



Received: 16 July 2018
Accepted: 12 November 2018
First Published: 14 November 2018

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SPORTS & EXERCISE | RESEARCH ARTICLE

Habitual sleep patterns of junior elite athletes in cross-country skiing and biathlon: A descriptive study

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Abstract: Sleep is an essential part of athletes' recovery process. Evidence of the habitual sleep patterns among junior elite athletes is however limited. Most previous sleep studies on this population have typically spanned short periods and employed instruments with restricted validity. Overcoming these limitations, the current study investigated the habitual sleep patterns of 31 junior elite athletes over up to four consecutive months, using a non-invasive radio ultra-wideband radar technology for sleep monitoring. The athletes obtained $07:21 \pm 1:21$ h of sleep per night, with an average sleep efficiency of $89.5 \pm 5.5\%$. Sleep patterns were affected by weekends and the competitive season. Longer total sleep time, later sleep onset and later sleep offset characterized the weekends, while longer total sleep time and earlier sleep onset were registered during the competitive season. Further, changes in sleep onset and sleep offset carried over to the subsequent day (i.e. the value of these variables at one night depended on the values of the same variable on the night before). It is concluded that junior elite athletes do not adhere to regular sleep-wake patterns, which may lead to various negative consequences. The current study provides novel normative data of junior elite athletes' habitual sleep

ABOUT THE AUTHORS

The research activities of our group are focused on sleep in elite athletes. More specifically, we are interested in quantifying the habitual sleep patterns of this extraordinary group, as well as context-specific alternations in sleep patterns: during overload periods such as competitions, and during weekly periods of weekdays vs. weekends. The research activities of our group are based on an overarching goal of identifying the ways in which day-to-day variations in cognitive, emotional and physical loads influence the sleep patterns of elite athletes. Quantifying the habitual sleep patterns of elite athletes over a prolonged period of time brings our group closer to closing the gaps in the current academic knowledge on this topic. Our academic research team closely collaborates with coaches, physiotherapists, medical doctors, nutritionists and athletes themselves to design research projects that will fulfill both the theoretical and applied research interests.

PUBLIC INTEREST STATEMENT

Elite athletes face extraordinary pressures and stresses on a continuous basis. The current knowledge of sleep and recovery in elite athletics comes from short-term studies, utilizing tools with known limitations. Therefore, the current study aims to overcome these gaps in existing research. The normative sleep patterns of 31 elite athletes from cross-country skiing and biathlon were investigated by utilizing novel, valid and unobtrusive technology that allowed the sleep monitoring to span up to 4 consecutive months. The results of this study showed relatively short sleep durations, with high variability on a number of measured variables. Despite these findings, average sleep efficiency was good. This study provides novel, normative overview of habitual sleep patterns of junior endurance elite athletes from cross-country skiing and biathlon. A reliable quantification of the sleep status provides the first step in understanding the effects of high-level athletics on the recovery processes and overall functioning of junior elite athletes.

patterns spanning up to four months, with evidence of large variabilities in the measured sleep parameters, including effects of weekends and competition season.

Subjects: Sport and Exercise Science; Sports Psychology; Exercise Psychology; Sports Medicine and Therapy; Individual Sports; Health Psychology; Sport Psychology; Sleep Medicine

Keywords: habitual sleep patterns; sleep; junior elite athletes; athletes; recovery; cross-country skiing; biathlon

1. Introduction

In their struggle to become future elite athletes, junior elite athletes are exposed to heavy physical and psychological load. Potential stressors include school-related duties, frequent trainings, demanding competitions and keeping up with peer groups socially (Compas, Connor-Smith, Saltzman, Thomsen, & Wadsworth, 2001; Moen, Myhre, & Sandbakk, 2016). These loads may lead to performance impairment, injury, overtraining, athlete burnout or development of eating disorders (Furrer, Moen, & Firing, 2015; Meeusen et al., 2006; Moen, Federici, & Abrahamsen, 2015; Sabato, Walch, & Caine, 2016; Van Cutsem et al., 2017). Several strategies may be implemented to balance stress loads and recovery in order to ensure optimal functioning of the junior elite athlete (Sabato et al., 2016). One of the most important recuperative factors is without doubt sleep (Halson, 2014).

Sleep helps to restore the immune, nervous, skeletal and muscular systems (Krueger, Frank, Wisor, & Roy, 2016). Importantly for athletes, research has shown that poor sleep has detrimental implications for psychological state (Scott, McNaughton, & Polman, 2006), metabolic and immune function (Spiegel, Tasali, Penev, & Van Cauter, 2004; Vgontzas et al., 2007) as well as cognitive performance (Belenky et al., 2003). Indeed, impairments related to poor sleep may be detrimental to the recovery process, and hence impair the physical and psychological adaptation to training, and the ability to maintain continuity in training (Dijkstra, Pollock, Chakraverty, & Alonso, 2014). Poor sleep is also associated with impaired athletic performance (Thun, Bjorvatn, Flo, Harris, & Pallesen, 2015). Thus, adequate sleep in junior elite athletes is crucial when focusing on effective recovery, improved performance and overall optimal health.

Sufficient sleep duration requirements vary with age across the lifespan, and inter-individual differences in sleep need exist (Hirshkowitz et al., 2015). Generally, it is recommended that young adults aged 18–25 should get 7–9 h of sleep each night (Hirshkowitz et al., 2015). Another crucial factor of sleep assessment pertains to its quality of which sleep efficiency, the ratio of total sleep time and the total recording time multiplied by 100, is an important parameter. Sleep efficiency of $\geq 85\%$ is regarded as good sleep quality (Ohayon et al., 2017). Importantly for elite athletes, lifestyle factors such as intense training schedules, workloads and stress influence the need for sleep as well as its quality (Shapiro, Bortz, Mitchell, Bartel, & Jooste, 1981). Therefore, due the heavy physical and psychological loads that junior elite athletes face on a continuous basis, sleep requirements of junior elite athletes should correspond to the upper limits of the general recommendations (Simpson, Gibbs, & Matheson, 2017; Watson et al., 2015). In this regard, it should also be noted that extending sleep duration beyond the recommended duration has been associated with improved athletic performance (Mah, Mah, Kezirian, & Dement, 2011).

Despite the indisputable importance of sleep to the functioning of junior elite athletes, research is only beginning to reliably investigate sleep habits in this population. The existing research typically provides an overview of sleep patterns during limited time periods (e.g. one week). For instance, one study utilized objective sleep monitoring, and found sleep durations to be below 8 h with high standard deviations and unstable sleep patterns (Robey et al., 2014). Furthermore, the effect of overload training periods (e.g. training camps) in this population was investigated, and evidence of disturbed and inadequate sleep length was found (Kolling et al., 2016). Together, these

studies highlight the impact of high training loads on recovery in junior elite athletes. Importantly, other existing research exploring sleep in junior elite athletes has employed inadequate methodology. For instance, two studies used only a single question about athletes' subjective perception of sleep duration to make inferences about the role of sleep in injury (Milewski et al., 2014; von Rosen, Frohm, Kottorp, Friden, & Heijne, 2017).

Further research providing evidence of inadequate sleep in elite athletes comes from the adult elite athlete population. Elite athletes have been found to obtain from 6.5 to 7.9 h of sleep per night (Lastella, Roach, Halson, & Sargent, 2015b; Leeder, Glaister, Pizzoferro, Dawson, & Pedlar, 2012; Swinbourne, Gill, Vaile, & Smart, 2016; Teng, Lastella, Roach, & Sargent, 2011). Compared to controls however, elite athletes spent more time in bed, took longer to fall asleep and thus had lower estimated sleep quality than controls (Leeder et al., 2012). The acute effects of competition have been assessed, but yielded conflicting results. One study showed a significant increase (Shearer, Jones, Kilduff, & Cook, 2015), while another study showed a significant decrease in total sleep time on the night before competition (Lastella et al., 2015a). The reason for this discrepancy is not clear, and thus the understanding of how sleep changes prior to competitions remains to be elucidated.

Interestingly, in the study by Erlacher et al. (2011), about half of the sample did not recognize any daytime consequences of one night of poor sleep. Typically, athletes are able to compensate for short-term sleep loss, and thus their performance levels remain unaffected. However, long-term inadequate sleep may be significantly more challenging to deal with than a single night of poor sleep. This may serve as an explanation to why one night of poor sleep did not affect performance for a large proportion of the elite athletes in the study by Erlacher et al. (2011). Furthermore, this research underlines the need to understand the long-term sleep patterns of elite athletes. Without quantification of the sleep status long term, it is not possible to detect the implications and to investigate the effects of relevant countermeasures of short and inadequate sleep (Taylor, Christmas, Dascombe, Chamari, & Fowler, 2016).

It is important to note that the field of sleep assessment in elite athletics is faced with significant methodological shortcomings. Two most commonly used measures for large-scale sleep monitoring of human subjects covering extended periods of time are actigraphy and sleep diaries. Studies investigating the validity of actigraphy in the identification of sleep and wake show relatively high epoch-by-epoch concordance rates (>85%) with the "gold standard" of sleep measurement, polysomnography (PSG). However, upon closer inspection, low specificity of actigraphy in detecting wakefulness has been identified (35–50%, a level equivalent to chance) (Paquet, Kawinska, & Carrier, 2007). Furthermore, when compared to PSG, research has consistently found that actigraphy tends to overestimate total sleep time (Matthews et al., 2018) and sleep efficiency (de Souza et al., 2003; Insana, Gozal, & Montgomery-Downs, 2010; Paquet et al., 2007). On the other hand, it tends to underestimate time taken to fall asleep (de Souza et al., 2003; Tryon, 1996). Similar problems exist with sleep diaries. Unlike actigraphy however, sleep diaries tend to overestimate the amount of sleep obtained by the respondents (Mukherjee et al., 2015).

Despite these findings, and due to the fact that PSG is unsuitable for use in long-term, large-scale sleep research due to its complex and costly setup and analysis (Roebuck et al., 2014), both actigraphy and sleep diaries are extensively used. In order to improve the quality of sleep assessment, sleep monitoring should be externally valid (i.e. non-invasive and easy to implement away from a laboratory, training ground, etc.), portable (i.e. for away fixtures and training camps) whilst possessing high validity and reliability when compared to PSG (Taylor et al., 2016).

In the last two decades, development of reliable non-invasive physiological monitoring has been a subject of focus in health-care research. The microwave Doppler radar (DR) is one of the technologies that has gained considerable attention (Droitcour, Boric-Lubecke, Lubecke, Lin, & Kovacs, 2004). Monitoring with systems based on DR can be used to measure physiological

parameters, such as cardiopulmonary functions (Morawski, Miękina, & Bajurko, 2015; Tariq & Ghafouri-Shiraz, 2011) and respiration (Zakrzewski, Raittinen, & Vanhala, 2012). A DR registers physiological movements of the body in the form of phase modulation, which allows the identification of human movement and respiration rates by processing the baseband signal (de Chazal, O'Hare, Fox, & Heneghan, 2008; Mostov, Liptsen, & Boutchko, 2010; Qiao, He, Hu, & Li, 2014). Interestingly, a recent study showed high validity for sleep monitored by DR and its associated algorithm, when compared to the gold standard PSG (Pallesen et al., 2018).

There is a marked lack of objective and long-term studies investigating sleep patterns of junior elite athletes. Therefore, the present study aims to provide a descriptive overview of habitual sleep patterns of junior elite athletes over a period of up to four months, covering both the competition season and the transition to and beginning of the basic preparatory phase of the annual training plan, using a non-invasive microwave DR sleep monitor. Sleep patterns at different times of the week (weekdays/weekends) and different periods of the year (in competition season and outside competition season) will be explored. In addition, possible within and between subjects' variations will be investigated.

2. Method

2.1. Participants

Forty Norwegian junior athletes competing at a national and/or international level in cross-country skiing and biathlon participated in this study. Participants were recruited from two high schools specialized for elite sports. Athletes from these schools were randomly chosen. To be included, athletes had to be in good health, and not be previously diagnosed with any type of sleep disorder. Prior to data collection, participants were given information about the background and purpose of the study. Furthermore, participants were informed that all data would be kept confidential, that participation was voluntary and that the Norwegian Social Science Data Services (NSD) approved the project.

2.2. Procedure and instrumentation

Participants completed a demographic questionnaire, asking about age, gender and type of sport. Sleep data was collected over a period of up to four months (due to individual start time of data collection), spanning the second half of the competition season, and the transition to and beginning of the basic preparatory phase of the annual training plan. However, due to the individual start time of data collection, not all athletes had equal opportunity for number of collected nights, and similarly, the distribution of nights in competitive and preparatory phase of the season was not equal. Only nighttime sleep was monitored and analyzed.

The radar device Novelda XeThru model X2 was used to monitor sleep (Novelda AS). This is an impulse radio ultra wideband (IR-UWB) pulse-DR with an unfiltered bandwidth of 0.9–9.6 GHz. XeThru has been shown to hold full to moderate agreement with PSG in terms of accuracy, sensitivity and specificity calculations (Pallesen et al., 2018). The same algorithm was used to calculate sleep measures as in the validation study of the device (Pallesen et al., 2018). This algorithm separates sleep and wake in 30-s epochs through the night, and calculates relevant sleep parameters (see Table 1 for an overview of variables). To secure the quality of the collected data, qualified personnel instructed participants on how to set up the radar, and provided individual practical and technological guidance. Athletes were instructed to place the radar in the bedroom that they most often used.

Specific inclusion and exclusion criteria were applied when processing the raw sleep data from the period of data collection. Data was excluded from analysis if the quality was disturbed during the night due to incorrect positioning of the radar (out of range that was set to 1.8 m) or due to other technical issues (e.g. poor signal quality, failed initiation of data collection). Thus, sleep data was only included if it contained good quality, undisturbed signals from the whole night. In

Table 1. Descriptions and units of the investigated sleep variables

Variable	Units	Description
Sleep onset	hh:mm	Time from when a sleep period of at least 10 min was established.
Sleep offset	hh:mm	Time of last awakening before absence from bed was registered.
Total sleep	hh:mm	Total sleep time obtained from sleep onset to sleep offset.
Sleep efficiency	%	Percentage of time from sleep onset to sleep offset spent asleep.

addition, data was missing from nights when the athletes did not sleep in their main bedroom, or when they failed to connect the sleep radar to an internet connection when away from their main bedroom. These instances occurred during travels for holidays, competitions or training camps. In total, 881 nights (31.5% of all monitored nights) of potential radar data was not included in the analysis due to these types of issues. Only athletes who had more than 25 nights of sleep data spanning both competition season and preparatory season during the period of data collection were included in the final analyses, to ensure representativeness of each participating athlete in both periods of data collection.

2.3. Statistical analysis

Sleep was calculated from the evening before and until the morning of a specific day. Thus, when referring to sleep on Monday, this refers to sleep from Sunday night until Monday morning. When days are grouped as weekdays and weekends, sleep from Sunday evening to Friday morning was considered “weekday sleep”, whereas sleep from Friday evening to Sunday morning was considered “weekend sleep”.

Descriptive statistics were used to obtain means and standard deviations for sleep parameters. Throughout the study, these are presented as mean \pm SD. T-tests were applied to compare means for sleep onset, sleep offset, total sleep and sleep efficiency across genders, with alpha value of less than 0.05 used as the level of statistical significance. These analyses were conducted using IBM SPSS (v25.0).

A dynamic structural equation modelling analysis (DSEM) was conducted using MPLUS 8.0 (Muthén & Muthén, 2017). DSEM is a combination of a multilevel analysis and a time-series analysis with lagged autocorrelations between consecutive measurement points. The DSEM procedure uses Bayesian estimation, meaning that no standard model fits or significance values are reported. Instead, the posterior parameter trace plots are inspected to determine model convergence (non-convergence would be indicated by deviations from the “thick caterpillar” form of the plots), and 95% credibility intervals are inspected to determine “significance” of the results.

The DSEM analysis was used to investigate the following four components: (1) mean lagged relation between consecutive days—to what extent the value of a variable at one night depends on the value of the same variable on the night before; (2) within-person variance—the variability of total sleep duration within each athlete. The within person mean and variance component contains log transformed values and back transformed values; (3) mean effects of weekends as compared to weekdays; (4) mean effects and variance of competitive season against non-competitive season. For each component, between-person variance analysis was performed.

3. Results

3.1. Demographics

Due to technical issues with the radar and insufficient number of nights collected during the period of data collection, nine athletes were excluded from the analysis. Participants thus included 19

men and 12 women (18.6 ± 0.8 years). In all, 21 of the athletes had biathlon as their main sport (14 men), whereas cross-country skiing was the main sport for 10 athletes (5 men).

3.2. Average sleep patterns

Once the disturbed sleep data was removed, the final database included 1884 nocturnal sleep recordings. On average, athletes fell asleep at 00:08 h, and woke up at 08:22 h. In this period, they obtained $07:21 \pm 1:21$ h of sleep, with an average sleep efficiency of $89.5 \pm 5.5\%$. Independent sample *t*-tests showed a significant gender difference on average sleep onset time ($00:13 \pm 1:23$ for men and $00:03 \pm 1:12$ for women, $p < .01$) and sleep efficiency ($90.5 \pm 5.0\%$ for men and $88.3 \pm 5.9\%$ for women, $p < .001$). No gender differences were found in terms of total sleep time and sleep offset.

3.2.1. Sleep through the week

Out of all monitored nights, 1438 were weekdays and 446 were weekends. During weekdays, on average, athletes fell asleep at $00:01 \pm 1:16$, woke up at $08:13 \pm 1:28$, and slept for total duration of $07:21 \pm 1:17$. The sleep efficiency during weekdays was $89.6 \pm 5.6\%$. During weekends, on average, athletes fell asleep at $00:31 \pm 1:21$, woke up at $08:48 \pm 1:31$ and slept for total duration of $07:22 \pm 1:31$. The sleep efficiency during weekends was $89.1 \pm 5.3\%$. Daily distribution of sleep onset and sleep offset are shown in Figure 1.

3.2.2. Sleep patterns in and outside competitive season

Out of all nights, 882 were in the competitive season, and 1002 were outside the competitive season. On average, athletes fell asleep at $23:51 \pm 1:08$ during and at $00:24 \pm 1:24$ outside the competitive season. Athletes woke up at $08:15 \pm 1:25$ during, and at $08:28 \pm 1:35$ outside the competitive season. Total sleep duration was $07:30 \pm 1:13$ during and $07:13 \pm 1:26$ outside the competitive season, while sleep efficiency was 89.5 ± 5.6 during and 89.5 ± 5.4 outside the competitive season. Daily distribution of sleep onset and sleep offset time during the competitive season and outside the competitive season are shown in Figure 2.

3.3. Dynamic structural equation modelling analysis of sleep data

Results of the DSEM analysis are presented in Table 2. Analysis of the lagged relation between consecutive days showed significant estimates for sleep onset and sleep offset. Sleep onset one hour later sleep during the previous night lead to 9 min later sleep onset the next night. Furthermore, sleep offset one hour later significantly affected the sleep offset time the next day by 9 min. The analysis of variance revealed significant between-persons differences in all investigated sleep variables.

Figure 1. Graphical representation of mean sleep patterns across the week, with standard deviation error bars.

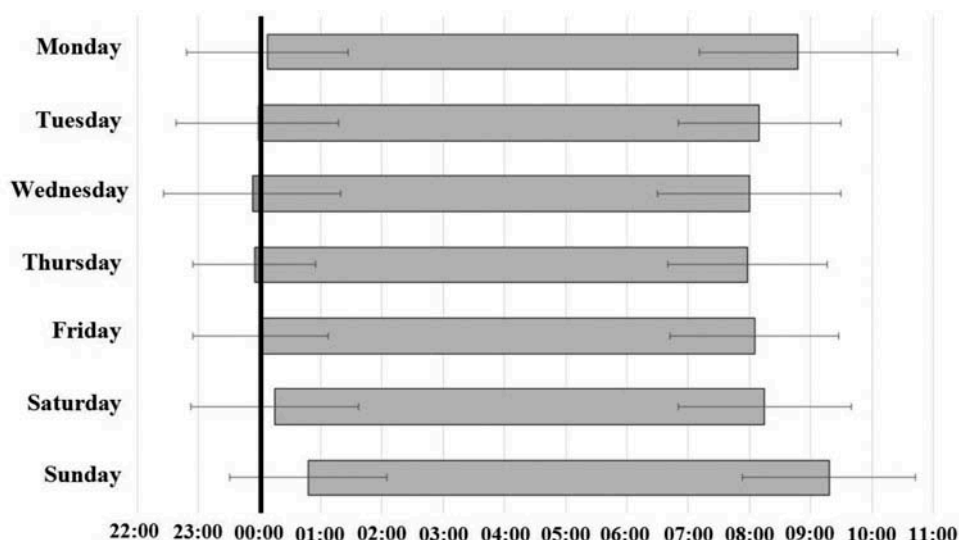
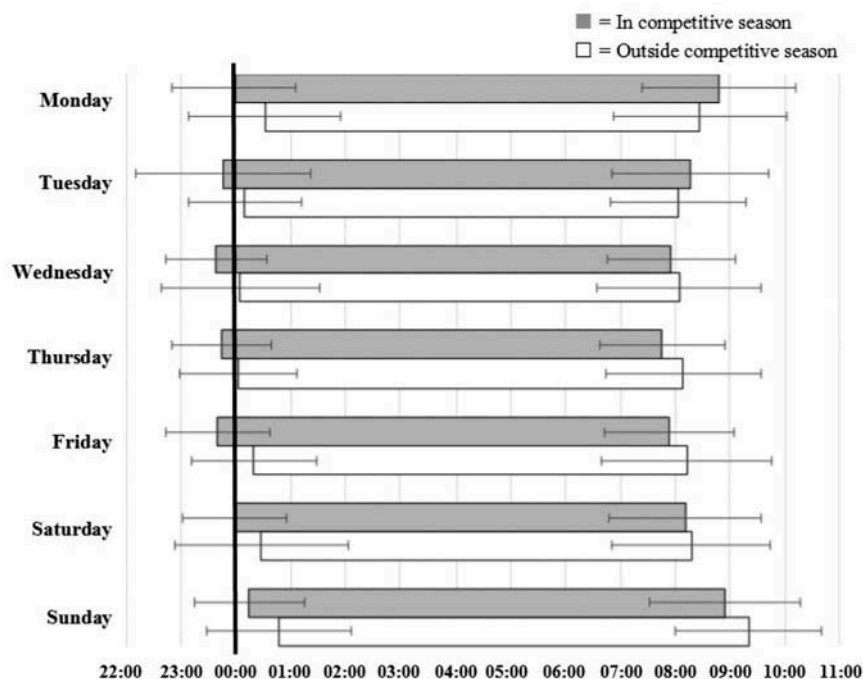


Figure 2. Graphical representation of mean sleep patterns in and outside the competitive season, with standard deviation error bars.



Analysis of within-person variance showed that on average, there was a considerable variation within athletes in terms of total sleep time per night by 39 min, in terms of sleep offset time by 48 min and in sleep efficiency by 5.1%. In addition, within-person variance also varied between athletes, suggesting that some athletes have a rather stable sleep amount, whereas for others there is a lot of variation.

Results of the weekend effect analysis revealed a positive significant effect on mean total sleep time (longer by 26 min), sleep onset (delayed by 46 min) as well as sleep offset (delayed by 74 min) compared to weekday sleep. Furthermore, between-person variance was significant for all measured sleep variables. Furthermore, there was a significant effect of competitive season on total sleep time (17 min longer) and sleep onset (27 min earlier). Furthermore, between-person variance was significant for all measured sleep variables.

4. Discussion

The aim of the present study was to investigate the habitual sleep patterns of junior elite athletes covering a period of up to four months, using a non-invasive microwave DR sleep monitor. The findings in this study give insight into normative sleep patterns of this group, and lead to questions whether the measured sleep is sufficient for adequate recovery from the loads these athletes are exposed to.

4.1. Total sleep time

Athletes in the present study obtained on average 7 h and 21 min of sleep per night. This is on the lower end, but still within the range of healthy sleep, based on guidelines for the general populations in this age group (Hirshkowitz et al., 2015). Junior elite athletes are exposed to heavy physical and psychological loads from sport, school and peer groups (Compas et al., 2001; Moen et al., 2016), and are potentially exposed to performance impairment, injuries and athlete burnout if these loads are not balanced properly against recuperative measures (Moen et al., 2015; Van Cutsem et al., 2017). In addition, the intense training sessions of junior elite athletes likely increase the need for sleep as well (Kelley & Kelley, 2017). Therefore, it is relevant to question whether the amount of sleep recorded in

Table 2. Results from the dynamic structural equation modelling analysis

	Lagged relation between consecutive days			Within person variance				Weekend effect		Competitive season effect	
				Log transformed		Back transformed					
	M	VAR		M	VAR	M	VAR	M	VAR	M	VAR
Sleep variables											
Total sleep	-.004	.016*		.359*	.254*	1.432	1.289	.434*	.610*	.281*	.165*
	14 s	-		-	-	39 min ^b	-	26 min ^c	47 min ^a	17 min ^e	24 min ^a
Sleep onset	.142*	.031*		-.025	.560*	.975	1.751	.759*	.175*	-.452*	.140*
	9 min	-		-	-	59 min ^b	-	46 min ^c	25 min ^a	-27 min ^e	22 min ^a
Sleep offset	.145*	.025*		.493*	.205*	1.637	1.229	1.233*	.400*	-.192	.156*
	9 min	-		-	-	48 min ^b	-	1.14 ^c	38 min ^a	-12 min ^e	24 min ^a
Sleep efficiency	.062	.027*		-5.979*	.242*	.003	1.274	-.004	.001*	.001	.001*
	-	-		-	-	5.0% ^d	-	-0.4%	3.2% ^d	0.1% ^e	3.2% ^d

*=Bayesian 95% credible interval does not include 0 which corresponds to a significant result.

^a Standard deviation in minutes.

^b Within person standard deviation in time.

^c Difference as compared to a weekday.

^d Standard deviation in percent.

^e Difference between a night within the competitive season and outside the competitive season.

the current study is sufficient to prevent the neurobehavioral deficits associated with sleep loss, and to give the athletes optimal physical and mental recovery from their demanding schedules.

There were significant variations in total sleep time at between- and within-persons level. Athletes slept for considerably shorter than recommended, while at times they markedly extended the sleep period. Furthermore, some athletes slept considerably more than the average value, while some slept considerably less. There may be two explanations to this finding. Firstly, the significant variation in total sleep time at between- and within-persons level may reflect real individual differences in sleep need. Alternatively, these findings may point to significant individual differences in the ability to maintain a regular sleep-wake cycle, which is largely in accordance with previous findings of sleep patterns in elite athletes (Leeder et al., 2012; Robey et al., 2014). Increased variability in sleep duration has been associated with psychosocial and physiological stress in normal populations (Mezick et al., 2009). With the current population exposed to frequent stress of both psychological and physiological nature, future research should explore these as possible causes for variations in total sleep time in junior elite athletes. In addition, future studies should investigate how the individual sleep patterns relate to injuries, training motivation and athletic progress.

In addition, total sleep time was extended during the competition season and during the weekends. This suggests that a greater need for recovery accompanied the challenging period of competitions, as well as the typically recuperative periods of weekends. It may also reflect that during these periods, the athletes probably partook to a smaller degree in social events, which otherwise could have curtailed their sleep. The present results elucidating the effect of competition season are in accordance with the study by Shearer et al. (2015), but in opposition to the study by Lastella et al. (2015a). The reason for the discrepancy across studies may be the number of nights studied. Lastella and colleagues only measured 42 nights of sleep during competitions (21 athletes were monitored for 2 competition nights), while the results in the present study spanned a significantly longer period, specifically 882 nights (in 31 athletes). The present results covered the whole season, and thus investigated how competitive season influences sleep on a long-term basis, while the aforementioned study only covered the “acute” effects of competition.

4.2. Sleep onset and offset

On average, athletes fell asleep at 00:08 h, and woke up at 08:22 h. The time of sleep onset and offset on one day significantly influenced the time of sleep onset and offset on the next day, suggesting that junior elite athletes are sensitive to alternations in bedtimes and wake up times and that this might have influenced their circadian rhythm.

Furthermore, there were significant within- and between-person variations in these two variables, pointing to irregular bedtime schedules. Similarly as for total sleep, this irregularity may be due to psychosocial and physiological stress (Mezick et al., 2009), and further research warrants thorough investigation of the underlying causes to this variation.

A significant effect of weekends and competitive season on sleep onset and wake-up time further underlines the concern that junior elite athletes do not maintain regular sleep-wake cycles. Athletes fell asleep later and woke up significantly later during weekends, which is in line with studies showing that youths typically delay their sleep time in weekends, probably due to social factors (Saxvig, Pallesen, Wilhelmsen-Langeland, Molde, & Bjorvatn, 2012). Furthermore, during the competitive season, athletes went to sleep significantly earlier, emphasizing a greater need for recovery during competitions. These results bring novel insight into the habitual sleep patterns of this population, as no previous research examined the longitudinal effects of weekends and competitive season on sleep of junior elite athletes.

4.3. Sleep efficiency

Generally, athletes' sleep efficiency was above $\geq 85\%$, which reflects good sleep quality among teenagers (Ohayon et al., 2017). Significant gender differences were revealed, with male athletes reaching higher sleep efficiency than female. This is in contrast to previous research, which found females to have higher sleep efficiency in a population of young healthy sleepers (Goel, Kim, & Lao, 2005), as well as elite athletes (Leeder et al., 2012), but is in line with a large study of Norwegian adolescents (Hysing et al., 2015).

4.4. Limitations

Some limitations of the present study should be noted. Firstly, the DR sleep radar used has so far been only validated in one pilot study (Pallesen et al., 2018). In the validation study, a cohort of older adults than those in the current study was used for the purpose of validation of the DR sleep radar against PSG. The pilot study showed the discrepancy between PSG and the sleep radar to be smaller than what is typically reported between PSG and actigraphy. Similarly, the overall specificity and inter-rater agreement was found to be higher than for actigraphy. However, the DR sleep radar has not yet been directly validated against actigraphy, and the present study did not include an age-matched control group. Although the aforementioned characteristics make the DR sleep radar a promising tool for unobtrusive and accurate sleep measurement, more evidence is required before well-founded conclusions about the validity, specificity and accuracy of the DR sleep radar can be inferred.

Another limitation of the present study is the large number of nights missing from the period of sleep monitoring. In all, 866 nights of data (31% of the total intended number of nights) were lost due to poor signal quality, incorrect positioning of the radar or athletes not sleeping in their main bedroom (during travel or holidays). Furthermore, the sleep radar only analyzed nighttime sleep, and daytime naps were unaccounted for. The data is still likely to be representative of the population, although the missing data may have affected the results presented in this study and should therefore be interpreted with caution.

4.5. Conclusion

To conclude, objective sleep monitoring over up to four months in 31 junior elite athletes, spanning both competitive and preparatory season, showed large between- and within-persons variations and instability in sleep parameters at the micro level (weekdays vs. weekend) and at the macro level (period of the annual training plan). Weekends increased total sleep time and delayed sleep onset and sleep offset, while competitive season significantly increased total sleep time and advanced sleep onset. Changes in sleep onset and sleep offset carried over to the subsequent day. Summarizing these results, it is clear that junior elite athletes do not hold regular sleep-wake patterns, quite the contrary. The present study provides novel normative data for young athletes with evidence of large variabilities in the measured sleep parameters, gender effects, weekend effects and competition season effects.

Maintaining an effective recovery process is crucial for junior elite athletes' continuous performance development. When evaluating the potential implications of insufficient sleep, one must look beyond the short-term effects, and consider the importance of sufficient and stable sleep for performance development over time. Various negative consequences, like difficulties in maintaining focus and concentration, lowered motivation, involuntary breaks from training and disturbance of the important continuity in training, injuries and psychosocial stress, are all likely to occur due to insufficient sleep. Future research warrants further investigations into the causes and consequences of the highly variable habitual sleep patterns of junior elite athletes. An individual approach to facilitate improvement of sleep seems warranted.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Competing Interests

The authors declare no competing interest.

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Compliance With Ethical Standards

Ethics approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Citation information

Cite this article as: Habitual sleep patterns of junior elite athletes in cross-country skiing and biathlon: A descriptive study, Maria Hrozanova, Frode Moen, Kenneth Myhre, Christian Klöckner & Ståle Pallesen, *Cogent Medicine* (2018), 5: 1548549.

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