【Original paper】

Characteristics of Overtraining Indices in National Collegiate Athletic Association Division I Female Cross Country Runners During a Single Competitive Season

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ABSTRACT

This study aimed to investigate the season-long characteristics of overtraining markers in 9 National Collegiate Athletic Association (NCAA) Division I female cross country runners (N=9, Age=19.0 ± 0.8 yrs) and to determine group differences in these markers when divided by training volume and injury status. Participants underwent pre, mid-1, mid-2, and post season data collections throughout the cross country season. Resting Heart Rate Variability (HRV) collection and completion of the sport-specific Recovery Stress Questionnaire (RESTQ) were conducted monthly. HRV time and frequency domain measures, $\dot{V}O_2$max (ml/kg/min), RESTQ scores, average weekly training mileage, and chronic injury incidence were collected. No significant team changes in HRV, $\dot{V}O_2$max, or RESTQ scores were observed during the season. When divided into training groups (Cutoff=36 miles/week) $\dot{V}O_2$max was significantly higher in the high mileage (HM) group than the low mileage (LM) group ($p<0.05$). Significant main effects ($p<0.05$) between training groups were found in 8 stress RESTQ subscales and in the Total Stress category ($p<0.05$). Observable, non-significant differences in HRV trends throughout the season suggested progressively decreasing autonomic nervous system recovery in the HM group. Significantly higher Emotional Stress, Social Stress, Physical Complaints, Injury, and Total Stress ($p<0.05$) were discovered in the injured group. The data suggests that no state of overtraining was reached by the entire team over the season, however the increased perceived stressed measures and trends of decreasing HRV observed in the HM training group indicated a tendency towards overtraining, and warrants caution in any further training without adequate rest.

KEYWORDS: Recovery, HRV, Overtraining, Stress

I. Introduction

For collegiate athletes, sport participation when injured negatively affects competitive performance as well as regular daily activities associated with the college lifestyle[29, 31]. Previous research has suggested that at least 80% of student athletes from a single National Collegiate Athletic Association (NCAA) Division II college claimed that they sometimes or frequently experienced physical and mental fatigue during a competitive season[32]. Without adequate recovery, continued training at high intensities with frequent athletic exposures and added academic obligations places the collegiate athlete at considerable risk for injury[28, 29, 34]. In endurance athletes, the risk of suffering from an overuse injury has been reported to increase up to fivefold for those who are not adequately recovered[28]. It is of pivotal importance for health care professionals to monitor athlete's recovery status, and to be able to recognize possible signs and symptoms of the physiological state known as overtraining[32].

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Overtraining occurs when a given training load exceeds adequate recovery, resulting in health and performance deterioration[24)]. Classifications of overtraining are defined by time to recovery of normal health and performance, and range from functional overreaching (symptoms lasting days to weeks) to overtraining syndrome (symptoms lasting for several months or longer)[8)]. Physical and psychological symptoms including performance decrements and varying degrees of fatigue, depression, bradycardia, irritability, insomnia, hypertension, and loss of motivation are exhibited by overtrained athletes[18)]. Previous research has investigated a variety of indicators for identifying this complex phenomenon, which include survey questionnaires[5, 15)], physical and psychomotor test performance[24)], and autonomic nervous system control[1, 22, 24)].

The state of excessive stress induced by overtraining has been associated with a shift in normal autonomic nervous system (ANS) modulation, especially evident in the cardiac cycle[8, 24)]. This autonomic imbalance can be detected noninvasively by analyzing heart rate variability (HRV), the variation of time between consecutive heartbeats (i.e., RR intervals) influenced by each branch of the ANS[9, 10, 25)]. Heart rate variability is quantified using both time and frequency domain measures (Table 1) utilizing the electrocardiography (ECG). Time domain measures express overall variability via the standard deviation of normal to normal intervals (SDNN), while the square root of the mean of the sum of squares of differences between adjacent normal to normal intervals (RMSSD) represents vagal modulation. Frequency domain measures indicate both parasympathetic and sympathetic input via high frequency (HF) power and the ratio of low to high frequency powers (LF/HF), respectively. Low frequency (LF) power indicates both sympathetic and parasympathetic modulation of the cardiac cycle[3)]. Trained athletes have demonstrated an increased overall HRV and parasympathetic modulation over sedentary controls[7)], yet in a state of overtraining a shift to sympathetic dominance has been shown to occur[12, 25)] . Given the ANS's sensitivity to heavy training, HRV may be a useful tool for monitoring stress and recovery[26)].

Overtraining has been correlated to skill level, as research suggests that up to 64% of elite athletes may experience overtraining at least once in their career[4)]. Additionally, considering a higher risk of overtraining among endurance athletes[4)] with a greater prevalence of running injuries in females versus males, the NCAA Division I female cross country runners are potentially vulnerable population to overtraining and injury[16, 32)] [27)] To our knowledge, the literature regarding characteristics in HRV, as well as other overtraining markers, in competitive athletic seasons among the NCAA Division I

Table 1: Abbreviations and descriptions of heart rate variability time and frequency domain measures and their relation to the modulation of HRV by each branch of the autonomic nervous system [3].

Time Domain Measures of HRV			
Variable	**Unit**	**Description**	**Relation**
RR	ms	Interval between adjacent R-R peaks	Total variability
SDNN	ms	Standard deviation of all normal-to-normal (NN) beat intervals	Total variability
RMSSD	ms	Square root of the mean of the sum of the squares of differences between adjacent NN intervals	Parasympathetic
NN50	count	Number of pairs of adjacent normal R-R intervals that differ by more than 50 ms	Parasympathetic
PNN50	%	NN50 count divided by total number of all NN intervals	Parasympathetic
Frequency Domain Measures of HRV			
LF	normalized unit	Low frequency power	Sympathetic-parasympathetic
HF	normalized unit	High frequency power	Parasympathetic
LF/HF	ratio	Ratio of the low-to-high frequency power	Sympathovagal balance

female cross country athlete is scarce[8].

Therefore, the purpose of this study was to investigate the season-long characteristics of overtraining markers including HRV indices, perceived stress and recovery, injury, and performance throughout a single competitive season in a team of NCAA Division I female cross country runners. The comparisons of those overtraining marker were made based on the effects of a weekly training mileage and the status of injury. It was hypothesized that post-season measurements would reveal significantly increased overtraining markers demonstrated by increased perceived stress and injury, decreased perceived recovery, HRV, and performance when compared to baseline. It was also hypothesized that athletes who experienced higher training volume during the season and those who were chronically injured would present with increased overtraining markers than lower training volume group and injury-free groups, respectively.

Ⅱ. Methods

1. Research Design

A repeated measures design was conducted, consisting of four data collection periods before, during and after the competitive NCAA Division I cross country season (August to November 2016). The pre-season data collection was completed prior to, or during the first week of practice. Two mid-season collections were completed at the end of first and second months of the season. The post-test data collection was administered during a tapering period following the last competition, which was determined individually based on each athlete's qualification for post-season competition. Training load was recorded daily for the duration of the season. Independent variables included time, training volume, and injury status. Dependent variables were overtraining markers including HRV indices, the Recovery-Stress Questionnaire for athletes (RESTQ-Sport) scores, and performance measure as indicated by maximal oxygen consumption ($\dot{V}O_2max$).

2. Participants

Nine NCAA Division I female cross country athletes (Age= 19.0 ± 0.8) participated in this study. Inclusionary criteria included classification as low-risk according to American College of Sports Medicine (ACSM) guidelines for exercise testing[23]. Exclusionary criteria included actual or suspected pregnancy and any lower extremity injury in which the athlete must be removed from activity for 3 weeks or longer[6]. The procedures used in the present study were approved by a university institutional review board committee on human subjects.

3. Procedures

All data were collected over a total of 6 sessions at the University of Hawai‘i, Mānoa's Human Performance Laboratory. Participants were given standardized written and verbal instructions prior to the start of all test sessions, and were asked not to consume caffeine or alcohol, or exercise at least 3 hours prior to collection. Participants gave informed consent and completed a health history questionnaire at the first testing session. Pre- and post-season collections consisted of two separate 60-minute test sessions each. For both pre- and post-season collections, the first test session consisted of HRV measurement and completion of the RESTQ, and the second test session included collection of anthropometric measurements including skinfold and waist circumference and completion of the graded exercise testing (GXT) protocol. Two mid-season collections were conducted; each included one 60-minute session for HRV and completion of the RESTQ.

1) Electrocardiographic HRV Analysis

Following collection of anthropometric data, participants were instructed to lie supine or semi-reclined on a massage table, in a comfortable position in which they remained throughout the HRV data collection period. The HRV data were collected using CardioCard™ Software Version 6.01i (Nasiff Associates, Inc., NY, USA). For the ECG, electrode placement sites were cleaned and prepped according to current recommendations[17]. The right and left arm electrodes were placed below the right and left clavicles, respectively. The right and left leg electrodes were attached to the right and left sides of the trunk, below the tenth rib on the anterior axillary line. The V5 chest electrode was placed to the left of the fifth intercostal space on the anterior axillary line. Participants were instructed to relax and breathe at a normal, self-determined pace, remain as steady as possible, and to remain awake during the data collection period[19]. Participants had an initial 10-minute acclimatization period, after which the five-lead ECG was set up to collect inter-beat intervals as well as average heart rate (HR).

Electrocardiographic data was exported from CardioCard™ Software and artifacts and ectopic beats were rejected and interpolated. The series was then imported into Kubios Heart Rate Variability Software Version 2.0 (University of Kuopio, Kuopio, Finland)[30] where low-level artifact correction was applied and the sample length was set to five minutes and adjusted to find a stable pattern. Trend components were removed using a "Smooth n Priors" method[3]. Window width for fast Fourier transformation was set at 512 seconds with the window overlap set at 50%. Interpolation of the inter-beat intervals (RR series) was set at 4 Hz. Frequency bands for HRV analysis were set as follows: Very Low Frequency (VLF=0-0.04 Hz), Low Frequency (LF=0.04-0.15 Hz), and High Frequency (HF=0.15-0.4 Hz) for 15 minutes[3]. The time domain parameters (RR series) addressed the magnitude of variability (SDNN) and provided information about the vagal modulation (RMSSD, NN50, pNN50) of the heart. The frequency domain parameters provided information about parasympathetic modulation (HF), sympathovagal balance (LF), and sympathetic modulation (LF/HF)[3].

2) Body Composition Assessment and GXT

The second testing session (to occur within one week of the first session) included body composition assessment and a GXT. Body mass index was calculated using height and body mass. Body composition was calculated using waist circumferences and skinfold thickness measurements[23]. Jackson and Pollock's three skinfold site protocol was used to determine skinfold thickness[13]. All measurements were assessed on the right side of the body at the triceps, supra-ilium, and thigh, and assessed in an alternating pattern to allow for skin elasticity restoration. The average of two measurements was taken if the second was within 2 mm of the first. Otherwise, the average of 3 measurements was recorded[21].

For the GXT a HR monitor was dampened and tightly fitted to the bare skin over the xiphoid process. Blood was taken via the finger-prick method to determine pre-test blood lactate concentrations. Each participant was given verbal explanation of the Borg's 15-point Ratings of Perceived Exertion (RPE) scale[2] and the multi-stage modified Astrand protocol on a Star Trac Treadmill (Unisen Inc., CA, USA). Determination of self-selected running pace was conducted prior to the start of the GXT, with participants unaware of the treadmill speed chosen for the test. Participants were allowed to warm up and stretch prior to 5 minutes of near-race pace running on the treadmill, followed by 3 minutes of rest and then a second blood lactate measurement. The participants were then fitted with headgear, mouthpiece, and nose clip, after which they began the GXT. The first 3-minute stage of the GXT was conducted at the predetermined speed (mph) selected for the five-minute near race-pace running and at a 0% grade. Incremental increases in percent grade continued every 2 minutes for the duration of the GXT while speed remained constant. Ratings of perceived exertion, HR, respiratory exchange ratio, and $\dot{V}O_2$ (ml/kg/min) were recorded at the end of every stage of the GXT. Verbal encouragement was provided to each participant for the duration of the GXT. The test was terminated at volitional exhaustion. Immediately following termination of the GXT, participants completed a five-minute self-directed active cool-down and a grade of 0%. Seven minutes after completion of the GXT, post-test blood lactate concentration was measured. Determination of maximal effort was based on ACSM guidelines for maximal exertion, including RPE >17, > 8 mmol blood lactate concentration, a plateau in oxygen consumption, respiratory exchange ratio greater than 1.10, and a failure of HR to increase with increased exercise intensity[23)]. The same GXT protocol was employed at the end of the season measurement.

3) Perceived Stress Measures

The Recovery-Stress Questionnaire for Athletes (RESTQ), was used to aid in the detection of overtraining symptoms[4, 15, 24)]. The RESTQ-Sport consisted of 19 different subscales of the physical, emotional, and social aspects of stress and recovery. There were seven Stress Subscales (General Stress, Emotional Stress, Social Stress, Conflicts or Pressure, Fatigue, Lack of Energy, and Physical Complaints), five Recovery Subscales (Success, Social Relaxation, Physical Relaxation, General Well-being, and Sleep Quality), three sport-specific Stress Subscales (Fitness, Emotional Exhaustion, and Disturbed Breaks), and four sport-specific Recovery Subscales (Being in Shape, Personal Accomplishment, Self-regulation, and Self-efficacy). Each scale had four items, each rated on a 7-point Likert scale (0=Never, 6=Always). A Total Stress category was also included, which added the RESTQ's 10 general and sport-specific stress subscales and provided a comprehensive measure for physical, emotional, and social stressors including fatigue and injury.[14)]. The RESTQ scores were obtained at 4 data collection periods.

4) Daily Training Load, Treatment, and Injury Tracking

Training load (daily training time and miles including running and cross training) was self-recorded by the athletes daily via the Running2Win smartphone application (Athletic Performance Tools, LLC, OH, USA), and collected by the team's Board of Certification (BOC) certified athletic trainer (ATC). In order to retain equal sized low and high mileage training groups, 36 average weekly miles was chosen as a cutoff point. Athletes also self-recorded maintenance and injury-specific treatments received in the athletic training room by way of a NExTT kiosk (Vivature, TX, USA) containing a finger-print login system which allowed the athlete to pick the body part being treated and type of treatment received. Treatment options available on the kiosk included heat and cold therapy, manual therapy, rehabilitation exercises, and various modalities including electrical stimulation and ultrasound.

Injury and illness data was collected throughout the season by the cross country team's ATC using NExTT injury tracking software. Athletes were assigned to an injury group based on classification by injury type and time loss as documented by the team's ATC. The non-injured group (NI) either reported no injuries during the season or experienced a chronic or acute injury that required less than 2 weeks of normal training alterations, while the injured group (CI) experienced one or more injuries that affected normal training for two weeks or longer.

4. Statistical Analysis

Data were analyzed using the Statistical Package for the Social Services (SPSS) version 23. Descriptive statistics were reported for pre-season physical characteristics and HRV characteristics at each time point. Mixed method two-way repeated measures analysis of variance (ANOVA) was used for comparison of team overtraining markers (RESTQ scores and HRV) and performance ($\dot{V}O_2max$) data over time, and then to investigate the differences between low mileage (LM) and high mileage (HM) groups, as well as injured and chronically injured group on overtraining markers and performance data over time. Adjustments were made to RESTQ scores (a value of 4 added to each subscale) in order not to violate statistical assumptions and remove any zero measures. Partial eta squared was utilized for reporting effect size as follow: 0.01 (small), 0.09 (medium) and 0.25 (large). The statistical significance was determined at an alpha level of p<0.05. Pearson's correlation coefficient was used to assess relationships between injury incidence, treatment received, and average training miles.

Ⅲ. Results

1. High vs Low Mileage Groups

Pre-season physical characteristics of the participants (N=9) are listed in Table 2. All 9 participants completed all the data collection sessions, and competed in the entire season. Overall, there were no changes throughout the season in max and body composition. The low mileage group (LM ≤ 36 average weekly miles) had significantly lower $\dot{V}O_2$max scores (LM= 49.5 ± 3.3 ml/kg/min, HM= 58.9 ± 5.4 ml/kg/min). Weekly training miles in season ranged from 21.8 to 79.3, with an average of 41.6 ± 17.3 miles as a team. For the analysis. the team was divided into two training groups with a cutoff of 36 average weekly miles in order to obtain comparable group sizes (LM= ≤ 36 mi/week; n=5: HM= > 36 mi/week; n=4). There was no significant interactions between groups overtime, in any of the HRV indices, body composition, and $\dot{V}O_2$max performance, however, the LM group presented a significantly lower $\dot{V}O_2$max (49.5 ml/kg/min, $F_{(1,7)}$=10.32, p=0.015) than the HM group (58.9 ml/kg/min). Time and training group interactions as well as time and group main effects were also not significant in HRV measures, although RMSSD neared significance ($F_{(1,3)}$=3.004, p=0.064) in time and training group interaction (Table 3). In the RESTQ subscale scores, time and training interactions did not reach significance, nor did scores change significantly over time. Significant main effects between training groups were found in 8 RESTQ subscales and in the total stress category, which are listed in Table 4.

2. Injured vs Non-injured Groups

When divided the participants into non-injured (n=5) and injured group (n=4), no significant differences were observed in $\dot{V}O_2$max scores between groups, nor were interactions observed between injury group and time (pre and post measurements). The only HRV component significantly different in the group main effect was SDNN ($F_{(1,6)}$=11.1, p=0.021) and no significant group-time interactions were observed. A significant main effect in group was observed in emotional stress, social stress, physical complaints and injury, as well as the total stress scores (ps<0.05: Table 5).

3. Daily Treatment and Injury Status

Thirteen (7 acute, 6 chronic) injuries and illnesses were logged in the NExTT tracking system during the cross country season. Fifty five percent of these occurred in the upper leg (hip, thigh, and knee), while lower leg (leg, ankle, foot), back, and illnesses each made up about 15% of remaining reported conditions. Over the season a total of 294 treatments were logged, with the highest number of these recorded in the second month of the season, and the fewest during the last month, or at the post-season, data collection. A moderate but non-significant correlation of r=0.661 (p=0.052) was found between total treatments received and total injuries recorded during the season. There was a significant negative correlation (r=-0.882, p=0.002) between the number of treatments received and

Table 2: Total team, training group*, and injury group** average pre-season physical characteristics of the University of Hawaii women's cross country athletes.

	Unit	Total (N=9) Mean ± SD	LM Group (n=5) Mean ± SD	HM Group (n=4) Mean ± SD	NI Group (n=5) Mean ± SD	CI Group (n=4) Mean ± SD
Age	yrs	19.0 ± 0.8	18.8 ± 0.5	19.6 ± 1.3	19.0 ± 1.2	19.0± 0.0
Height	inches	65.5 ± 3.2	67.5 ± 2.4	62.9 ± 2.6	63.8 ± 2.8	67.6 ± 2.8
Body Mass	lbs	124.0 ± 16.6	128.4 ± 15.7	118.4 ± 20.6	118.3 ± 21.0	131.1 ± 10.9
Resting Heart Rate	bpm	48.7± 5.8	52.8± 4.7	44.5 ± 4.4	46.6 ± 6.4	52.0 ± 4.6
Percent Body Fat	%	16.2 ± 3.1	15.2 ± 2.3	17.5 ± 4.2	16.5 ± 4.0	15.8 ± 2.6
Maximum Heart Rate	bpm	185.5 ± 8.6	185.8 ± 9.2	185.0 ± 9.1	189.0 ± 9.9	181.0 ± 3.9
VO_2max	ml/kg/min	53.7 ± 6.4	49.5 ± 3.3†	58.9 ± 5.4	55.0 ± 7.9	52.1 ± 4.5

No significant changes throughout the season; SD=Standard diviation; *Training groups indicated by Low Mileage (=LM: ≤36 average weekly miles) and High Mileage (=HM: >36 average weekly miles); **Injury groups indicated by Non-Injured (NI) and Chronically Injured (CI); †Significant different at p=0.015

Table 3: Season-long Heart Rate Variability Time and Frequency Domain Data (Mean ± SD) by groups (Mileage and Injury Status)

Measure (unit)	Pre-season	Mid-season 1	Mid-season 2	Post-season
SDNN (ms)				
LM	72.6 ± 33.6	74.2 ± 24.4	81.8 ± 33.5	105.0 ± 30.5
HM	58.3 ± 24.0	51.4 ± 17.7	48.0 ± 32.7	46 ± 24.4
NI†	51.0 ± 4.9	48.7 ± 15.5	35.4 ± 10.2	61.8 ± 49.8
CI	82.0 ± 20.5	77.9 ± 20.5	98.6 ± 49.8	85.4 ± 25.0
Total	64.3± 26.9	61.2 ± 22.5	62.4 ± 35.1	71.9 ± 40.1
HR (bpm)				
LM	54.2 ± 4.8	57.1 ± 8.7	54.5 ± 1.9	51.1 ± 3.7
HM	44.2 ± 10.5	44.6 ± 7.3	44.2 ± 5.8	44.4 ± 4.3
NI	42.0 ± 8.0	47.0 ± 13.0	45.0 ± 7.0	44.0 ± 4.0
CI	56.0 ± 2.0	52.0 ± 5.0	53.0 ± 3.0	51.0± 4.0
Total	48.5± 9.5	50.0 ± 9.9	48.6 ± 7.0	47.3 ± 5.9
RMSSD (ms)				
LM^	49.2 ± 40.2	95.0 ± 40.1	109.2 ± 39.5	163.7 ± 70.1
HM	87.8 ± 47.3	77.2 ± 27.7	69.4 ± 48.2	65.1 ± 39.1
NI	80.6 ± 50.0	69.2 ± 26.6	51.1 ± 16.9	100.8 ± 98.5
CI	58.8 ± 45.9	105.7 ± 28.8	133.6 ± 12.2	116.1 ± 28.3
Total	71.3 ± 45.6	84.9 ± 31.8	86.5 ± 46.2	107.3 ± 72.0
NN50 (count)				
LM	130.9 ± 31.1	133.0 ± 25.2	142.0 ± 36.2	180.0 ± 35.8
HM	94.9 ± 60.7	99.8 ± 71.9	80.3 ± 67.6	74.0 ± 69.8
NI	97.3 ± 60.4	94.5 ± 66.8	63.5 ± 41.5	104.5 ± 101.9
CI	127.8 ± 36.5	140.7 ± 28.2	164.0 ± 12.3	139.3 ± 40.1
Total	110.3 ± 50.4	114.3 ± 55.9	106.6 ± 61.6	119.4 ± 77.9
LF (n.u)				
LM	35.1 ± 13.7	42.6 ± 8.9	34.1 ± 11.8	26.8 ± 14.7
HM	24.7 ± 11.5	31.0 ± 9.5	37.1 ± 14.8	37.9 ± 23.6
NI	26.3 ± 13.0	38.4 ± 6.5	41.3 ± 7.9	27.8 ± 24.9
CI	33.0 ± 13.7	32.7 ± 16.0	28.4 ± 15.5	40.2 ± 10.0
Total	29.2 ± 12.6	36.0 ± 10.8	35.8 ± 12.6	33.1 ± 19.7
HF (n.u)				
LM	62.3 ± 12.5	54.8 ± 11.2	62.8 ± 13.6	70.1 ± 16.4
HM	70.2 ± 17.5	66.5 ± 10.0	57 .0± 17.7	60.2 ± 25.2
NI	69.6 ± 17.9	59.0 ± 8.0	52.6 ± 10.3	70.3 ± 26.9
CI	63.1 ± 12.3	64.8 ± 16.3	68.7 ± 17.3	56.7 ± 7.8
Total	66.8 ± 14.9	61.5 ± 11.4	59.5 ± 15.1	64.5 ± 20.8
LF/HF (ratio)				
LM	0.61 ± 0.40	0.80 ± 0.31	0.59 ± 0.33	0.43 ± 0.28
HM	0.41 ± 0.28	0.49 ± 0.20	0.75 ± 0.44	0.90 ± 0.88
NI	0.44 ± 0.30	0.67 ± 0.21	0.83 ± 0.32	0.66 ± 0.94
CI	0.56 ± 0.33	0.58 ± 0.42	0.48 ± 0.40	0.74 ± 0.29
Total	0.49 ± 0.29	0.63 ± 0.29	0.68 ± 0.37	0.69 ± 0.69

n.u=normalized unit; SD=Standard diviation; Training groups indicated by Low Mileage (=LM: ≤36 average weekly miles) and High Mileage (=HM: >36 average weekly miles); **Injury groups indicated by Non-Injured (NI) and Chronically Injured (CI); SDNN= Standard diviation of all normal-tonormal (NN) beat intervals; HR= Heart rate; RMSSD= Square root of the mean of the sum of the squares of differences between adjacent NN intervals; NN50= Number of pairs of adjacent normal R to R intervals that differ by more than 50 ms; LF= Low frequency power; HF= High frequency power; LF/HF= Ratio of the low-to-high frequency power; ^Group x Time interaction neared significance: p=0.064; †Significant group main effect: p=0.021

Table 4: Recovery Stress Questionnaire (RESTQ) scores (Mean ± SD) in low mileage versus high mileage subgroups with training group as main effect.

RESTQ Subscale	LM* Group (*n*=5) Average Score (Mean ± SD)	HM** Group (*n*=4) Average Score (Mean ± SD)	*F*	*p*	Effect Size ($\eta 2p$)
General Stress	9.8 ± 3.2	6.6 ± 2.0	15.2	0.008††	0.721
Emotional Stress	11.1 ± 3.8	7.9 ± 1.8	16.6	0.007††	0.734
Social Stress	9.9 ± 3.8	7.9 ± 1.6	8.0	0.03††	0.571
Fatigue	13.4 ± 4.5	8.1 ± 3.0	38.7	0.001††	0.866
Physical Complaints	11.6 ± 4.3	10.3 ± 3.4	7.9	0.03††	0.570
Disturbed Breaks	8.9 ± 2.4	6.1 ± 2.2	7.2	0.036†	0.547
Emotional Exhaustion	11.0 ± 3.5	7.1 ± 2.1	34.3	0.001††	0.851
Injury	14.9 ± 6.8	10.7 ± 4.2	8.2	0.028†	0.578
Total Stress	80.3 ± 29.5	49.4 ± 22.2	32.1	0.001††	0.843

SD=Standard Diviation; Training groups indicated by Low Mileage (=LM: ≤36 average weekly miles) and High Mileage (=HM: >36 average weekly miles); †Significant group main effect at p<0.05; ††Significant group main effect at p<0.01.

Table 5: Recovery Stress Questionnaire (RESTQ) scores (Mean ± SD) in stress subscales based on injury status with the group as main effect.

RESTQ Subscale	*N*	CI* Group (*n*=5) Average Score	NI* Group (*n*=4) Average Score	*F*	*p*	Effect Size (*η2p*)
General Stress	**9**	3.1 ± 3.1	5.0 ± 2.5	0.84	0.40	0.122
Emotional Stress	**9**	4.0 ± 2.1	6.4 ± 3.3	6.55	0.04†	0.522
Social Stress	**9**	3.6 ± 1.5	5.9 ± 3.6	10.91	0.02†	0.645
Fatigue	**9**	5.3 ± 3.7	9.2 ± 5.8	4.37	0.08	0.421
Physical Complaints	**9**	5.6 ± 3.4	8.5 ± 3.7	10.50	0.02†	0.636
Disturbed Breaks	**9**	2.0 ± 2.5	5.1 ± 2.3	3.52	0.11	0.370
Emotional Exhaustion	**9**	3.6 ± 2.3	6.7 ± 4.0	3.38	0.12	0.360
Injury	**9**	6.6 ± 2.7	12.0 ± 3.9	7.18	0.04†	0.545
Total Stress	**9**	51.6 ± 22.9	72.9 ± 34.0	7.91	0.03†	0.569

SD= Standard diviation; *Injury groups indicated by Non-Injured (NI) and Chronically Injured (CI); †Significantgroup main effect at $p<0.05$

average weekly training miles.

Ⅳ. Discussion

The premise of this study was to examine both objective and subjective responses to a cross country season's worth of training in the context of overtraining markers typically seen in endurance athletes. The traditional unexplained underperformance associated with non-functional overreaching and overtraining[18] was not observed over the course of the season for this team: autonomic nervous system modulation (HRV), RESTQ scores indicating perceived stress and recovery, and maximal oxygen consumption (i.e., our indicator of performance) were not significantly altered from the beginning to the end of the season. What was readily apparent, however, is that unlike typical team sport athletes, these cross country runners underwent diverse training regimens in regards to daily

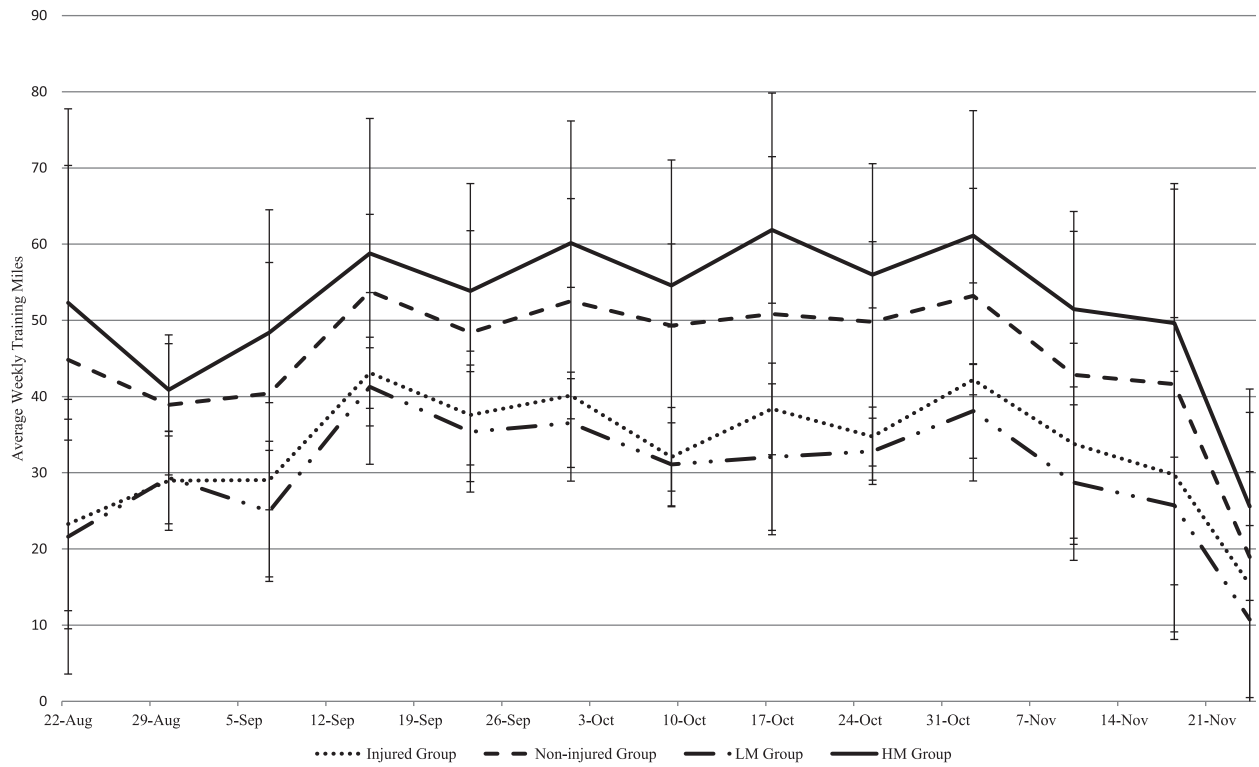

Figure 1. Average weekly training miles in low versus high training subgroups, compared with chronically injured versus non-injured subgroups

mileage. Although the week-to-week variation in training appeared similar between groups (Figure 1), the highest trained athlete ran or cross-trained upwards of 90 miles during some weeks, while LM athletes may have only run 25 miles per week. This may be due, in part, to injury and treatment status, considering that three of the four LM athletes in this study were considered chronically injured but remained competitive as indicated by the significant negative correlation (r=-0.882, p=0.002) between the number of treatments received and average weekly training miles. The prevalence of running injuries among competitive NCAA Division I female cross country athletes in the current study was not surprising as the previous studies reported that female runners would have much higher prevalence of running injuries when compared with the male counterpart[4, 16, 27, 32)]. The training mileage could also have been influenced by the fact that many cross country runners also competed in the spring track and field season. As such, the varying training demands of different track events (e.g., a “middle distance” 800m run versus a “long distance” 10k run) may be another possible explanation for the widely-varied training volume between athletes during the fall season. Nonetheless, this variation in training provided researchers an interesting opportunity for comparing training responses between the LM and HM athletes.

When divided into groups based on training miles, the low mileage group (LM ≤ 36 average weekly miles) had significantly lower $\dot{V}O_2$max scores (LM= 49.5 ± 3.3 ml/kg/min, HM= 58.9 ± 5.4 ml/kg/min). Additionally and interestingly, the LM group scored significantly higher scores in 8 of 10 stress subscales of the RESTQ, indicating that LM group had a higher perception of stress. While the causative factor of poorer $\dot{V}O_2$max scores and higher stress levels in the group with less training volume cannot be explained from the results of current study, it could be hypothesized that the stress level did lead to a negative performance in the training outcome.

Season-long differences between training groups did not reach statistical significance, nonetheless trends in season changes were observed between training groups both in objective and subjective overtraining markers. As shown in Figure 2 on the season changes in the RESTQ scores, while absolute perceived stress markers in the LM group began significantly higher than the HM group, they tended to decrease over the season. Conversely, while the HM group’s absolute stress scores were lower in most cases than the LM group, the stress subscales disturbed breaks, emotional exhaustion, injury, general stress, emotional stress, social stress, fatigue, and physical complaints all remained greater than baseline at the post-season measurements.

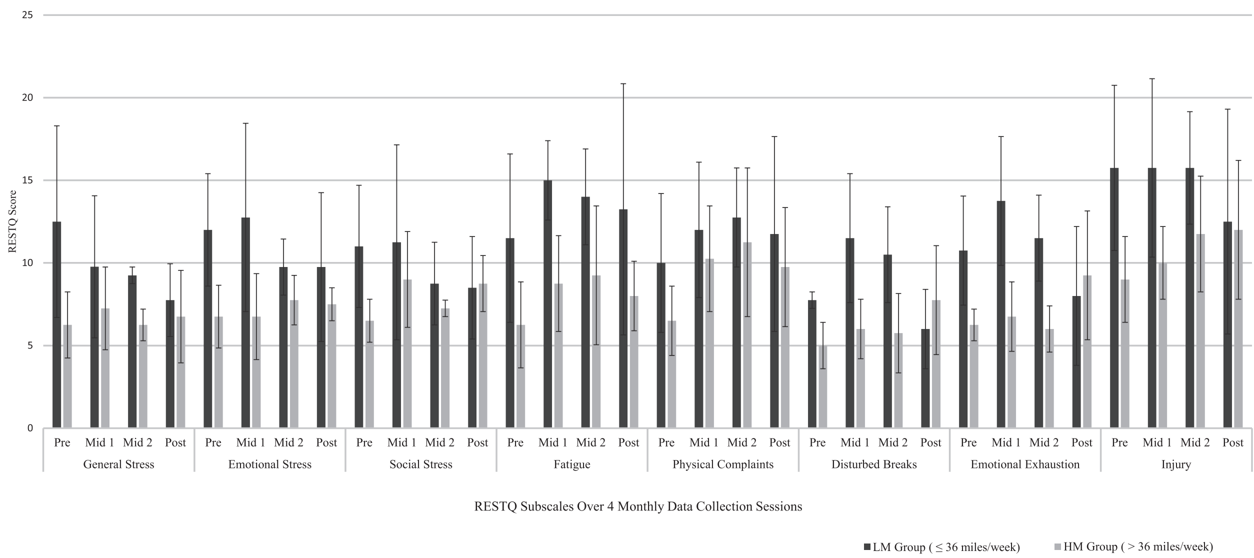

Figure 2. Graphic representation of season changes in RESTQ Subscales Between Training Groups (LM ≤ 36 miles/week, HM ＞ 36 miles/week)

Likewise, differences in season-long changes did not reach significance in HRV indices; however again the opposite behaviors were seen in nearly every time and frequency domain measure between groups. The LM group demonstrated increases in SDNN (overall variability), RMSSD, NN50, PNN50, and high frequency power (parasympathetic modulation) over time. Furthermore, the low to high frequency ratio which indicates sympathovagal balance, or sympathetic input, was decreased over the season.[3] As it has been theorized that parasympathetic hyperactivity does occur during functional overreaching, the shift from sympathetic to parasympathetic modulation we noted in these measures would indicate a normal adaptation to the imposed training load, such has been found in previous studies where an intensified training load was applied by the researchers[20]. In the HM group however, time domain measures including SDNN, RMSSD, NN50 and PNN50 all decreased with the season's end, suggesting decreased parasympathetic input on the cardiac cycle. Additionally, an increase in the LF power and LF/HF power ratio increased at each time point during the season, demonstrating a shift towards sympathetic drive of the ANS. Although the existing literature on ANS state and overtraining is conflicting, the trending decreased vagal activity that was noted in the HM group is consistent with research that has been conducted on overtrained triathletes and middle distance runners, although the subjects in said studies were observed over more acutely imposed training loads[25, 26].

From an injury standpoint, higher training mileage did not appear to increase the incidence of injury. Three of the four runners in the HM group were free of injury, and the one who did sustain a chronic injury during the season had a history of similar injury within the previous year, thereby making it difficult to directly relate injury to the current season's training volume. This begs the question of whether the HM athletes could run more because they were uninjured, or whether they were uninjured because they were better trained and therefore better able to adapt to the high training load demanded of them without becoming injured, as research has suggested that athletes who experience high chronic workloads are more resistant to injury, especially when subjected to spikes in acute workload[11]. The chronically injured (CI) group of participants exemplified higher RESTQ stress measures and lower $\dot{V}O_2$max (although non-significant) values than the uninjured (NI) runners, and yet they appeared to have significantly higher SDNN than the non-injured group, indicative of greater overall heart rate variability and suggesting that they recovered well over the season[25, 26]. This increased autonomic recovery could be a result of the lower mileage most these athletes sustained due to injury, but also could have been affected by athlete initiative in visiting the athletic training room for recovery and maintenance treatments. Of course, the higher RESTQ stress scores in the CI group could be explained by the stress of coping with injury. However, another explanation for this phenomenon which has been suggested by researchers in a study of Division I athletes using the Positive States of Mind scale (PSOM), is that athletes who are able to adopt more positive mind states; or perhaps less perceived stress-are less at risk for injury[33].

One factor limiting the long-term clinical relevance of this study was the length of time that the athletes were monitored. As previously mentioned, Division I cross country athletes commonly, after a short tapering period, continue training and competition for 5-6 months following the conclusion of cross country season as they participate in both indoor and outdoor track seasons. According to the training response measures used in this study, the LM athletes were recovered by the end of the season and may have been at an advantage for shortly beginning training again over the HM group, who appeared not to be as well-recovered. To detect a negative response to the long duration of training that Division I athletes realistically face, future research should pursue these athletes through continued training to see if changes in recovery, stress, injury and performance changed in the following track seasons. Additionally, daily or weekly measurements of HRV may give better information the autonomic nervous system modulation in response to training throughout the season as opposed to only 4 measurements. There are many possible confounding factors that could affect stress and recovery in the collegiate athlete. Among components such as academic pressures, college sport experience, nutrition, and travel, athlete progression into post-season competition (i.e. NCAA regional and national competitions) may also have an influence the post-season recovery status. A study which included these factors could gain a more comprehensive understanding of the training response.

In conclusion, from a statistical approach the training regimen in this particular team did not induce a state of overtraining, demonstrated especially by maintenance of a high level of performance throughout the season. However, as the training load imposed on these runners varied greatly, so did the stress, recovery, and performance measures observed during the season, making it of little use to draw conclusions about the team's overtraining state as one whole. While the higher mileage athletes generally exhibited higher $\dot{V}O_2$max values and lower absolute RESTQ stress subscale scores, they also showed decreased overall heart rate variability in addition to vagal modulation of the ANS, and they reported to the athletic training room for recovery treatments less than the LM group. As the season progressed, their perceived stress levels increased and HRV decreased, which inspires us to question what would happen if these highly trained athletes who, as collegiate cross country runners often do, continue heavy training into indoor and outdoor track seasons. The stress and recovery measures that were utilized in this study were able to give us snapshots in time of the many-faceted nature of overtraining status, however the short duration of our study and infrequent data collections were somewhat of a limitation to the clinical application of this information in the long-term; longer observation of this population is necessary because as clinicians it is important to be aware of the risks posed on athletes who undergo the type of training that may put them at risk for the illness, injury, or poor performance that we know can result from a lack of recovery. Future research should consider longitudinal effects of a training season on cross country athletes which extends past the cross country season itself. Additionally, coaches, athletic trainers, and athletes should be aware that their higher training volume athletes may not continue exhibiting the same high levels of performance if trends of physiological and perceived stress continue in the fashion observed in this study.

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