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Internal Training Load Measures During a Competitive Season in Collegiate Women Lacrosse Athletes

JENNIFER B. FIELDS†[1,2], MICHAEL R. ESCO‡[3], JUSTIN J. MERRIGAN†[1,2], JASON B. WHITE‡[1,4], and MARGARET T. JONES‡[1,2]

[1]Frank Pettrone Center for Sports Performance, George Mason University, Fairfax, VA, USA; [2]School of Kinesiology, George Mason University, Manassas, VA, USA; [3]Department of Kinesiology, University of Alabama, Tuscaloosa, AL, USA; [4]Exercise Physiology, Ohio University, Athens, OH

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(4): 778-788, 2020. Monitoring internal load provides useful and non-invasive markers of training stress and adaptation. However, the relationship between internal load measures across a competitive window remains inconclusive and limited. The purpose of this study was to report various internal load measures, as well as their relationship, across a season in Division I women lacrosse athletes (n = 20). Ultra-short natural logarithm of the root mean square of successive differences (lnRMSSD), salivary testosterone, cortisol, the testosterone:cortisol ratio, and self-reported measures of fatigue and recovery were collected weekly for 13 weeks. Means ± SD were calculated to provide descriptive values and a repeated measure analysis of variance (ANOVA) was used to analyze changes in testosterone, cortisol, testosterone:cortisol ratio (n = 8), and lnRMSSD (n = 8) over the course of the season. Pearson correlations assessed relationships between all internal load measures. No significant time effect was observed in testosterone (p = 0.059), cortisol (p = 0.544), testosterone:cortisol ratio (p = 0.120), or lnRMSSD (p = 0.062). lnRMSSD was correlated with testosterone (r = 0.265), cortisol (r = -0.232), testosterone:cortisol ratio (r = 0.345), and fatigue (r = -0.256) (p < 0.05). More research is needed to examine relationships among markers of internal stress across all phases of the training cycle. Routine monitoring may help practitioners optimize training programming to reduce injury, illness, and overtraining.

KEY WORDS: Athlete monitoring, internal stress

INTRODUCTION

A primary goal of training for sport is to enhance performance. Progressive overload, defined as the gradual increase of stress on the body during exercise, has been shown to elicit training adaptations. However, a balance between periods of overload and recovery must be achieved if adaptations are to be engendered and overtraining prevented (16). It is the internal stress that provides a quantification of an athlete's training response to a given stimulus and should be a major consideration when monitoring athlete load (17).

There are currently 375 National Collegiate Athletic Association (NCAA) women's lacrosse programs with participation increasing steadily since 2001 (23). Despite its popularity and the high physical demands associated with the sport, no studies have examined training load responses in women's collegiate lacrosse. Lacrosse has been described as the "fastest game on two feet" and is considered one of the most strenuous women's team sports (30). The game involves two halves lasting 25-30 minutes, each, and requires quick transitions with abrupt changes in speed and direction, continuous activity, and high-intensity sprints up and down the field over a long duration. Therefore, lacrosse elicits the involvement of both aerobic and anaerobic energy systems, with collegiate women players averaging a VO_{2max} of 42.8 ± 4.4 ml $kg^{-1} \cdot min^{-1}$ (9, 30, 34). The sport's physical demands tax the cardiovascular, muscular, and endocrine systems (9, 30). However, research is needed to explore the stress response associated with these high demands.

There are several markers that are used to quantify an athlete's internal stress response to a given training stimulus, including physiological, hormonal, and self-assessment scales. Resting heart rate variability (HRV), as measured by the natural logarithm of the root mean square of successive differences (lnRMSSD), has been suggested as an effective tool for monitoring fitness and recovery status due to its non-invasive and time efficient nature (7,11). Additionally, the testosterone (T) to cortisol (C) ratio (T:C) provides information in regard to the anabolic-catabolic hormonal balance in response to training. Since women produce 5-to-7 times less T, it is believed C responses may differ from those of their male counterparts (3). Thus, specific research toward these hormonal responses to training specifically in women athletes are needed. In addition, there are many objective markers for monitoring training load, yet the value of self-assessment scales should not be underestimated. High levels of fatigue and poor ratings of recovery have been related to sport performance (3, 5), but little is known about their relationship to physiological and hormonal markers.

Internal training load markers have been measured on a limited basis in women collegiate athletes, with no data reported on women lacrosse athletes. In women collegiate soccer athletes, changes in lnRMSSD were positively associated with changes in fatigue and soreness across a pre-season window (14). In addition, starters demonstrated a significantly steeper increase in C in response to competitive season play compared to non-starters (18). Further, T and C were significantly disrupted in women collegiate field hockey players from pre-season into their season play as a result of intensified training (35). While soccer and lacrosse share similar characteristics, as both are intermittent field sports and have similar positional identities (e.g., forwards/attackers, midfielders, defenders), distinct differences between sports do exist (9) and thus it is expected these sports elicit different training responses. Further, inverse relationships between lnRMSSD and fatigue have been reported in elite male swimmers and endurance athletes, while fatigue has inconclusive associations with T, C, and T:C values across a variety of athletes (20, 28).

Consistent load monitoring, particularly over a competitive season, may aid in determining athletes' stress responses to a given training stimulus in order to enhance sport performance, improve overall health, and reduce the risk of injury and overtraining. To date, no studies have examined seasonal internal loads within this population.

Therefore, the purposes of the current study were to 1) monitor resting hormonal and physiological responses across a competitive season in National Collegiate Athletic Association Division I (NCAA-DI) women lacrosse athlete and 2) determine the relationship between measures of hormonal, physiological, and self-assessments of fatigue and recovery. We hypothesized 1) the lnRMSSD and T:C would decline throughout the competitive season and 2) the lnRMSSD, T:C, fatigue, and recovery would be related.

METHODS

Participants

Women collegiate lacrosse athletes (n = 20, aged 18-24) from NCAA-DI, which is the highest level of American collegiate sport, participated in the study. All athletes were under the direction of a strength and conditioning coach and were following sport-specific training regimens with neuromuscular demands particular to their respective sport and training program. Furthermore, nutritional programming was provided by the University's registered sports dietitian. All participants completed a medical history form and had been cleared previously for intercollegiate athletic participation. Risks and benefits were explained to athletes and an institutionally approved consent form was signed prior to participation. The Institutional Review Board for Human Subjects approved all procedures and followed all principles outlined in the Declaration of Helsinki. All procedures have complied with each of the ethics statements required by this journal (24).

Protocol

Measurements were obtained weekly throughout the 13-week lacrosse season, which extended from the end of January to the beginning of May. Depending upon the number of weekly games, lacrosse practice was held between three and six days per week (Monday–Saturday) and lasted approximately two hours in duration. Samples were collected one day per week (Tuesday). Between one and three competition games were played each week, usually on Wednesday, Friday, or Sunday. Resting HRV and self-assessments of recovery and fatigue were obtained across 13 weeks, while salivary T and C were obtained across 11 weeks (Figure 1). All measurements were obtained in the morning (~10:50am), prior to the team's scheduled practice time (11am-1pm).

Seventeen total games were played throughout the study as follows: 0 games during weeks 1-3 (pre-season); 1 game in week 4; 0 games in week 5; 2 games in week 6; 3 games in week 7; 2

games in week 8; 2 games in week 9; 2 games in week 10; 2 games in week 11; 2 games in week 12; and 1 game in week 13 (Figure 1).

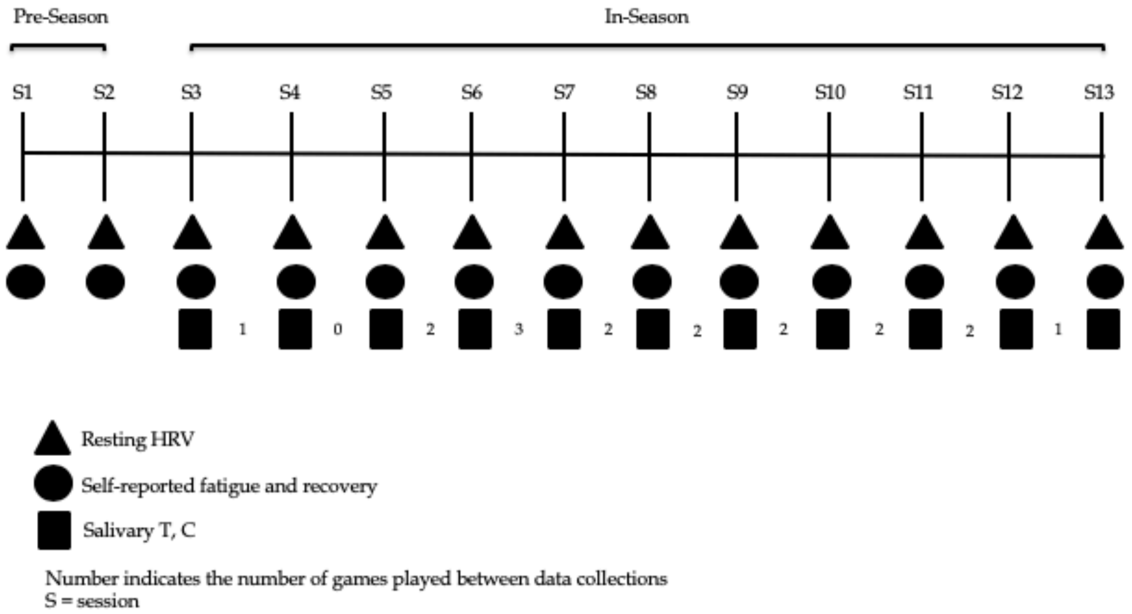

Figure 1. Timeline of data collection procedures.

Heart Rate Variability: Heart rate monitors were used to record R-R intervals (First Beat Sports Monitor, Jyvaskyla, Finland) for all athletes, who were familiar with the monitors and had prior experience wearing them. Heart rate measurements were obtained at the same time of day (10:50am) prior to the scheduled practice time (11am-1pm). By this time, players had been awake, on average, for two to three and many of the players had early morning classes (9-10:15am) prior to training. Heart rate was recorded for 1-min, preceded by a 1-min stabilization period (11, 22) while the participants were seated comfortably and motionless and breathed naturally. Because of the skewed nature of HRV, the natural logarithm of the root mean square of successive differences (lnRMSSD) was recorded, which is an accepted marker of cardiac-parasympathetic activity, and is the preferred HRV metric for field-based monitoring (7). The R-R interval data was saved on a personal computer and synced to Firstbeat Sports using proprietary software (Firstbeat Sports) to perform an automated analysis of lnRMSSD for each one-minute segment. Measurement errors and abnormal heartbeats were eliminated by an automatic artifact detection filter process of the proprietary software.

Saliva Samples: Saliva samples were collected using the SalivaBio Oral Swab (Salimetrics, State College, PA) at the same time of the day prior to the scheduled practice time (10:50am) (12). Participants were instructed to avoid food and drinks prior to testing in order to avoid contaminating the saliva sample. Athletes sat quietly with the saliva swab under their tongues for two minutes. When prompted, athletes spit the swab into the swab storage tube, which was immediately spun in the centrifuge in preparation for pipetting. All samples were stored in a freezer at -80 degrees C until completion of the study. Batch analysis was performed for free testosterone (T, 4.2% coefficient of variation (CV)), and cortisol (C, 6.3% CV) via enzyme-linked immunosorbent assay (ELISA).

Self-Reported Measures: Recovery was assessed using the Perceived Recovery Status scale (PRS), which has been previously validated as a reliable questionnaire that may correlate with athlete performance and overreaching (19, 31). Fatigue was assessed using the Overall Fatigue Scale (OFS), which asks participants to rate their fatigue on a scale from 0 to 10 (32).

Statistical Analysis

SPSS version 25.0 (IBM, Armonk, NY, USA) was used for data analysis. Summary statistics for weekly lnRMSSD, T, C, and T:C are reported as mean ± standard deviation. A natural log-transformation was applied prior to analysis for any non-normally distributed variable. A repeated measures ANOVA was used to analyze changes in T, C, T:C ($n = 8$), and lnRMSSD ($n = 8$) over the course of the season. T, C, and T:C was assessed using weeks 3, 5, 7, 9, and 11. lnRMSSD was assessed using weeks 1, 3, 4, 8 and 9. Alpha was $p < 0.05$. Bivariate Pearson correlation coefficients were used to examine relationships between lnRMSSD, T, C, T:C, recovery, and fatigue. Moderate correlations were defined as R-values of 0.41-0.70 and strong correlations were defined as R-values of 0.71-0.99.

RESULTS

Average (mean ± SD) values for lnRMSSD ranged from 3.3 ± 0.6 (week 1) to 3.9 ± 0.5 (week 12); T:C from 0.031 ± 0.022 (week 6) to 0.047 ± 0.031 (week 11); T from 0.151 ± 0.091 $\text{nmol}\cdot\text{L}^{-1}$ (week 9) to 0.224 ± 0.083 $\text{nmol}\cdot\text{L}^{-1}$ (week 11); and C from 5.51 ± 1.77 $\text{nmol}\cdot\text{L}^{-1}$ (week 9) to 6.81 ± 3.52 (week 4) (Table 1).

All data are presented as descriptive values. The inconsistent participation resulted in limited sample sizes across weeks and likely prevented statistically significant findings. Weekly lnRMSSD, T:C, T, and C responses are displayed in Table 1. Despite no significance, athletes demonstrated a higher relative lnRMSSD (% change: 12%) and T (15%), and a lower C (5%) at week 13 compared to week 1. There was an 18% increase in perceived recovery and a 2% reduction in perceived fatigue.

Table 1. Descriptive lnRMSSD, T:C, T, and C across a competitive lacrosse season.

Week	lnRMSSD	T:C	T (nmol·L^{-1})	C (nmol·L^{-1})
1	3.3 ± 0.6 (*n* = 12)	N/A	N/A	N/A
2	3.4 ± 0.3 (*n* = 12)	N/A	N/A	N/A
3	3.3 ± 0.6 (*n* = 13)	0.036 ± 0.026 (*n* = 18)	0.170 ± 0.049	6.14 ± 2.66
4	3.6 ± 0.4 (*n* = 14)	0.033 ± 0.020 (*n* = 18)	0.181 ± 0.076	6.81 ± 3.52
5	3.5 ± 0.6 (*n* = 5)	0.034 ± 0.017 (*n* = 17)	0.176 ± 0.076	5.95 ± 2.14
6	3.4 ± 0.4 (*n* = 9)	0.031 ± 0.022 (*n* = 20)	0.156 ± 0.079	5.97 ± 2.46
7	3.9 ± 0.4 (*n* = 6)	0.041 ± 0.028 (*n* = 14)	0.185 ± 0.099	5.52 ± 1.88
8	3.3 ± 0.7 (*n* = 13)	0.033 ± 0.016 (*n* = 16)	0.168 ± 0.077	5.61 ± 1.86
9	3.8 ± 0.5 (*n* = 12)	0.031 ± 0.020 (*n* = 16)	0.151 ± 0.091	5.51 ± 1.77
10	3.6 ± 0.5 (*n* = 5)	0.035 ± 0.017 (*n* = 17)	0.203 ± 0.083	6.13 ± 1.64
11	3.7 ± 0.3 (*n* = 7)	0.047 ± 0.031 (*n* = 16)	0.224 ± 0.083	5.77 ± 3.02
12	3.9 ± 0.5 (*n* = 7)	0.044 ± 0.011 (*n* = 8)	0.191 ± 0.053	4.49 ± 1.15
13	3.7 ± 0.4 (*n* = 5)	0.036 ± 0.018 (*n* = 11)	0.196 ± 0.072	5.84 ± 1.54

Values are mean ± SD

No significant time effect was observed in T ($p = 0.059$), C ($p = 0.544$), T:C ($p = 0.120$), or lnRMSSD ($p = 0.062$) for 8 players across the season. Though no significant time effect was observed, T increased from week 3 through week 7 (mean difference; 95% CI: 0.036; -0.048-0.120), but decreased at week 9 (-0.019; -0.058-0.20). The highest T was observed at week 11 (0.224 nmol·mL^{-1}). C increased from week 3 to week 5 (0.448; -1.38-2.28), decreased at week 7 (-0.097; -2.21-2.02), but increased from week 7 to week 9 (0.690; -1.97-3.35). C values were the highest at week 9 (5.92 nmol·L^{-1}). T:C decreased from week 3 to week 5 (-0.003; -0.033-0.026), increased at week 7 (0.007; -.038-0.024), decreased at week 9 (-0.008; -0.026-0.009), and increased to its highest value at week 11 (0.018; -0.009-0.045). lnRMSSD decreased from week 1 to week 3 (-0.095; -0.551-0.357), increased from week 3 to week 9 (0.430; -0.201-0.906). While no changes were significant, large inter-individual variability was observed, reinforcing the need for individualized monitoring.

Weak to moderate correlations among lnRMSSD, T, C, T:C, recovery, and fatigue are shown in Table 2. LnRMSSD was negatively associated with C ($r = -0.232$) and fatigue ($r = -0.256$), and positively associated with T ($r = 0.265$) and T:C ($r = 0.345$).

Table 2. Correlations and 95% CI among internal stress measures for the team.

	T	C	T:C	Recovery	Fatigue
LnRMSSD	0.265* (0.29-0.41)	-0.232* (-0.21- -0.01)	0.345** (0.12-0.56)		-0.256* (-0.29-0.13)
T	1		0.626*** (0.51-0.75)		
C		1	-0.591*** (-0.72--0.47)	-0.185* (0.02-0.35)	
T:C			1	0.208* (0.03-0.34)	
Recovery				1	-0.672*** (-0.81- -0.59)
Fatigue					1

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

DISCUSSION

This is the first study to examine measures of internal stress across a competitive season (13 weeks) in NCAA DI women lacrosse athletes. The purposes were to 1) monitor resting hormonal and physiological responses across a competitive season in National Collegiate Athletic Association-Division I (NCAA-DI) women lacrosse athletes and 2) determine the relationship between measures of hormonal, physiological, and self-assessments of fatigue and recovery. Contrary to our hypotheses, the main findings of this study were that no changes in T, C, T:C, or lnRMSSD were observed throughout the season, indicating athletes did not experience maladaptation to in-season training loads. Further, weak to strong correlations existed among internal load measures, demonstrating weak or lacking relationships among physiological, hormonal, and psychological markers of load.

The lnRMSSD appears to follow an upward trend throughout the season. This may be suggestive of a positive physiological adaptation that occurred in response to season training. Interestingly, highest lnRMSSD was reported in week 7 (3.9 ± 0.4), which followed three competition games, the highest number of games played in one week. While we expected to observe a reduction in lnRMSSD due to fatigue from cumulative playing load, this may be indicative of a positive response from the increased training.

In previously published data (10, 14, 15) from collegiate women soccer athletes, the lnRMSSD displayed greater fluctuation than the lacrosse athletes in the current study (3.07 to 5.35 (15) vs. 3.3 ± 0.6 to 3.9 ± 0.4). However, in the aforementioned study with soccer athletes, data were collected over a 3-week macrocycle, thus making it difficult to compare with the 13-week sport season from the current study. Further, soccer athletes were tested during the off-season and pre-season, and thereby exposed to different training demands than the lacrosse athletes who were in-season. Frequently, lacrosse is compared to soccer due to similar high-intensity and intermittent demands of each sport (9); however, there are field location restrictions placed upon certain lacrosse positions. With soccer, these restrictions are nonexistent, which may result in a higher level of fitness when compared to lacrosse athletes. Further, the lack of consistent sample sizes across weeks reduces the power in the current study, making comparisons difficult.

While no studies have routinely assessed lnRMSSD throughout an entire season in women collegiate field athletes, lnRMSSD response was shown to be position-specific in collegiate American football players during their pre-season training camp (13). While mid-skill positions demonstrated no meaningful changes across the 13 days (range: 3.87 ± 0.48 to 4.10 ± 0.46), skill positions demonstrated small-moderate progressive increases from days 3-8 (4.05 ± 0.41 to 4.37 ± 0.43), with a large peak on day 12 (4.42 ± 0.31), and linemen positions experienced a moderate reduction on day 2 (3.58 ± 0.56) and a large peak on day 12 (4.49 ± 0.36) (13). The progressive increases in HRV observed in skill and linemen may suggest a positive physiological adaptation, as skill positions demonstrated the greatest training load, and linemen the lowest training load.

In the current study the T:C exhibited little change from the beginning of in-season play to its completion with the lowest peak observed at week 9 and the highest peak observed at week 11. The T:C is less commonly and conclusively studied in women athletes because women produce 5-7x less testosterone than males (3), making the response difficult to interpret. Acutely, others have observed heightened serum and salivary T and C in women volleyball, tennis, net ball, and soccer athletes following a single bout of sport competition (8, 18, 21, 25, 26).

Previous research with women runners (20), professional women football players (21), and soccer athletes (1), reported no change in salivary (1) and serum T (8). While runners demonstrated a lower salivary T:C post-competition (20), serum T:C alone was not a sufficient measure to assess cumulative fatigue in rowers (33). In lieu of related literature (1, 8, 20, 33), it is possible that the T:C ratio is not a valuable metric to monitor accumulating levels of physiological stress throughout a season in women athletes. Therefore, T:C may be better used in conjunction with other load markers to clarify the stress response. While these data provide useful information in regard to an athlete's stress response to a single bout of competition, much less is understood about the athlete's response over a competitive season.

A 14-week study in women swimmers reported serum C concentrations were lower in T2 (week 3) compared with T1 (baseline) but increased in T3 (week 10) and T4 (week 14), and the T:C did not change (28). Elite women volleyball players were assessed four times (i.e. September, November, January, May) over their competitive season and T:C decreased by 30% across measures ($p = 0.009$), before returning to baseline levels (27). Clearly more research is needed in this area from a wide variety of women's sports in order to create hormonal reference values.

There is limited research published evaluating the relationship between self-assessment scales and objective internal stress markers in conjunction with one another. In the current study, lnRMSSD was positively correlated with fatigue, with starters exhibiting a greater association than non-starters. Flatt et al. used a 5-point Likert scale across a 2-week period in collegiate women soccer players and reported a strong correlation between average fatigue and the coefficient of variation in lnRMSSD (14). Further, greater variation in lnRMSSD was associated with greater perceptions of fatigue in collegiate and elite men swimmers (2) and elite endurance athletes (20).

Our results show that T:C was positively related to perceived recovery. Previous research has shown that fatigue, as measured from the Profile of Mood States, exhibited moderate relationships to C (6), and strong relationships to T:C (29); however, other studies reporting this relationship in professional men soccer and rugby players showed no correlation between T, C, and T:C to fatigue (29,36). The relationship between recovery and hormones remains limited and contrasting and warrants further investigation to help practitioners determine the efficacy of self-assessment scales. While studies have assessed relationships between exercise heart rate and hormones, no studies have examined the association between resting lnRMSSD and resting hormonal secretion. The current study showed a positive, yet weak, relationship between lnRMSSD and resting T:C, suggesting physiological measures may represent anabolic-catabolic balance and thus be a practical measure to monitor hormonal status.

The main strength of this study is the use of routine, weekly longitudinal monitoring across an entire competitive season. Additionally, women lacrosse athletes are underrepresented in published research and this population warrants further investigation. However, limitations do exist. First, the small sample sizes and inconsistent participation across weekly assessments makes statistical analysis difficult. Hence, only descriptive information can be presented. Last, no external load measures were obtained during this period and therefore, we cannot attribute any changes in internal stress to the physical work incurred during training.

In conclusion, we sought to understand the responses of selected IL measures throughout the course of an entire competitive season in collegiate women lacrosse athletes. Further, relationships were examined among IL measures, which may prove useful for practitioners who are determining which measures to utilize with their athletes. Despite no significant time effect, a pattern was observed in that T, C, and lnRMSSD increased over the course of the season, whereas T:C tended to show more fluctuation across measurements. Large inter-individual differences were observed in markers, and thus an individualized approach to load monitoring is recommended. In addition, lnRMSSD demonstrated associations with T, C, T:C, and fatigue, indicating the suitability of these measures. However, correlations were weak and thus, further research is needed to examine these relationships across all phases of the training cycle. Routine monitoring may help strength and conditioning practitioners, athletic trainers, and sport coaches optimize training programming to reduce injury, illness, and overtraining. Reductions in lnRMSSD or T:C, or elevations in C and fatigue, during a season may suggest a subsequent need for rest in order for athletes to sufficiently recover. Understanding the relationship between IL measures may be useful to practitioners who are beginning to implement training load monitoring in their programming.

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