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Self-reported sleep quantity, quality and sleep hygiene in elite athletes

MELANIE KNUFINKE[1], ARNE NIEUWENHUYS[1], SABINE A. E. GEURTS[1], ANTON M. L. COENEN[2] and MICHIEL A. J. KOMPIER[1]

[1]Behavioural Science Institute, Radboud University, Nijmegen, the Netherlands; [2]Donders Centre for Cognition, Radboud University, Nijmegen, the Netherlands

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Correspondence
Melanie Knufinke, Behavioural Science Institute, Radboud University, Room A.08.26, Montessorilaan 3, P.O. Box 9104, 6500 HE Nijmegen, the Netherlands.
Tel.: +31 243615667;
fax: +31243611798;
e-mail: m.knufinke@psych.ru.nl

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SUMMARY

Sleep is essential for recovery and performance in elite athletes. While actigraphy-based studies revealed suboptimal sleep in athletes, information on their subjective experience of sleep is scarce. Relatively unexplored is also the extent to which athletes' sleep is adversely affected by environmental conditions and daytime behaviours, that is sleep hygiene. This study aimed to provide insight in sleep quantity, quality and its putative association with sleep hygiene. Participants were 98 elite (youth) athletes competing at the highest (inter-)national level. Sleep quantity, quality and sleep hygiene were assessed once covering a 1-month period by using established (sub)clinical questionnaires, and repeatedly during 7 consecutive days. Sleep quality was generally healthy, although 41% of all athletes could be classified as 'poor sleeper', and 12% were identified as having a sleep disorder. Daily self-monitoring revealed sleep durations of 8:11 ± 0:45 h, but elevated wake after sleep onset of 13 ± 19 min. Sleep quality, feeling refreshed, and morning vigor were moderate at best. Regarding sleep hygiene, general measures revealed irregular sleep–wake patterns, psychological strain and activating pre-sleep behaviours. At the daily level, blue-light exposure and late-evening consumption of heavy meals were frequently reported. General sleep hygiene revealed significant associations with sleep quality ($0.45 < r > 0.50$; $P < 0.001$). Results indicate that there is ample room for optimization, specifically in onset latency and in wake after sleep onset. Subtle improvements in sleep seem possible, and optimizing sleep hygiene, such as regular sleep–wake patterns and reducing psychological strain, may facilitate this sleep upgrading process.

INTRODUCTION

Sleep is crucial for recovery and performance capacity in elite athletes (Samuels, 2008; Venter, 2012). This implies that suboptimal sleep can hamper the ability to reach full athletic potential. Assessing sleep quantity, sleep quality and identifying potential threats to adequate sleep in elite athletes is important in order to identify potential areas for sleep optimization.

Actigraphy-based sleep estimates indeed reveal suboptimal sleep in athletes, expressed in relatively high sleep fragmentation, low sleep efficiency and consequently low sleep durations (Lastella *et al.*, 2015; Leeder *et al.*, 2012). However, the extent to which athletes also experience their sleep as suboptimal remains unclear. This may be important as the need for sleep varies between individuals: some may complain about poor sleep quality although objective markers indicate sufficient sleep quality, while others report good sleep quality despite objective markers of poor sleep (Krystal and Edinger, 2008). Hence, assessing subjective sleep quantity and quality is a valuable extension to the current actigraphy-based sleep estimates. Insight in subjective markers of sleep sheds light on sleep need and recovery status in elite athletes and, importantly, it highlights areas for sleep optimization.

In order to optimize elite athletes' sleep, it has been suggested to improve their sleep hygiene (Lastella *et al.*, 2015). Sleep hygiene encompasses all conditions and practices that promote continuous and effective sleep, including regularity of bed- and rise times, restriction of alcoholic and caffeinated beverages, regular exercise, nutrition, and environmental factors that enhance restful sleep (American Academy of Sleep Medicine, 2001). Evidence suggests that anxiety, noise, the need to use the bathroom and unfavourable competition times disrupt sleep in athletes (Lastella *et al.*, 2014). Unsurprisingly, adherence to sleep hygiene is especially challenging in athletes due to factors such as inter-meridian travel (Fowler *et al.*, 2015), unfavourable training schedules (Sargent *et al.*, 2014) and late competition times (Reilly and Edwards, 2007). Therefore, it is important to have a complete picture of elite athletes' sleep hygiene practices, and to what extent specific daytime behaviours and environmental conditions are related to sleep. Apart from a few studies that have investigated the prevalence and impact of selected sleep hygiene factors such as blue-light exposure and pre-competitive anxiety (Fietze *et al.*, 2009; Lastella *et al.*, 2014; Romyn *et al.*, 2016), such information is currently lacking.

Working towards future interventions, the present study aimed first, to shed light on subjective sleep quantity and sleep quality in elite athletes; second, to identify their sleep hygiene practices; and third, to investigate associations between sleep hygiene, sleep quantity and sleep quality. Thereby, this study aims to identify areas for sleep optimization in athletes. To provide a robust answer for these aims, a large group of elite athletes was recruited, and their subjective sleep quantity and quality, as well as their current sleep hygiene practices were assessed. All measures were obtained by using (sub)clinical questionnaires providing insight in general sleep and sleep hygiene behaviours, as well as day-to-day measurements over a representative 7-day self-monitoring period, providing insight in daily-monitored sleep and sleep hygiene behaviours. Associations between general and daily-monitored measures were calculated to indicate converging or diverging evidence. It was hypothesized that subjective measures of sleep quantity and quality resemble sleep insufficiencies based on actigraphy (e.g., Leeder *et al.*, 2012). Because sleep hygiene generally concerns 'conditions and practices that promote continuous and effective sleep' (p. 347, American Academy of Sleep Medicine, 2001), associations between sleep hygiene, sleep quantity and quality, both at the general and daily-monitored level, were expected. The results of the present study are expected to aid the development of interventions that directly target sleep, and to identify critical sleep hygiene aspects that can be integrated into sleep hygiene protocols for athletes.

MATERIALS AND METHODS

Participants

Participants were recruited through the Netherlands Olympic Committee*Netherlands Sport Federation (NOC*NSF) or through the coaches of the national associations. Participants were 98 Dutch elite (youth) athletes aged 18.8 ± 3.0 years (range 15–32 years), including 56 females, who were all part of the national (youth) selection team in their respective sports and competed on the highest national and international (youth) level. Athletes competed either in individual sports (n = 38: road cycling, n = 26; triathlon, n = 8; mountain bike, n = 4) or team sports (n = 60: handball, n = 13; volleyball, n = 30; soccer, n = 17). Participants had an average body mass index of 21.3 ± 1.6 kg m^{-2}, had practiced their sport for an average of 10.0 ± 3.5 years, and spent on average 19.3 ± 5.1 h $week^{-1}$ on training and competition. The study was approved by the faculty's ethical committee, and all participants or responsible parents or caregivers signed informed consent.

Measures and procedure

With respect to the current study, data collection consisted of two parts: (a) general sleep measurements; and (b) daily-monitored sleep measures. General sleep was assessed once using an online survey that consisted of well-validated questionnaires on sleep quality, sleep disturbances and sleep hygiene. Subsequently, these sleep parameters were also assessed for 10 consecutive days using pen-and-paper-based diaries. This was done just before sleep and upon awakening. Athletes slept in their habitual or training environment, and the self-monitoring period was free from competition with the exception of exhibition matches. Road cyclists and soccer players were assessed during a training-camp abroad, with inter-meridian travel for the female cyclists only (n = 9). In the latter case, the 10-day self-monitoring period started after an adaptation period of 3 days.

Sleep quantity and quality

General measures

General sleep quantity and quality were measured with the Pittsburgh Sleep Quality Index (PSQI; Buysse *et al.*, 1989) and the Holland Sleep Disorder Questionnaire (HSDQ; Kerkhof *et al.*, 2013). The PSQI is a 19-item self-report questionnaire assessing sleep quantity and quality over a 1-month period. Seven component scores were assessed: (1) subjective sleep quality; (2) sleep latency; (3) sleep duration; (4) habitual sleep efficiency; (5) sleep disturbances; (6) use of sleep medication; and (7) daytime dysfunctioning. Answer scores ranged from 0 to 3 ('not during the past month' – 'three or more times a week'), which were assessed for each component and combined into a Global Sleep Quality Score ranging from 0 to 21. A global score ≥5 was taken as an indicator of poor sleep quality (Samuels, 2008). Treating each of the component scores as items, a Cronbach's α of 0.45 was observed in the current sample, which reflects the heterogeneous nature of the different components.

The HSDQ consists of 32 items, which were used to screen for six potential sleep disorders: (1) insomnia;

(2) parasomnia; (3) circadian rhythm sleep disorder; (4) hypersomnia; (5) restless legs/periodic limb movement disorder (RLS/PLMD); and (6) sleep-related breathing disorder (SBD). Each item was rated on a five-point Likert scale, with averaged sum scores ranging from 1 to 5 ('not at all applicable' – 'applicable'). A higher score indicated more serious sleep complaints. A clinical cutoff of 2.02 was used as an indication of a self-reported sleep disorder based on the entire questionnaire (Kerkhof *et al.*, 2013). Cronbach's α was 0.85 in the current sample.

Daily-monitored measures

Daily-monitored sleep quantity was assessed using the following aspects of the morning section of the Expanded Consensus Sleep Diary (CSD-E; Carney *et al.*, 2012). The CSD-E assesses bedtime (h:min), lights-off time (h:min), sleep onset latency (min), frequency of wake after sleep onset (#), wake after sleep onset (min), rise time (h:min), total sleep time (h:min), as well as quality and refreshment of sleep, with scores ranging from 1 to 10, and 10 indicating high sleep quality/refreshment.

Daily-monitored sleep quality was assessed using the Groningen Sleep Quality Scale (GSQS; Mulder-Hajonides Van Der Meulen *et al.*, 1981). The GSQS assessed sleep quality on a 14-item scale. Scores range from 0 to 14, with scores between 0 and 2 indicating normal, refreshing sleep, and scores ≥6 indicating disturbed sleep (Meijman *et al.*, 1990). In the current study, a cutoff score ≥3, indicating intermediate sleep disturbances, was used (Kompier, 1988). Cronbach's α for the current sample was 0.82.

The Global Vigor and Affect Scale (GVA; Monk, 1989) was used to assess vigor and affect just before going to sleep and upon awakening. The subscale 'Vigor' was based on four items concerning alertness, sleepiness, motivation loss (effort) and weariness. The subscale 'Affect' was based on four items concerning happiness, sadness, calmness and tension. Scores were calculated using an established algorithm, and range from 0 to 100 (Monk, 1989). Additionally, one question concerning the perceived level of fitness was added. Higher GVA scores indicate higher arousal/alertness/fitness and greater positive affect. Cronbach's alpha's for global 'Vigor' and global 'Affect' were $\alpha = 0.90$ and $\alpha = 0.71$ for the morning measurements, and $\alpha = 0.85$ and $\alpha = 0.75$ for the evening measurements.

The Karolinska Sleepiness Scale (KSS; Åkerstedt and Gillberg, 1990) was used to assess alertness/sleepiness upon awakening and before sleep. A nine-point verbally anchored scale ranging from 1 to 9 ('extremely alert' – 'extremely sleepy' – 'fighting sleep') was used. Higher scores indicate higher sleepiness.

Table 1 Mean, standard deviation, cutoff values and scale properties for all sleep quality and quantity measures

	All M (SD)	*# Athletes ≥ (cutoff)*
Demographics		
N	98	
Age	18.72 (3.02)	
Female	56	
General sleep measures		
PSQI total (0–21)	4.61 (2.04)	40 (5)
HSDQ total (0–5)	1.64 (0.35)	12 (2.02)
Daily-monitored sleep measures		
Sleep quantity		
Bed time (h:min)	23:11 (0:47)	
Wakeup time (h:min)	7:57 (0:37)	
Total sleep time (h:min)	8:11 (0:44)	6 (≤7)
Sleep onset latency (min)	20.17 (13.70)	18 (≥30)
Awakenings (#)	1.19 (0.90)	4 (≥3)
Wake after sleep onset (min)	12.56 (19.19)	18 (≥20)
Sleep quality and morning state		
GSQS (0–14)	2.93 (1.68)	47 (≥3)
Quality (1–10)	6.84 (0.92)	16 (≤6)
Refreshed (1–10)	6.13 (1.12)	39 (≤6)
Vigor AM (0–100)	53.70 (13.98)	
Affect AM (0–100)	67.98 (13.65)	
KSS AM (1–9)	4.79 (1.30)	

Daily-monitored values reflect averages over the 7-day monitoring period.
GSQS, Groningen Sleep Quality Scale; HSDQ, Holland Sleep Disorder Questionnaire; KSS, Karolinska Sleepiness Scale; PSQI, Pittsburgh Sleep Quality Index.

Sleep hygiene

General measures

General sleep hygiene was measured with the Sleep Hygiene Index (SHI; Mastin *et al.*, 2006). The SHI consists of 13 items covering the occurrence of inappropriate sleep behaviour, and is based on criteria set forth in the International Classification of Sleep Disorders (American Academy of Sleep Medicine, 2001). Each item is rated on a five-point Likert scale ('never' – 'always'). Item scores were summed to a total score ranging from 13 to 65, with higher sum scores indicating poorer sleep hygiene. Cronbach's α was 0.61 in the present sample. For analysis purpose, the 13 SHI items were grouped into six broader categories adopted from Storfer-Isser *et al.* (2013), including: regularity (items #2, #3, #5); environment (items #10, #11); psychological strain (items #8, #13); active behaviour (items #4, #7, #9, #12); naps (item #1) and substances (item #6). For each category, item scores were averaged.

Daily-monitored measures

Daily-monitored sleep hygiene (10 items) was assessed by the evening section of the CSD-E (CSD-E; Carney *et al.*, 2012). This section asked for daytime naps (length and timing), alcoholic and caffeinated consumptions (amount, sort and timing), and sleep medication. In addition, items on sleep location, bed-/room partner, nutrient intake 2–3 h before bedtime, activities within 1 h before bedtime, and bedtime routine were added to match SHI subcategories. Daily-monitored sleep hygiene practices were dummy coded (yes/no) for each day, summed and averaged by the number of monitoring days, resulting in a score between 0 and 100. This score expressed the percentage of nights that individuals engaged in certain sleep hygiene behaviours.

Data processing

General sleep quantity, sleep quality and sleep hygiene measures were processed as described in the original validation papers. Total scores for the PSQI could not be calculated for two participants, due to missing values on one or more items.

Daily-monitored sleep quantity, sleep quality and sleep hygiene measures were also processed as described in the original validation papers. In the self-monitoring study, the first 3 days of the 10-day self-monitoring period served as habituation time and were excluded from further analysis. Data of the remaining 7 days were averaged.[1] Because morning- and evening measures of vigor, affect and sleepiness (KSS) were highly correlated (r-values ranging between 0.48 and 1.00), only morning measures are reported. One participant was excluded because of invalid diary entries.

Statistical analysis

To assess elite athletes' subjective sleep quantity and quality, descriptive statistics were performed for both general and daily-monitored measures of sleep. All measures were compared with cutoff values obtained from the original validation papers or other meaningful reference values. Pearson correlation coefficients were calculated to investigate associations between general and daily-monitored sleep.

To assess sleep hygiene behaviours in elite athletes, descriptive statistics were performed for general and daily-monitored sleep hygiene. Again, to investigate associations between general and daily-monitored sleep hygiene, Pearson correlation coefficients were calculated.

Finally, to investigate associations between sleep hygiene and sleep quantity and sleep quality, Pearson correlation coefficients were calculated. All analyses were performed using IBM SPSS Statistics Package 22.0 (IBM, Armonk, NY, USA). Significance levels were set at 0.05.

RESULTS

Sleep quantity and quality

General sleep

Table 1 provides an overview of general sleep quality, sleep disturbances and the number of athletes scoring above clinical cutoff values. Based on the PSQI, 58 out of 98 athletes reported 'healthy sleep quality', while 40 athletes (41%) were classified as 'poor sleepers' (cutoff ≥5; Table 1). These 40 'poor sleepers' scored rather close to the cutoff values, indicating that their sleep was suboptimal but not too worrisome. With regard to the HSDQ, 12 athletes (12%) scored above the clinical cutoff (≥2.02), indicating the potential presence of one or more sleep disorders. Sixteen athletes (16%) scored above the clinical cutoff on one or more of the HSDQ subscales. The HSDQ subscale 'RLS/PLMD' was most prevalent, with six athletes (6%) scoring above cutoff. Nine athletes (9%) scored above the general cutoff of both PSQI and HSDQ.

Daily-monitored sleep

Table 1 also provides an overview of daily-monitored sleep quantity, sleep quality and morning state measures. On average, athletes reported a total sleep time of 8:11 ± 0:44 h, a sleep onset latency of 20.17 ± 13.70 min and a number of 1.19 ± 0.90 awakenings after sleep onset. Wake after sleep onset was 12.56 ± 19.19 min, with large standard deviations, indicating large individual differences.

Self-reported sleep quality was on average 6.84 ± 0.92 (1–10 scale). More specifically, athletes experienced a weekly average of 2.93 ± 1.68 sleep disturbances per night (GSQS), and reported an average score of 6.13 ± 1.12 on feeling refreshed, 4.79 ± 1.30 on sleepiness (KSS; scale 1–9), 53.70 ± 13.98 on vigor (GVA; scale 0–100) and 67.98 ± 13.65 (GVA; scale 0–100) on affect in the morning.

Associations between general and daily-monitored sleep

As displayed in Table 3, half (i.e. four out of eight) of the general sleep measures were significantly associated with daily-monitored sleep quantity measures, with moderate effect sizes ($0.26 < r > 0.48$; Cohen, 1992). All general sleep measures were significantly associated with almost all daily-monitored sleep quality measures, with moderate effect sizes ($0.24 < r > 0.45$).

Sleep hygiene

General sleep hygiene

Table 2 provides overall and subscale scores for the SHI. Athletes' sleep hygiene scores ranged between 'rarely' and 'sometimes' (i.e. 30.94 ± 5.21). Grouping items into different categories revealed that 'regularity', 'psychological strain' and 'active behaviour' contributed the most to the overall SHI score (Table 2).

Daily-monitored sleep hygiene

Table 2 also displays the percentage of nights that athletes were engaged in specific sleep hygiene practices during the self-monitoring period. To facilitate interpretation, these

[1]Due to practical reasons that occurred during data collection, analysis of the volleyball data ($n = 30$) and soccer data ($n = 17$) covered 8 and 6 days, respectively.

practices are reported based on the same grouping that was used for the general sleep hygiene. ‘Substances’ were regularly consumed before bedtime (meal 26%; caffeine 22%), with an exception for alcohol (2%) and sleep medication (3%). Athletes indicated ‘active behaviour’ within 1 h before bedtime in 2% of the nights, and ‘naps’ were taken on 18% of the monitored days. A bedtime routine was followed in 25% of the nights. In 70% of the monitored nights, athletes engaged in sedentary (blue-light emitting) activities within the last hour before bedtime.

Associations between general and daily-monitored sleep hygiene

As displayed in Table 3, general sleep hygiene was poorly associated with daily-monitored sleep hygiene. None of the 10 associations reached significance and effect sizes were low ($0.04 < r > 0.18$).

Associations between sleep hygiene, sleep quantity and sleep quality

Associations between general sleep hygiene and sleep quality and disturbances

Moderate correlations were observed between SHI and PSQI, with $r(94) = 0.45$, $P < 0.001$; and high correlations between SHI and HSDQ, with $r(96) = 0.50$, $P < 0.001$ (Cohen, 1992), thereby confirming an association between general sleep hygiene and general sleep quality (Table 3).

Table 2 Mean, standard deviation, cutoff values and scale properties for all sleep hygiene measures

	All n = 98 *M (SD)*	*# Athletes ≥(cutoff)*
General sleep hygiene		
SHI total (13–65)	30.94 (5.21)	0 (4)
Regularity (1–5)	2.59 (0.67)	3 (4)
Environment (1–5)	1.71 (0.79)	1 (4)
Psychological strain (1–5)	2.75 (0.78)	6 (4)
Active behaviour (1–5)	2.67 (0.60)	0 (4)
Naps (1–5)	1.77 (0.78)	1 (4)
Substances (1–5)	1.91 (1.00)	9 (4)
Daily-monitored sleep hygiene		
Heavy meal (%)	26 (33)	10 (80)
Caffeine after 18:00 hours (%)	22 (28)	7 (80)
Alcohol after 20:00 hours (%)	2 (6)	0 (80)
Sleep medication (%)[c]	3 (1.3)	1 (80)
Bed partner/roommate (%)	49 (46)	40 (80)
Bedtime routine (%)	25 (38)	16 (80)
Nap (%)	18 (20)	1 (80)
Intense activity (%)	2 (11)	1 (80)
Blue-light (%)	70 (29)	51 (80)

Daily-monitored values reflect average occurrence of sleep hygiene behaviours (% of nights) during the 7-day monitoring period.
[c]Melatonin was the only sleep aid encountered.
SHI, sleep hygiene index.

Associations between daily-monitored sleep hygiene and sleep quantity and quality

Daily-monitored sleep hygiene was associated with sleep quantity in eight out of 40 possible cases, with correlations ranging between $0.20 < r > 0.36$ (Table 3). Consuming a heavy meal within the last 3 h before bedtime was associated with longer sleep durations and more frequent wake after sleep onset. The use of sleep medication was associated with longer sleep onset latencies and higher frequencies of wake after sleep onset. Having a bed-/room partner was associated with longer sleep duration. The presence of a bedtime routine was associated with higher frequencies and longer durations of wake after sleep onset. Contrary to expectations, exposure to blue-light was associated with shorter sleep onset latency. No significant correlations were observed for caffeine, alcohol, napping and intense physical activity before bedtime.

In addition to its associations with sleep quantity, daily-monitored sleep hygiene was associated with sleep quality in four out of 60 possible cases, with significant correlations ranging between $0.21 < r > 0.28$. Sleep medication was related to higher sleepiness (KSS); having a bed-/room partner was related to more positive affect in the morning; and having a bedtime routine was related to poorer sleep quality (GSQS). Intense activity during the last hour before bedtime was related to lower morning vigor. No significant correlations were observed for meal, caffeine and alcohol consumptions, naps, and sedentary activities in which blue-light was emitted.

In summary, significant correlations between sleep hygiene, sleep quantity and sleep quality were indicated at the general level as well as at the daily-monitored level. It is remarkable, however, that associations were medium to large at the general level but only incidental and weak at the daily-monitored level (Cohen, 1992).

DISCUSSION

The present study had three research aims: first, to shed light on subjective sleep quantity and sleep quality of elite athletes; second, to identify their sleep hygiene practices; and third, to establish associations between sleep hygiene, sleep quantity and sleep quality. All measures were first assessed once to retrospectively capture typical behaviour over a 1-month period (‘general sleep measures’) and, subsequently, were also monitored on a day-to-day basis to indicate more specific behaviour during a representative period of training (‘daily-self-monitoring’).

Subjective sleep quantity and quality

Based on the PSQI, analyses of general sleep quantity and quality revealed that the sleep of elite athletes is generally of

Table 3 Pearson correlations between general and daily-monitored sleep quantity, sleep quality and sleep hygiene (n = 97)

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
General sleep quality and hygiene													
1. PSQI													
2. HSDQ	0.59**												
3. SHI	0.45**	0.50**											
Daily-monitored sleep quantity													
4. TST	−0.06	−0.10	−0.11										
5. SOL	0.48**	0.31**	0.06										
6. # WASO	0.28**	0.17	0.06										
7. WASO	0.18	0.26**	0.11										
Daily-monitored sleep quality													
8. GSQS	0.39**	0.45**	0.12	−0.31**	0.40**	0.48**	0.48**						
9. Quality	−0.27**	−0.38**	−0.14	0.19	−0.28**	−0.32**	−0.36**						
10. Refreshed	−0.32**	−0.33**	−0.20	0.42**	−0.15	−0.13	−0.27**						
11. Vigor	−0.32**	−0.24*	−0.14	0.30**	−0.16	−0.07	−0.04						
12. Affect	−0.29**	−0.38**	−0.24*	0.27**	−0.17	−0.06	−0.15						
13. KSS	0.30**	0.18	0.11	−0.25*	0.18	0.18	0.05						
Daily-monitored sleep hygiene													
14. Meal	0.19	0.03	0.18	0.32**	0.14	0.20*	0.10	0.02	0.09	0.12	−0.03	0.07	0.05
15. Caffeine	−0.14	−0.14	−0.07	0.02	0.01	−0.01	−0.08	−0.06	0.08	0.07	0.01	0.04	0.04
16. Alcohol	0.01	−0.01	−0.04	−0.09	0.01	−0.06	−0.07	0.02	0.05	−0.03	0.02	0.01	−0.08
17. Sleep med.	0.42**	0.30**	0.17	0.03	0.30**	0.27**	−0.08	0.13	−0.13	−0.04	−0.13	−0.18	0.28**
18. Bedpartner	0.05	−0.04	−0.09	0.25*	−0.03	0.16	0.13	0.00	−0.02	0.19	0.17	0.29**	−0.13
19. Routine	0.06	0.11	−0.08	0.08	0.14	0.22*	0.36**	0.26*	−0.13	−0.05	−0.04	−0.04	0.07
20. Nap	0.14	0.22*	−0.15	0.07	0.06	0.07	−0.02	0.09	0.02	0.03	−0.10	−0.08	0.12
21. Active	0.14	−0.14	−0.13	−0.17	0.15	−0.20	−0.13	−0.09	0.13	0.05	−0.21*	−0.14	0.16
22. Blue-light	−0.11	0.00	0.04	−0.10	−0.29**	−0.12	−0.11	−0.12	0.08	0.03	0.05	0.17	0.08

GSQS, Groningen Sleep Quality Scale; HSDQ, Holland Sleep Disorder Questionnaire; KSS, Karolinska Sleepiness Scale; PSQI, Pittsburgh Sleep Quality Index; SHI, Sleep Hygiene Index; SOL, sleep onset latency; TST, total sleep time; # WASO, frequency wake after sleep onset; WASO, wake after sleep onset (min).
Meal = heavy meal within 3 h before bedtime; Caffeine = caffeine after 18:00 hours; Alcohol = alcohol after 20:00 hours; Sleep med. = sleep medication (melatonin only); Bedpartner = bedpartner or roommate; Routine = bedtime routine; Active = intense physical activity within the last hour before bedtime; Blue-light = sedentary activity including exposure to blue-light. *$P < 0.05$; **$P < 0.001$.

appropriate quality, although a substantial minority of 41% athletes must be regarded as 'poor sleepers'. Although there is empirical discussion about which PSQI cutoff scores best reflect sleep problems in elite athletes (Samuels, 2008; Samuels *et al.*, 2016), performance margins are small and every gain that may result from optimized sleep, particularly in poor sleepers but perhaps also in moderate sleepers, could be crucial (Venter, 2014). That sleep of elite athletes indeed deserves improvement is further emphasized by scores on the HSDQ, which indicate that 12% of athletes could be identified as having a potential sleep disorder. More specifically, a small but notable number of athletes was identified with 'restless leg symptoms' (RLS/PLMD). The current prevalence of potential sleep disorders compares with the general population and is in accordance with previous findings among athletes (Swinbourne *et al.*, 2016; Tuomilehto *et al.*, 2017), thereby highlighting the need for sleep monitoring and potentially treatment of sleep disorders in elite athletes.

Daily-monitored sleep quantity and sleep quality largely resembled the results obtained at the general level. Average sleep duration was 8 h, and thereby longer than the recommended 7 h (Watson *et al.*, 2015). Nevertheless, self-reported sleep onset latencies and wake after sleep onset were slightly elevated and indicate room for improvement. In interpreting these data, it is important to note that while subjective ratings are considered reliable instruments for sleep–wake estimation (Rogers *et al.*, 1993), they often diverge from objective (e.g. actigraphy-based) values due to an overestimation of sleep onset latency and an underestimation of nocturnal awakenings in subjective reports (Baker *et al.*, 1999; Lauderdale *et al.*, 2008). Although wake after sleep onset was found to be elevated more distinctively in previous actigraphy-based studies, our results are in line with existing literature (Lastella *et al.*, 2015; Leeder *et al.*, 2012) and provide further indication that the sleep of many athletes may indeed be suboptimal.

Moving beyond sleep quantity, analyses of daily-monitored sleep quality revealed that with the given amount of sleep, athletes felt only moderately refreshed, alert and vigorous in the morning. While in our study, these measures were explicitly taken to reflect sleepiness and sleep quality, it is important to note that, given the activity level of elite athletes, feelings of (physical) fatigue may be considered fairly normal. Nevertheless, knowing that subjective experiences of sleepiness can influence motivation and daytime functioning (Hull *et al.*, 2003), these results underline the importance of understanding how these experiences are brought about and how they may be improved. In this respect, strong associations between wake after sleep onset and most sleep quality variables (Table 3; Krystal and Edinger, 2008) suggest that besides increasing overall sleep duration (Bompa and Haff, 2009), targeting augmented wake after sleep onset may prove to be critical.

Elite athletes' sleep hygiene practices

General sleep hygiene was acceptable; however, regularity in sleep–wake patterns, psychological strain and activating pre-sleep behaviour are subcategories that could deserve some improvements (Table 2).

Daily-monitored sleep hygiene appeared to be adequate, with only few suboptimal behaviours. Notable exceptions include frequent engagement in sedentary activities that involve artificial light exposure (i.e. 70% of nights; Table 2). Although the current study indicates an association in the opposite direction (see below), blue-light, as emitted by screens, could delay sleep onset (Cajochen *et al.*, 2011). Other behaviours that may interfere with sleep were frequent late-evening consumptions of heavy meals and caffeinated beverages (American Academy of Sleep Medicine, 2001). Finally, and in line with Lastella *et al.* (2015), daytime naps were taken relatively infrequently (i.e. 18% of days). Whilst ensuring that naps do not interfere with nighttime sleep, athletes may thus be encouraged to increase their napping behaviour with the potential benefit to improve daytime recovery and performance (Waterhouse *et al.*, 2007).

In comparing general and daily-monitored sleep hygiene, no significant associations were observed. Although daily-monitored items largely resembled the items included in the SHI, it is important to note that the SHI asks for broad categories of behaviour, while daily-monitored items asked for specific behaviours. As such, both types of measures should be regarded as complementary rather than being identical. This approach offers a broader insight in elite athletes' sleep hygiene.

In conclusion, the present study indicated adequate overall sleep hygiene behaviour in elite athletes, while certain daytime behaviours such as irregular bedtimes, psychological strain, pre-sleep activities and taking late-evening consumptions can be improved. Consequently, it is suggested here to critically assess the possibility to adjust training times, to reduce evening activities and to introduce stress-reduction strategies to further optimize sleep hygiene and facilitate sleep.

Associations between sleep hygiene, sleep quantity and sleep quality

General measures showed a moderate to strong association between poor sleep hygiene and poor sleep quality, thereby confirming findings with non-athletes (Mastin *et al.*, 2006).

Daily-monitored sleep hygiene was also associated with sleep quantity and sleep quality, but to a lesser extent and with smaller effect sizes. Some associations were in line with expectations (e.g. active pre-sleep behaviour was associated with reduced morning vigor), while others were less straightforward. For instance, the present study showed a shortening of sleep onset latency to be associated with sedentary behaviour that encompasses blue-light exposure, while it has been reported that blue-light, as emitted by screens, could delay sleep onset (Cajochen *et al.*, 2011). Potentially, the negative effect of the blue-light exposure on sleep was outweighed by the arousal-reducing nature of the accompanying activity (e.g. watching a movie, engaging in social media). Another unexpected finding concerns the negative relation between bedtime routine and the duration and frequency of wake after sleep onset. A potential explanation for this may be that athletes with sleep problems tend to engage in bedtime routines, while undisturbed sleepers do not. In general, associations between sleep hygiene, sleep quantity and sleep quality – both at the general and daily-monitored level – indicate that specific daytime behaviours and environmental circumstances may bear relevance for sleep. Although the correlational design used in this study prevents conclusions regarding causality, practical strategies such as regularity in sleep–wake patterns and practices that target sleep more directly, such as relaxation strategies in the evening are suggested to facilitate sleep in athletes. Future research is required to test actual implications of such strategies.

CONCLUSION

The current study provided a detailed overview of self-reported sleep quantity, sleep quality and sleep hygiene practices in a large cohort of elite athletes. Although on average sleep quality appeared to be appropriate, a substantial minority of athletes could be classified as poor sleepers and morning states were moderate at best. These results imply substantial room for improvement. Sleep hygiene appeared to be adequate overall, but adjustments with respect to specific behaviours, such as in reducing irregularity in sleep–wake patterns, decreasing high psychological strain and avoiding activating behaviours in evening hours may prove fruitful. Based on associations between sleep hygiene, sleep quantity and sleep quality, it is suggested that improvement in critical sleep hygiene practices (such as regular sleep–wake patterns and reducing psychological strain) may help to further optimize sleep in elite athletes.

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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