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Analysis of Sleep, Nocturnal Physiology, and Physical Demands of NCAA Women's Ice Hockey Across a Championship Season

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Abstract

Merrigan, JJ, Stone, JD, Kraemer, WJ, Friend, C, Lennon, K, Vatne, EA, and Hagen, JA. Analysis of sleep, nocturnal physiology, and physical demands of NCAA women's ice hockey across a championship season. *J Strength Cond Res* 38(4): 694–703, 2024—The aims of this study were to evaluate the (a) relationships between daily physical demands and nighttime sleep, heart rate (HR), and heart rate variability (HRV); (b) weekly changes in physical demands and sleep; and (c) differences among positions and between training and competition during a competitive season in National Collegiate Athletic Association (NCAA) women's ice hockey. Twenty-five NCAA Division I women's ice hockey athletes wore a sensor at night to monitor sleep quantity or quality (e.g., time asleep and sleep efficiency) and physiology (e.g., HR and HRV). During training and competitions (31 regular season and 7 postseason), athletes wore performance monitoring systems to assess workload demands (e.g., training impulse and TRIMP). As internal workload (TRIMP, Time >80% of HRmax, Average HR) during training or competition increased, nocturnal HRV decreased, HR increased, and Sleep Duration, Sleep Score, and Readiness Score decreased that night. Across the season, athletes experienced lower HRV, but exhibited longer sleep durations. Training Distance, Duration, Time >80% HRmax, Average HR, and TRIMP decreased, whereas competition Total Distance, Duration, and TRIMP increased across weeks throughout the season. There were differences across positions and season blocks when evaluating these data at the mesocycle level. Athletes slept longer before competition compared with training, but physiological data did not differ. Competitions had greater physiological demands than training. We speculate that the increased focus on sleep hygiene, as evidenced by the increase in sleep over the season, may have served as a recovery aid to combat physiological stress of accumulated demands of competitions that increased over time into postseason tournaments.

Key Words: heart rate variability, TRIMP, sport science, load monitoring, parasympathetic nervous system

Introduction

National Collegiate Athletics Association Women's Ice Hockey is generally considered a high-intensity intermittent sport, including a brief intensive preseason, 30+ game regular season, and potential extension to championship conference and national tournaments. Typically, competitive weeks include 2 back-to-back games (i.e., Friday and Saturday) that consist of three 20-minute periods. Short on-ice shifts requiring moderate to very fast bouts of speed skating are dispersed by intermittent rest periods, which places relatively high aerobic and anaerobic demands on athletes (42). Resultantly, fatigue accumulates leading to higher physiological requirements (3) and potentially reduced performance capabilities later in the game (i.e., third period) (15,34,42). Considering these game demands (25), it is unequivocal that greater physiological demands occur during dense game schedules (3), such as postseason tournaments (5), which may explain tapering of training demands during weekdays leading into game day (5). Furthermore, demands on day-to-day recovery increase over a season as stressors accumulate such as skeletal muscle damage from blunt force trauma during games and in-season strength and conditioning programs. Thus, it is important to understand long-term physiological responses throughout a competitive season to mitigate perceptions and manifestations of fatigue, reduced performances, hindrances in postseason results, and long-term risks of nonfunctional overreaching or even overtraining and injury.

For these reasons, many sports teams across various playing levels have adopted some sort of athlete monitoring to capture individual health and performance-related psychophysiological responses to various stressors (26). By identifying negative and positive adaptations, practitioners can modify training and recovery plans that yield healthy and high-performing athletes. Common strategies often observed in athlete monitoring protocols comprise physiological responses and required physical demands of training and competition that integrate tracking heart rate (HR) throughout, which may be used to derive training impulse (TRIMP, volume in minutes over intensity as Average HR in beats per minute) (2,4,37) or identify HR zone durations (17). To date, most of the research longitudinally assessing workloads has examined male athletes, with limited research involving female athletes (5,9,14,29,43). Further, almost no research has involved collegiate women's ice hockey despite the intense training regimens needed to prepare for stressors and improve physical conditioning in preparation for game demands and high impact collisions while also accounting for additional stressors of student athletes (e.g., travel, academics, media interactions, and

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social life restrictions) (44). Of the existing literature in collegiate and national women's ice hockey teams, findings noted more physiological demands (higher TRIMP) during competitions than training sessions and during dense scheduling periods compared with lighter competition requirements (5,14). However, these studies resided in other nations that follow different programs with fewer games across a competitive season (28 vs. 34 games) (34) warranting further investigation.

The cumulative effects of these demands have shown that athletes struggle with recovery across competitive seasons, showing reduced parasympathetic states (21), increased perceived feelings of fatigue (44), and reduced neuromuscular performance capabilities (44). Because HR may also be directly affected by the amount of effort given during an activity, trends in resting HR and heart rate variability (HRV) are used to understand daily physiological states (18,19,21). Collectively, these metrics may demonstrate cardiac parasympathetic or sympathetic nervous system activity (30) in response to various stressors (1), which require appropriate balance to maintain health and performance. In commercial technologies, HRV is most commonly reported as root mean square of successive beat-to-beat differences (rMSSD) (39). Overall, HRV is considered a noninvasive measure of autonomic balance of sympathetic and parasympathetic activity (41). Greater HRV resembles parasympathetic modulation and restorative recovery facilitations, which is why attenuations of these physiological processes often lead to accumulations of fatigue (i.e., overreaching) (38), thus allowing the ability to identify and alter training programs for athletes experiencing more sympathetic states and inability to achieve parasympathetic balance over the course of a season (16,21). With more affordable and time-efficient means of assessing HRV (8,40,41), practitioners are more easily able to monitor individual autonomic states across competitive seasons.

Resting HRV acquisition can be most practically assessed overnight, which may improve wear compliance by athletes. Newer technologies allow accurate assessment of nocturnal HR and HRV, which prove useful for identifying fitness and fatigue (13,32), while also providing valid assessments of sleep quantity or quality (40). Because sleep has been routinely identified as an important factor contributing to optimal athletic performance and can be negatively influenced by psychophysiological stressors, it may be useful to simultaneously monitor sleep hygiene and nocturnal physiology (7). For example, some collegiate athletes have noted decreased sleep durations across preseason training preparations (19). This is problematic because of the negative consequences of sleep deprivation on mental and physical well-being and performances (6), warranting an understanding of the impact of training workload and weekly alterations of sleep hygiene across a competitive season. Thus, the aims of this study were to (a) determine the relationship of daily physical demands on that night's sleep and nocturnal HR and HRV; (b) evaluate changes in weekly sleep patterns and nocturnal HR and HRV over the course of a competitive season in National Collegiate Athletic Association (NCAA) Women's ice hockey; and (c) determine overall differences among positional groups and between days and nights before training and competition.

Methods

Experimental Approach to the Problem

In this investigation, we had the unique opportunity to examine an elite group of collegiate NCAA Division I athletes in women's ice hockey to gain new insights into sleep and recovery processes from training and competition during a National Championship season. To evaluate relationships and changes among physical demands, sleep, and nocturnal physiology, a cross-sectional longitudinal retrospective analysis was conducted. Athletes were provided with and encouraged to wear a wearable sensor (Oura Ring; Ōura Health, Oulu, Finland) every night throughout the season (~74% average daily compliance across the season) to assess sleep hygiene and nocturnal physiology. Strength and conditioning staff equipped athletes with a performance monitoring system (Polar Team Pro) for every training session and competition to assess workload demands. The athletes competed in 31 competitions across the season (25 wins and 6 losses) before achieving 7 postseason competition wins, including their NCAA National Championship Title.

Subjects

Twenty-five NCAA Division I women's ice hockey athletes (age = 20.7 ± 1.6 years; body mass = 69.7 + 6.1 kg; and body height = 167.6 + 6.0 cm) were included in the current analysis. All athletes (forwards, $N = 12$; defenders, $N = 9$; and goalies, $N = 4$) were under direct supervision from sport coaches, strength and conditioning, and sports medicine staff to follow similar sport-specific training programs during the season. General layout of their strength and conditioning program in season is displayed in Table 1. All athletes were previously medically cleared for intercollegiate athletic participation. The Ohio State University's Institutional Review Board for use of human subjects (#2022H0036) approved the retrospective analysis of these athletic databases.

Procedures

Physical Workloads and Demands. Athletes wore a performance monitoring system (Polar Team Pro; Polar Electro, Kempele, Finland) during all training sessions and competitions. One sensor was positioned on the upper-torso between the scapulae (back-mounted) in a manufacturer-designed shirt (Polar Electro), and the other sensor was positioned on the center of the chest at the level of the xiphoid process via a manufacturer-designed strap (Polar Electro) worn in accordance with the supplied instructions. The ice hockey sport profile was used for all sessions. For indoor sports, the system uses the accelerometer, gyroscope, digital compass, HR monitor, and proprietary software to determine sports performance metrics related to external workload (speed, distance covered, and sprints). Heart rate zones were coded as above or below 80.0% of the athlete's maximal HR (e.g., Time >80% HRmax). Unlike HR metrics, speed metrics are unreliable during ice skating, according to previous research, and thus were not included in these data (12). Additionally, TRIMP was calculated as volume of training in minutes divided by the intensity of training as Average HR in beats per minute (2,4,17,37).

Sleep and Nocturnal Physiology. Athletes were encouraged to wear the Oura Ring each night. The ring is a plethysmography-based device that provides valid measures of various parameters regarding the health, physical activity, and sleep of the user (40,41), such as HR and HRV. The HRV metric being reported by the ring is average rMSSD, or more specifically, the root mean square of the differences in adjacent heart beats (rMSSD). The average HRV is the mean of all 5-minute samples measured during sleep. This metric is often used in athlete monitoring protocols as a

Table 1

General strength and conditioning program overview.*

	Phase 1: Weeks 1–6	Phase 2: Weeks 7–10	Phase 3: Weeks 11–15	Phase 4: Weeks 16–19	Phase 5: Weeks 20–24
Resistance training intent	Unilateral absolute strength Bilateral accelerative strength	Bilateral absolute strength Bilateral strength speed	Bilateral accelerative strength (residual strength) Bilateral speed-strength	Unilateral strength Bilateral strength-speed (contrast)	Strength contrast† Bilateral speed-strength
Primary exercise (s)	Front loaded split squat Barbell front squat	Barbell front squat Barbell banded front squat	Barbell back squat Barbell banded box squat	Safety bar split squat Back squat	Barbell back squat Barbell banded box squat
Sets × reps range	4×3 to 3×4 5×3 to 3×3	4×3, 5×2, 6×2, 6×1 5×2	3×3 & 2×2 or 2×1 6×3	3×4, 3×5, 4×5, 4×6 4×3	3×3 or 5×3 & 3×2 5×2
Intensity range	80–90% 1RM No velocity req. 60–77.5% 1RM 0.55–0.75 $m \cdot s^{-1}$	80–95% 1RM No velocity req. ≥40% 1RM Stay >0.75 to >0.90 $m \cdot s^{-1}$	60 or 75% & 85–95% 0.6 or 0.75 $m \cdot s^{-1}$ No velocity req. ≥30% 1RM Stay >1.0 $m \cdot s^{-1}$	75–85% No velocity req. ≥50% 1RM Stay >0.75 $m \cdot s^{-1}$	60–75% to 75–80% 1RM 0.65–0.75 $m \cdot s^{-1}$ ≥30% 1RM Stay >0.95–1.05 $m \cdot s^{-1}$

*1RM = 1 repetition maximum.

†This day also included maximal effort plyometrics including trap bar drop jumps at 3 × 2 reps, band-assisted vertical jump (−15% body mass) for 3 × 3 reps, and reactive triple broad jumps 3 sets.

representation of parasympathetic activity (39). The current study evaluated the following metrics: (a) Time in Bed as detected by total time in bed in hours between bedtime and wakeup time; (b) Total Sleep as total time spent in light sleep, rapid eye movement (REM) sleep, and deep sleep; (c) Efficiency as the ratio of the time spent asleep compared with time spent awake while in bed; (d) Sleep Latency as the amount of time it takes to fall asleep into the longest portion of sleep that night; (e) Average HR as the Average HR while asleep, and (f) Average HRV as measured by rMSSD while asleep. Finally, we investigated 2 of the proprietary algorithm scores displayed as the most forefront metrics on the application (Sleep Score and Readiness Score), which are a derivation of all the metrics obtained by the device overnight.

Statistical Analyses

First, longitudinal hierarchical linear regression models were used to assess the relationship between daily physical demands (TRIMP, Duration, Total Distance, Time > 80% HRmax, Time < 80% HRmax, and Average HR) and that nocturnal physiology and sleep metrics. Days were nested within individuals, similar to previous models examining relations of external and internal load monitoring, to allow flexibility of time in modeling nonlinear and discontinuous changes across time and accommodate unequal numbers of observations across individuals (19). To determine trends in sleep and nocturnal physiology across the season, values were summarized by week and expressed as weekly changes over the course of the competitive season. Alike the prior models, time was treated as a within-subjects repeated-measure factor in determining variations in resting HR, HRV, sleep duration, efficiency, and Ōura Sleep Score. Additionally, multilevel correlations were used to determine relationships of weekly nocturnal physiology and workload demands across the competitive season while accounting for individual level relations for training and competitions separately as fixed effects. To further explore the changes of these metrics at the mesocycle level, 2-way analysis of variance tests were conducted with Season Blocks (Preseason, First Half, Winter Break, Second Half, WCHA Finals, NCAA Finals, and Offseason) and Position (Forward, Defense, Goalie) as the independent variables and workload and nocturnal physiology metrics as the dependent variables. Finally, average differences of nocturnal physiology and sleep before and during training and competition along with physiological load differences were assessed using paired samples T-tests. All statistical procedures were conducted using R, version 4.1.2 (R Core Team, Vienna, Austria; https://www.R-project.org) with alpha level set to 0.05.

Results

As daily physical workloads increased, such as TRIMP, Time > 80% of HRmax, and Average HR, there were decreases to that nocturnal HRV and increases to nocturnal HR (Table 2). All workload metrics were associated with decreases in Sleep Duration, Sleep Score, and Readiness Score that night. However, Sleep Efficiency was not affected by any physical workload metric (Table 2).

Although Readiness Scores and HRV were reduced across weeks of the competitive season, Time in Bed, Sleep Duration, Sleep Efficiency, and Sleep Score were increased across the season (Table 3). After splitting by training and competition, the Total Distance, Duration, Time > 80% HRmax, Average HR, and TRIMP all demonstrated negative slopes across the season when analyzing training data (Table 4). However, Total Distance, Duration, and TRIMP during competitions showed positive slopes across the season (Table 4). Readiness Score demonstrated negative slopes for both training and competitions (Table 4). Weekly changes in nocturnal physiology and sleep metrics, and TRIMP, are displayed in Figure 1.

Goalies had higher nocturnal HRV than forwards ($CI_{95\%}$ = 32.1, 38.9) and defensive players ($CI_{95\%}$ = 23.0, 30.2), whereas defenders had higher nocturnal HRV than forwards ($CI_{95\%}$ = 6.2, 11.6). There was a position by season block interaction for nocturnal HRV ($F = 2.77$; $p = 0.001$; Table 5). There was a main effect of position for nocturnal HR, with forwards having higher HR than defenders ($CI_{95\%}$ = 2.25, 3.82) and goalies ($CI_{95\%}$ = 2.48, 4.46). For Sleep Duration, there was a main position effect ($F = 13.89$; $p < 0.001$), season block effect ($F = 6.90$; $p < 0.001$), and position by season block interaction ($F = 2.35$; $p = 0.005$; Table 5). The goalies had less Sleep Duration than forwards (−0.44, −0.17) and defenders (−0.39, −0.10).

Table 2

Daytime physical workload associations with that nocturnal physiology and sleep.*†

Oura sleep	Polar training/comp	Intercept	Estimate	Relation
Average HRV (ms)	Training impulse (TRIMP)	91.42 ± 5.42	−0.67 ± 0.29	Negative*
	Duration	91.42 ± 5.42	−0.27 ± 0.29	NS
	Total distance	91.43 ± 5.41	0.09 ± 0.30	NS
	Time > 80% HRmax	91.43 ± 5.40	−1.45 ± 0.30	Negative*
	Time < 80% HRmax	91.42 ± 5.41	−0.06 ± 0.30	NS
	Average HR (%)	91.46 ± 5.36	−1.65 ± 0.33	Negative*
Average HR (b·min^{-1})	TRIMP	55.26 ± 1.45	0.27 ± 0.07	Positive*
	Duration	55.26 ± 1.47	0.10 ± 0.07	NS
	Total distance	55.21 ± 1.46	0.02 ± 0.07	NS
	Time > 80% HRmax	55.25 ± 1.45	0.61 ± 0.07	Positive*
	Time < 80% HRmax	55.26 ± 1.45	0.12 ± 0.07	NS
	Average HR (%)	55.24 ± 1.42	0.78 ± 0.08	Positive*
Sleep duration (h)	TRIMP	7.43 ± 0.09	−0.13 ± 0.02	Negative*
	Duration	7.43 ± 0.10	−0.13 ± 0.02	Negative*
	Total distance	7.43 ± 0.10	−0.12 ± 0.02	Negative*
	Time > 80% HRmax	7.43 ± 0.09	−0.09 ± 0.02	Negative*
	Time < 80% HRmax	7.43 ± 0.10	−0.13 ± 0.02	Negative*
	Average HR (%)	7.43 ± 0.09	−0.04 ± 0.02	Negative*
Sleep efficiency (ratio)	TRIMP	86.43 ± 0.67	−0.04 ± 0.08	NS
	Duration	86.52 ± 0.71	−0.03 ± 0.08	NS
	Total distance	86.63 ± 0.70	−0.09 ± 0.08	NS
	Time > 80% HRmax	86.43 ± 0.68	−0.07 ± 0.09	NS
	Time < 80% HRmax	86.43 ± 0.67	−0.01 ± 0.09	NS
	Average HR (%)	86.43 ± 0.68	−0.10 ± 0.09	NS
Sleep score (au)	TRIMP	71.83 ± 1.12	−1.52 ± 0.14	Negative*
	Duration	71.82 ± 1.13	−1.41 ± 0.14	Negative*
	Total distance	71.81 ± 1.16	−1.33 ± 0.14	Negative*
	Time > 80% HRmax	71.85 ± 1.13	−1.27 ± 0.14	Negative*
	Time < 80% HRmax	71.83 ± 1.11	−1.35 ± 0.14	Negative*
	Average HR (%)	71.86 ± 1.11	−0.78 ± 0.16	Negative*
Readiness score (au)	TRIMP	78.19 ± 0.70	−0.74 ± 0.15	Negative*
	Duration	78.19 ± 0.83	−0.58 ± 0.15	Negative*
	Total distance	78.19 ± 0.79	−0.66 ± 0.16	Negative*
	Time > 80% HRmax	78.20 ± 0.70	−0.90 ± 0.16	Negative*
	Time < 80% HRmax	78.20 ± 0.71	−0.57 ± 0.16	Negative*
	Average HR (%)	78.22 ± 0.72	−0.89 ± 0.17	Negative*

*HRV = heart rate variability; HR = heart rate; TRIMP = training impulse.
†*Negative**, negative association; as physical workloads increase by 1 unit, there was a *decrease* on the sleep metric by a magnitude equal to the "estimate." *Positive**, positive association; as physical workloads increase by 1 unit, there was a *decrease* on the sleep metric by a magnitude equal to the "estimate."

There was a main effect of position ($F = 5.60$; $p = 0.004$) and season block ($F = 29.3$; $p < 0.001$) on training or competition Duration, where goalies had longer durations, and NCAA finals had longer durations than the first ($CI_{95\%} = 7.9, 28.5$) and second ($CI_{95\%} = 13.1, 34.7$) halves of the season, and the WCHA finals ($CI_{95\%} = 1.4, 27.9$). Goalies had higher Average HR than forwards ($CI_{95\%} = 0.54, 2.22$) and defenders ($CI_{95\%} = 0.41, 2.20$). Average HR was higher than preseason during the first half ($CI_{95\%} = 2.06, 4.50$), second half ($CI_{95\%} = 1.40, 4.02$), WCHA finals ($CI_{95\%} = 2.45, 5.91$), and NCAA finals (2.49, 6.04). Winter break had lower Average HR than the first half ($CI_{95\%} = 2.15, 5.88$), second half ($CI_{95\%} = 1.52, 5.37$), WCHA finals ($CI_{95\%} = 2.68, 7.16$), and NCAA finals ($CI_{95\%} = 2.73, 7.27$). Overall, TRIMP was not different across positions but was higher during NCAA finals compared with

Table 3

Weekly changes of physical workload, nocturnal physiology, and sleep.*

Oura sleep	Intercept	Estimate	Relation
Average heart rate variability (HRV, ms)	93.45 ± 5.42	−0.155 ± 0.032	Negative*
Average heart rate (b·min^{-1})	55.01 ± 1.45	0.018 ± 0.007	Positive*
Time asleep (h)	7.36 ± 0.10	0.006 ± 0.002	Positive*
Time in bed (h)	8.53 ± 0.08	0.006 ± 0.002	Positive*
Sleep latency (min)	11.79 ± 0.67	0.072 ± 0.021	Positive*
Sleep efficiency (ratio)	86.34 ± 0.69	0.010 ± 0.009	NS
Sleep score (au)	71.32 ± 1.15	0.045 ± 0.016	Positive*
Readiness score (au)	80.12 ± 0.73	−0.151 ± 0.017	Negative*

Negative, negative association; as season continued weekly from preseason, the value of the metric decreased by a magnitude equal to the "estimate." *Positive**; positive association, as season continued weekly from preseason, the value of the metric increased by a magnitude equal to the "estimate."

Table 4

Multilevel correlations over the competitive season by training and competition.*

Metric	Training r	Training t	Comp r	Comp t
Nocturnal average HRV (ms)	−0.031	−1.490	−0.056	−1.471
Nocturnal average heart rate (b·min^{-1})	−0.018	−0.859	0.026	0.672
Time asleep (h)	0.058	2.775	0.043	1.110
Time in bed (h)	0.070	3.326	0.026	0.684
Sleep efficiency (ratio)	0.037	1.779	−0.033	−0.861
Oura sleep score (au)	0.067	3.194	0.031	0.807
Oura readiness score (au)	−0.145	−6.964†	−0.142	−3.748†
Total distance (m)	−0.113	−5.407†	0.141	3.699†
Duration (min)	−0.163	−7.853†	0.270	7.309†
Duration > 80% HRmax (min)	−0.203	−9.831†	0.042	1.105
Average heart rate (HR, %)	−0.147	−7.062†	0.001	0.037
Training impulse (TRIMP)	−0.192	−9.283†	0.179	4.742†

*HR = heart rate; HRV = heart rate variability.
†Indicates statistically significant relationship between variables.

preseason, first and second half, and winter break. Offseason had lower TRIMP than all, and the WCHA was different than the second half season. Furthermore, the time in bed and time asleep were greater in nights before competitions than nights before training sessions (Figure 2). All physiological and workload metrics were higher on days of competitions compared with training (Figure 3).

Discussion

To our knowledge, this study was the first to evaluate longitudinal trends and associations in sleep and workloads across a NCAA DI Women's ice hockey championship season. Overall, greater TRIMP, Time > 80% of HRmax, and Average HR were associated with altered recovery as indicated by lower nocturnal

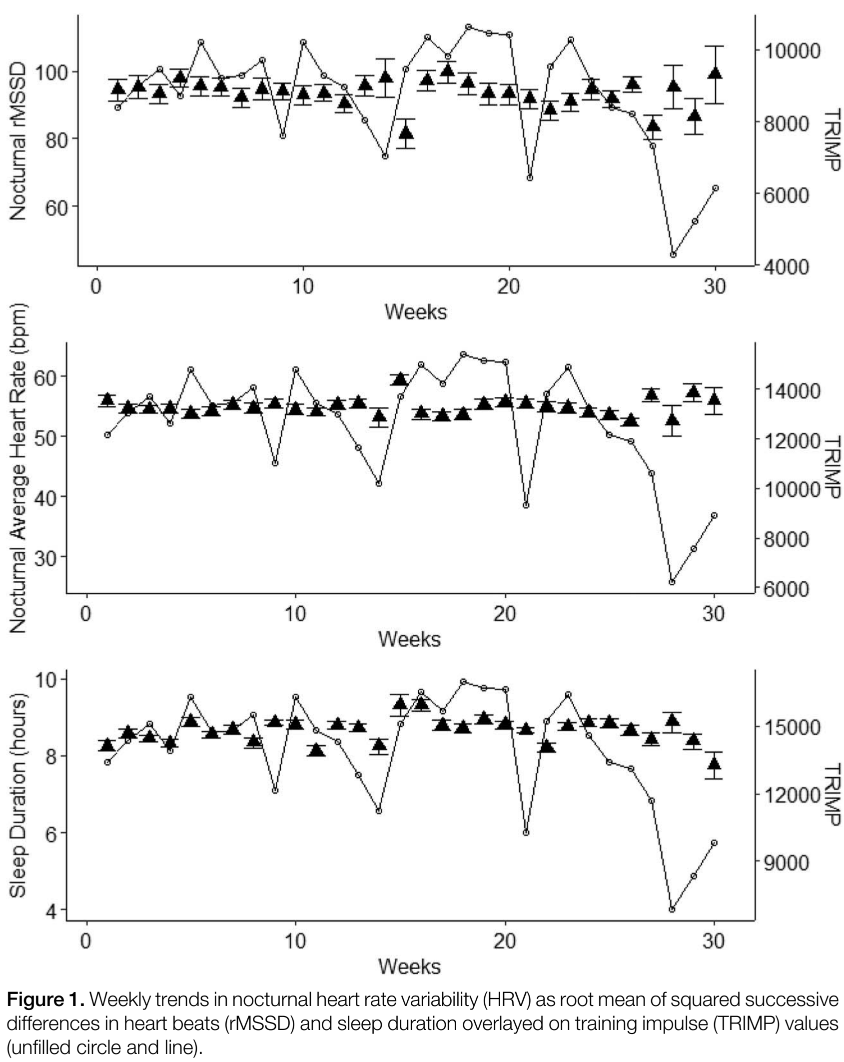

Figure 1. Weekly trends in nocturnal heart rate variability (HRV) as root mean of squared successive differences in heart beats (rMSSD) and sleep duration overlayed on training impulse (TRIMP) values (unfilled circle and line).

Table 5
Mean ± *SD* of select nocturnal physiology and sleep metrics and physical workloads (PW).*†

Season block	Sleep HRV	Sleep time	Sleep HR	PW (min)	PW HR	PW (TRIMP)
Whole team						
Preseason	94.2 ± 33.7	7.3 ± 1.1^{2nd,WF,WB}	55.0 ± 8.7	132.8 ± 31.1	67.9 ± 6.2	8,979 ± 2,160
First half season	94.2 ± 30.4	7.4 ± 1.1	54.7 ± 8.3	139.8 ± 46.6	64.6 ± 7.0	9,079 ± 3,252
Winter break	93.6 ± 27.3	7.8 ± 1.2^{1st,NF,Off}	54.9 ± 7.4	136.5 ± 51.4	68.6 ± 6.7	9,377 ± 3,569
Second half season	93.2 ± 30.4	7.5 ± 1.0	54.8 ± 8.0	145.3 ± 48.5	65.2 ± 7.1	9,511 ± 3,401
WCHA finals	93.0 ± 28.0	7.7 ± 1.1^{1st,NF,Off}	53.8 ± 7.6	136.2 ± 46.1	63.7 ± 7.3	8,727 ± 3,295
NCAA finals	91.0 ± 28.9	7.4 ± 1.3	54.2 ± 8.5	121.6 ± 60.7	63.6 ± 7.0	7,856 ± 4,363
Off-season	90.8 ± 36.1	7.2 ± 1.2	56.2 ± 10.5	81.3 ± 31.3	65.8 ± 6.4	5,328 ± 2060
Defense						
Preseason	93.8 ± 32.6^{g}	7.2 ± 1.1	54.1 ± 7.1	130.9 ± 29.6	68.3 ± 5.6	8,925 ± 2072
First half season	95.5 ± 28.2^{f,g}	7.3 ± 1.2	52.8 ± 6.1	137.8 ± 45.7	65.1 ± 6	9,027 ± 3,199
Winter break	91.3 ± 24.5	7.8 ± 1.2	53.1 ± 7.4	132.6 ± 48.8	68.9 ± 6.6	9,119 ± 3,308
Second half season	90.1 ± 29.9^{g}	7.6 ± 1.1	53.9 ± 6.8	144.7 ± 50	65 ± 6.7	9,461 ± 3,496
WCHA finals	90.6 ± 30.4^{g}	7.8 ± 1.1	53.1 ± 7.2	135.9 ± 46.3	64 ± 6.5	8,743 ± 3,282
NCAA finals	95.0 ± 25.7	7.6 ± 1.3	52.3 ± 5.8	122 ± 63.6	63.2 ± 5.9	7,817 ± 4,481
Off-season	106.3 ± 28.2	7.2 ± 0.9	52.7 ± 8.1	79.5 ± 30.1	65.7 ± 5.5	5,160 ± 1825
Forwards						
Preseason	85.4 ± 32.1^{g}	7.4 ± 1.1	56.7 ± 10.1	133.6 ± 27.3	68.4 ± 6.3	9,094 ± 1893
First half season	84.2 ± 27.5^{g}	7.6 ± 1.1	56.6 ± 9.7	138.7 ± 42.7	64.8 ± 7.1	9,050 ± 3,046
Winter break	87.1 ± 26.0^{g}	7.9 ± 1.3	55.9 ± 8.1	129.1 ± 47.1	67.9 ± 7.3	8,795 ± 3,274
Second half season	86.6 ± 27.5^{g}	7.5 ± 1.0	56.1 ± 9.2	143.7 ± 44.1	65.7 ± 7	9,471 ± 3,148
WCHA finals	85.7 ± 23.4^{g}	7.7 ± 1.1	54.6 ± 8.8	136 ± 44.1	63.9 ± 7.4	8,735 ± 3,201
NCAA finals	82.6 ± 28.8^{g}	7.2 ± 1.4	55.6 ± 10.2	117.6 ± 59.0	63.7 ± 7.7	7,685 ± 4,477
Off-season	69.6 ± 27.3^{2nd}	7.0 ± 1.4	59.2 ± 12	85.3 ± 33.1	67.1 ± 6.7	5,736 ± 2,328
Goalies						
Preseason	121.2 ± 26.2	7.0 ± 1.2	51.8 ± 5.8	134.4 ± 43.1	65.6 ± 6.9	8,758 ± 2,967
First half season	121.6 ± 24.5	7.1 ± 1.1	52.8 ± 5.3	146.5 ± 57.5	63.2 ± 8.0	9,258 ± 3,883
Winter break	117.4 ± 22.7	7.7 ± 1.2	54.7 ± 4	165.8 ± 59.6	70.3 ± 4.7	11,599 ± 4,109
Second half season	122.9 ± 23.0	7.3 ± 1.0	52.5 ± 5	152.2 ± 58.2	64.3 ± 8.3	9,759 ± 3,991
WCHA finals	117.6 ± 20.7	7.6 ± 0.8	52.8 ± 4.1	137.3 ± 52.3	62.8 ± 8.2	8,672 ± 3,649
NCAA finals	108.3 ± 26.4	7.3 ± 1.0	53.3 ± 6.2	132.4 ± 60.3	64.4 ± 7	8,437 ± 3,829
Off-season	115.1 ± 40.5	7.6 ± 1.3	55.6 ± 8.9	74.5 ± 29.1	62.9 ± 6.5	4,601 ± 1,570

*HRV = heart rate variability; HR = heart rate; PW = physical workloads of either training or games; TRIMP = training impulse; WCHA = Western College Hockey Association; NCAA = National Collegiate Athletic Association.

†Significant differences at $p < 0.05$ are indicated with "g" when different then goalies, "f" when different than forwards, "1st" when different than first half of the season, "2nd" when different than second half of the season, "Off" when different than offseason, "WF" when different than Western College Hockey Association (WCHA) finals, "WB" when different then winter break, and "NF" when different than National Collegiate Athletic Association Finals.

HRV and higher nocturnal HR. Days with higher workloads were also associated with decreases in Sleep Duration, Sleep Score, and Readiness Score that night. Across the season, athletes experienced autonomic imbalance (lower HRV) but exhibited longer Sleep Durations. Training Distance, Duration, Time > 80% HRmax, Average HR, and TRIMP revealed negative slopes across weeks in the competitive season, whereas competitions noted positive slopes (increases) for Total Distance, Duration, and TRIMP. There were also differences across positions and season blocks when evaluating these data at the mesocycle level. Finally, no differences existed in nocturnal physiology before game days, but time in bed and sleep duration were longer nights before competitions compared with training nights.

Nocturnal Average HRV and HR were reflective of more sympathetic states following days with greater TRIMP, durations above 80% of HRmax, and Average HR but were not affected by overall physical workload durations or distances. These findings agree with previous research that observed the acute responses of HRV to be mainly affected by exercise intensity (31,35). However, when examining a short high volume and intensity preseason, male soccer athletes did not experience altered morning HRV (19). In that same cohort of male soccer athletes, morning HRV was not associated with external load measures that afternoon (19). In other elite male soccer athletes, those with higher HRV were able to express greater equivalent distance indexes (distance the player would have covered with the same running at a constant speed over the total distance covered) (10). However, it may be difficult to capture the true abilities of athletes based on HRV that morning or previous night because the associations may be a result of preplanned periodization periods allowing recovery via lower physical workloads. In NCAA DI football athletes, chronic 4-week player loads were associated with morning HRV (22). Thus, associations among nocturnal physiology (HRV and Average HR) and physical workloads may be dependent on many factors such as the direction of relationships and fitness levels. In female soccer athletes, those with higher fitness levels and lower perceived fatigue levels noted less reductions to HRV (20). Because gender influences resting HRV metrics (45), it is also possible that changes to HRV from stressors may be different for men and women. Others have reported that physical fitness statuses, and sleep, play an important role in the recovery of parasympathetic states (36,38). It is important to note, however, that the relationships among these metrics may also be falsely inflated by violating the assumption of independent samples by summing scores across weeks (19).

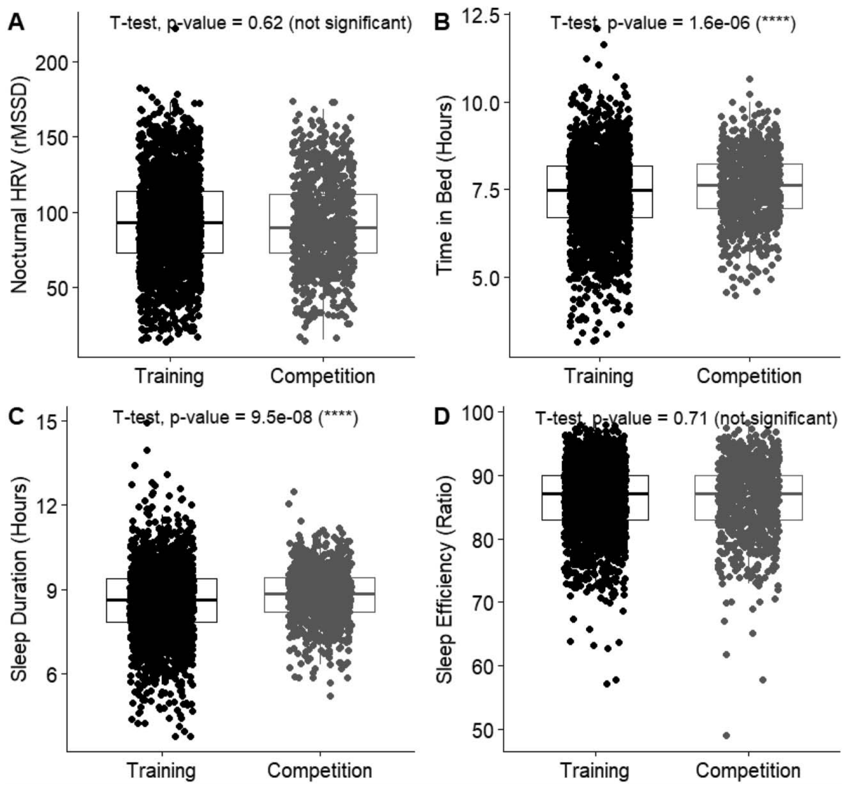

Figure 2. Nocturnal physiology and sleep metrics from the night before training and competitions with respective T-test results.

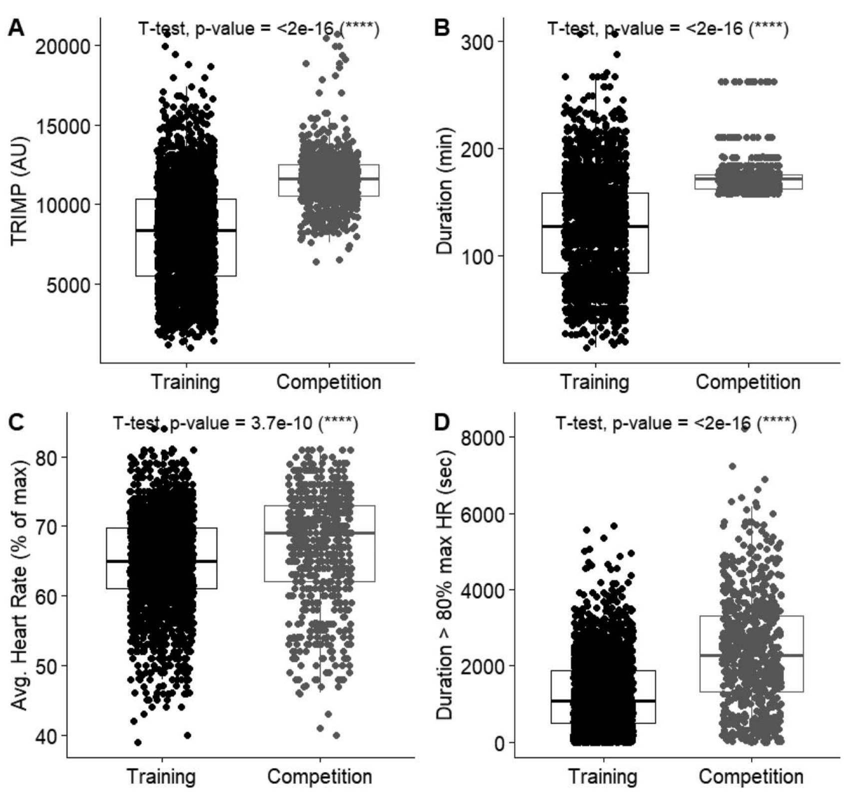

Figure 3. Physiological workload metric differences between days of training and competitions.

Furthermore, Sleep Duration and manufacturer algorithm-based metrics of Sleep and Readiness Scores were negatively associated with all physical workload metrics. However, Sleep Efficiency was not affected by any physical workload measure. In a 7-day training period, researchers have found no relation of perceived training efforts and sleep duration or quality (28). Others have found decreased sleep quality during congested schedules in professional basketball athletes (11). During high-volume training periods in endurance athletes, sleep disturbances have also been noted and associated with periods of overreaching (24). Evidence suggests that sleep extension may have the most beneficial effects on subsequent performance (7), of which sleep education may assist in improving sleep time and long-term sleep habits (6). Regardless of coach and performance practitioner influence on athlete sleep regimens, the current athletes demonstrated additional emphasis on sleep hygiene as the season proceeded. This may have been a natural response to reduced parasympathetic states according to decreased nocturnal HRV and increased HR.

The emphasis of sleep was also noted when comparing sleep before competitions and training. Athletes in the current study spent more time in bed, which lead to additional sleep durations on nights before competitions compared with training. However, nocturnal HRV was not different between competitions and training. This is important because physical workloads are generally greater during competitions than training sessions, such as via higher TRIMP in male ice hockey athletes (4), and are shown here in Figure 3. Others have also suggested greater demands during competitions compared with training that focuses more on technical and tactical skills and fitness (5,14). However, other data have shown greater workloads during training in male ice hockey athletes compared with competitions (33). In the current study, the physical workload metrics (Total Duration, Distance, Average HR, and TRIMP) during training sessions generally decreased across the competitive season. Meanwhile, the physical workloads of competitions, such as Total Distance, Duration, and TRIMP, seemed to increase as the season proceeded. Thus, although previous research has shown microcycle-level tapering across days of the week leading into competitions in elite male and female ice hockey teams (4,5), the current findings allude to possible tapering of training demands or changes in training focus (i.e., technical vs. physical) across the season to combat accumulated fatigue and innate increases in physical workloads of competitions as seasons progress into high stakes postseason play (e.g., Conference and NCAA tournaments).

Previous research demonstrated that goalies exhibited higher internal demands during training compared with forwards and defenders (4), whereas others have suggested higher internal demands in training and competitions in female ice hockey forwards compared with defenders (14). Others have also found that forwards had higher TRIMP during training and competitions compared with defenders (4). Thus, despite less time on ice (14,27), forwards may see higher HR during their playing times because of more time spent moving at higher velocities compared with defensive players (27). According to the current findings, when examining total weekly workloads, forwards and defenders did not differ in internal load demands. However, goalies had higher Average HR and required longer physical workload durations than forwards and defenders, which may be because of goalies playing majority of the game without the frequent line changes seen in other positions. Furthermore, average weekly TRIMP was not different across positions. In previous research of female ice hockey, goalies had the highest internal TRIMP, but forwards and defenders did not differ (5). Thus, although positional differences may exist when examining competition demands, it is possible that the overall weekly demands are generally equivalent. It is also plausible that the degree to which positions differ with respect to internal and external workloads may vary team-to-team and sport-to-sport because they are likely sensitive to coaching and playing styles or preferences.

The current findings are the first to allude to positional differences in nocturnal physiology and sleep in elite NCAA DI women's ice hockey athletes. Goalies had higher nocturnal HRV than forwards and defenders, whereas the defenders had higher nocturnal HRV than forwards. Similarly, goalies and defensive players had lower Average HR overnight than forwards, collectively suggesting that forwards had less parasympathetic modulation than goalies and defenders. However, goalies also demonstrated less sleep durations than forwards and defenders. The mesocycles in this study were categorized into distinct phases throughout the competitive season as dictated by the team's performance staff (Preseason, First Half, Winter Break, Second Half, WCHA Finals, NCAA Finals, and Offseason). Sleep was highest during the winter break and WCHA finals. Training and competition durations during NCAA finals were longer than First Half and Second Half Regular Season and WCHA finals. Average HR was higher than preseason and winter break during the first half, second half, WCHA finals, and NCAA finals. Training impulse was higher during NCAA finals compared with preseason, first and second half, and winter break. Offseason had lower TRIMP than all phases, and the WCHA was different than the second half season. However, previous research has found higher TRIMP during the regular season compared with preseason and postseason (4). The authors speculated that this was because of the congested scheduling of 2 or more games played per week, which may be different scheduling than the current regular season in NCAA women's ice hockey. Thus, it is possible that all phases of the season are demanding, as seen in other varsity women's ice hockey athletes (5). The current study also split the regular season into 2 blocks considering the mandated winter break for examination periods and holiday, which can be followed by a mini preparatory period to start the second half of the regular season as seen in previous work (5). As mentioned, the current study did not find overall differences between the preparatory and competitive phases of the season, but again, this is thought to be attributed to the schedule of the competitive ice hockey season (5).

The current study has great value for human performance practitioners by demonstrating longitudinal monitoring analyses of physiological workloads and subsequent responses across an entire season, which also included a successful postseason ending with a NCAA National Championship title. Some refer to these responses to cumulated physiological or mental stressors as allostatic load, which involves chronic activation of biological systems (i.e., sympathetic system) and can be reflected by HRV fluctuations (23). We concomitantly assessed daily workload and nighttime sleep and physiology throughout an entire NCAA women's ice hockey season. Greater physiological workloads (TRIMP, Time > 80% of HRmax, and Average HR) during training and competitions was associated with elevated sympathetic states as indicated by lower nocturnal HRV and higher nocturnal HR, and decreased Sleep Durations. Over the course of the season, athletes demonstrated lower HRV (autonomic imbalance) but spent more time asleep, which may have been a mechanism for coping with the accumulated stressors via a natural recovery aid. Training workloads showed negative slopes over time, whereas competition workloads demonstrated positive slopes over time. Requirements of play resulted in differences of total physical workload durations and Average HR for goalies compared with forwards and defense, but weekly TRIMP was not different across positions. Sleep was highest during the winter break and WCHA finals, whereas overall training or competition durations and TRIMP were highest during the NCAA finals. Average HR was higher than preseason and winter break during the first half, second half, WCHA finals, and NCAA finals. These findings help understand workload demands and physiological responses within NCAA DI women's ice hockey, although providing a framework for applying sport science methods within this population throughout a National Championship Season.

Practical Applications

The aims of the current sport science procedures have demonstrated the ability to (a) reliably procure physiological workloads during training and competitions, (b) assess physiological responses to training via nocturnal data collection that limit disruptions to the athletes' routines, and (c) simultaneously assess sleep quality and quantity to understand and ensure the natural recovery aid of proper sleep hygiene. The findings add to the scarce scientific body of knowledge including NCAA DI women's ice hockey athletes. Uniquely, the higher physiological workloads noted in the NCAA Finals include a successful National Championship Title that attracted additional media attention and increased pressure to perform. In conjunction with the accumulated stress noted across the competitive season and mental stressors from pressure to perform to prevent tournament elimination, the highly competitive nature of postseason hockey results in greater internal physiological responses. However, one mechanism at play for the current athletic population was emphasizing sleep hygiene as a recovery aid and in preparation for competition performances. Considering the reduction in parasympathetic states throughout the demanding season, further understanding of recovery strategies may help mitigate accumulated stress responses during periods of intense game schedules and long season durations. Thus, we suggest identifying periods of autonomic imbalance and in real-time and using restorative recovery modalities to promote parasympathetic restoration in a personalized and enhanced manner, which may limit accumulated stressors across the season. Moreover, it is worthwhile to consider the sport-specific periodization cycles as they likely have a significant role in the stress-recovery state of athletes. Analytical approaches similar to the ones deployed herein may aid other sport scientists and human performance practitioners when aiming to associate workload prescriptions and the resulting athlete responses and adaptations to them. Continuations of this work may help performance, and athlete health, by understanding balances of high and low workloads and recovery aids that improve preparedness and limit fatigue accumulations throughout long competitive seasons as noted in NCAA ice hockey.

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