Impaired Sleep Mediates the Negative Effects of Training Load on Subjective Well-Being in Female Youth Athletes

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Background: Although increased training load (TL) and impaired sleep are associated with decreases in subjective well-being in adult athletes, these relationships among female youth athletes are unclear. It is unknown whether the effects of sleep and TL on well-being are independent or whether alterations in sleep mediate the effects of TL on subjective well-being.

Hypothesis: Sleep and TL exert independent effects on subjective well-being among youth athletes, although alterations in sleep mediate a significant portion of the effect of TL on well-being in female youth athletes.

Study Design: Prospective cohort study.

Level of Evidence: Level 4.

Methods: A total of 65 female soccer athletes (age range, 13-18 years) were monitored for 1 year. Daily TL was determined by session rating of perceived exertion and converted to z-scores. Every morning, participants recorded sleep duration in hours and rated stress, mood, fatigue, and soreness on a scale from –3 to +3 (worst to best). Linear mixed-effects models and mediation analysis were used to evaluate the independent effects of TL and sleep on well-being.

Results: Average sleep duration was 7.9 ± 1.4 hours during the study period. In the multivariable model, TL and sleep duration were independently associated with fatigue (TL: β = –0.19, $P < 0.001$; sleep: β = 0.15, $P < 0.001$), mood (TL: β = –0.030, $P = 0.014$; sleep: β = 0.13, $P < 0.001$), stress (TL: β = –0.055, $P = 0.001$; sleep: β = 0.13, $P < 0.001$), and soreness (TL: β = –0.31, $P < 0.001$; sleep: β = 0.022, $P = 0.042$). Sleep duration mediated a significant portion of the effect of TL on mood (26.8%, $P < 0.001$), fatigue (12.6%, $P < 0.001$), and stress (24.5%, $P < 0.001$).

Conclusion: Among female youth athletes, decreased sleep duration and increased TL are independently associated with impairments of subjective well-being. In addition, decreased sleep mediates a significant portion of the negative effect of increases in TL on subjective well-being.

Clinical Relevance: Monitoring and promoting sleep among female adolescent athletes may significantly improve subjective well-being, particularly during periods of increased TL.

Keywords: mood; stress; fatigue; soreness

Although increases in training load (TL) may be needed to promote physiologic adaptation in athletes, increases in acute TL create short-term negative effects on several elements of one's well-being.[5,8] Prior studies have demonstrated increased soreness after periods of increased external TL, which may ultimately predispose an athlete to an increased risk of injury.[2] Increases in TL are also associated with fatigue, mood, and stress in athletes.[21] In addition to undermining performance, decreases in subjective well-being carry a risk of injury and may represent early signs of overtraining.[10,21]

Increased acute TL has been shown to negatively influence sleep duration and quality in athletes.[7,11,18] In a group of female adolescent athletes, increases in daily TL (but not weekly or monthly) were shown to be inversely associated with

subsequent sleep duration and quality.[21] Decreases in chronic sleep increased risk of injury in youth athletes,[13] suggesting that impaired sleep may potentiate some of the injury risk associated with relatively high TL.

Decreased sleep duration is also associated with worse subjective well-being. It is unclear whether the influences of TL on subjective well-being are independent or mediated by sleep itself. In addition to the psychological benefits, greater levels of subjective well-being appear to predict better tolerance of an increased workload later in the same day.[6] This may help explain why lower ratings of subjective well-being, such as mood, fatigue, stress, and soreness, are associated with increased injury risk in athletes.[1,2,10,21] Interventions to reduce the maladaptive effects of increases in TL, such as increased sleep, could facilitate the physiological adaptations beneficial to performance while at the same time improving well-being and even reducing the risk of injury and illness. Prior research in this area has been conducted almost entirely in adults and adolescent male athletes. Therefore, the purposes of this study were to determine whether acute TL and sleep are independent predictors of subjective well-being and whether sleep mediates the influence of acute TL on subjective well-being in female youth athletes.

METHODS

Study Design

All procedures performed in this study were approved by the institutional review board of the University of Wisconsin–Madison. Written, informed assent was provided by participants who were minors, and written, informed consent was provided by adult participants and parents of minors. A total of 65 female youth soccer athletes (mean age, 15.5 ± 1.6 years; mean height, 164.7 ± 6.6 cm; mean weight, 57.3 ± 8.2 kg) provided self-reported TL, sleep, and well-being data throughout a calendar year, including 10 months of training and competition. Each morning during the study period, prior to any soccer events, athletes were asked to provide daily ratings of fatigue, mood, soreness, stress, and sleep quality on a Likert-type scale from –3 (worst) to +3 (best), with descriptive text prompts as well as sleep duration in hours to the nearest half hour, using an online software program (fitfor90.com). Immediately after all physical activity, participants provided the duration (minutes) and intensity (1 to 10) of the activity, which were multiplied to yield a session rating of perceived exertion value as a measure of internal TL.[3,4] Compliance with the completion of daily TL and well-being ratings was encouraged periodically throughout the study period by coaching staff.

Statistical Analysis

Data were initially evaluated for normality using descriptive statistics and histogram analysis. Mean TL, sleep duration, and sleep quality were compared across age groups (U14, U15, U16, U17, U18) using least squares means from linear mixed-effects models to account for individual repeated measures as a random effect. For each individual, days were initially grouped by TL z-score from the previous day as low (<–1.0), moderate-low (–1 to 0), moderate-high (0 to 1), or high (>1); sleep quality z-scores as low (<–1.0), moderate-low (–1 to 0), moderate-high (0 to 1), or high (> 1); and hours of sleep the preceding night (<6, 6-7, 7-8, 8-9, >9). Linear mixed-effects models were used to compare least squares means for fatigue, mood, stress, and soreness across groups, adjusting for age and individual repeated measures. Separate linear mixed-effects models were developed to predict fatigue, mood, stress, and soreness with prior day TL, prior night sleep duration, and age group as fixed effects and individual repeated measures as a random effect. Finally, separate mediation analyses were used to evaluate whether prior night sleep duration mediates the effect of the prior day TL on each measure of subjective well-being, adjusting for age group and individual repeated measures. Significance level was determined a priori at 0.05, and all tests were 2-tailed. For all comparisons of least squares means between groups, the Tukey method was used to adjust for multiple pairwise comparisons. All statistical analyses were performed using R statistical software.[15]

RESULTS

Data were initially evaluated descriptively to determine missing data in TL and well-being variables. Compliance was found to be 76.0% overall, and no obvious differences in missing data were found with respect to date, age group, or specific individual participants. As a result, missing values were ignored, and all available data were included for analysis. Mean daily TL was 422 ± 252 arbitrary units, and mean sleep duration was 7.9 ± 1.4 hours for the entire group during the study period. Of the 65 participants, 40 (61.5%) were found to average less than 8 hours of sleep. Differences in TL, sleep duration, and sleep quality during the study period are shown in Table 1.

Mood, fatigue, stress, and soreness were all found to decrease significantly with increasing prior-day TL (Figure 1). On the other hand, fatigue, mood, stress, and soreness were all found to improve significantly after nights with increased sleep (Figure 2) and with greater sleep quality (Figure 3). After inclusion in the multivariable model adjusting for age and repeated measures, TL and sleep duration were found to be significant and independent predictors of mood, fatigue, stress, and soreness (Table 2). Similarly, TL and sleep quality were significant and independent predictors of mood, fatigue, stress, and soreness (Table 3). In both multivariable models, the effects of TL on fatigue, mood, and stress were reduced after accounting for the effects of sleep. Finally, sleep duration mediated a significant portion of the effect of TL on mood (26.8%, $P < 0.001$), fatigue (12.6%, $P < 0.001$), and stress (24.5%, $P < 0.001$). On the other hand, TL mediated 41.0% of the influence of sleep duration on soreness ($P < 0.001$).

Table 1. Mean in-season daily training load, sleep duration, and sleep quality by age group among adolescent female soccer athletes[a]

Variable	U14	U15	U16	U17	U18
Training load, AU	395 (345-444)	384 (321-446)	435 (377-493)	474 (423-525)[b,c]	487 (423-550)[b,c]
Sleep duration, hours	8.45 (8.2-8.7)	7.91 (7.6-8.2)[b]	7.79 (7.5-8.1)[b]	7.69 (7.4-8.0)[b]	7.56 (7.2-7.9)[b]
Sleep quality	1.57 (1.2-1.9)	0.87 (0.5-1.2)[b]	0.65 (0.3-1.0)[b]	0.91 (0.6-1.2)[b]	0.80 (0.4-1.2)[b]

AU, arbitrary units.
[a]Data are presented as mean (95% confidence interval). Sleep quality ranges from −3 (worst) to +3 (best).
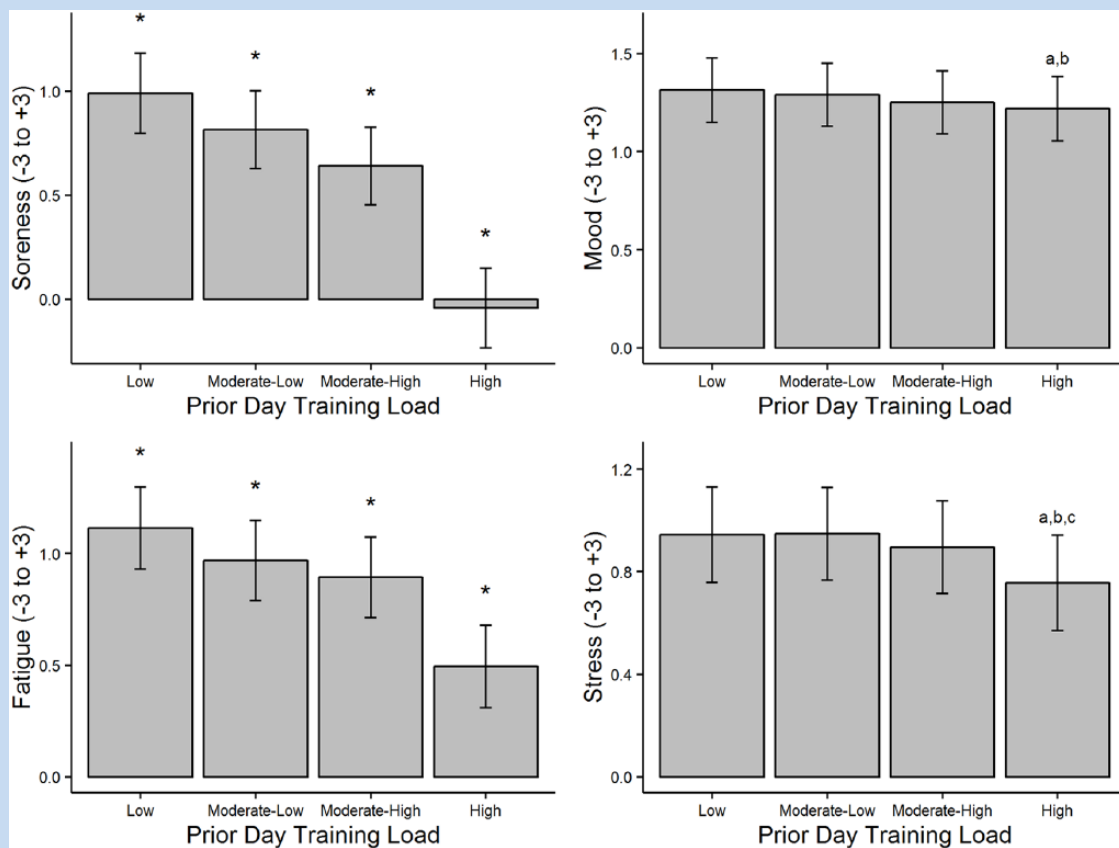[b]$P < 0.05$ versus U14.
[c]$P < 0.05$ versus U15.

Figure 1. Comparison of subjective well-being measures by prior-day training load among adolescent female soccer athletes using least squares means from linear mixed-effects models adjusted for age group and individual repeated measures. Data are shown as means and 95% confidence intervals. *$P < 0.05$ versus all other groups; [a]$P < 0.05$ versus low; [b]$P < 0.05$ versus moderate-low; [c]$P < 0.05$ versus moderate-high.

DISCUSSION

In this study of adolescent female soccer athletes, increased daily TL was associated with significant decreases in each of our measures of subjective well-being the next day. This relationship between TL and subjective well-being is well documented,[17] and these findings are consistent with prior research demonstrating that acute increases in TL negatively affect well-being in a dose-dependent manner.[9,12,20] While well-being is an important primary health endpoint, decreased mood is associated with increased injury risk in female athletes,[21] and TL, soreness, and fatigue may interact to increase injury and illness risk.[2,10]
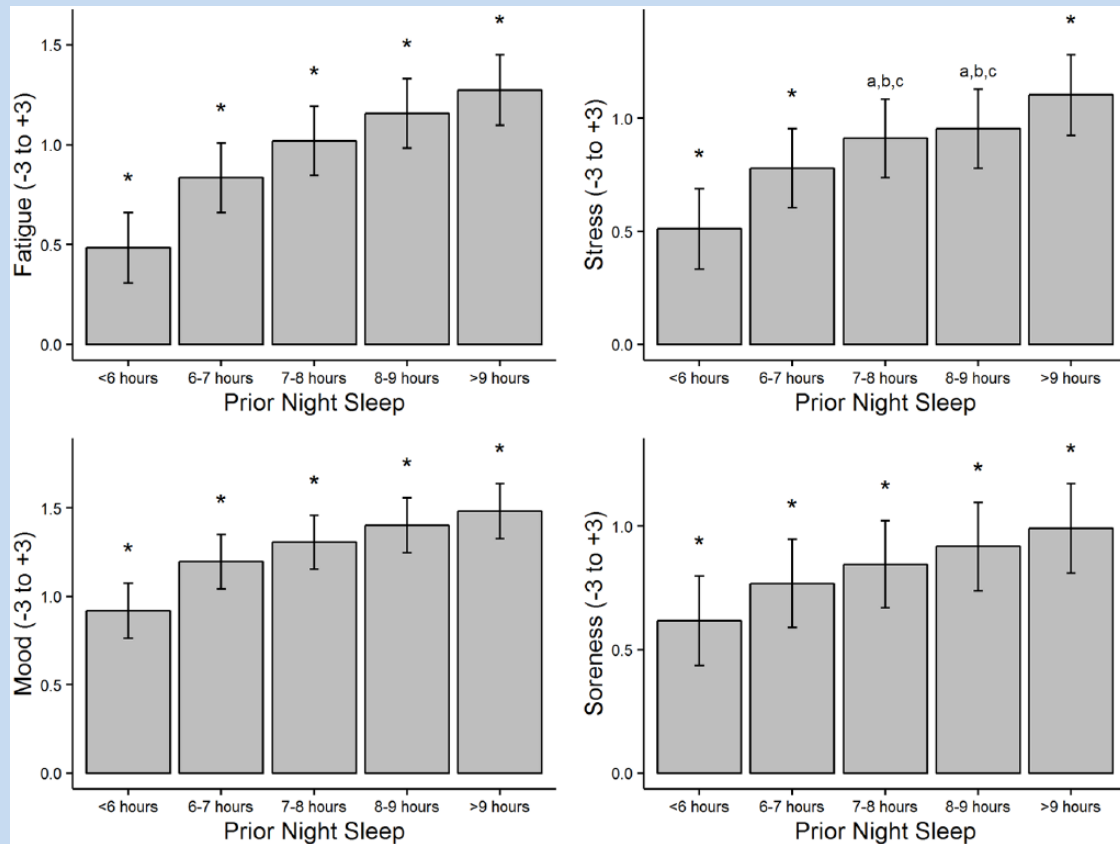
Figure 2. Comparison of subjective well-being measures by prior-night sleep duration among adolescent female soccer athletes using least squares means from linear mixed-effects models adjusted for age group and individual repeated measures. Data are shown as means and 95% confidence intervals. *$P < 0.05$ versus all other groups; [a]$P < 0.05$ versus <6 hours; [b]$P < 0.05$ versus 6-7 hours; [c]$P < 0.05$ versus >9 hours.

Table 2. Independent effects of prior-day training load and prior-night sleep duration on subjective well-being in female youth soccer athletes using linear mixed-effects models adjusted for age group and individual repeated measures[a]

	Fatigue		Mood		Stress		Soreness	
Variable	β	P	β	P	β	P	β	P
Prior day TL, AU	−0.19	<0.001	−0.030	0.014	−0.055	0.001	−0.31	<0.001
Prior night sleep, hours	0.15	<0.001	0.13	<0.001	0.13	<0.001	0.022	0.042

AU, arbitrary units; TL, training load.
[a]Fatigue, mood, stress, and soreness range from −3 (worst) to +3 (best).

Significant increases were identified in all well-being measures as nightly sleep duration and sleep quality increased. Previous research has demonstrated the vital importance of sleep in athletes, and this may be even greater among adolescent athletes who are developing physically and attempting to navigate complex social and academic environments while also attempting to achieve athletic success.[19] Adolescents often do not obtain the recommended duration of sleep, and adolescent sleep has been decreasing over the past century.[14,16,19] Adolescent athletes may be at even greater risk of sleep deprivation as a result of training, competition, travel, and dyssynchronous academic and athletic schedules.[19]

Both TL and sleep duration exert independent effects on fatigue, mood, and stress after controlling for the effect of age.
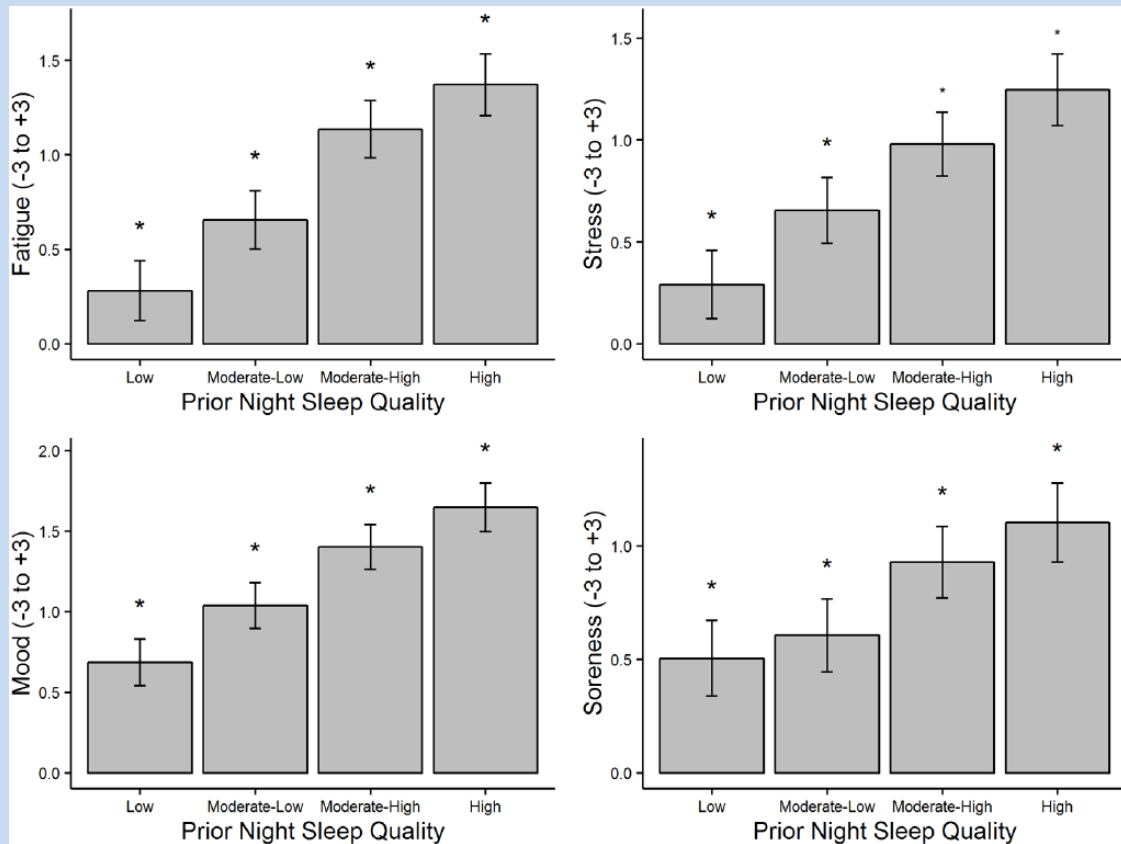
Figure 3. Comparison of subjective well-being measures by prior-night sleep quality among adolescent female soccer athletes using least squares means from linear mixed-effects models adjusted for age group and individual repeated measures. Data are shown as means and 95% confidence intervals. *$P < 0.05$ versus all other groups.

Table 3. Independent effects of prior-day training load and prior-night sleep quality on subjective well-being in female youth soccer athletes using linear mixed-effects models adjusted for age group and individual repeated measures[a]

	Fatigue		Mood		Stress		Soreness	
Variable	β	P	β	P	β	P	β	P
Prior day TL, AU	−0.18	<0.001	−0.028	0.014	−0.054	0.001	−0.32	<0.001
Prior night sleep quality	0.26	<0.001	0.23	<0.001	0.21	<0.001	0.12	<0.001

AU, arbitrary units; TL, training load.
[a]Fatigue, mood, stress, soreness, and sleep quality range from −3 (worst) to +3 (best).

After accounting for the influence of sleep, however, the effect of TL on fatigue, mood, and stress was significantly reduced, and a significant portion of the influence of TL on mood, fatigue, and stress was mediated by the effects of TL on sleep. In other words, the negative impact of TL on well-being is exacerbated by reduced sleep and minimized by increased sleep. This suggests that efforts to prioritize sleep, particularly during periods of high acute TL, may help reduce the negative impacts on subjective well-being and even potentially reduce the risk of injury and illness.

This study has its limitations. There was not perfect compliance with the daily data collection, and as a result, data were missing. The authors did not identify any obvious relationship between compliance and date or specific individuals. This study also used a commercially available software program rather than previously validated

questionnaires regarding sleep duration and quality. It is possible that additional confounding variables not included in these models could influence these relationships. Finally, this study included only adolescent female soccer athletes and may not be generalizable to other populations.

CONCLUSION

This study found that increases in acute TL have a negative impact on fatigue, mood, stress, and soreness. After accounting for the effect of TL and age, increased sleep was significantly associated with improved fatigue, mood, and stress. In fact, a significant portion of the effect of TL on subjective well-being was due to the effects of TL on sleep. Promoting sleep among adolescent athletes may help minimize the negative effects of acute TL on several elements of subjective well-being.

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