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Original Research

Relationships Between Training Load, Perceived Cognitive Load and Sleep in Student-Athletes

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Abstract

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Sleep is particularly important for student-athletes in the pursuit of both academic success and athletic performance. The primary aim of this study was to investigate the relationship between training load (TL), perceived cognitive workload, and sleep in varsity male volleyball athletes. The secondary aim was to understand the physiological and cognitive mechanisms leading to sleep disturbances following a match. Twelve varsity players on a men's university volleyball team were examined for 12 weeks of the competitive season. Sleep, internal TL and cognitive load were assessed using daily surveys. External TL was assessed using wearable jump monitors during training and matches. Participants filled the Pre-Sleep Arousal Scale to assess pre-sleep arousal and the Ottawa Mental Skills Assessment Tool to assess mental skills after eight matches. Our results show that the perceived cognitive load had a negative impact on total sleep time ($p = 0.003$) and sleep quality ($p = 0.048$). Moreover, internal TL had detrimental effects on sleep quality ($p = 0.04$). We also observed a negative association between cognitive pre-sleep arousal and sleep efficiency ($p = 0.004$). and sleep onset latency ($p = 0.03$). Finally, no effect was found between mental skills and post-match sleep. Our results suggest that assessing perceived cognitive workload is essential when monitoring student-athletes. Moreover, higher sleep onset latency and lower sleep efficiency were associated with elevated levels of cognitive arousal supporting the idea that post-match sleep difficulties are due to cognitive arousal rather than physiological arousal.

Keywords: Arousal, competition, sports, volleyball, RPE

Introduction

Sleep is an integral part of the recovery process for athletes but meeting the sleep recommendation can be particularly difficult for student-athletes. For example, studies comparing student-athletes to non-athlete students showed that student-athletes had greater variability in their sleep schedules such as time in bed ($d = 0.73$, $SD = 0.52$) and bedtime ($d = 0.88$, $SD = 0.50$)[1] and reduced total sleep time (mean = 6:50 hours, SD = 1:13 vs. mean = 7:06 hours, SD = 0:53, for student-athletes and non-athlete, respectively, $p < 0.05$; $d = 0.20$),[2] possibly due to the time constraint imposed by the combination of sport and academic schedules. This finding is concerning, given that adequate sleep is linked to academic success.[3] In addition, some studies have shown that a higher academic workload could be associated with lower sleep quality.[4,5] More specifically,

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Jansen et al[4] found that lower sleep quality was associated with a higher perceived intensity of mental work during schoolwork, as measured by a self-rated scale from 1 to 5 capturing the perceived intensity of mental effort. It is now common to monitor physical load in athletes to improve practice planning. Still, the perceived academic load is not usually part of this monitoring process, even though it is a significant part of a student-athletes' workload.

In addition to the demands of their academic program, numerous physiological and psychological demands associated with training and competing could also explain the sleep deficiencies often reported by athletes. Among them, current data shows an association between the variations in training load (TL) and sleep.[6,7] TL encompasses an external dimension, i.e., the physical work, typically planned by the coaching staff, and an internal dimension, i.e., the perceived effort[8] in response to this work. Both dimensions have been found to influence sleep. For example, in a simulated cycling grand tour, the sleeping time of cyclists decreased by 20 minutes per week, on average, as the external load increased.[9] Similarly, sleep quantity and quality have been shown to decrease with high internal loads.[10]

It is also noteworthy that competitive seasons are punctuated with matches against opponents. These events differ from the regular training days and are associated with their sleep disturbances. For example, matches can potentially increase the physiological load[11] and somatic and cognitive anxiety[12]. Evening games can be particularly challenging for athletes with the delayed start time and the disturbances associated with late-night traveling. As an evidence, a meta-analysis showed that total sleep time was 80 minutes shorter, and sleep efficiency reduced by 3-4 % on the night following an evening competition compared to previous nights.[13] Similarly, it has been shown that the sleep of football players during the night following a match was shorter than following training sessions, this being due, among other things, to a later bedtime and an early morning awakening.[14]

Although several studies reported sleep disturbances during competitions (as summarized in Roberts et al),[13] the underlying mechanisms remain poorly understood.[15] While modulation of neuroendocrine and physiological variables caused by physical activity seems to be the most frequently proposed explanation for the decrease in sleep, Juliff et al[15] have shown that elevated cortisol level post-match in netball players had returned to baseline at bedtime. Moreover, elevated levels of adrenaline and noradrenaline were not associated with sleep measures.[15] Together, these results cast doubts on the hypothesis that post-competition sleep disturbance has a hormonal cause. On the other hand, it is noteworthy that athletes with a high trait of cognitive activation, a stable predisposition to heightened mental arousal and difficulty down-regulating cognitive activity, had decreased sleep efficiency (r_s = -.611) following an evening match,[15] thus pointing towards a psychological explanation for the sleep disturbance.

While the many causes affecting the sleep of student-athletes have received recent research interest,[16] few studies have looked at the interaction between TL, academic workload, and sleep in student-athletes. Therefore, the first aim of this study was to gain information on the association between these variables using daily surveys and wearable jump monitors. The study's second aim was to better understand better the mechanisms leading to sleep disturbances following a match by assessing the athletes' somatic and cognitive activation at bedtime and their mental skills. It was hypothesized that higher cognitive and training loads would reduce sleep quantity and quality. It was also hypothesized that athletes with higher mental ability scores and lower activation levels would have better quality sleep following a match.

Methods

Participants

A convenience sample of 12 varsity players on a men's university volleyball team (age: 21.4 ± 1.8, height: 187 ± 6 cm, body mass: 84.0 ± 7.4 kg; five attackers, three blockers, two setters, and two liberos) took part in the experiment. Participants were full-time university students and were expected to participate in four evening team training sessions and one morning skill training session every week. The study was approved by the Health Sciences Research Ethics Committee of the Université de Montréal (CERC-19-081-D) and was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science* and in accordance with the ethical standards of the Helsinki declaration.[17] Written informed consent was obtained from all participants before the experiment. Participants were excluded if they had a diagnosed sleep disorder.

Protocol

Participants completed an online survey every evening for 12 weeks during the competitive season (November 2019 to February 2020) to assess sleep-wake patterns, physical and cognitive workload. The questionnaire was sent via SMS at 8 pm every evening. Sleep patterns were assessed through the Consensus Sleep Diary,[18] a sleep diary developed by a team of sleep experts, and included questions about the previous night's bedtime, wakeup time, number of awakenings during the night, and perceived time to fall asleep (sleep onset latency). This method is simple, cost effective and has previously been used with an athletic population. [19–21] Participants were also asked to report their subjective sleep quality on a scale of 0 (very bad) to 10 (very good). To assess the perceived cognitive load associated with school activities (i.e., studying, class participation, homework), participants had to indicate the approximate time allocated to these activities and rate the effort they invested in them using the Paas Subjective Rating Scale,[22] a scale reported to allow for the detection of small changes in task complexity.[23] In addition to analyzing raw effort scores, we calculated an exploratory effort × duration index (Paas rating multiplied by task time in minutes) to approximate cumulative cognitive load, what will be referred to hereafter as the perceived cognitive load. This derived measure is not part of the validated scale but was included to account for both perceived intensity and exposure time, alongside separate analyses of effort and time-on-task.". Finally, the internal TL was assessed using the Borg ratio-10 scale,[24] where participant rated their perception of effort during training on a Likert-type scale ranging from 0 (not at all) to 10 (very, very difficult). Each session's rating of perceived exertion was then multiplied by the session duration (in minutes) to provide the s-RPE.[25] Since the participants could take part in multiple training sessions during a single day, the intensity and time allocated to each session were multiplied, and the sum of all sessions provided the daily internal TL. A total of 10 matches were included in the analysis. Matches took place from Friday to Sunday, and athletes played an average of 1.67 ± 0.52 (SD) matches per week.

To monitor the external TL, participants were required to wear a *Vert* sensor device (Mayfonk Athletic, Florida, USA). This small sensor (4.98 cm in length, 0.79 cm in depth, and 2.18 cm in height) was worn on an elastic belt at waist-level beneath the clothing and throughout volleyball training sessions and games. It provided information on the vertical displacements of each athlete. The *Vert* sensor was reported to have a mean bias of 3.57-4.28 cm compared to gold-standard methods, such as video analysis or force platforms.[26] The external TL for each session was assessed using the load index proposed by Charlton et al., (2017). It is calculated as the product of the jump count and the average kinetic energy (KE), allowing for jumps of greater heights to be weighted more

heavily. KE was computed using the athlete's final velocity (vfin) before landing, considering the known relationship between gravity (g) and vertical displacement (vd). Subsequently, the KE, in kilojoules, was computed from the athlete's mass (m) and vfin.

$$\text{vfin} = \sqrt{2g\ x\ vd}$$

$$\text{KE} = \frac{1}{2} m\ x\ \text{vfin}^2$$

To identify the variables affecting sleep during the night following a game, and to account for potential confounding effects of game timing and location on sleep outcomes, eight games of the regular schedule were selected: two evening home-based games, two evening games away, two daytime home-based games, and two daytime games away. Evening games started at 6:00 p.m. or later. The morning following the game, participants completed the Pre-Sleep Arousal Scale (PSAS)[27] to assess their subjective pre-sleep arousal at bedtime. The PSAS consists of 16 items divided into two subscales, one for evaluating cognitive activation and the other for somatic activation at bedtime. Each item was rated on a Likert scale of 1 (not at all) to 5 (extremely). Before the study, participants also filled the Ottawa Mental Skills Assessment Tool (OMSAT).[28] This 48-question questionnaire assesses 12 mental skills classified into three main categories: fundamental skills (goal setting, self-confidence, commitment), psychosomatic skills (stress reaction, fear control, activation, relaxation), and cognitive skills (concentration, imagery, mental practice, competition planning, distraction control). In the current study, internal consistency was satisfactory for the PSAS, $\alpha = 0.86$, and the OMSAT, $\alpha = 0.74$.

Statistical Analysis

Statistical analysis was performed using the lme function of the nlme package (version 3.1-152) in R (R Core Team, 2020). A linear mixed model was chosen since it can handle unbalanced design, missing data points, and repeated measures.[29] The missing data were considered missing at random. For the analysis, the weekly mean of each participant was calculated for every variable when the daily survey was completed three or more times during the week. The dependent variables: total sleep time, sleep onset latency, sleep efficiency, and sleep quality, were analyzed in separate models. Each model included a per-participant random effect and fixed effects for internal TL, external TL, and cognitive load. A First-Order autoregressive AR-1 correlation structure was applied to the models to represent the chronological relationship between weeks all variables were scaled beforehand.

The mixed models for the analysis of post-match sleep contained the same dependent variables as the models mentioned above with a random effect for participants. The fixed effects included the PSAS cognitive scale, the PSAS somatic scale, and the external load. Both subscale scores of the PSAS were split into two, representing either low (score < 9) or high arousal (score > 9). Different models were fit using the same sleep parameters and the OMSAT subscales as fixed effects. The scores on the three OMSAT subscales were also categorized as low or high (low being < 17, < 20, and < 30 for the three subscales, respectively). Assumptions for the normality of residuals (visual inspection of Q-Q plots) and homoscedasticity (Breusch-Pagan test) were verified beforehand for all models. The significance level was set at $p < 0.05$. Beta values were used as an indicator of effect size. A beta value between 0.1 and 0.29 was considered small, between 0.3 and 0.49 was moderate, and ≥ 0.5 was large.[30]

Results

Table 1 provides an overview of the descriptive statistics of the participants' daily monitored sleep variables and the training and cognitive loads measured over the 12-week period. The questionnaire response rate was 79.7%.

Table 1. Overview of the daily sleep variables, training, and cognitive workload, PSAS scores, and OMSAT scores.

Bedtime (hh:mm)	00:48 ± 1.22
Wake up time (hh:mm)	09:05 ± 1:24
Total sleep time (h:mm)	7.79 ± 1.49
Sleep onset latency (min)	15.7 ± 19.7
Sleep efficiency (%)	94.1 ± 6.04
Sleep quality (1-10)	6.1 ± 1.73
Internal TL (AU)	375.32 ± 485.22
Cognitive Load (AU)	950.89 ± 1092.64
External TL (AU)	$3.92 \times 10^4 \pm 1.72 \times 10^4$
PSAS cognitive	11.08 ± 2.94
PSAS somatic	10.71 ± 3.94
Fundamental skills	17.21 ± 1.52
Psychosomatic skills	19.58 ± 2.92
Cognitive skills	28.27 ± 2.85

Values are mean ± standard deviation (SD). AU, Arbitrary units; PSAS, Pre-Sleep Arousal Scale.

Table 2 shows the results of the mixed-effects model analysis that tested the associations between cognitive and physical loads on sleep characteristics during the competitive season. Internal TL (*B* = -0.28; 95% CI [-0.53, -0.02], p = 0.04, t = -2.2) and perceived cognitive loads (*B* = -0.36; 95% CI [-0.72, -0.003], p = 0.048, t = -2.07) were negatively associated with sleep quality. Perceived cognitive load was significantly associated with total sleep time (*B* = -0.42; 95% CI [-0.68, -0.15], p = 0.003, t = -3.24). Conversely, no association was observed between external TL and any of the sleep parameters (p > 0.05).

Table 2. Overview of the mixed-effects models testing the effect of training and academic load on sleep.

	Total sleep time			**Sleep onset latency**			**Sleep efficiency**			**Sleep quality**		
Fixed effects	*B*	CI	p	*B*	CI	p	*B*	CI	p	*B*	CI	p
(Intercept)	0.004	[-0.40, 0.5]	0.99	-0.09	[-0.49, 0.3]	0.00	0.08	[-0.38, 0.53]	0.73	0.18	[-0.34, 0.7]	0.48
Internal TL	0.06	[-0.14, 0.27]	0.53	0.01	[-0.25, 0.27]	0.22	-0.07	[-0.15, 0.29]	0.52	-0.28	[-0.53, -0.02]	0.04*
External TL	0.06	[-0.21, 0.33]	0.65	-0.19	[-0.49, 0.11]	0.95	0.23	[-0.03, 0.48]	0.08	0.13	[-0.17, 0.43]	0.38
Cognitive load	-0.42	[-0.68, 0.15]	0.003*	-0.2	[-0.53, 0.13]	0.21	0.07	[-0.38, 0.24]	0.65	-0.36	[-0.72, -0.003]	0.048*

CI, Confidence intervals. *$p < 0.0.5$.

Table 3. Overview of the mixed models testing the effect of arousal at bedtime, match external load and mental skills (OMSAT) on sleep.

	Total sleep time			**Sleep onset latency**			**Sleep efficiency**			**Sleep quality**		
Fixed effects	*B*	CI	p	*B*	CI	p	*B*	CI	p	*B*	CI	p
Model: PSAS and external load												
(Intercept)	0.12	[-0.58, 0.82]	0.72	0.39	[-0.24, 1.03]	0.21	-0.52	[-1.07, 0.04]	0.78	-0.11	[-0.94, 0.73]	0.79
External load	0.16	[-0.44, 0.75]	0.58	-0.16	[-0.68, 0.36]	0.36	-0.12	[-0.59, 0.35]	0.6	0.02	[-0.58, 0.62]	0.94
PSAS Somatic	-0.16	[-1.27, 0.95]	0.76	0.39	[-0.56, 1.33]	0.39	-0.19	[-1.08, 0.69]	0.64	0.31	[-0.7, 1.32]	0.52
PSAS cognitive	-0.27	[-1.28, 0.75]	0.59	-1.01	[-1.93, 0.09]	0.03*	1.3	[0.48, -2.11]	0.004*	-0.08	[-1.2, 1.03]	0.87
Model: OMSAT and external load												
(Intercept)	0.34	[-0.63, 1.31]	0.46	-0.6	[-1.47, 0.26]	0.16	0.38	[-0.45, 1.21]	0.34	0.55	[-0.92, 2.03]	0.44
External load	0.1	[-0.48, 0.69]	0.72	-0.18	[-0.7, 0.35]	0.48	-0.05	[-0.55, 0.45]	0.83	-0.1	[-0.67, 0.46]	0.7
Fundamental	-0.28	[-2.6, -2.03]	0.65	0.09	[-1.98, 2.16]	0.87	0.03	[-1.95, 2]	0.96	0.48	[-2.64, 3.61]	0.58
Cognitive	-0.22	[-2.52, 2.08]	0.72	0.56	[-1.41, 2.54]	0.34	-0.02	[-1.98, 1.94]	0.97	-1.25	[-4.33, 1.83]	0.22
Psychosomatic	-0.31	[-2.53, 1.9]	0.6	0.002	[-1.12, 1.12]	0.99	-1.21	[-3.1, 0.68]	0.11	-0.03	[-3.32, 2.72]	0.71

CI, Confidence intervals; OMSAT, Ottawa Mental Skills Assessment Tool; PSAS, Pre-Sleep Arousal Scale. *$p < 0.05$.

Table 3 shows the results of the mixed-effects model analysis that tested the match characteristics and pre-sleep arousal and the mental skills on sleep parameters. Low cognitive arousal was significantly associated with sleep efficiency (B = 1.3; 95% CI [0.48, -2.11], p = 0.004, t = 3.42) and negatively associated with sleep onset latency (B = -1.01; 95% CI [-1.93, -0.09], p = 0.03, t = -2.36). No association between the external load, somatic activity and sleep parameters was found (p > 0.05). Finally, mental skills and external load were not significantly associated with sleep parameters (p > 0.05).

Discussion

The present study's first aim was to investigate the relationship between internal TL, external TL, perceived cognitive load, and sleep in student-athletes during a competitive volleyball season. The second aim was to understand better the mechanisms leading to post-match sleep disturbances. Our results showed that, during the competitive season, a high perceived cognitive load had a negative impact on both total sleep time and subjective sleep quality. In addition, a high internal TL had deleterious effects on subjective sleep quality. With regards to post-match sleep disturbance, we observed a negative association between cognitive pre-sleep arousal and both sleep efficiency and sleep onset latency.

Our results showed that a high perceived cognitive load had the most detrimental effect on total sleep time and sleep quality, despite the inclusion of the two common training load variables in the models. This finding is important given that many of the studies investigating load monitoring in athletes have focused on the physiological construct of load while neglecting its cognitive construct.[31] A plausible explanation for the importance of cognitive workload in our models is

the fact that student-athletes dedicated a lot of time to academic activities: the average weekly time allocated to schoolwork was two times higher than the time allocated to training (17.92 ± 18.78 and 8.75 ± 8.87 hours, respectively). This is consistent with studies of college students which revealed that spending many hours on schoolwork during the day hampers sleep.[4,5] Recently, Davis et al[32] reported in a cohort of student-athletes that academic requirements were strongly correlated with perceived stress ($r = 0.47$), a state not compatible with sleep. Another non-exclusive explanation is that the increase in the number of hours allocated to academic activities (which led to high levels of cognitive load) was obtained by decreasing sleep time. Because the time requirement of many activities during the day cannot be compressed (e.g., practice time, class time), reducing sleeping time may represent the easiest solution to accommodate an increase in academic activities. Although the scope of the current study did not consider the timing of the daily cognitive workload, it is not rare for student-athletes to complete school projects during the evening. Heavy cognitive workload before bedtime has been associated with unrefreshing sleep.[5] Moreover, the use of electronic devices in the evening can prolong the time it takes to fall asleep and delay the circadian clock.[33]

Subjective sleep quality was also negatively associated with internal TL, an observation frequently reported by others.[10,9] In contrast, our results did not show any association between external TL and sleep variables. One explanation for this discrepancy is the possibility that the Vert sensor used in the current study may underestimate the actual physiological demands of volleyball, with the frequent lateral displacements with large accelerations and decelerations performed by the players being not accounted for by the Vert sensor. It is also possible that internal TL has more influence on sleep than external TL since it encompasses a subjective evaluation based on physiological and cognitive constructs and may thus better depict the psychophysiological stress imposed on the athlete. [34] More specifically, a specific external load may be experienced differently depending on contextual factors, either between or within athletes.[8] For example, a single workout could be objectively (external TL) easy. Still, it could be perceived as difficult if it occurs in a high-workload period with little rest (internal TL). The TL may also differ between athletes due to possible differences in physiological or psychological demands of the position played. Our results support the idea that there is a dissociation between internal and external TL as we observed no correlation between the two variables ($r = 0.15$, $p = 0.08$). Thus, it appears that internal TL is a better indicator of the physiological demand imposed on the athlete.

Regarding the second objective of the study, our results revealed that cognitive arousal had a detrimental effect on sleep efficiency and sleep onset latency, thus supporting the hypothesis that psychological rather than physiological factors cause post-match sleep disturbances. Supporting this idea, Juliff et al[15] refuted the common view that neuroendocrine and physiological variables are responsible for the sleep disturbances following a match. However, they found that athletes with high arousal reported more sleep complaints after a match. It has also been shown that increases in mental strain of athletes are associated with decreased total sleep time and sleep efficiency.[35] This could be explained, in part, by a phenomenon called "sleep reactivity".[36] When athletes experience a situation perceived as a stressor in their recent past (e.g., a match), they may worry and ruminate at bedtime, leading to the overactivation of the psychological and neurobiological systems, which, in turn, may cause sleep disturbances.[36] Therefore, after a game, athletes would benefit from short and easily implemented strategies at bedtime like progressive muscles relaxation and breathing techniques, known to improve sleep.[37] On the other hand, we did not find an association between mental skills and post-match sleep. This could be due, in part, to the fact that athletes in our study were considered to have overall high levels of mental skills, which did not allow us to discriminate the effect of having low mental skills on sleep.

Certain additional elements should be considered when interpreting the results of this study. First, the athletes always slept home after a match, except on one occasion. So, they did not have to sleep in an unfamiliar environment. Moreover, reliable transportation was always available to the athletes following a match, thus reducing travel time and the associated stress. Secondly, the team won all their matches during the season. Since it has been shown that athletes report lower sleep quality after a loss than after a victory,[38] sleep quality may have been higher in our dataset than what is usually reported during a more balanced season. Additionally, it cannot be ruled out that these circumstances may have modulated the activation level at bedtime by reducing the stress associated with a match. Another limitation of this study is the relatively small sample size (n = 12), which restricts statistical power and increases sensitivity to missing data. While linear mixed-effects models appropriately handle missing-at-random observations and allowed us to include all available data, findings should be interpreted cautiously, and replication in larger samples is warranted.

In conclusion, student-athletes face unique stressors like the double burden of performing in academic and sport settings. The current study showed that perceived cognitive workload and internal TL have detrimental effects on subjective sleep quality. We thus provide novel insight that assessing perceived cognitive workload is essential and should be considered when monitoring student-athletes. There is therefore reason to believe that student-athletes could be more sensitive to sleep disturbance over certain periods of the year (e.g., during exams) and that coaches should consider the academic workload of athletes in their planning. In addition, higher sleep onset latency and lower sleep efficiency were associated with elevated levels of cognitive arousal at bedtime following a match. These results allow us to support the idea that post-match sleep difficulties are due to cognitive arousal rather than physiological arousal.

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