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Pre-sleep feeding, sleep quality, and markers of recovery in division I NCAA female soccer players

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ABSTRACT

Pre-sleep nutrition habits in elite female athletes have yet to be evaluated. A retrospective analysis was performed with 14 NCAA Division I female soccer players who wore a WHOOP, Inc. band – a wearable device that quantifies recovery by measuring sleep, activity, and heart rate metrics through actigraphy and photoplethysmography, respectively – 24 h a day for an entire competitive season to measure sleep and recovery. Pre-sleep food consumption data were collected via surveys every 3 days. Average pre-sleep nutritional intake (mean ± sd: kcals 330 ± 284; cho 46.2 ± 40.5 g; pro 7.6 ± 7.3 g; fat 12 ± 10.5 g) was recorded. Macronutrients and kcals were grouped into high and low categories based upon the 50th percentile of the mean to compare the impact of a high versus low pre-sleep intake on sleep and recovery variables. Sleep duration ($p = 0.10, 0.69, 0.16, 0.17$) and sleep disturbances ($p = 0.42, 0.65, 0.81, 0.81$) were not affected by high versus low kcal, PRO, fat, CHO intake, respectively. Recovery ($p =$ 0.81, 0.06, 0.81, 0.92), RHR ($p = 0.84, 0.64, 0.26, 0.66$), or HRV ($p =$ 0.84, 0.70, 0.76, 0.93) were also not affected by high versus low kcal, PRO, fat, or CHO consumption, respectively. Consuming a small meal before bed may have no impact on sleep or recovery.

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1. Introduction

Both nutrition and sleep influence recovery from exercise may mitigate the effects of injury. Pre-sleep nutrition is one such strategy that may be utilized to enhance sleep

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and influence recovery metrics [1]. Consumption of protein specifically before sleep has been shown to augment muscle protein synthesis and appears to promote recovery in some [2,3] but not all studies [4]. Pre-sleep protein consumption has been the primary topic in research surrounding sleep nutrition, as sleep is typically the longest post-absorptive period, and a time where growth hormone concentrations are elevated [5]. As such, pre-sleep protein consumption may help to augment muscle protein synthesis with the increase in growth hormone concentrations. There is a paucity of data in the literature, however, surrounding the effects of pre-sleep food consumption on sleep and recovery metrics. Additionally, much of the research within the field of sports nutrition has been conducted in males, with only a mere 6% of studies conducted in female-only samples [6]. With the prevalence of male-centric data, the conclusions and recommendations cannot always be translated to females due to the inherent physiological and endocrinological differences [7]. To date, there are no studies regarding the effects of pre-sleep feeding on recovery and sleep in Division I female athletes despite similarly known results in male athletes [1]. This is also the first study to examine repeated measures for pre-sleep nutrition habits in female athletes.

It is well established that sleep is a key factor for optimal physiological function, including which is necessary to optimize athletic performance [8]. Sleep is a time where growth and recovery occur; metabolic activity is at its lowest point and higher rates of growth hormone are secreted, which allows for physiological restitution [1]. It is also known that acute and chronic sleep deprivation can negatively influence internal markers of recoveries such as resting heart rate (RHR) and heart rate variability (HRV), all of which influence recovery, adaptation to training, and readiness to perform, which can be defined by a low RHR and high HRV. Alongside neurological responses during sleep, overall recovery and anabolic processes also are impacted. Physiological repair and growth occur most during slow wave sleep (SWS), which is facilitated by low metabolic activity [9]. As such, elite athletes look to sufficient sleep as an important tool to improve recovery.

Many wearable technologies have been developed to help athletes quantify their recovery by tracking activity, sleep, and heart rate metrics. Wrist worn activity trackers can provide users with a recovery score (%) based upon their activity, recovery, and heart rate parameters including RHR and HRV. Many athletes look to HRV to quantify their recovery as it serves as a measure of autonomic nervous system function and an indicator of physical fitness and readiness to perform [10]. Generally, a higher HRV is indicative of improved fitness levels, meaning that the body is highly receptive to both the sympathetic and parasympathetic nervous system's innervation to heart rate regulation [10,11]. Generally, elite athletes exhibit an average HRV above 80 ms, and in a study examining elite male and female athletes, the average HRV was above 100 ms [10,12]. As such, tracking recovery metrics, as well as utilizing pre-sleep feeding techniques, may provide athletes with another opportunity to improve their performance. Therefore, the purpose of this study was to examine the influence of pre-sleep nutrition on sleep quality and recovery in elite female athletes over the course of the 2020–2021 competitive season. We hypothesize that athletes who consume more protein before going to bed will have improved recovery (as determined by lower

RHR, higher HRV, and recovery score) compared to athletes who consumed less protein before sleep.

2. Materials and methods

2.1. Subjects

Fourteen Division I female soccer players ($n = 14$; mean ± sd: age 20.8 ± 1.4 years; height 167.9 ± 4.87 cm; weight 64.1 ± 6.9 kg; BMI 22.7 ± 0.5 kg/m^2; oral contraceptive use: $n = 6$) from four universities that regularly utilize WHOOP technology including Florida State University, University of North Carolina at Chapel Hill, South Dakota State University, and University of Nebraska-Lincoln participated in this study (Table 1). WHOOP, Inc. deidentified all data prior to sending to the research team and, thus, this study was approved by the IRB at Florida State University as not involving human subjects (ID00001584).

2.2. Study design

A biometric capture device (WHOOP Inc., Boston, MA, USA) was utilized to non-invasively collect athlete's RHR, HRV, and time spent in slow wave sleep. Athletes wore WHOOP continuously and as part of their usual training and competition as requested by their strength and conditioning staff and were recommended to wear the band on their dominant wrist, a centimeter proximal to the radial styloid process. They received the bands early in the 2020 fall semester. Data were collected 24 h a day for the entirety of the athlete's 2020–2021 season (Figure 1). Upon receiving the bands, athletes were asked to complete an initial intake survey that included questions about their menstrual cycles, activity levels, sleep and dietary patterns, injury history, and anthropometrics. Questionnaires were sent through the WHOOP application every three days via their phone app to collect data on the athlete's pre-sleep (defined as 2 h or less before bed) nutrition habits, resulting in a total of 10 food logs over the course of a month (Figure 2).

Table 1. Descriptive characteristics.

	n = 14
Height (cm)	167.9 ± 4.87
Weight (kg)	64.1 ± 6.9
BMI (kg/m^2)	22.7 ± 0.5
Age (yrs)	20.8 ± 1.4

Cm centimeters, *kg* kilograms, *kg/m^2* kilogram/meters^2, *yrs* years. Data presented as mean ± standard deviation.

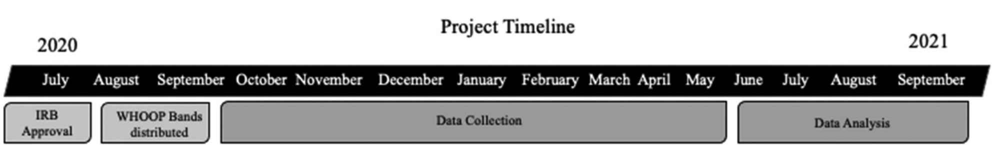

Figure 1. Overall project timeline.

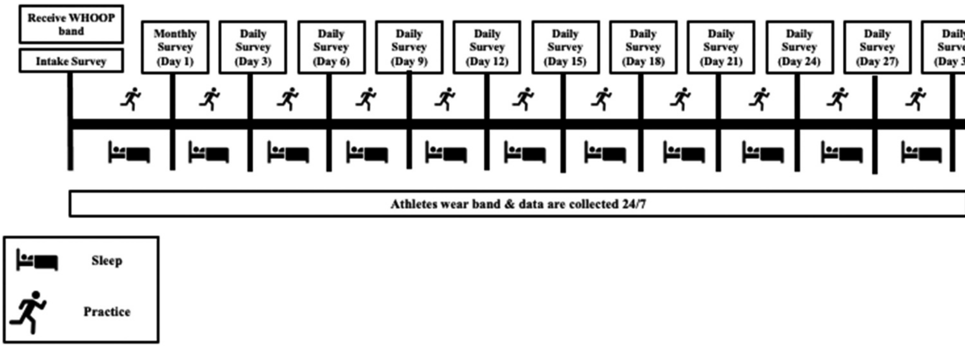

Figure 2. Sample monthly timeline.

Upon opening the survey, athletes were asked if they ate the night before; if they indicated that they did eat, they were asked how close to bed they ate, to describe what they ate, to estimate how much they ate, and if they took any supplements to help them fall asleep.

Athlete's recovery score (%), HRV, and RHR were all recorded by the WHOOP, Inc. bands. According to WHOOP, Inc., recovery score is a proprietary metric of the WHOOP, Inc. platform that combines nighttime measures of heart rate, HRV, respiratory rate, and sleep duration into a once-daily metric used to guide recommended training load [13]. Recovery ranges from 0% to 100% with higher values indicating greater readiness to adapt to a training load. All measures have been previously validated in female athletes as a means to quantify training load and training stress [13].

Food Processor program (ESHA research, Salem, OR, USA) was used to analyze macronutrient content of the meals logged by the athletes in their daily survey. Daily survey results were distributed to the researchers in monthly batches, and the data analyzed included total kilocalories, and grams of protein (PRO), fat, and carbohydrates (CHO). Two research technicians split the data and performed dietary analysis on their respective halves. To maintain integrity of the data analysis, the technicians blindly overlapped on a sample of 10 entries on every analysis, where a third party tested the overlapping data using test-retest reliability (ICC) and coefficient of variation (CV) tests. The CV between the two technicians among all data sets and macronutrients was 11 ± 5.9%. The overlapping data points were then averaged and used for analysis.

2.3. Statistical analyses

All variables were assessed via null-hypothesis testing, and the significance was set at $p \leq 0.05$. Confidence intervals were set to 95%. Analyses were conducted using R (Version 4.0). Data are presented as means ± SD. To adequately determine the effect of pre-sleep nutrition on sleep quantity and quality, macronutrients and kcals were considered categorical variables and were grouped into high and low categories based upon the 50th percentile of the mean to effectively compare the impact of a high versus low pre-sleep intake on sleep and recovery variables. The categories were broken down as follows: >5 grams of protein, >10 grams of fat, > 45 grams of

Table 2. Average pre-sleep macronutrient intake.

	n = 14
Kilocalories	330 ± 284
Carbohydrate (g)	46.2 ± 40.5
Protein (g)	7.6 ± 7.3
Fat (g)	12 ± 10.5

kcals kilocalories, *g* grams. Data presented as mean ± standard deviation.

carbohydrates, and > 246 kcals were all considered high. To determine the impact of pre-sleep nutrition on sleep quantity and quality, kilocalorie, PRO, fat, and CHO contents were assessed against sleep quantity and sleep quality to see if a statistically significant difference existed. Sleep data were derived from data captured using a wrist-worn multisensory (tri-axial accelerometer, optical heart rate sensory, capacitive touch sensor, and ambient temperature sensor) on the WHOOP device [14]. Linear mixed models were performed using sleep and recovery metrics as the dependent variable, macronutrient intake as the independent variable, and each athlete as a random effect to account for repeated measures.

The impacts of pre-sleep nutrition (as measured by kilocalorie, PRO, fat, and CHO content split into high and low values based upon the 50th percentile mark of the means) on aim 1: sleep (as measured by sleep quality and sleep quantity) and aim 2: recovery (as measured by RHR, HRV, and recovery score) were evaluated. Upon examining the relationships, models were created for each explanatory and response variable. A regression model was used, including p-values and confidence intervals where appropriate.

3. Results

Table 2 provides the average pre-sleep food consumption characteristics (mean ± sd: kcals 330 ± 284; pro 7.6 ± 7.3 g; fat 12 ± 10.5 g; cho 46.2 ± 40.5 g). Average pre-sleep food intake typically consisted of snack foods or small desserts, including popcorn, cheese sticks, yogurt, ice cream, or cookies. Table 3 outlines high and low pre-sleep macronutrient intake, as well as the associated sleep and recovery metrics. To examine the impact of pre-sleep feeding on recovery and sleep, models were run for the cases when grams of

Table 3. Pre-sleep macronutrient intake and recovery and sleep metrics.

			Recovery			Sleep	
		Amount	RHR (bpm)	HRV (ms)	Recovery (%)	Sleep (hrs)	Wake Periods
Kcals	Low	144.4 ± 59.0	50.5 ± 7.0	98.6 ± 36.4	64.2 ± 21.3	6.9 ± 2.1	13.3 ± 3.6
	High	427.0 ± 220.0	50.5 ± 6.5	85.3 ± 35.0	63.2 ± 27.4	8.3 ± 1.5	14.7 ± 4.2
Pro (g)	Low	2.2 ± 1.3	51.2 ± 5.8	91.4 ± 19.1	73.9 ± 14.6	7.6 ± 1.1	13.9 ± 3.3
	High	15.6 ± 7.5	50.6 ± 7.7	91.7 ± 50.1	51.2 ± 23.7	7.0 ± 2.3	12.7 ± 4.1
Fat (g)	Low	5.2 ± 2.6	50.8 ± 7.8	88.5 ± 25.2	63.1 ± 23.4	6.7 ± 2.3	14.2 ± 3.0
	High	18.8 ± 7.6	50.7 ± 6.3	95.3 ± 46.8	62.0 ± 26.7	7.8 ± 1.3	13.6 ± 4.5
Cho (g)	Low	22.7 ± 9.2	52.0 ± 7.7	89.3 ± 40.2	61.2 ± 25.1	7.1 ± 2.0	13.3 ± 3.6
	High	66.3 ± 30.9	47.4 ± 2.0	99.1 ± 26.7	62.1 ± 12.2	8.1 ± 1.1	14.7 ± 13.8

g grams, % percent, *ms* milliseconds, *bpm* beats per minute, *hrs* hours. Data presented as mean ± standard deviation.

Table 4. Recovery linear regression data.

	RHR			HRV			Recovery Score		
Predictors	Estimates	CI	P	Estimates	CI	P	Estimates	CI	P
Kcal Intercept	51.14	47.47–54.81		91.56	71.37–111.76		62.97	52.16–73.79	
Kcal (high)	0.3	−2.41–3.1	0.836	1.34	−11.37–14.06	0.836	1.46	−10.46–13.38	0.81
Pro Intercept	50.92	47.08–54.77		93.58	72.84–114.31		69.48	60.18–78.78	
Pro (High)	0.71	−2.22–3.63	0.637	−2.67	−16.06–10.73	0.696	−11.41	−23.18–0.36	0.057
Fat Intercept	50.57	46.82–54.31		91.17	70.99–111.35		64.32	53.72–74.93	
Fat (High)	1.55	−1.16–4.26	0.262	1.98	−10.52–14.48	0.756	−1.44	−13.17–10.29	0.81
Cho Intercept	51.79	47.66–55.92		92.6	70.90–114.30		64.08	51.34–76.83	
Cho (low)	−0.65	−3.55–2.25	0.661	−0.61	−13.83–12.60	0.927	−0.61	−13.05–11.84	0.924

Table 5. Sleep linear regression data.

	Sleep Duration			**Sleep Disturbances**		
Predictors	Estimates	CI	P	Estimates	CI	P
Kcal Intercept	422.47	369.11-475.82		10.26	8.18-12.35	
Kcal (high)	34.85	-6.77 - 76.47	0.101	0.84	-1.2-2.88	0.421
Pro Intercept	432.23	373.16-491.30		10.93	8.79-13.06	
Pro (high)	8.86	-35.37-53.09	0.695	-0.49	-2.61-1.63	0.652
Fat Intercept	423.23	367.86-478.59		10.77	8.72-12.83	
Fat (high)	29.36	-11.51-70.24	0.159	-0.25	-2.27-1.77	0.809
Cho Intercept	460.06	399.25-520.86		10.84	8.43-13.25	
Cho (low)	-30.42	-73.88-13.04	0.17	-0.26	-2.41-1.89	0.814

protein, fat, and carbohydrates were greater than zero. Macronutrients and kcals were included in the model as fixed effects. There was no significant impact of pre-sleep consumption of protein, fat, carbohydrate, or kcal on recovery score, RHR, HRV, hours of sleep, or wake episodes.

While there were no significant effects of the macronutrients on sleep and recovery metrics (Table 4 , 5), there was a trend toward significance ($p = 0.06$) in recovery score based upon protein intake, whereby those who had more than 5 g of protein before bed had a recovery score of 11.41 percentage points lower than those who ate less than 5 g of protein pre-sleep (Table 4).

4. Discussion

We examined the effect of pre-sleep nutrition on sleep (as demonstrated by sleep quality and sleep quantity) and next-day recovery (as demonstrated by RHR, HRV, and recovery score). The primary findings of this investigation were as follows: there were no significant effects of pre-sleep consumption of protein, fat, or carbohydrates on sleep quantity or sleep quality, as measured by hours of sleep and frequency of sleep disturbances. Furthermore, there were no significant effects of pre-sleep consumption of protein, fat, or carbohydrates on metrics of recovery, including HRV, RHR, and recovery score. Therefore, our hypotheses were not accepted, in that consuming foods higher in protein did not have a significant effect on recovery and consuming a higher kilocalorie content before bed did not improve metrics of sleep. Context is important, however, where 7.6

g of protein was considered high in the present study, a high amount of protein in a real-world setting would be over 20 g [15]. Finally, it is important to note that habitual pre-sleep food intake does not appear to negatively affect sleep quantity or quality.

While the present study did not find any significant effects between protein consumption on sleep metrics, likely due to such low consumption rates, there is conflicting evidence among the literature to suggest the effects that protein consumption may have on sleep. Similar to the present study, Trommelen et al. reported no difference in sleep duration, sleep time, wake time, or sleep-onset latency (SOL) in participants given 20 g of protein post-exercise, pre-sleep [15]. In unpublished data collected on all WHOOP, Inc. users, however, researchers found that eating within 30 min of going to bed caused an average loss of 26 min of sleep per night, and a decrease of 3% in REM sleep [10]. Similarly, in a study examining elite male athletes, every 1 MJ (~239 kcal) increase in pre-sleep intake was associated with an increase in SOL of 5 min ($p = 0.01$) [16]. Conversely, Lindseth et al. reported that 4 days of a high protein diet (56% of intake) decreased wake episodes throughout the night [17]. Falkenberg et al. also discovered that for every 1 g increase of evening protein intake was correlated with a decrease in SOL of 2 s ($p = 0.01$) in professional male athletes [18]. While there is a paucity of data surrounding the effects of pre-sleep protein consumption on sleep quality or sleep quantity, the studies that are available provide conflicting evidence. Thus, our lack of significant findings is not out of the ordinary, and perhaps the protein consumption was too low to elicit any changes in sleep.

Among 14 athletes, those who consumed more than 5 g of protein close to bed had a recovery score of 11.41 percentage points lower than those who ate less than 5 g of protein before sleep, which approached statistical significance ($p = 0.06$). Our data agree with unpublished data from VanDeusen et al. as their findings demonstrate that eating before bed is associated with an average decrease of 10% in recovery score among all WHOOP, Inc. users [5]. Previous research, however, has indicated benefits of pre-sleep protein consumption, including improved next morning RMR, strength and power metrics, and time to recover [1–3]. Among all these studies, however, protein intake was higher (above 30 g), where our findings indicated no response to protein intake before sleep, likely because the average intake was much lower (around 5 g). Our findings were consistent with Gillen et al., where upon surveying 553 elite Dutch athletes, the average pre-sleep protein consumption was only 7 g [19]. According to Trommelen & VanLoon, a dose of at least 40 g of protein before bed is needed to elicit overnight muscle protein synthesis and to stimulate recovery in men and women [5]. When compared to a non-protein placebo, the authors found that overnight muscle protein synthetic rates were 22% higher when consuming a bolus of 40 g of protein immediately prior to bed, which would be recommended for both men and women [5]. Elite athletes have a high caloric demand, and a bolus of pre-sleep protein may not only help them reach their daily macronutrient goals, but may also improve their skeletal muscle recovery [20]. In the present study, it is possible that the association between a higher protein intake and a lower recovery score may have approached significance because the “high” protein consumption group (>5 g) still falls well below the recommended pre-sleep protein intake (30–40 g). Thus, there is not enough of a stimulus to elicit a positive response in recovery. Much of the current literature found the performance or protein synthesis benefits associated with pre-sleep protein consumption may be due to an evening exercise versus a morning exercise bout in conjunction with pre-sleep feeding [2,4]. In the present study, however, timing of exercise throughout the day was not recorded; therefore, this may explain the possible lack of significant, positive findings of the effects of pre-sleep protein consumption on recovery metrics. Nevertheless, there is no negative consequence to eating protein before sleep for performance, sleep, metabolism, or recovery.

Furthermore, the potential negative impact of pre-sleep protein intake on recovery, as well as the lack of significant findings from pre-sleep fat and carbohydrate consumption, is limited by a lack of controlling for confounders. The reported negative consequences of eating more protein before sleep may be associated with eating non-nutrient-dense foods, a higher caloric intake, inconsistent sleep, alcohol intake, or a higher strain accumulation throughout the day [21]. Higher protein consumption occurred on the weekends (Friday through Sunday) may be associated with higher kcal intake in general, alcohol consumption, or later bedtimes – all of which may poorly affect sleep and recovery [16]. Furthermore, more activity throughout the day may be associated with poorer sleep, as maximal exercise and prolonged exercise have been shown to delay the onset of REM sleep [22]. It is important to account for potential confounding factors when examining the implication behind our findings of possible negative trends, or lack of significant findings of pre-sleep macronutrient intake on recovery.

Our findings also indicated no significant effect of carbohydrate consumption on sleep metrics. Previous research, however, has indicated both positive and negative effects of consuming carbohydrate before sleep. Notably, Halson reported that consumption of a high glycemic-index food, in this instance, 200 g of jasmine rice, before sleep shortened sleep-onset latency by 48.6% when compared to a low-glycemic intake before bed [23]. Furthermore, the consumption of carbohydrates also promotes enhanced tryptophan and serotonin concentrations. Melatonin, the hormone associated with circadian rhythm control, is converted from serotonin and its precursor, tryptophan [23]. Consuming high glycemic foods may therefore promote enhanced sleep quality through the production of melatonin by increasing tryptophan and serotonin concentrations. In a systematic review examining the effects of nutrition prior to sleep, St. Onge et al. reported numerous study findings indicating benefits of pre-sleep carbohydrate intake, including increased REM sleep and decreased SOL [24]. In this study, a low-carbohydrate intake was defined as 100 g, and a high-carbohydrate intake as 600 g [24]. While our findings indicate no significant impact of nighttime carbohydrate feedings on sleep architecture, it may be due to the low consumption of carbohydrates. Within our findings, the average pre-sleep carbohydrate intake was 46 g. This falls well below the average carbohydrate intake for the studies that displayed positive results, such as reduced SOL and increased REM sleep [24]. Finally, data from the present study also indicated no significant effects of pre-sleep carbohydrates on RHR, HRV, or recovery score. Additionally, there are little available data on the effects of pre-sleep carbohydrate intake on recovery metrics.

While our research indicated no significant effects of pre-sleep fat consumption on sleep metrics, there is evidence to suggest that consuming fat may be associated with shorter SOL [25]. Researchers of one study indicated the benefits of a low-carbohydrate, high-fat pre-sleep meal, where deep sleep was increased by 11–15 min when compared to a high-carbohydrate, low-fat, or non-calorically dense placebo [26]. The type of fat may be of importance, however, as St. Onge et al. reported that a higher intake of saturated fats may induce poor sleep quality [24]. In a study examining higher saturated fat intakes among healthy adults, SWS was reduced by about 5 min, and SOL was increased by about 12 min when compared to lower saturated fat intakes (10% vs 7.5% intake) [8]. While this is interesting, participants in the present study only consumed 12 g of fat a night on average and therefore, the impact on sleep is unlikely. Additionally, the fat quality that the athletes consumed was unable to be determined, and therefore, the true impact of pre-sleep fat consumption may not be ascertained from the present study. Finally, our investigation found no significant results between pre-sleep fat intake on metrics of RHR, HRV, or recovery score.

4.1. Limitations

There were several limitations to this study. This study was retrospective, thus, we were unable to influence the questions being asked of the athletes. The time of eating was limited to within 2 h of going to sleep, and the exact time of day is unknown. Specific timing of the pre-sleep food intake (such as time of day) was not provided. Total daily caloric intake was not recorded; thus, assumptions cannot be made about sufficient serving sizes. This study was only designed to examine the influence that macronutrients had on sleep and recovery despite known influences that micronutrients or other factors, such as glycemic index, have on sleep. Additionally, the menstrual cycle was not accounted for which can influence sleep and recovery, and therefore, data were collected among all phases of the menstrual cycle. Finally, due to the nature of field-based studies, athlete compliance was low. Seven athletes were excluded from the study due to a lack of consistent WHOOP band use as well as inconsistent and insufficient reporting of pre-sleep feeding. As a result, the sample size was significantly reduced and standard deviations for nutritional intake data were high. Nevertheless, we were able to gain a real-life context of how the athletes eat before sleep.

5. Conclusion

In the present study, there was no significant effect of pre-sleep nutrition on sleep metrics or recovery in Division I female soccer players. However, more research is necessary to evaluate the effects of a pre-sleep nutrition intervention in a controlled setting, where recommended dosing of the macronutrients may occur. It is evident that elite female athletes do not consume enough protein in the evenings to elicit a higher, and more optimal recovery. Future research should be completed to understand the effects of pre-sleep eating beyond the scope of the effects of sleep, and additional studies should be completed that examine the effects of internal markers of recovery, such as RHR and HRV. Additionally, future aims of this research include conducting a controlled feeding study in the laboratory, as opposed to our present field study, are warranted.

Disclosure Statement

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Declaration of interst

KEH and DMP are employees of WHOOP.

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