Effects of consecutive domestic and international tournaments on heart rate variability in an elite rugby sevens team

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Abstract

Objectives: The purpose of this study was to evaluate heart rate variability and athlete self-report measures of recovery status (ASRM) in response to consecutive domestic and international tournaments among an elite rugby sevens team.

Design: Retrospective

Methods: Olympic-level rugby sevens players ($n = 10$) recorded post-waking natural logarithm of the root mean square of successive differences (LnRMSSD) and ASRM (sleep quality, energy, soreness, recovery and mood) throughout a 1-week baseline period and daily thereafter throughout a domestic and subsequent international tournament, separated by five days. Linear mixed models and Hedge's effect sizes ± 95% confidence interval (ES ± 95% CI) were used to evaluate variation in LnRMSSD and ASRM relative to baseline.

Results: Decrements in various ASRM were observed in response to both tournaments (ES = -0.80 ± 0.91 – -1.73 ± 1.03, $p < 0.05$) and international travel (ES = -1.03 ± 0.93 – -1.70 ± 1.02, $p < 0.05$) whereas decrements in LnRMSSD were only observed in response to the international tournament (ES = -0.89 ± 0.92 – -1.21 ± 0.96, $p = 0.02 – 0.07$). No clear differences in internal or external training load parameters were observed between tournaments (ES = -0.35 ± 0.88 – 0.13 ± 0.88, $p > 0.05$).

Conclusions: **Greater decrements in cardiac-autonomic activity were observed in response to an international tournament relative to a domestic tournament, despite no difference in match-physical demands. Thus, factors separate from competition alone may impact players' cardiac-autonomic response to an international tournament.**

Key Works: Autonomic, Cardiac-Parasympathetic, Sports Science, Recovery

1. Introduction

Rugby sevens competitions are held in tournament format, with teams playing up to six competitions within a two-day period. During matches, players cover distances of ~1.6 km and maintain a playing intensity >80% of maximal heart rate as they perform high intensity sprints, changes of direction and collide with opponents in an effort to gain or defend field position.[1] The physical demands of tournament-play have been shown to impair neuromuscular performance,[2] increase creatine kinase concentrations[2] and alter immune system function[3] in elite players. What's more, tournaments are often held over consecutive weekends and frequently involve multiple time-zone travel to and from international venues. Thus, teams are challenged with recovering from one tournament and preparing for another within a 5-day period. Of concern to sports medicine staff is the high injury rate observed in rugby sevens, recently attributed to both match-to-match and day-to-day fatigue during tournament-play.[4] Collectively, the intense physical demands of training and competing,[1,5] the inadequate recovery time between tournaments[2] and the added stress of international travel[6] warrant further investigation into recovery status monitoring among elite sevens players.

While previous studies have examined neuromuscular,[2] biochemical,[2] and immunological responses[3] to elite sevens competition, cardiac-autonomic responses have received little investigation. Vagal function regulates allostatic processes and can be assessed non-invasively through heart rate variability (HRV).[7] The parasympathetic branch of the autonomic nervous system facilitates restorative and vegetative processes and is reflected in increased HRV.[7] In contrast, parasympathetic withdrawal and activation of the sympathetic system mobilizes energy in response to stress and is characterized by reduced HRV.[7] It has recently been demonstrated that vagal-related HRV may be useful for evaluating adaptations in elite sevens players throughout preparatory training.[8,9] Indeed, HRV is sensitive to a variety of factors relevant to an athletes recovery status including training load and intensity,[10] sleep quality[11] and travel-related stress.[12] **Moreover, previous studies have reported significant alterations in endocrine, inflammatory and biochemical markers lasting several days following elite-level competition from various rugby codes.[13,14] Thus, it is possible that the combination of a short recovery time between**

tournaments, obligatory international travel requirements and intense competition may disrupt cardiac-vagal activity. However, this hypothesis has yet to be investigated.

Subjective indicators of recovery status are widely used among sports teams to monitor the athletes' perceptual response to competition due to their sensitivity to fatigue and convenient implementation.[15] For example, decrements in athlete self-report measures (ASRM) of stress and fatigue have been observed in response to training and competition in elite rugby players.[16] While debate surrounds the preferential use of subjective versus objective markers for monitoring fatigue and recovery status in athletes,[15] it is likely that inclusion of both objective (e.g., HRV) and subjective markers enable a more complete evaluation of individual responses.[17] The physiological expression of stress, mediated by the autonomic nervous system,[7] may be upregulated by decrements in wellbeing-related factors such as perceived sleep quality, fatigue or psychological stress that can be identified via ASRM.**[18]** **Hypothetically,** these parameters would inform support staff regarding the magnitude of physiological stress (i.e., size of decrement in HRV) and potential contributing sources reported via ASRM. Targeted efforts can then be made by support staff to address the specific factor(s) contributing to the adverse physiological response.

The usefulness of HRV and ASRM for reflecting fatigue and recovery responses to consecutive elite sevens tournament-play has received little investigation. This research is needed because practitioners may use this information to plan recovery interventions and develop coping strategies to support player health and performance amidst competitions. Therefore, the purpose of this study was to evaluate HRV and ASRM responses to consecutive tournaments involving international travel among an elite rugby sevens team. We hypothesized that greater decrements in HRV and ASRM variables would be observed in response to the international tournament versus the domestic tournament.

2. Methods

Adult male players (n = 12) selected for the 2016 Olympic team were eligible for inclusion. One player was excluded due to insufficient data and another was excluded due to missing a tournament. Therefore, n = 10 players (height = 185.1 ± 6.8 cm, weight = 91.9 ± 7.1 kg; sum of 8 skinfolds = 61.9 ±

15.1 mm) were included in the analysis. Ethical approval for retrospective analysis of the de-identified data was provided by the Institutional Review Board.

The team competed in a domestic tournament (260 km travel by bus) and an international tournament (1650 km travel by flight and bus, 1 h time-zone loss), separated by five days. Travel took place 2 days before each tournament. The domestic travel day involved no early wake-up requirements due to a 1 pm departure time. The international travel day involved a 6 am wake-up and a missed flight connection, causing the team to complete the travel by bus and arrive at the hotel at ~3 am. Post-waking HRV and ASRM **were averaged** throughout the 1-week period prior to the first travel day to serve as baseline and daily thereafter until 2-days post-international tournament. HRV and ASRM from domestic tournament travel day (D-Travel), 1-day pre-domestic competition (DC-Pre1), day 1 and 2 of domestic competition (DC-1 and DC-2, respectively), 1 and 2 days post-competition (DC-Post1 and DC-Post2, respectively), mid-way between tournaments (Mid) and the same time-points for international competition (I-Travel, IC-Pre1, IC-1, IC-2, IC-Post1 and IC-Post2) were compared to baseline. **Thus, the five days between tournaments in consecutive order were DC-Post1, DC-Post2, Mid, I-Travel and IC-Pre1. The team advanced to the finals on both occasions and thus competed in 6 matches at the domestic tournament and 6 matches at the international tournament.** Both tournaments involved competition versus elite level opposition. Players were in bed by no later than 11 pm during tournaments.

HRV procedures were replicated from a previous study featuring the same cohort that took place over the 3 weeks preceding baseline of the current study.[9] Briefly, HRV was recorded in the seated position for 60-sec following a ~60-sec stabilization period, each morning after waking. R-R intervals were obtained via Bluetooth heart monitor (H7, Polar Electro, Kempele, Finland) synched with a smartphone application (Elite HRV, Asheville, North Carolina, USA).[9] The vagal-related natural logarithm of the root mean square of successive R-R interval differences was used for analysis in accordance with recent recommendations.[17] Compliance with daily HRV measures was 97 ± 5%.

ASRM procedures were also replicated.[9] **Each morning following HRV measurement**, athletes rated their perceived levels of sleep, energy, recovery, muscle soreness and mood on a 10-point scale. The wellbeing questionnaire was adapted from McLean et al, previously used to monitor fatigue and recovery responses in elite rugby players.[16] Higher ratings reflected better perceptual responses and vice-versa. Ln transformations were applied due to non-normality assessed by Shapiro-Wilks tests ($p < 0.05$). Compliance with ASRM was 99 ± 2%.

Daily HRV responses may be effected by the volume or intensity of physical activity.[10] Thus, competition workloads via 10 Hz global positioning system devices (GPS) (Viper Pod, STATSports, Newry, Ireland) were assessed. Validity and reliability of GPS devices using a 10 Hz sampling frequency for quantifying running-based movement has been previously established.[19] GPS devices were positioned between the scapulae, embedded within a compression shirt. Total meter distance (TD) and high-speed running meter distance (>18 $km \cdot h^{-1}$) were obtained from each competition **to quantify total and high intensity running volume, respectively, for comparison between tournaments**. Internal load was quantified via the session rating of perceived exertion (sRPE) method where competition duration in minutes was multiplied by the reported RPE value from the Borg scale.[20]

Variation in LnRMSSD and ASRM variables relative to baseline were evaluated with mixed effects linear models. Day was included as a within-subjects repeated measure and athlete identification was included as a random effect. Competition workload values for each competition day were compared with the same procedures. Overall tournament workload means were compared via paired t-tests. Post-hoc analyses were carried out using Tukey's Honestly Significant Difference tests. Hedge's G effect sizes ± 95 confidence intervals (ES ± 95 CI) were used to evaluate the magnitude of differences among LnRMSSD and ASRM relative to baseline.[21] ES were interpreted qualitatively as follows: <0.2 = trivial, 0.2 – 0.59 = small; 0.60 – 1.19 = moderate; >1.20 = large.[22] If the 95% CI of the ES overlapped both substantially positive (0.2) and negative (-0.2) values, the **ES** was deemed unclear.[23] In addition, the intra-individual LnRMSSD coefficient of variation from baseline was calculated and averaged across the team yielding a mean value of ~6%. Thus, ± 3% (0.5*6%) was used as the smallest worthwhile change for group LnRMSSD.[17] P values <0.05 were considered statistically significant. Procedures were carried out using JMP Pro 12 (SAS Institute Inc. Cary, NC, USA) and Microsoft Excel (Redmond, WA, USA).

3. Results

Significant main effects were observed for LnRMSSD (p = 0.002), LnSleep (p < 0.001), LnEnergy (p <0.0001), LnSoreness (p <0.0001) and LnRecovery (p <0.0001). LnMood did not differ from baseline throughout the observation period (p >0.05). **Decrements in LnRMSSD were only observed in response to the international tournament (p = 0.02 – 0.07). Decrements in LnSleep and LnEnergy were observed in response to both tournaments and international travel (p <0.05). Additionally, decrements in LnSoreness and LnRecovery were observed only in response to the domestic tournament (p <0.05), although similar decrements in ES magnitude were also observed in response to the international tournament (p >0.05).** Mean ± 95% CI for LnRMSSD and ASRM parameters are displayed in Figure 1. **The proportion of players who demonstrated a reduced LnRMSSD relative to baseline for each day using the intra-individual SWC (0.5*baseline CV) is displayed at the bottom of Figure 1.** ES ± 95% CI relative to baseline for LnRMSSD and ASRM parameters are presented in Table 1.

FIGURE 1 HERE

TABLE 1 HERE

No significant effects were observed for TD (p = 0.324), HS (p = 0.291) or sRPE (p = 0.073) across tournament days (Table 2). No significant difference was observed for TD (ES = -0.35 ± 0.88, p = 0.258), HS (ES = 0.13 ± 0.88, p = 0.682), or sRPE (ES = -0.21 ± 0.88, p = 0.511) between tournaments (Table 2).

TABLE 2 HERE

4. Discussion

This study evaluated daily HRV and ASRM responses to consecutive domestic and international tournaments among an elite rugby sevens team. The main finding was that despite no significant difference in match-loads, significant reductions in LnRMSSD were observed only in response to the international tournament and were preceded by travel-related decrements in perceived sleep quality and energy levels.

In agreement with our finding of no significant difference in LnRMSSD post-domestic tournament, Douglas et al. found that LnRMSSD was consistently restored to pre-match levels by ~120 min post-match simulation among amateur adult sevens players.[24] However, significant decrements in vagal-related HRV have been reported among youth rugby league players one day post-match.[25] **While statistical significance was not obtained for DC-Post1, it should be noted that ~80% of the team (7 of 9 players due to a missing data point) experienced a reduction in LnRMSSD that exceeded the intra-individual SWC (bottom of Figure 1). Previous studies have reported significant elevations in cortisol concentrations[13] as well as markers of inflammation (high sensitivity C-reactive protein) and immune system activation (various leukocytes) among elite rugby league players on the day following a match.[14] Elevations in cortisol and markers of inflammation and immune function may all negatively affect vagal-related HRV.[26] Thus, a domestic tournament may still affect cardiac-autonomic activity at the individual level in elite sevens players based on the observed homogeneity in LnRMSSD responses at DC-Post1, although of lesser magnitude than an international tournament.**

The hypothalamic-pituitary adrenocortical and sympatho-adrenomedullary axes mediate the stress response, which can be triggered in anticipation of or in response to homeostatic needs and metabolic requirements.[27] A progressive reduction in LnRMSSD was observed between I-Travel – IC-Post-1 (Figure 1), with large and moderate reductions in LnRMSSD occurring on IC-2 and IC-Post-1, respectively. Travel-related stressors experienced by athletes include disrupted daily routines and meal times, airport hassles, dehydration and disturbed chronobiology.[6] Accordingly, we speculate that the decreasing trend in LnRMSSD was initially influenced by **a combination of** the early wake-time, long and chaotic travel and ~3 am hotel arrival which resulted in **moderate – large ES reductions in LnSleep and LnEnergy on I-Travel and IC-Pre1**. **The substantial decrements in LnRMSSD from IC-2 and IC-Post-1 cannot be explained by the assessed workload metrics (TD, HS and sRPE) in isolation given that they were not different from the previous tournament** (Table 2). **However, the number and magnitude of impacts and collisions were not available for the current analysis. McLellan et al. found that the number of heavy collisions (>8.1 *G*) were related with higher concentrations of creatine kinase (CK) levels**

following a match in elite rugby league players.[13] Thus, potential for inter-tournament differences in body impacts and their effects on muscle damage and inflammation cannot be ruled out for contributing to the observed differences in LnRMSSD responses.

Though not all achieved statistical significance, **a few key differences in ASRM were observed between tournaments when considering magnitudes of the ES** (Table 2), apart from the travel-related decrements discussed above. First, LnSoreness and LnRecovery were each moderately improved relative to baseline on DC-1 but not on IC-1, **whilst each were moderately reduced (i.e., worsened) at DC-Post1 and IC-Post1**. Second, moderate and large decrements in LnSleep and LnSoreness, respectively, were observed on IC-2 but not DC-2. **Last, LnSleep was moderately reduced on IC-Pre1 but not DC-Pre1**. **Of the ASRM parameters, perceived sleep quality has demonstrated the greatest association with LnRMSSD in athletes.[18] Additionally, poor sleep has been associated with increased catecholamine concentrations and elevated proinflammatory cytokines.[28] The association between LnRMSSD and LnSleep was inconsistent in the current study. For example, when ~80 – 90% of the team experienced a reduced LnRMSSD (DC-Post1, I-Travel, IC-2 and IC-Post1, bottom of Figure 1), moderate reductions in LnSleep were also observed. However, LnRMSSD was less affected among players on Mid and IC-Pre1, despite concurrent moderate decrements in LnSleep. Perceived soreness did not relate with post-waking LnRMSSD among sprint-swimmers during preparatory training[18] whereas associations between CK and vagal-HRV have been observed in cyclists[29] but not weightlifters.[30] Our results showed that decrements of the greatest magnitude (Large ES) for both LnRMSSD and LnSoreness occurred on the same day (IC-2). Previous research among elite rugby league players demonstrated that CK levels peak at 24 h post-match, but remain elevated for several days.[13] Thus, the potential causal effect of rugby-induced elevations in CK for suppressing LnRMSSD requires further investigation. Ultimately, no consistent attributions to specific ASRM or match-load parameters can be made for explaining LnRMSSD responses in the current study. This is likely due to a myriad of variables known to affect HRV that include endocrine, biochemical, hemodynamic, psychological, environmental and dietary factors.[26] LnRMSSD responses to the international**

tournament were therefore likely influenced by a combination of variables associated with, but not limited to altered sleep, a disrupted travel itinerary and the process of relocation which interacted with the physical and psychological stress associated with tournament-play.

This study was limited by the small sample of elite players and inclusion of only one pair of consecutive tournaments. **Moreover, this was the team's first exposure to consecutive tournaments in at least 6 weeks, which may serve as a relatively novel stimulus that elicited a heightened stress response, exacerbated by the unforeseen travel events from the preceding days.** Thus, we caution readers that the findings from this study may not be observed when players have become (re-)familiarized with consecutive tournaments or when travel to international tournament destinations is not disrupted as in the current study. In addition, lack of standardized performance testing and other physiological indicators of stress and impaired recovery (e.g., immune, endocrine and inflammatory markers) limit extrapolation of performance or health-related consequences of reduced LnRMSSD versus unchanged LnRMSSD in response to tournament competition.

5. Conclusion

The findings of the current study support the hypothesis that cardiac-autonomic activity is disturbed to a greater extent during an international tournament relative to a domestic tournament. **Given that LnRMSSD was within baseline for 70% of the team by Mid, the discrepancy in LnRMSSD responses were unlikely due to the duration of recovery time between tournaments. In addition, similarity in the assessed workloads between tournaments would indicate that match-physical demands in isolation could not explain the greater decrements in LnRMSSD observed in response to the international tournament.**

Practical Implications

- **Greater decrements in cardiac-autonomic activity were observed in response to an international tournament relative to a domestic tournament**, despite no difference in match-physical demands. Thus, factors separate from competition alone appear to impact players' physiological response to an international tournament.

- **Factors such as chaotic travel events, process of relocation and decrements in perceived sleep quality and energy levels may contribute to a heightened physiological response to competition, reflected in substantial decrements in LnRMSSD.**
- Interventions aimed at facilitating cardiac-parasympathetic recovery during international tournaments may be worth considering for practitioners.

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Figure Caption:

Figure 1. Mean ± 95% confidence interval for the natural logarithm of the root mean square of successive differences (LnRMSSD) and athlete self-report measures across time **and proportion of players with a reduced LnRMSSD relative to baseline.** * denotes significant difference from baseline ($p < 0.05$). Shaded gray area represents the smallest worthwhile change thresholds for LnRMSSD. D-Travel = domestic travel day; DC-Pre1 = 1 day pre-domestic competition; DC-1 = day 1 of domestic competition; DC-2 = day 2 of domestic competition; DC-Post1 = 1 day post-domestic competition; DC-Post2 = 2 days post-domestic competition; **Mid = mid-way point between tournaments;** I-Travel = international travel day; IC-Pre1 = 1 day pre-international competition; IC-1 = day 1 of international competition; IC-2 = day 2 of international competition; IC-Post1 = 1 day post-international competition; IC-Post2 = 2 days post-international competition.

Table 1. Effect Size ± 95% confidence interval for the natural logarithm of the root mean square of successive differences (LnRMSSD) and athlete self-report measures relative to baseline.

Baseline vs.	LnRMSSD	LnSleep	LnEnergy	LnSoreness	LnRecovery	LnMood
D-Travel	-0.26 ± 0.88	-0.09 ± 0.88	-0.31 ± 0.88	-0.21 ± 0.88	-0.11 ± 0.88	-0.26 ± 0.88
DC-Pre1	-0.02 ± 0.88	-0.23 ± 0.88	0.00 ± 0.88	0.67 ± 0.90	0.68 ± 0.90	-0.09 ± 0.88
DC-1	0.06 ± 0.88	0.40 ± 0.89	0.67 ± 0.90	0.85 ± 0.91^{M}	1.10 ± 0.94^{M}	0.35 ± 0.88
DC-2	-0.43 ± 0.89	-0.38 ± 0.89	-0.19 ± 0.88	-0.69 ± 0.90	-0.21 ± 0.88	0.10 ± 0.88
DC-Post1	-0.37 ± 0.89	-1.04 ± 0.95^{M}	-1.73 ± 1.03^{L}	-1.02 ± 0.93^{M}	-1.01 ± 0.93^{M}	-0.80 ± 0.91^{M}
DC-Post2	0.00 ± 0.88	-0.56 ± 0.89	-0.48 ± 0.89	-0.83 ± 0.91^{M}	-0.59 ± 0.90	0.38 ± 0.88
Mid	-0.13 ± 0.88	-1.17 ± 0.95^{M}	-0.60 ± 0.90	-0.65 ± 0.90	0.16 ± 0.88	-0.08 ± 0.88
I-Travel	-0.35 ± 0.88	-1.03 ± 0.93^{M}	-1.70 ± 1.02^{L}	-0.62 ± 0.90	-0.41 ± 0.88	-0.68 ± 0.90
IC-Pre1	-0.46 ± 0.89	-1.16 ± 0.95^{M}	-1.24 ± 0.96^{L}	-0.17 ± 0.88	-0.59 ± 0.89	-0.64 ± 0.90
IC-1	-0.60 ± 0.89	-0.21 ± 0.88	0.26 ± 0.88	0.60 ± 0.89	0.52 ± 0.89	0.30 ± 0.88
IC-2	-1.21 ± 0.96^{L}	-0.71 ± 0.90^{M}	-0.59 ± 0.90	-1.41 ± 0.98^{L}	-0.55 ± 0.89	-0.38 ± 0.88
IC-Post1	-0.89 ± 0.92^{M}	-1.17 ± 0.95^{M}	-1.63 ± 1.02^{L}	-1.15 ± 0.94^{M}	-1.13 ± 0.94^{M}	-0.66 ± 0.90
IC-Post2	-0.35 ± 0.89	-0.63 ± 0.90	-0.70 ± 0.90^{M}	-0.42 ± 0.88	-0.64 ± 0.90	0.25 ± 0.88

D-Travel = domestic travel day; DC-Pre1 = 1 day pre-domestic competition; DC-1 = day 1 of domestic competition; DC-2 = day 2 of domestic competition; DC-Post1 = 1 day post-domestic competition; DC-Post2 = 2 days post-domestic competition; **Mid = mid-way point between tournaments;** I-Travel = international travel day; IC-Pre1 = 1 day pre-international competition; IC-1 = day 1 of international competition; IC-2 = day 2 of international competition; IC-Post1 = 1 day post-international competition; IC-Post2 = 2 days post-international competition; ^{M} = moderate effect size; ^{L} = large effect size.

Table 2. Mean ± 95% confidence interval for competition workloads.

	DC-1	DC-2	IC-1	IC-2
sRPE (au)	488 ± 118	717 ± 185	567 ± 149	758 ± 246
TD (m)	3415 ± 536	3909 ± 808	3819 ± 692	4239 ± 758
HS (m)	593 ± 144	688 ± 212	553 ± 103	676 ± 172
	Mean Domestic		Mean International	
sRPE (au)	602 ± 241		658 ± 277	
TD (m)	3662 ± 967		4018 ± 973	
HS (m)	641 ± 251		611 ± 191	

DC-1 = day 1 of domestic competition; DC-2 = day 2 of domestic competition; IC-1 = day 1 of international competition; IC-2 = day 2 of international competition; sRPE = session rating of perceived exertion; TD = total distance; HS = high speed distance.

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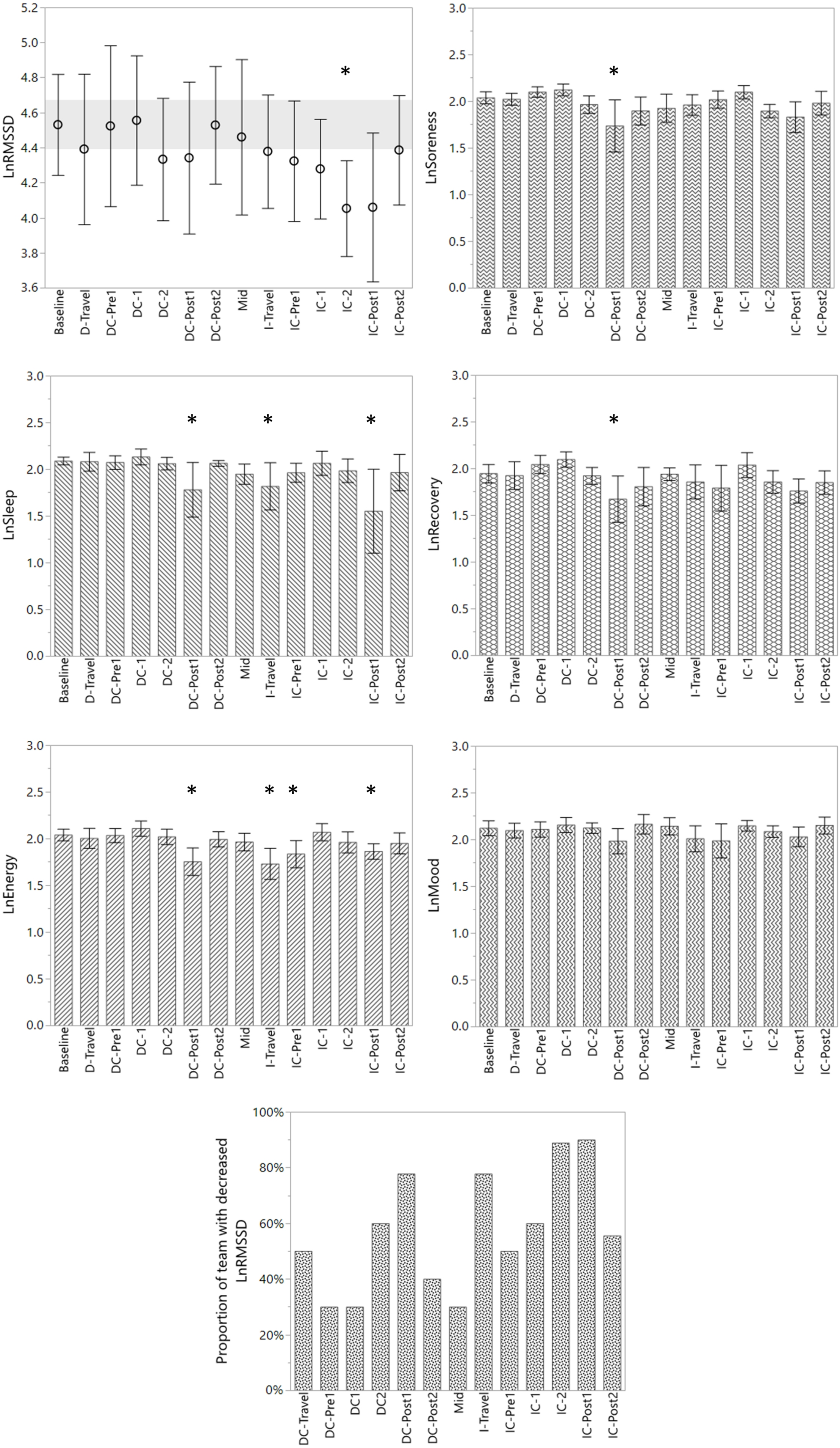

LnRMSSD
LnSoreness
LnSleep
LnRecovery
LnEnergy
LnMood
Proportion of team with decreased LnRMSSD
Baseline
D-Travel
DC-Pre1
DC-1
DC-2
DC-Post1
DC-Post2
Mid
I-Travel
IC-Pre1
IC-1
IC-2
IC-Post1
IC-Post2
DC-Travel
DC1
DC2
*