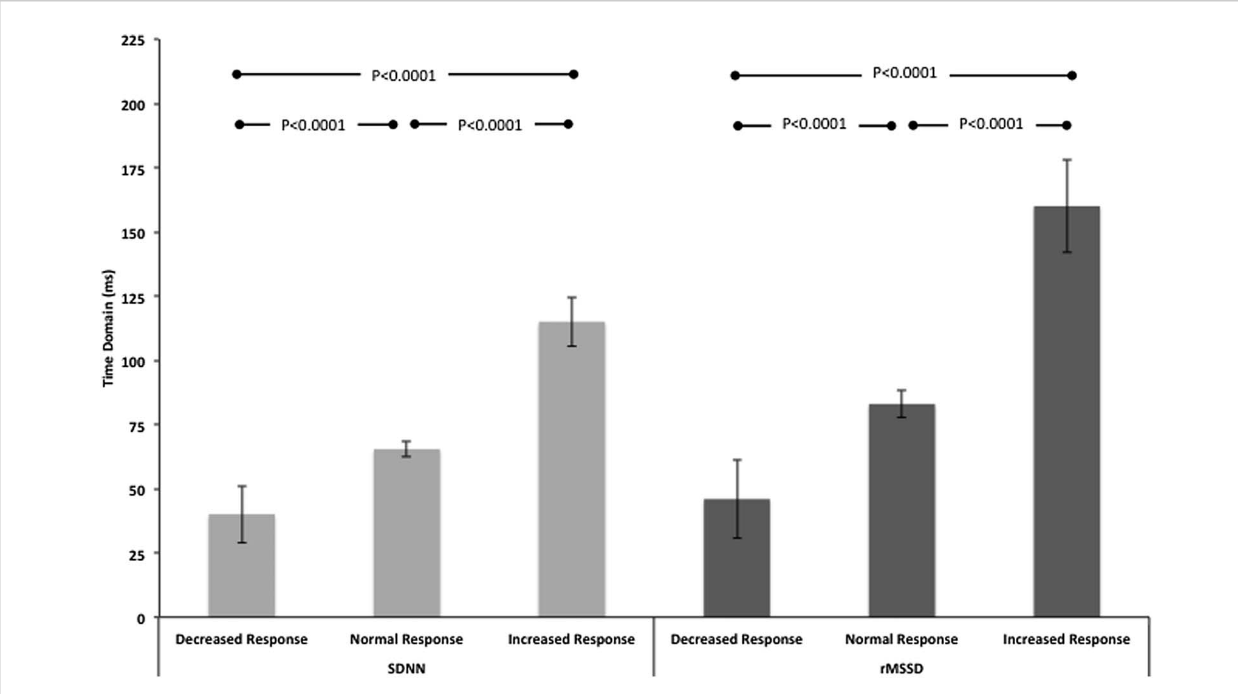

Figure 1. Data are mean and 95% confidence interval for the time domain indices representing the standard deviation of all normal RR intervals (SDNN) and the square root of the mean of the sum of the squares of differences between adjacent RR (rMSSD). All pairwise comparisons are significant ($p < 0.0001$).

were performed between 1900 and 2200 hours (before sleep time and in order not to disturb sleep) in the supine position in a quiet setting on the Sunday evening after the athletes had a full recovery. For a given athlete, she was assessed at the same time each week to avoid circadian variations among individuals (24). Room temperature and humidity were controlled at 26 ± 1° C and 50 ± 5%, respectively.

The Classification of Functional Overreaching/Nonfunctional Overreaching

As mentioned previously, the definition of FOR/NFOR/OTS used to classify athletes was derived from the previous reference data (4,26), which was then integrated with the suggestions of the experienced national coaches.

Overreaching (OR) for female wrestlers is a state of training because of an increment of training load or other stresses, such that the athletes are unable to sustain high-intensity training and have a decreased performance capacity. Although they are usually able to start a normal training program, they are unable to complete the training load they are given and hence have to significantly adjust their training program load. After 2 weeks of appropriate recovery regimens for the athlete, full recovery may occur and the process of OR may have stimulated a supercompensation effect, with performance increasing to a level higher than previously attained, which is called FOR. Athletes were categorized as NFOR if episodes lasted from 2 to 6 weeks or as OT if the episodes lasted for >6 weeks. If the wrestler could not maintain the normal training program and the performance decrement continued beyond 6 weeks, they were dropped from the national team. Altogether, we defined the NFOR period from 2 to 6 weeks, and hence, this research concentrated on the overreaching analysis.

Performance Assessments

Wrestling is a complex sport that demands a number of specific characteristics, such as maximal strength, aerobic endurance, and high anaerobic capabilities to achieve success in competition (20,39). Hence, it is difficult to select 1 or 2 specific performance indices, which are related to competition performance, and it is also difficult to design tests that diagnose specific performance under laboratory conditions. Furthermore, it is impractical to measure the specific capacity index each week, especially in the pre-competition training. In this study, the evaluation of improvement in competition performance was scored by experienced coaches using a 5-point scale combined of competition rank, behavior, and score rate. A grade of 0 indicates that the athlete is "off her game" and performance is significantly decreased, whereas grade 1 means the performance is "better than 0" but still "well below normal." Grade 2 denotes that the performance of the athlete is "slightly" below normal. Grade 3 represents "no improvement" from the original level and grade 4 shows that the performance is "slightly enhanced." A score of grade 5 indicates that the performance has increased significantly and the athlete is performing at a high level. For example, 1 athlete won the third place in the

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TABLE 2. Frequency domain parameters for HRV in normal recovery and overreached female wrestlers.*

	State	*N*	Mean	95% CI Lower bound	95% CI Upper bound
TP (ms²)	Decreased response†	29	865.76	258.95	1,472.57
	Normal response	216	1,655.17	1,451.46	1,858.87
	Increased response‡	32	5,422.59	4,427.95	6,417.24
LF (ms²)	Decreased response	29	228.86	65.77	391.95
	Normal response	216	318.26	278.70	357.82
	Increased response‡	32	1,052.19	781.33	1,323.05
HF (ms²)	Decreased response†	29	539.59	106.74	972.44
	Normal response	216	1,224.37	1,039.67	1,409.08
	Increased response‡	32	4,151.81	3,196.84	5,106.78
LF/HF	Decreased response†	29	0.7276	0.4511	1.0041
	Normal response	216	0.4079	0.3414	0.4743
	Increased response	32	0.3656	0.2392	0.4921
VLF (ms²)	Decreased response	29	97.24	29.13	165.35
	Normal response	216	112.59	100.05	125.13
	Increased response‡	32	218.56	151.35	285.77

**N* = the total number of measurements of all athletes when they are normal recovery or overreaching state accompanying with the decrease or increase of HRV parameters; HRV = heart rate variability; CI = confidence interval.
†$p < 0.05$ for decreased response vs. normal response.
‡$p < 0.0001$ for increased response vs. normal response.

World Championships held in 2007, and she also got the third place in 2010. At the same time, the score rate was decreased compared with that in 2006 and she lost to the opponent who had been defeated by her in the last year. We defined her as in "2" grade. After 2 weeks of recovery, the athlete got grade "0" or "1," and she was considered to be in NFOR state during the preparation for the competition.

Training Load Assessment

Three main approaches have been adopted to quantify weekly and annual training loads by the coaches. The first was the observational approach, based on documented training details, including program arrangement, type and duration of a training session, fulfillment scale of the plans and training behaviors, absence in programmed training sessions, fluid intake, and athlete's injury on a daily basis. The second approach consisted of monitoring heart rate, blood lactate concentration, and blood ammonia concentration during training to obtain information on the intensity of training. Diet, nutritional intakes, medication, and weight were also monitored weekly. The third approach consisted of obtaining the self-assessment of the athlete by daily/weekly monitoring of self-scored questionnaires and a subjective estimate by the coaches. The questionnaires examined the athlete's perception of training adaptation, general stress levels, fatigue, quality of sleep, infection, concentration, anxiety, irritability, and muscle soreness. The evaluations of the coaches on some of these parameters were also recorded.

Statistical Analyses

All analyses were performed using SPSS (version 13.0; SPSS, Inc., Chicago, IL, USA). Normal recovery data are presented as mean and 95% confidence interval (CI) for mean. The comparisons of HRV parameters between overreaching states and normal recovery were analyzed by the 1-way analysis of variance (ANOVA), using athlete's age as the covariate. Post hoc test (Fisher's least significant difference) was used to determine where significant differences were present if the ANOVA showed a significant difference. To minimize the risk of a Type I error arising from numerous between-group comparisons, all statistical analyses were corrected for mass significance (13). The level of significance was set a priori at $p < 0.001$.

RESULTS

Nonfunctional Overreaching Incidence Rate

During the monitoring period, 7 athletes were diagnosed to be in the NFOR state (21%). Among them, 2 athletes were diagnosed with NFOR twice, and there were therefore 9 cases of NFOR. Two athletes were diagnosed to be in the FOR state once.

Valuable Markers and Assessment Reference Thresholds

The overreaching state was concurrent with the fluctuation of HRV parameters. When these elite athletes were in an overreached state, the HRV parameters seemed to have 2

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types of changes. One was a significant decrease, whereas other wrestlers exhibited a significant increase in HRV indices. Those with a normal response were classified as "normal" and examples of these responses for the time domain indices of rMSSD and SDNN are presented in Figure 1. The time domain indices SDNN and rMSSD were statistically significant for each pairwise comparison (all, $p < 0.0001$).

Table 2 shows the frequency domain parameters for HRV in normal recovery and overreached female wrestlers. As for TP, HF, LF, and very low frequency, there was significant difference between increased response and normal response athletes (all, $p < 0.0001$) but not between those exhibiting a decreased response and those with showing a normal response to training. As for LF:HF, there was significant difference between decreased and normal responders ($p = 0.002$); however, there was no significant difference between the high and normal responders ($p = 0.662$).

Discussion

The primary finding from this study is that we were able to identify athletes involved in strenuous international competition using HRV to determine FOR and NFOR. Interestingly, these athletes demonstrated either an increase or decrease in several HRV indices examining parasympathetic and mixed nervous system activities. For those athletes experiencing NFOR, the associated change in HRV indices persisted for 3 weeks or more, each with a concurrent decrease in physical performance. Overall, therefore, periods of excessive training with inadequate rest likely result in ANS imbalance. Despite the observation of both an increased and decreased HRV responses, our observations and hypotheses are supported in the literature by studies showing increased exercise-induced plasma levels and the unstable urinary excretion of catecholamine's in overtrained athletes (21,23).

In general, 2 clinical forms of overtraining have been noted involving sympathetic and parasympathetic changes (22). The early stages of overtraining, often referred to overreaching phase, are characterized by an increase in sympathetic autonomic tone. If overreaching continues, overtraining develops and is marked by a predominance of parasympathetic tone (22). Under this scenario, it has been postulated that sympathetic tone increases because of an overstimulation of the sympathetic nervous system secondary exercise training and inadequate periods of recovery. Eventually, this condition evolves into a combination of inhibition, desensitization, and exhaustion of the neuroendocrine system, whereby the parasympathetic modulation then dominates (1,8,22,38). Thus, the relative state of overreaching/overtraining reflected by the neuroendocrine system may account for the varied response in HRV indices we observed in this study.

Unfortunately, it is difficult to determine the neuroendocrine contributions of HRV perturbations because only rMSSD (1,9,27) and HF (25) can be used to examine parasympathetic activity, whereas SDNN and LF represent mixed sympathetic and parasympathetic tones. Moreover, although there are no blood values to substantiate the directionality of the HRV changes we observed, the HRV changes we did observe are easy to obtain and noninvasive. Thus, from a practical standpoint, if an athlete did present with persistent increases or decreases in HRV accompanying training, they could then follow-up with blood work rather than undertake the cost burden of sequential blood work and analysis.

Overall, it is our opinion that based on our findings and the results of others that HRV can be used as an "early warning system" to detect whether an athlete is overreaching, or more importantly, overtraining. In our study, we found 2 distinct HRV fluctuation patterns that if exceeded for 2 weeks, regardless of directionality, impeded recovery time. One pattern is where the HRV indices, rMSSD, SDNN, and HF, were significantly reduced, and simultaneously, the LF:HF ratio was significantly increased. In essence, if the LF:HF ratio encompasses both sympathetic and parasympathetic tones, then an increase in the LF:HF ratio would be driven by the decrease in HF, which serves as the denominator of the HRV LF:HF ratio equation. This NFOR state seemed to be the consequence of an imbalance between prolonged periods of training, where the training load was too high, with too little time for recovery.

The second pattern is where the HRV parameters were significantly increased. During this increased NFOR state, we observed that athletes were under too much accompanying psycho-emotional stress, such as too many competitions and too many nontraining stress factors (social, educational, occupational, economical, nutritional, travel, and time stress). These latter points cannot be ignored as the ANS function is associated not only with overreaching/overtraining, but with cardiovascular disease risk and a number of health-related issues, such as mood, depression, anthropometry, cognitive, executive functioning, and vagal control of the cardiovascular system (5,7,14,17–19,34). Thus, contributors to alterations in HRV can be caused by various physical and psychological stimuli, which can ultimately be "exhausting" and should be given equal consideration when attempting to assess an athlete's health while in an overreached or overtrained state. Therefore, it is conceivable that NFOR can be both sympathetically and parasympathetically driven, potentially giving coaches insight into both the physical and psychological components of an athlete's health.

The information about changes in HRV because of overreaching/overtraining is sparse, and the findings are inconsistent. Hedelin et al. (8) investigated 9 canoeists before and after a training regimen corresponding to 50% increase in normal training load applied for 6 days. No significant differences were found in HRV parameters, and they concluded that the HRV data did not support an altered autonomic balance in these athlete. A case study by the same authors in a junior cross-country skier showed increased HF and total

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power in the supine position compared with before and after, and no significant change in LF power, suggesting an increased parasympathetic activity (12). In another study, the HRV parameters, rMSSD, TP, LP, HP, and LF/HF of 12 severely overtrained athletes, were measured during sleep and when awake. Overtrained athletes had lower HRV especially SDNN and LF component that control athletes after awakening. This difference could not be seen during night sleep; however, overtrained athletes had larger decreases in awakening HRV components than control athletes (15).

Pichot et al. (29) assessed ANS activity in 7 middle distance male runners during their usual training cycle (3 weeks heavy training, followed by a relative resting week). The HF and HFnu showed a significant decrease from week 1 to week 3 and a significant increase from week 3 to week 4. Their results confirmed that heavy training shifted the cardiac autonomic balance from parasympathetic to sympathetic drive. Uusitalo et al. (37) studied a study in which 15 endurance-trained women were divided into either high- or low-intensity training groups. This resulted in an overtraining of the former group after a period of 6–9 weeks. The main finding from this group was a significant increase in the LF component in high-intensity group when obtained in the supine position but not in the low-intensity training group. Iellamo et al. (16) studied 7 Italian junior rowers during a 20-day period before the rowing World Championship. At 100% training load, the LF showed an increase, whereas the HF component decreased. The study by Iellamo et al. (16) and Uusitalo et al. (37) supports the previous study by Pichot et al. (29). However, the work of Portier et al. (30) is contradictory to these 3 studies (16,29,37).

These authors (30) tested 8 runners twice, after a relative rest period of 3 weeks, followed by a 12-week intense training period for endurance. They found that the LF was significantly lower in the supine position. In another study (28), 6 sedentary men successfully completed 2 months of intensive cycle ergometer training and 1 month of overload training followed by 2 weeks of recovery. During the intensive training period, physical performance increased significantly as did the HRV parameters HF, rMSSD, PNN50, and SDNN. There was also a significant shift in the ANS toward a predominance of its parasympathetic arm (LF/HF, LFnu, HFnu). During the overload training period, there were no significant changes in the parasympathetic indices (PNN50, rMSSD, SDNN, and HF), which suggest a progressive increase in the sympathetic activity as determined by the LF:HF ratio (28).

A strength of this study is that we examined a relatively large cohort of international female wrestlers, who showed that an increase and decrease of parasympathetic activity were both accompanied by the occurrence of overreaching. In a practical training environment, the state of OR/OT is caused by the sport-specific stress caused by the periodization of training (physiological stress) or nontraining factors (psychological and social stresses) or a combination of the 2. This may be manifested by various symptoms of overreaching/overtraining and then fluctuations in a variety of HRV parameters. However, this study is not without potential limitations. Because the subjects were top athletes, the sample was still somewhat small, despite being larger than similar studies from other athletic populations. As to a given athlete, 1 or 2 HRV parameter data were not measured during preparing for a given competition because she had changed training plan or had participated in meetings or social activities. It should also be noted that we cannot report on the athletes' body composition and rapid fluctuations in anthropometry may affect HRV. We also do not have any laboratory performance parameters to help substantiate these findings. Still, it must be remembered that wrestling is a complex sport that demands a number of specific characteristics, such as maximal strength, aerobic endurance, and high anaerobic capabilities to achieve success in competition (20,39). Hence, it is difficult to select 1 or 2 specific capacity indices, which are related to competition performance, and it is also difficult to design tests that diagnose specific performance under laboratory conditions. We could also be criticized for not accounting for hydration status and acute dietary restrictions that often accompany weight loss practices in wrestlers. However, it is not standard practice for Chinese wrestlers to engage in acute weight loss practices during training or before matches through dehydration or food reduction. Specifically, the athletes are monitored to avoid this scenario. These are, however, points that should be carefully considered when monitoring an athlete when using HRV. Overall, we feel that these results are intriguing as coaches must bear in mind that the elite athlete is also young and does not live in a cloistered environment but must exist with a number of psycho-social stressors also influencing their lives.

In the overreaching state, the HRV parameters (SDNN and rMSSD) measured at night and before sleep increased or decreased significantly compared with normal recovery in the supine position. Although athletes in a FOR state needed only 1–2 weeks to recover, those moving into an NFOR state needed more than 3 weeks to recover regardless of the directionality of the HRV indices we measured.

Practical Applications

This study provided additional information regarding the assessment of overreaching using the noninvasively derived indices of HRV as a diagnostic criterion. Therefore, HRV may serve as an easily derived "early warning system" that is easily obtainable. When large perturbations in HRV are noted for an athlete that persisted for longer than 2 weeks, this may aid in determining further follow-up testing that is more invasive in nature, such as measuring plasma catecholamine's and inflammatory markers. Coaches and athletes can use the HRV parameters reference thresholds to monitor training and hence avoiding

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the occurrence of NFOR/OT in preparing for important international competitions.

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