

## Article title:

Deconstructing athletes' sleep: A systematic review of the influence of age, sex, athletic expertise, sport type, and season on sleep characteristics

## Authors:

Angelos Vlahoyiannis,<sup>a</sup> George Aphasidis,<sup>a</sup> Gregory C. Bogdanis,<sup>b</sup> Giorgos K. Sakkas,<sup>c,d</sup> Eleni Andreou,<sup>a</sup> and Christoforos D. Giannakia,<sup>\*</sup>

## Abstract

### Purpose

This systematic review aimed to describe objective sleep parameters for athletes under different conditions and address potential sleep issues in this specific population.

### Methods

PubMed and Scopus were searched from inception to April 2019. Included studies measured sleep only via objective evaluation tools such as polysomnography or actigraphy. The modified version of the Newcastle–Ottawa Scale was used for the quality assessment of the studies.

### Results

Eighty-one studies were included, of which 56 were classified as medium quality, 5 studies as low quality, and 20 studies as high quality. A total of 1830 athletes were monitored over 18,958 nights. Average values for sleep-related parameters were calculated for all athletes according to sex, age, athletic expertise level, training season, and type of sport. Athletes slept on average  $7.2 \pm 1.1$  h/night (mean  $\pm$  SD), with  $86.3\% \pm 6.8\%$  sleep efficiency (SE). In all datasets, the athletes' mean total sleep time was  $<8$  h. SE was low for young athletes ( $80.3\% \pm 8.8\%$ ). Reduced SE was attributed to high wake after sleep onset rather than sleep onset latency. During heavy training periods, sleep duration and SE were on average 36 min and 0.8% less compared to pre-season and 42 min and 3.0% less compared to in-season training periods, respectively.

### Conclusion

Athletes' sleep duration was found to be short with low SE, in comparison to the general consensus for non-athlete healthy adults. Notable sleep issues were revealed in young athletes. Sleep quality and architecture tend to change across different training periods.

**Keywords:** Actigraphy, Polysomnography, Sleep architecture, Sleep duration, Sleep quality

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Graphical Abstract

Image, graphical abstract

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## 1. Introduction

Growing evidence suggests that more than half of active athletes report poor sleep during various occasions.<sup>1</sup> This fact bears high significance not only due to the detrimental effect of poor sleep on physical and mental performance, but also because of its impact on athletes' health, as sleep is related to vital functions and may be associated with various pathological conditions and health problems.<sup>2, 3, 4</sup>

Sleep is a multidimensional construct that can be measured by both objective and subjective tools; thus, sleep evaluation methods may be crucial when attempting to draw safe conclusions about its impact on athletic performance.<sup>5,6</sup> Briefly, sleep can be subjectively assessed using specific questionnaires and sleep diaries, whereas validated objective measurements of sleep include polysomnography (PSG) and actigraphic devices.<sup>7</sup>

An objective and detailed sleep measurement should assess the progress from wakefulness to sleep and its intermediate stages. Sleep evolves as follows: wakefulness, light sleep, deep sleep, and rapid eye movement (REM) sleep. These different states of brain activity compose the "sleep architecture". According to the American Academy of Sleep Medicine (AASM),<sup>8</sup> there are 4 distinct sleep stages: three are non-REM (N1, N2, and N3); and the last is the REM sleep stage. Usually, the first 2 non-REM stages (N1 and N2) are denominated as "light sleep" and the third non-REM stage as "deep sleep" or slow wave sleep.

To measure these variations in brain function, sleep electroencephalography (EEG) or PSG is required. Specifically, a typical PSG study includes central, frontal, and occipital EEG, recording of eye movements, chin, and muscle activity, electromyography, electrocardiogram, pulse oximetry, respiratory effort, nasal and oral airflow, and body position sensors.<sup>8</sup> PSG is considered to be the gold standard method for assessing sleep and sleep disorders despite its associated practical difficulties.<sup>7</sup> Another critical measure for sleep is its duration, which is often referred as total sleep time (TST), while the percentage of duration of TST relative to the total time in bed is referred as sleep efficiency (SE). An additional way to estimate TST and SE is via actigraphy, which translates activity/inactivity to wake/sleep cycles,<sup>9</sup> and has been adequately validated against PSG in athletes.<sup>10</sup> Thus, actigraphy and PSG effectively measure sleep-related parameters and they are objective tools of sleep assessment. In addition, subjective methods for assessing sleep duration and quality are very popular and include various self-reported sleep logs and questionnaires. However, their validity is unclear, since it has been shown that many athletes tend to overestimate their self-reported sleep.<sup>5,6</sup> Subjective sleep monitoring tools may be used as initial screening tools for sleep disorders in athletes, such as obstructive sleep apnea.<sup>11</sup> However, PSG examination should be performed to diagnose relevant disorders,<sup>12</sup> and it is proposed that it could be potentially used as an indicator of poor physical recovery.<sup>13</sup>

Recent reviews that have systematically examined the prevalence of sleep disorders in athletes, as well as the effect of training or competition on sleep, have included studies that both objectively and subjectively measured sleep data.<sup>1,14</sup> These reviews showed that athletes may experience several sleep issues<sup>1,14</sup> and differentiations in sleep characteristics in relation to training,<sup>15,16</sup> competition,<sup>17</sup> or other related factors, such as chronotype<sup>16</sup> and sports discipline.<sup>18,19</sup> To address these issues regarding athletes' sleep, the research community tested acute sleep hygiene strategies in order to improve athletes' sleep.<sup>20</sup> Nevertheless, sleep guidelines have thus far not differentiated between athletes and non-athletes,<sup>21</sup> making it difficult to design targeted sleep optimizing interventions. Thus, there is a need to gather more information about athletes' sleep and to develop specific guidelines for this population.<sup>22</sup>

Based on our literature review, quantitative information about sleep quality, sleep quantity, and architecture in athletes, using only objectively measured sleep-related data, is poorly systematized. Thus, the current review aimed to extract from the literature typical sleep characteristics of athletes according to sex, age groups, level of competence, or type of sport and summarize these data. Specifically, this review aims to:

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Provide data about objectively measured sleep quantity, quality, and architecture of athletes according to their (1) sex, (2) age, (3) athletic expertise, (4) training season, and (5) type of sport (primarily aerobic, anaerobic, or mixed sport, and individual sports vs. team sports).

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Address potential sleep issues and sleep fluctuations in athletes in relation to these categories.

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## 2. Methods

### 2.1. Information sources and search strategy

This review was performed in accordance to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.<sup>23</sup> Two electronic databases (PubMed and Scopus) were systematically searched by two of the authors (AV and CDG) for studies published from inception to April 2, 2019. For both databases, search terms included the following combination of keywords: ("athlete" OR "competitive" OR "sport" OR "elite" OR "player") AND ("sleep" OR "electroencephalography" OR "actigraphy" OR "polysomnography"). Retrieved records from PubMed search were limited according to article type (clinical trial, controlled trial, randomized control trial, observational study, comparative studies, and case reports) and language (English). Retrieved records from the Scopus search were limited according to source type (journal), document type (article), and language (English). A supplementary search for relevant studies was conducted from the reference list of the screened manuscripts.

### 2.2. Eligibility criteria

The eligibility of retrieved records for inclusion in our review was determined by two of the authors (AV and CDG) according to the following criteria: studies were written in English and measured sleep-related parameters objectively via PSG, EEG, or actigraphy, or a combination of these 3 methods. No restrictions in study design were applied. Articles were excluded if (1) participants did not take part systematically in any sport or had a history of major diseases, (2) athletic expertise or sleep-related data were inadequately described, and (3) sleep-related data were assessed after travel or any other manipulated intervention (e.g., dietary intervention, altitude, or light exposure); only the pre-intervention baseline sleep data from these studies were included, where available.

### 2.3. Study selection and data extraction

The process used for the literature research is depicted in Fig. 1. After removal of duplicated records, titles (and, where required, the abstracts of the remaining studies) were evaluated to select potentially relevant studies for full-text article screening. Reasons for excluding a shortlisted article during full-text screening were recorded (Fig. 1).

Fig 1

Fig. 1

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart for study selection.

A standardized data extraction form was employed to obtain the following: (1) publication details—name of first author and year of publication; (2) participant characteristics—sample size and sex; (3) sports-related data—type of sport and training season; (4) sleep-related data—nights recorded, TST, SE, wake after sleep onset (WASO), sleep onset latency (SOL), REM onset latency, and sleep stages (REM, N1, N2, and N3). If data were graphically presented, Plot Digitizer (Version 2.6.8; SourceForge, San Diego, CA, USA) was used to extract data of interest. Where possible, data were extracted in as many sets as possible, separating datasets for age, sex, or other sports-related parameters. The mean and SD for all data were recorded. Where required, SD was calculated from reported confidence intervals. The assumption that all groups of data were merely sub-samples of a single group was made. Thus, mean values and SDs were combined according to nights recorded.

### 2.4. Evidence quality appraisal

All studies were assessed for their methodological quality using a version of the Newcastle–Ottawa Scale (NOS) for cross-sectional studies (Supplementary Table 1). This is an established tool, adapted by Gupta and colleagues,<sup>1</sup> and used in other relevant studies.<sup>14</sup> The NOS evaluates evidence through 8 items measuring selection, comparability and outcome criteria. These criteria were modified by 2 reviewers (AV and CDG) to represent adequately the aims of this review. When a criterion was satisfied, a score of 1 (or in case of Criterion 7, a score of 2) was awarded to the corresponding item. Otherwise, a score of 0 was awarded the corresponding item. The sum of the scores was used to categorize overall study evidence quality as low (<5), moderate (5–7), or high (>7).

## 2.5. Definitions of sleep-related parameters and terminology

The extracted sleep parameters are defined in Table 1. These parameters were selected for the integrative view of sleep quantity (TST), quality (WASO, SE, and SOL), and architecture (REM onset latency, REM, N1, N2, and N3).

Table 1

Definition of sleep-related terms used in data extraction.

Term	Definition	Estimated by polysomnography/electroencephalography	Estimated by actigraphy
Nights recorded	The number of the nights that sleep-related parameters were evaluated, multiplied by each participant.	+	+
TST	The total amount of time whilst asleep in bed, presented in hours.	+	+
SE	TST expressed as percentage of total time in bed. SE is used as an indicator of sleep quality, and a value of <85% is indicative of sleep disorders. $SE = (TST/Time\ spent\ in\ bed) \times 100$ .	+	+
Sleep onset latency	The time elapsed from laying down on the bed until N1 stage sleep onset, presented in minutes.	+	+
REM onset latency	The time elapsed from laying down on the bed until REM stage sleep onset, presented in minutes.	+	–
Wake after sleep onset	The total amount of wakefulness from N1 stage sleep onset until the final awakening, presented in minutes.	+	+
REM stage sleep	The stage of sleep during which REM and dreaming occurs, presented in minutes.	+	–
N1 stage sleep <sup>a</sup>	The first sleep stage, represented in minutes.	+	–
N2 stage sleep <sup>a</sup>	The second stage of sleep, represented in minutes.	+	–
N3 stage sleep	The third stage of sleep, often referred as “deep sleep”, presented in minutes.	+	–

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Notes: The symbol “+” denotes that the sleep-related parameter can be measured by the specific sleep measure. The symbol “–” denotes that the sleep-related parameter can not be measured by the specific sleep measure.

<sup>a</sup> The combination of N1 and N2 stages of sleep, often referred as “light sleep”.

Abbreviations: REM = rapid eye movement; SE = sleep efficiency; TST = total sleep time.

All TST values were transformed into hours for purposes of uniformity. Data in regards to sleep stages were presented in min, as measured in the majority of the studies in literature. In case of merged N1 and N2 stages of sleep (as light sleep), the results are presented but not included in the calculation of the general or subgroup mean. In the case of sleep scoring with 5 stages (REM, N1, N2, N3, and N4), the N3 and N4 stages were combined and noted accordingly.<sup>8</sup>

## 2.6. Sample characteristics assessment and organization

Extracted datasets were categorized according to (1) sex—males and females; (2) age—available data were categorized into 3 groups according to the participants' age: (i) children and adolescents, 6–17 years, (ii) young adults, 18–24 years, and (iii) middle-aged adults, 25–40 years; (3) sports parameters—datasets were classified according to (i) sports reliance on different types of energy production pathway (primary aerobic, anaerobic, or mixed), (ii) individual or team sports, and (iii) the season of data collection (pre-season/tapering, in-season/competition phase, and heavy training phase), and (4) athletes expertise—all participants were evaluated according to the model for classifying the validity of expert samples in sport psychology<sup>24</sup> to identify their level of competence (Supplementary Table 2). This tool evaluates athletic expertise by within-sports (level of performance, success, and experience) and between-sports (competitiveness of the sport in the country and in the world) criteria. Due to limited data regarding athletes' expertise and success, a modified version was used that had been previously employed in other studies.<sup>1,14</sup> The calculated score from the modified equation Eq. (1) was used to categorize athletes as elite (score of  $\geq 8$ ) or semi-elite (score of  $< 8$ ):<sup>1,14</sup>

$$A \times ((D+E)/2)$$

Eq. (1)

where A = standard of performance, D = competitiveness in country, and E = global competitiveness of sport.

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## 3. Results

### 3.1. Studies selection

During the literature research, 3992 studies were identified (Fig. 1). After duplicate removal, 3683 records were screened by title and, where required, by abstract. A total of 159 full-text articles were assessed for eligibility. Through full-text screening, 96 articles were excluded and 18 additional records were identified, resulting in a total of 81 studies that were included in the qualitative synthesis.

### 3.2. Studies' characteristics

Included studies were published from 1978 to 2019, with 55.6% of the studies being published between 2016 and 2019. The sample included 1830 participants, with 230 females, 1040 males, and 560 combined (without clear sex segregation), of which 177 were children and adolescents, 1080 were young adults, and 410 were middle-aged adults; the age of 163 participants was not reported. The age of the participants was  $22.2 \pm 5.5$  years (mean  $\pm$  SD). Overall, 12 of the studies evaluated sleep-related parameters using PSG, 4 studies used EEG, 61 studies used actigraphy, and 4 studies performed PSG or EEG in conjunction with actigraphy, resulting in 206 datasets (PSG/EEG,  $n = 37$ ; actigraphy,  $n = 169$ ). A total of 18,958 recorded nights were extracted, of which 4.2% were obtained from PSG/EEG measurements and 95.8% from actigraphy. A total of 555 nights were recorded in children and adolescents, 6298 in young adults, and 2330 in middle-aged adults; 9775 nights of the 163 participants of undefined age were excluded in this specific analysis.

### 3.3. Evidence quality appraisal

According to the NOS, evidence quality of 5 studies was classified as low, 56 as medium, and 20 as high (Supplementary Table 1). The first NOS evaluation component, sample selection, had a median score of 2 (0–4). The second component, comparability of studies, received a median score of 2 (0–2), and the third component, outcome measurement, had a median score of 3 (2–3).

### 3.4. Athletes expertise appraisal

Using the modified version of the model for classifying the validity of expert samples in sport psychology, the participants were categorized as elite (44 studies; females  $n = 117$ , males  $n = 716$ , combined males and females  $n = 470$ ) or as semi-elite (37 studies; females  $n = 113$ , males  $n = 324$ , combined males and females  $n = 90$ ) (Supplementary Table 2). Elite athletes were represented in 113 datasets of 13,262 nights recorded and semi-elite athletes in 93 datasets of 5696 nights recorded.

### 3.5. Overall sleep data (quality, quantity, and architecture)

Analytical sleep-related data obtained from PSG/EEG and actigraphy measures are presented in Tables 2 and 3, respectively. Datasets that included daytime naps,<sup>25</sup> or assessed sleep during ultra-endurance competition (duration of  $\geq 6$  h), in single<sup>26</sup> or multiday races,<sup>27, 28, 29</sup> and individual<sup>26,28</sup> or team ultra-endurance events,<sup>27,29</sup> are presented separately and only their baseline data were used for the analysis. Overall results are showed in Table 3. Athletes slept approximately  $7.2 \pm 1.1$  h/night. SE was  $86.3\% \pm 6.8\%$ , with mean SOL time of  $14.8 \pm 17.0$  min and WASO of  $52.7 \pm 32.0$  min. According to PSG/EEG measures, REM stage occupied  $114.1 \pm 35.4$  min of sleep, N1 stage occupied  $47.9 \pm 31.0$  min, N2 occupied  $240.5 \pm 53.6$  min, and N3 occupied  $91.5 \pm 35.8$  min (Table 4).

Table 2

Sleep-related data measured with either polysomnography or electroencephalography (mean  $\pm$  SD).

First author (publication year)	n	Sex	Age (year)	Type of sport	Training season		
Nights recorded	TST (h)	SOL (min)	ROL (min)	SE (%)	WASO (min)	REM (min)	
N1 (min)	N2 (min)	N3 (min)					
Walker (1978)	55	10	M	19.3 ± NR	Distance running	Competition phase	
10	7.6 ± 0.2	12.1 ± 6.2	78.4 ± 21.9	–	6.6 ± 11.3	117.0 ± 15.2	
–	–	–					
20	7.7 ± 0.1	15.2 ± 6.3	90.8 ± 26.2	–	4.0 ± 2.9	113.7 ± 17.8	–
–	–						
Shapiro (1981)	56	6	M	21.7 ± NR	Running	Competition phase	6
7.1 ± NR	–	–	–	–	116.3 ± NR	18.3 ± NR	198.9 ± NR
90.5 ± NRa							
6	8.2 ± NR	–	–	–	65.5 ± NR	38.3 ± NR	175.7 ± NR
214.1 ± NRa							
6	8.9 ± NR	–	–	–	93.0 ± NR	15.7 ± NR	212.4 ± NR
212.1 ± NRa							
6	7.8 ± NR	–	–	–	141.5 ± NR	23.2 ± NR	180.8 ± NR
119.8 ± NRa							
6	7.5 ± NR	–	–	–	126.1 ± NR	20.1 ± NR	213.5 ± NR
89.0 ± NRa							
Trinder (1982)	85	10	M	22.3 ± 2.3	Distance running	NR	20
± 1.1	17.0 ± 8.1	88.0 ± 46.2	–	–	121.0 ± 27.1	64.0 ± 30.5	9.2
87.0 ± 26.0							278 ± 49.8
10	22.5 ± 2.6	Weightlifting and bodybuilding	20	8.4 ± 1.8	33.0 ± 52.0		
91.0 ± 44.7	–	–	103.0 ± 34.1	71 ± 40.5	271 ± 55.1	61.0 ± 33.0	
10	21.1 ± 2.2	Multi-sports	20	8.9 ± 0.8	26.0 ± 25.5	73.0 ± 19.7	–
–	125.0 ± 28.0	61 ± 15.4	280 ± 43.8	69.0 ± 21.7			
Driver (1994)	26	8	M	30.0 ± NR	Ultra-triathlon	Competition phase	8
± 0.8	9.0 ± 9.0	90.0 ± 31.0	–	–	–	–	7.3
8	6.9 ± 1.0	10.0 ± 6.0	77.0 ± 26.0	–	–	–	–
8	7.6 ± 0.5	8.0 ± 7.0	81.0 ± 24.0	–	–	–	–
Ultra-endurance competition phase			8	10.4 ± 1.6	8.0 ± 4.0	186.0 ± 83.0	–
–	–	–	–				
Taylor (1997)	57	7	F	19.0 ± 2.0	Swimming	Competition phase	7
± 0.5	19.3 ± 3.5	73.3 ± 37.6	–	4.4 ± 6.4	–	–	7.5
Competition phase							
–	–	7.9 ± 1.0	16.6 ± 5.6	64.3 ± 16.0	–	9.0 ± 13.8	
–	–	–					
Tapering	7	7.6 ± 0.2	16.9 ± 8.8	60.7 ± 8.9	–	9.1 ± 5.3	–
–	–	–					



George (2003) 86	52	M	25.5 ± 2.4	Football	Pre-season	52	6.0
± 0.5 21.7 ± 20.3	–		90.3 ± 6.8	–	–	–	–
Hoshikawa (2007)87	8	M	21.9 ± 1.6	Distance running	Heavy training		
phase 8 7.6 ± 0.3			9.7 ± 3.4	86.6 ± 26.3	94.6 ± 3.7	22.6 ± 15.4	
97.8 ± 22.3	61.3 ± 14.0		209.3 ± 34.1	86.1 ± 22.3			
Gosselin (2009)88	7/4	M/F	22.6 ± 2.4	Multi-sports	NR	11	7.6 ± 0.3
8.6 ± 7.3	65.6 ± 13.8		94.8 ± 4.3	17.0 ± 7.6	–	–	–
Hoshikawa (2010)89	7	M	21.7 ± 1.6	Distance running	Heavy training		
phase 7 7.6 ± 0.3			9.3 ± 3.4	91.2 ± 24.6	94.4 ± 3.9	23.5 ± 16.4	
97.6 ± 24.1	60.9 ± 15.1		208.9 ± 36.8	86.0 ± 24.1			
Hoshikawa (2013)80	7	M	–	NR	Heavy training phase	7	7.6 ± 0.1
8.6 ± 3.3	–		94.5 ± 1.7	22.2 ± 8.5	103.1 ± 13.0	52.2 ± 25.0	
236.9 ± 27.7	58.3 ± 22.7						
7	7.5 ± 0.2		14.6 ± 4.1	–	92.7 ± 2.9	24.7 ± 14.4	128.2 ± 28.3
56.0 ± 27.3			210.6 ± 30.4	50.0 ± 12.6			
Sargent (2013)78	10	M	15.6 ± 0.5	Soccer	Pre-season	10	8.0 ± 0.7
18.0 ± 8.0	–		86.0 ± 5.0	64.0 ± 39.0	107.0 ± 25.0	26.0 ± 13.0	
216.0 ± 28.0	130.0 ± 19						
Sargent (2016)10	16	M	19.3 ± 1.5	Cycling	Pre-season	122	8.5 ± 0.4
18.3 ± 12.6	–		89.6 ± 4.7	41.0 ± 22.2	–	–	–
Suppiah (2015)90	4	M	–	BowlingNA	8	6.5 ± 0.3	–
–	4.4 ± 1.5		106.4 ± 16.5	191.0 ± 7.4b	93.1 ± 7.0		–
4	Badminton	Heavy training phase	8	6.7 ± 0.3	–	–	–
± 0.4 105.5 ± 19.5		157.6 ± 25.4b	139.3 ± 19.6				1.0
Suppiah (2016)50	6	M	14.7 ± 1.3	Shooting	NA	6	6.4 ± 0.1
–	–		2.2 ± 1.7	100.8 ± 38.1	43.7 ± 6.8b	29.0 ± 11.5	
8	M	Track and field	Heavy training phase	8	6.4 ± 0.1	–	–
3.0 ± 2.4		102.9 ± 34.6	48.1 ± 6.6b	24.1 ± 3.8			–
Fuller (2017)91 21	M	22.5 ± 2.7	ARF and rugby	Pre-season	67	7.6 ± 0.8	
16.0 ± 15.5	–	88.7 ± 4.9	41.0 ± 21.6	–	–	–	–
Dunican (2017)12	25	M	25.0 ± 4.0	Rugby	Heavy training phase	25	6.6
± 0.6 13.0 ± 11.0	–	89.0 ± 7.0	37.0 ± 30.0	–	–	–	–
Estivill-Domenech (2018)35	9	F	16.0 ± 0.8	Basketball	In season	9	
6.7 ± 2.0	19.0 ± 13.6	–	95.2 ± 25.7	–	–	–	–
Gerber (2018)30	25	M/F	17.2 ± 1.6	NR	NR	26	7.0 ± 0.7
17.0 ± 18.0	–	91.3 ± 7.2	–	94.0 ± 21.0	14.0 ± 8.0	214.0 ± 47.0	
95.0 ± 26.0							
Knufinke (2018)49	98	M/F	18.8 ± 3.0	Multi-sports	In season	206	–
–	–	–	119.0 ± 42.0	234.0 ± 50.0b	97.0 ± 31.0		

Romyn (2018) <sup>25</sup>	12	M	18.3 ± 1.0	Soccer	NR	12	8.1 ± 0.7	–
–	89.7 ± 7.2		22.9 ± 11.5				198.2 ± 38.1	
	147.6 ± 38.9							
12	8.2 ± 0.5c	–	–	90.7 ± 5.7	25.3 ± 19.1	93.3 ± 29.1	28.3 ± 16.5	
	209.2 ± 46.4			158.8 ± 39.5				
12	8.0 ± 0.9c	–	–	89.4 ± 10.6	34.5 ± 37.1	90.3 ± 42.7	29.5 ± 12.4	
	204.5 ± 42.4			158.5 ± 36.5				

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Note: When available, the exact number of participants per sex was extracted.

a N3 sleep stage as deep sleep.

b Combination of N1 and N2 sleep stages as light sleep.

c Included daytime naps in the results.

Abbreviations: ARF = Australian Rules Football; F = female; M= male; NR = not reported; REM = rapid eye movement; ROL = REM onset latency; SD = standard deviation; SE = sleep efficiency; SOL = sleep onset latency; TST = total sleep time; WASO = wake after sleep onset.

Table 3

Sleep-related data measured with actigraphy (mean ± SD).

First author (publication year)	n	Sex	Age (year)	Type of sport	Training season			
Nights recorded	TST (h)	SOL (min)	SE (%)	WASO (min)				
Wall (2003) <sup>53</sup>	3/1	M/F	–	Swimming	Heavy training phase	8	–	–
	81.6 ± 4.4	–						
4	F	Heavy training phase	8	–	–	94.6 ± 4.8	–	
Richmond (2004) <sup>77</sup>	10	M	23.0 ± 2.0	ARF	In season	50	8.4 ± 0.1	
–	88.0 ± 3.8		57.0 ± 18.0					
Richmond (2007) <sup>92</sup>	19	M	24.1 ± 3.3	ARF	In season	76	8.9 ± 0.1	
–	93.1 ± 1.0	–						
Fietze (2009) <sup>93</sup>	9/15	M/F	27.0 ± 5.0	Dance	NR	168	7.0 ± 0.1	18.1 ± 9.5
	81.1 ± 4.4		72.1 ± 27.7					
168	6.5 ± 0.1		15.4 ± 7.0	78.6 ± 4.7	74.2 ± 27.0			

Leeder (2012)	9 11	M/F	–	Canoeing	Competition phase	44	8.5 ± 0.1
	19.1 ± 20.2		81.8 ± 4.3	66.0 ± 17.0			
14	Diving	56	8.8 ± 0.1	21.0 ± 19.0	80.9 ± 5.3	77.0 ± 19.0	
10	Rowing	40	7.8 ± 0.1	10.2 ± 6.6	82.5 ± 8.3	68.0 ± 32.0	
11	Short-track speed skating			44	9.2 ± 0.2	21.1 ± 15.1	77.2 ± 7.1
	98.0 ± 46.0						
Sargent (2014)	40	6/1	M/F	22.5 ± 1.7	Swimming	Heavy training phase	84
	5.4 ± 1.3		40.8 ± 43.2	70.7 ± 15.1	17.6 ± 8.8		
14	7.1 ± 1.2		31.8 ± 21.6	77.2 ± 7.5	16.2 ± 7.7		
Hoshikawa (2013)	80	7	F	19.6 ± 0.8	Distance running	Heavy training	
phase	49		8.2 ± 1.1	6.1 ± 8.6	93.6 ± 5.6	24.9 ± 20.4	
Lahart (2013)	273	M	37.5 ± 4.1	Cycling	Competition phase	3	7.2 ± 0.3
	19.0 ± 12.0		84.0 ± 2.0	–			
Ultra-endurance	competition phase			16	2.2 ± 0.3	24.0 ± 4.0	83.0 ± 6.0
							–
Roach (2013)	81 14	MM	15.6 ± 0.5	Soccer (U17)	Pre-season	84	7.0 ± 0.5
	–		80.0 ± 3.0	–			
12	17.4 ± 1.2		Soccer (U20)	72	6.4 ± 1.0	–	80.0 ± 6.0
							–
Robey (2013)	94 12		18.5 ± 1.4	Soccer	In season	72	7.2 ± 0.1
	89.4 ± 5.8		15.2 ± 10.9				20.6 ± 10.9
Fowler (2014)	95	6	M	23.4 ± NR	ARF	In season	6
	10.8 ± NR		82.3 ± NR	–			7.1 ± NR
6	8.6 ± NR		25.3 ± NR	83.3 ± NR	–		
6	6.1 ± NR		17.0 ± NR	83.7 ± NR	–		
6	6.7 ± NR		11.5 ± NR	83.6 ± NR	–		
6	8.2 ± NR		23.2 ± NR	84.8 ± NR	–		
Hausswirth (2014)	44	9	M	37.0 ± 6.0	Triathlon	Tapering	63
	± 0.1		9.0 ± 9.0	88.3 ± 6.3	–		6.5
63	6.7 ± 0.8		7.0 ± 7.0	89.0 ± 6.5	–		
63	6.8 ± 0.7		7.0 ± 7.0	88.4 ± 5.5	–		
9	M		35.0 ± 8.0	Tapering	63	7.4 ± 0.1	4.0 ± 4.0
	–						91.0 ± 1.9
Heavy training phase		63	7.2 ± 0.7	4.0 ± 4.0	90.0 ± 1.9	–	
Tapering		63	7.1 ± 0.5	6.0 ± 5.0	89.3 ± 2.8	–	
9	M		35.0 ± 5.0	Tapering	63	7.2 ± 0.1	4.0 ± 1.0
	–						90.0 ± 1.3

Heavy training phase	63		6.6 ± 0.9	5.0 ± 2.0	88.4 ± 1.7	–		
Tapering	63		7.1 ± 0.8	4.0 ± 2.0	89.4 ± 3.2	–		
Lastella (2015)36	57/9	M/F	21.8 ± 3.4	Multi-sports (individual)	Competition phase			
754	6.5 ± 1.1		22.0 ± 26.6	85.9 ± 6.1	–			
104/20 M/F	22.2 ± 3.0		Multi-sports (team)	613	7.0 ± 1.2	16.3 ± 20.1		
	86.4 ± 4.8	–						
Lastella (2015)96	21	M	19.9 ± 1.7	Cycling	Competition phase	126	7.4	
± 0.6	28.0 ± 13.7		86.4 ± 0.4	–				
21	7.3 ± 0.8		17.7 ± 1.7	86.9 ± 5.6	–			
21	6.9 ± 0.9		36.4 ± 2.7	85.3 ± 5.0	–			
21	6.5 ± 0.9		36.4 ± 2.9	84.9 ± 5.0	–			
21	6.7 ± 0.8		38.1 ± 4.6	85.8 ± 6.0	–			
21	6.9 ± 0.8		29.2 ± 2.3	81.7 ± 7.5	–			
Lastella (2014)97	16	M	18.8 ± 0.9	Football	Pre-season	16	6.3	
± 1.7	–		81.2 ± 6.7	–				
16	7.0 ± 1.4	–	83.1 ± 7.0	–				
16	6.2 ± 1.4	–	83.3 ± 6.7	–				
Fowler (2015)98	16	M	27.0 ± NR	ARF	Pre-season	16	7.1 ± 0.5	
–	–	–						
16	4.9 ± 0.6	–	–	–				
Killer (2017)52	10	M	25.0 ± 6.0	Cycling	NR	80	6.6 ± 0.2	–
	80.9 ± NR	–						
Lastella (2015)28	21	M	22.2 ± 2.7	Cycling	Tapering	124	7.4 ± 0.8	
–	86.6 ± 4.8	–						
142	7.2 ± 0.9	–	84.4 ± 5.3	–				
141	7.0 ± 0.9	–	84.9 ± 5.4	–				
Ultra-endurance competition phase	144		7.1 ± 1.0	–	85.1 ± 5.9	–		
Tapering	209		7.1 ± 0.9	–	85.7 ± 5.4	–		
Romyn (2015)99	8	F	19.6 ± 1.5	Netball	In season	56	8.2 ± 0.5	
	28.2 ± 26.2		85.2 ± 3.5	35.4 ± 7.6				
Sargent (2014)41	46/24	M/F	20.3 ± 2.9	Multi-sports	Heavy training phase	157		
	6.8 ± 0.1	–	85.3 ± 7.6	–				
769	6.5 ± 0.1	–	85.6 ± 7.1	–				

Sargent (2016)	10	16	M	19.3 ± 1.5	Cycling	Pre-season	128	7.6 ± 0.6	
	17.0 ± 14.0	85.0 ± 5.0		80.0 ± 28.8					
Schaal (2015)	100	10	F	20.4 ± 0.4	Synchronized swimmers			Heavy	
training phase	70	7.2 ± 0.2		17.0 ± 2.0	84.7 ± 1.3	–			
	70	6.9 ± 0.2		28.0 ± 6.0	82.7 ± 1.6	–			
Shearer (2015)	101	28	M	24.4 ± 2.9	Rugby	In season	112	7.1 ± 1.0	
	34.0 ± 40.0	79.0 ± 9.0		–					
	112	7.6 ± 1.2		28.0 ± 25.0	78.3 ± 11.3	–			
	112	6.0 ± 1.5		38.0 ± 34.0	74.7 ± 11.1	–			
Suppiah (2015)	90	6	M	14.8 ± 0.9	Bowling	NA	30	6.0 ± 0.1	6.7
	± 10.8	–		38.7 ± 18.1					
	5	Badminton		Heavy training phase	25	6.2 ± 0.1	3.4 ± 1.2	–	
		36.0 ± 15.1							
van Maanen (2015)	29	9/1	M/F	42.9 ± 8.0	Roparum (8 runners and 2 cyclists)				
		Ultra-endurance competition phase		20	7.7 ± 2.0	–	–	–	
Eagles (2014)	102	10	M	24.3 ± 2.6	Rugby	In season	120	7.7 ± 0.1	
	–	87.0 ± 2.0	–						
Fullagar (2016)	20	14	M	–	Soccer	Pre-season	14	6.9 ± 1.1	
		12.6 ± 11.6		89.2 ± 4.0	29.6 ± 17.0				
	14	6.2 ± 0.7		21.1 ± 16.9	84.6 ± 9.0	38.9 ± 27.5			
	14	7.0 ± 1.1		9.8 ± 15.3	91.2 ± 4.1	25.2 ± 14.7			
Louis (2016)	103	10	M	31.0 ± 4.7	Triathlon	Heavy training phase	210	6.5	
	± 0.1	10.0 ± 7.0		82.5 ± 6.8	–				
Pitchford (2017)	104	19	M	22.1 ± 3.5	ARF	Pre-season	152	7.0 ± 0.1	
	–	84.7 ± 6.5		68.9 ± 29.9					
	152	7.0 ± 0.1	–	78.7 ± 6.5	96.5 ± 33.7				
Sargent (2016)	73	22	M	22.1 ± 2.7	ARF	Pre-season	308	8.1 ± 0.8	
		17.9 ± 11.1		82.2 ± 3.8	–				
	308	7.7 ± 0.8		10.9 ± 13.3	83.5 ± 6.1	–			
Suppiah (2016)	50	29	M	14.7 ± 1.3	15 Shooting/14 track and field	NA	145		
		5.5 ± 0.1	–	80.9 ± 8.6	74.7 ± 22.6				
	58	6.8 ± 0.1	–	80.9 ± 6.9	86.7 ± 40.8				
Thornton (2017)	42	31	M	24.5 ± 3.9	Rugby	Pre-season	217	7.3 ± 0.1	
		21.0 ± 19.0		88.1 ± 4.2	42.2 ± 17.5				
	403	5.9 ± 0.1		9.0 ± 7.0	79.6 ± 8.3	81.6 ± 39.9			

Van Ryswyk (2017)	105	25	M	23.7 ± 2.0	ARF	Pre-season	100	7.1 ± 0.9	
–		82.3 ± 6.5	–						
Vitale (2017)	82	12	M	21.1 ± 2.3	Soccer (M-Type)	NR	12	–	
		10.6 ± 11.1	88.1 ± 5.7	–					
12	–	19.0 ± 17.8	78.3 ± 7.4	–					
12	–	11.9 ± 13.3	84.1 ± 7.7	–					
11	M	22.9 ± 2.9	Soccer (E-Type)	11	–	5.6 ± 2.4	87.2 ± 4.9	–	
11	–	13.4 ± 15.9	85.8 ± 5.5	–					
11	–	16.3 ± 16.2	83.3 ± 7.8	–					
Caia (2017)	43	7	M	24.3 ± 2.1	Rugby	Pre-season	49	6.9 ± 0.4	
		20.1 ± 14.0	87.3 ± 3.0	–					
In season		49	6.9 ± 0.4	17.0 ± 7.5	85.9 ± 1.8	–			
Caia (2017)	39	15	M	25.5 ± 3.7	Rugby	In season	49	7.5 ± 0.1	
		16.0 ± 18.0	87.8 ± 3.8	–					
15	22.4 ± 2.4	49	6.8 ± 0.1	20.0 ± 18.0	84.5 ± 5.8	–			
15	18.8 ± 0.9	49	7.3 ± 0.1	24.0 ± 27.0	85.7 ± 6.6	–			
Caia (2018)	5	63	M	–	Rugby	Pre-season	264	6.9 ± 0.1	–
–									
Choi (2018)	33	6	M/F	8.2 ± 0.5	Badminton	Heavy training phase	42	6.9	
± 0.2	13.0 ± 1.0	80.0 ± 2.9	77.0 ± 9.0						
7	M/F	7.9 ± 0.4	49	6.0 ± 0.1	18.0 ± 1.0	67.0 ± 2.0	142.0 ± 8.0		
Driller (2017)	38	8/11	M/F	20.0 ± 2.0	Multi-sports	Pre-season	133	7.6 ± 0.8	
–		92.3 ± 1.4	42.0 ± 29.0						
Duncan (2017)	6	9	M	17.2 ± 5.1	Judo	Pre-season	18	6.7 ± 0.8	
		29.5 ± 27.2	84.0 ± 9.3	7.5 ± 5.0					
1/8	M/F	18.9 ± 2.9	18	7.3 ± 0.8	46.0 ± 44.6	85.5 ± 5.6	6.5 ± 5.0		
Juliff (2018)	106	12	F	19.2 ± 0.9	Netball	In season	12	–	14.5 ± 15.1
–	–								
12	–	24.4 ± 27.4	–	–					
Juliff (2018)	48	42	F	19.2 ± 1.0	Netball	In season	504	7.3 ± 1.0	7.6
± 3.8	88.3 ± 3.5	–							
252	8.0 ± 0.6	12.1 ± 6.2	89.3 ± 2.9	–					
504	7.3 ± 0.9	5.9 ± 5.5	87.3 ± 4.3	–					
252	7.0 ± 0.5	9.3 ± 9.0	88.0 ± 5.7	–					

Miller (2017)	107	16	M	27.3 ± 3.4	ARF	NR	112	6.8 ± 1.2	
		18.0 ± 22.0	85.5 ± 5.7	70.0 ± NR					
7		M	Soccer	49	6.7 ± 2.0		10.0 ± 15.0	85.5 ± 5.7	56.0 ± NR
28		M	Rugby union	196	7.2 ± 1.6		9.0 ± 11.0	88.5 ± 4.2	57.0 ± NR
O'Donnell (2017)	108	26	F	23.0 ± 6.0	Netball	Pre-season	182	7.3 ± 0.1	
		28.6 ± 15.6	80.6 ± 6.5	–					
Staunton (2017)	109	17	F	–	Basketball	In season	323	7.5 ± 1.5	
		–	92.0 ± 3.0	–					
323		7.7 ± 1.7	–	91.0 ± 4.0	–				
323		7.4 ± 1.8	–	92.0 ± 4.0	–				
323		8.3 ± 1.6	–	93.0 ± 4.0	–				
Whitworth-Turner (2017)	110	11	M	18.0 ± 1.0	Soccer	In season	54	8.1	
		± 1.1	24.0 ± 15.0	94.0 ± 3.0	6.0 ± 9.0				
Blanchfield (2018)	65	11	M	35.0 ± 12.0	Running	Heavy training phase	44		
		7.0 ± 0.7	–	–	–				
44		6.7 ± 1.0	–	–	–				
11		6.9 ± 0.6	18.0 ± 15.0	93.0 ± 4.0	–				
11		7.0 ± 1.1	22.0 ± 22.0	92.0 ± 6.0	–				
Caia (2018)	62	24	M	25.4 ± 3.3	Rugby	In season	288	7.3 ± 0.8	9.3
		± 9.0	89.6 ± 2.9	–					
288		7.8 ± 0.3	11.1 ± 11.3	87.7 ± 3.9	–				
Carrico (2018)	111	25	M	26.3 ± 4.7	Soccer	In season	95	6.6 ± 0.1	
		24.0 ± 9.0	85.0 ± 5.0	30.0 ± 16.0					
75		5.6 ± 0.1	35.0 ± 28.0	78.0 ± 7.0	29.0 ± 13.0				
Costa (2019)	112	16	F	20.4 ± 2.1	Soccer	In season	368	7.3 ± 0.8	
		6.0 ± 4.0	88.0 ± 5.0	56.0 ± 30.0					
368		7.9 ± 0.7	4.0 ± 4.0	89.0 ± 4.0	55.0 ± 24.0				
Costa (2019)	113	17	F	21.6 ± 2.3	Soccer	In season	306	7.2 ± 0.5	
		8.0 ± 2.0	90.0 ± 4.0	37.0 ± 12.0					
51		9.0 ± 0.9	9.0 ± 2.0	89.0 ± 3.0	40.0 ± 10.0				
306		8.6 ± 0.6	4.0 ± 2.0	91.0 ± 3.0	44.0 ± 14.0				
Dunican (2019)	114	20	M	26.0 ± 3.0	Rugby	In season	20	6.4 ± 0.9	
		55.4 ± 4.4	78.7 ± 9.8	10.1 ± 8.0					
20		7.3 ± 1.3	44.8 ± 4.6	78.2 ± 10.3	10.9 ± 5.1				

20	7.8 ± 1.6	27.1 ± 4.8	83.0 ± 9.8	10.3 ± 7.7				
20	4.4 ± 2.7	28.1 ± 4.6	62.3 ± 30.0	9.2 ± 7.9				
20	6.7 ± 1.3	45.1 ± 4.8	80.8 ± 9.8	19.2 ± 23.7				
20	6.5 ± 1.1	31.2 ± 4.8	80.3 ± 12.5	10.7 ± 11.6				
20	7.3 ± 1.2	–	83.3 ± 7.5	10.6 ± 8.7				
Knufinke (2018)49	42/56	M/F	18.8 ± 3.0	Multi-sports	In season	282	7.5	
± 1.1	14.0 ± 17.0		88.7 ± 5.6					
Lalor (2018)115	45	M	22.1 ± 3.3	ARF	Pre-season	450	9.2 ± 0.1	
	12.0 ± 0.9		81.4 ± 0.4					
In season	450		8.1 ± 0.1	11.0 ± 1.3	85.6 ± 0.5	57.0 ± 2.3		
Nedelec (2019)116	20	M	26.0 ± 4.6	Soccer	In season	73	6.4 ± 0.9	
	38.0 ± 35.0		79.1 ± 10.5					
O'Donnell (2018)117	10	F	23.0 ± 6.0	Netball	In season	10	8.8 ± 0.1	
	27.5 ± 34.7		85.3 ± 7.2					
10	8.0 ± 0.1		38.5 ± 29.3	82.1 ± 8.9	–			
10	6.1 ± 0.1		67.0 ± 51.9	74.4 ± 10.1	–			
O'Donnell (2018)118	11	F	23.0 ± 4.0	Netball	In season	11	8.5 ± 1.0	
	23.4 ± 14.7		82.4 ± 6.4					
11	6.8 ± 0.8		21.7 ± 25.6	79.4 ± 6.1	–			
11	7.4 ± 0.3		33.1 ± 16.3	84.1 ± 6.7	–			
Rosa (2018)59	11/11	M/F	24.8 ± 3.4	Swimming	Pre-season	44	7.6 ± 0.6	
	21.0 ± 6.0		84.7 ± 0.7	49.0 ± 5.0				
Thornton (2018)119	14	M	26.1 ± 2.9	Rugby	Pre-season	585	6.9 ± 1.2	
	–		92.3 ± 3.0	35.0 ± 15.6				
Vitale (2019)17	12/12	M/F	26.0 ± 3.4	Volleyball	In season	24	–	9.0
± 5.1	81.1 ± 4.3		12.2 ± 2.7					
24	–		12.3 ± 4.4	80.7 ± 7.9	16.4 ± 3.6			
24	–		6.8 ± 3.1	86.7 ± 4.1	11.1 ± 2.9			
Lastella (2019)120	7	M	25.2 ± 3.2	Soccer	In season	63	7.0 ± 1.6	
	8.5 ± 11.1		87.5 ± 4.0					
Ramos-Campo (2019)121	14	M	27.6 ± 7.4	Distance running			Heavy	
training phase	14		6.8 ± 1.9	–	93.5 ± 4.0	–		
14	6.8 ± 1.1	–	88.2 ± 3.5	–				
14	6.2 ± 1.5	–	91.2 ± 5.2	–				



14	6.1 ± 1.2	–	84.3 ± 5.6	–				
Sekiguchi (2019)	58	10	F	19.0 ± 1.0	Running	Competition phase	70	
	6.7 ± 0.2	–	88.0 ± 0.0	–				
70	6.6 ± 0.2	–	89.0 ± 0.0	–				
70	7.0 ± 0.1	–	89.0 ± 0.0	–				
70	6.8 ± 0.3	–	88.0 ± 0.0	–				
70	7.2 ± 0.4	–	90.0 ± 0.0	–				
70	6.9 ± 0.1	–	90.0 ± 0.0	–				
70	6.9 ± 0.2	–	89.0 ± 0.0	–				
70	6.8 ± 0.4	–	88.0 ± 0.0	–				
70	6.7 ± 0.4	–	89.0 ± 0.0	–				
70	6.9 ± 3.0	–	89.0 ± 0.0	–				
70	7.1 ± 0.2	–	92.0 ± 0.0	–				
70	7.0 ± 0.3	–	87.0 ± 0.0	–				
Suppiah (2018)	64	12	M	13.8 ± 1.0	Shooting	NR	12	5.4 ± 0.6
	–	82.0 ± 9.2	70.6 ± 41.6					
12	5.6 ± 0.2	–	84.4 ± 7.6	60.5 ± 34.0				
19	M	14.8 ± 1.0	Track and field	Heavy training phase	19	5.4 ± 1.0	–	
	79.0 ± 8.0	80.3 ± 34.3						
19	5.5 ± 1.0	–	80.6 ± 9.3	78.4 ± 41.4				
Walsh (2019)	122	9/3	M/F	21.0 ± 2.0	Swimming	Heavy training phase	168	
	7.7 ± 0.7	19.0 ± 12.0	85.0 ± 5.0	–				
Tapering	168	7.9 ± 0.6	19.0 ± 6.0	85.0 ± 5.0	–			
46	8.9 ± 0.8	17.0 ± 9.0	82.0 ± 5.0	–				
Competition	67	7.9 ± 0.7	27.0 ± 11.0	82.0 ± 3.0	–			

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Note: When available, the exact number of participants per sex was extracted.

Abbreviations: ARF = Australian Rules Football; F = female; M = male; NA = non-applicable; NR = not reported; SD = standard deviation; SE = sleep efficiency; SOL = sleep onset latency; TST = total sleep time; WASO = wake after sleep onset.

Table 4

Overall sleep data calculations (mean  $\pm$  SD).

Categorization	Subgroup	Group/phase/sports				TST (h)	SOL (min)	SE (%)	WASO (min)
	ROL (min)	REM (min)	N1 (min)	N2 (min)	N3 (min)				
According to monitoring tool	Overall	7.2 $\pm$ 1.1	14.8 $\pm$ 17.0	86.3 $\pm$ 6.8	52.7 $\pm$ 32.0				
	81.1 $\pm$ 31.2	114.1 $\pm$ 35.4	47.9 $\pm$ 31.0	240.5 $\pm$ 53.6	91.5 $\pm$ 35.8				
Polysomnography/electroencephalography		7.6 $\pm$ 1.1	17.5 $\pm$ 17.6	90.2 $\pm$ 6.8					
	30.3 $\pm$ 25.3	–	–	–	–				
Actigraphy	7.2 $\pm$ 1.1	14.7 $\pm$ 16.9	86.3 $\pm$ 6.8	54.0 $\pm$ 31.9	–	NA	NA		
NA	NA								
According to sex	Male	7.2 $\pm$ 1.1	15.7 $\pm$ 17.0	85.2 $\pm$ 7.2	54.8 $\pm$ 32.9				
	84.9 $\pm$ 32.3	111.3 $\pm$ 26.0	55.8 $\pm$ 29.0	246.7 $\pm$ 53.3	82.9 $\pm$ 42.0				
Female	7.5 $\pm$ 1.2	9.7 $\pm$ 11.2	89.1 $\pm$ 4.8	46.6 $\pm$ 23.3	66.1 $\pm$ 23.5a	–	–		
NA	NA								
According to sex and monitoring tool	Polysomnography/electroencephalography	Male	7.7						
$\pm$ 1.1	17.7 $\pm$ 18.2	89.8 $\pm$ 5.5	32.3 $\pm$ 25.5	84.9 $\pm$ 32.3	111.3 $\pm$ 26.0	55.8 $\pm$ 29.0			
	246.7 $\pm$ 53.3	82.9 $\pm$ 42.0							
Female	7.4 $\pm$ 1.3	18.0 $\pm$ 8.8	95.2 $\pm$ 25.7a	7.5 a $\pm$ 9.1	66.1 $\pm$ 23.5a	–	–		
–	–								
Actigraphy	Male	7.2 $\pm$ 1.1	15.5 $\pm$ 16.9	85.1 $\pm$ 7.2	57.0 $\pm$ 32.7	–	NA		
NA	NA	NA							
Female	7.5 $\pm$ 1.2	9.6 $\pm$ 11.2	89.1 $\pm$ 4.7	47.1 $\pm$ 23.0	–	NA	NA	NA	
NA									
According to athletic expertise	Elite	7.2 $\pm$ 1.2	18.4 $\pm$ 19.4	85.9 $\pm$ 7.0	53.2 $\pm$ 32.2				
–	116.2 $\pm$ 40.9	14.0 $\pm$ 8.0a	214.0 $\pm$ 47.0a	96.8 $\pm$ 30.4					
Semi-elite	7.3 $\pm$ 1.0	9.5 $\pm$ 10.5	87.4 $\pm$ 6.1	52.1 $\pm$ 31.8	81.1 $\pm$ 31.2				
	111.3 $\pm$ 26.0	55.8 $\pm$ 29.0	246.7 $\pm$ 53.3	82.9 $\pm$ 42.0					
According to sex and athletic expertise	Elite	Male	7.3 $\pm$ 1.2	17.1 $\pm$ 17.7	84.9 $\pm$ 7.2				
	56.0 $\pm$ 31.7	–	–	–	–				
Female	7.4 $\pm$ 1.4	27.2 $\pm$ 18.1	89.5 $\pm$ 5.3	–	–	–	–	–	–
Semi-elite	Male	7.0 $\pm$ 1.0	11.4 $\pm$ 13.5	86.8 $\pm$ 6.8	50.1 $\pm$ 37.0	84.9 $\pm$ 32.3			
	111.3 $\pm$ 26.0	55.8 $\pm$ 29.0	246.7 $\pm$ 53.3	82.9 $\pm$ 42.0					
Female	7.6 $\pm$ 0.9	7.4 $\pm$ 7.4	88.7 $\pm$ 4.3	46.6 $\pm$ 23.3	66.1 $\pm$ 23.5a	–	–		
–	–								
According to age group	Children and adolescents (6–17 years)	6.3 $\pm$ 0.8	14.5 $\pm$ 13.2						
	80.3 $\pm$ 8.8	74.0 $\pm$ 40.8	–	98.8 $\pm$ 26.2	17.3 $\pm$ 10.9	214.6 $\pm$ 42.2			
	82.7 $\pm$ 43.3								

Young adults (18–24 years)	7.3 ± 1.1	15.1 ± 17.5	85.9 ± 6.4	53.7 ± 30.2		
	80.9 ± 32.0	116.8 ± 37.1	59.5 ± 29.1	254.0 ± 56.2	93.5 ± 33.9	
Middle-aged adults (25–40 years)	6.9 ± 1.0	13.8 ± 15.5	86.9 ± 7.2	40.4 ± 28.0		
	82.7 ± 26.5a	–	–	–	–	
According to age group and athletic expertise						
Children and adolescents (6–17 years)	Elite	6.4 ± 1.0	17.5 ± 16.8	82.0 ± 8.7	74.0 ± 37.8a	–
			214.0 ± 47.0a	95.0 ± 26.0a	–	94.0 ± 21.0a
						14.0 ± 8.0a
Semi-elite	6.1 ± 0.7	13.9 ± 12.3	79.0 ± 8.7	74.0 ± 41.3	–	104.1 ± 30.5
	26.0 ± 13.0a	216.0 ± 28.0a	69.5 ± 54.0			
Young adults (18–24 years)	Elite	7.2 ± 1.1	18.9 ± 19.6	84.7 ± 6.6	60.6 ± 31.2	
	–	119.0 ± 42.0a	–	–	97.0 ± 31.0a	
Semi-elite	7.6 ± 0.9	9.1 ± 10.9	88.7 ± 4.7	45.5 ± 26.7	80.9 ± 32.0	
	112.9 ± 26.1	59.5 ± 29.1	254.0 ± 56.2	85.1 ± 38.9		
Middle-aged adults (25–40 years)	Elite	7.0 ± 1.2	16.6 ± 18.6	87.6 ± 7.4		
	29.2 ± 17.5	–	–	–	–	
Semi-elite	6.8 ± 0.6	10.0 ± 8.7	85.5 ± 6.6	73.2 ± 27.3a	82.7 ± 26.4a	–
	–	–	–			
According to sports season						
Heavy training phase	6.7 ± 0.8	16.0 ± 17.9	84.5 ± 8.4			
	50.3 ± 46.4	88.7 ± 24.7	105.6 ± 25.4	57.7 ± 20.2	216.2 ± 32.9	74.6 ± 41.5
In-season/ Competition phase	7.4 ± 1.2	14.8 ± 18.3	87.5 ± 6.2	43.9 ± 25.4		
	81.6 ± 26.8	118.5 ± 39.7	–	–	97.0 ± 31.0	
Pre-season/tapering	7.3 ± 1.1	14.6 ± 13.3	85.3 ± 6.7	59.4 ± 33.2	60.7 ± 8.9a	
	107.0 ± 25.0a	26.0 ± 13.0a	216.0 ± 28.0a	130.0 ± 19.0a		
According to sport type						
Purely aerobic	7.2 ± 1.0	16.5 ± 15.6	86.4 ± 6.2	48.9 ± 36.6		
	82.3 ± 31.8	111.8 ± 24.5	62.8 ± 24.5	248.5 ± 55.3	78.2 ± 30.6	
Power/explosiveness	8.7 ± 0.9	24.2 ± 31.3	80.9 ± 5.3a	77.0 ± 19.0a	91.0 ± 44.7a	
	103.0 ± 34.1a	17.0 ± 40.5a	271.0 ± 55.1a	61.0 ± 33.0		
Mixed sports	7.4 ± 1.2	13.3 ± 15.5	86.6 ± 7.0	52.6 ± 30.8	–	107.9 ± 19.6
	27.3 ± 12.6	206.3 ± 34.3	139.5 ± 28.9			
Individual sports	7.0 ± 1.1	18.1 ± 20.4	86.1 ± 6.5	53.8 ± 38.2	84.0 ± 34.5	
	109.3 ± 27.5	65.8 ± 31.2	256.7 ± 55.8	66.9 ± 34.0		
Team sports	7.4 ± 1.2	13.5 ± 16.0	86.7 ± 6.8	51.6 ± 29.6	–	108.7 ± 20.1
	27.3 ± 12.6	206.3 ± 34.3	139.6 ± 32.1			

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Note: “–” denotes that there were no available data.

a Data were available only from 1 study.

Abbreviations: NA = not applicable; REM = rapid eye movement; ROL = REM onset latency; SE = sleep efficiency; SOL = sleep onset latency; TST = total sleep time; WASO = wake after sleep onset.

### 3.6. Sleep quantity and quality according to sex

Discriminating datasets for sex showed that male athletes slept a total of  $7.2 \pm 1.1$  h with  $15.7 \pm 17.0$  min SOL, and female athletes slept  $7.5 \pm 1.2$  h, with  $9.7 \pm 11.2$  min SOL. SE was  $85.2\% \pm 7.2\%$  and  $89.1\% \pm 4.8\%$  for males and females, respectively. Sleep architecture data were available for male athletes only, as none of the included studies reported sleep architecture specific to female participants. Therefore, available data show that male athletes' sleep stages comprised REM:  $111.3 \pm 26.0$  min, N1:  $55.8 \pm 29.0$  min, N2:  $246.7 \pm 53.3$  min, and N3:  $82.9 \pm 42.0$  min (Table 4).

### 3.7. Sleep quantity and quality according to athletic expertise

Classification based on athletes' level showed no differences in TST between elite and semi-elite participants. SOL was lower in semi-elite athletes than in elite athletes ( $9.5 \pm 10.5$  min vs.  $18.4 \pm 19.4$  min). SE was 1.5% less in elite athletes compared with semi-elite athletes. It was found that elite athletes' sleep was composed of less N1 and N2 sleep stages and more of N3 and REM sleep stages compared with semi-elite athletes' sleep. In comparing SE between male and female elite athletes, it was found that SE was 4.6% less in males than in females. Sleep architecture data for elite athletes were very limited in the literature (N1 and N2 are presented as data from one study).<sup>30</sup> To the best of our knowledge, there were no discrete data according to sleep stages for male or female elite athletes and for semi-elite female athletes (Table 4).

### 3.8. Sleep quantity and quality according to age

As shown in Table 4, TST varied significantly throughout age groups. Children and adolescent athletes slept on average 60 min less than the young adults group, and 36 min less than middle-aged adults. No significant difference in SOL was found among age groups. SE was 5.6% and 6.6% less in children and adolescents, compared to young and middle-aged adults, respectively. The same trend was present for WASO. According to sleep architecture, data were lacking for middle-aged adults. REM sleep stage was 15% less in children/adolescents than in young adults, whilst there were no available data for middle-aged adults. Athletic expertise classification between age groups showed that SOL was longer in each elite age group, as compared to the semi-elite corresponding group.

### 3.9. Sleep quantity and quality in relation to training season

For both sleep quality and sleep quantity, moderate fluctuations were present among training seasons. TST was less during heavy training phases than in pre-season/tapering phases or competition phases (6.7 h vs. 7.3 h vs. 7.4 h, respectively). SE was found to be less during heavy training phases and greater during in-season/competition phases (84.5% vs. 87.5%). According to sleep architecture, even if data are elusive, N3 sleep during the pre-season/tapering phase was reported to be longer than during the in-season/competition and heavy training phases (130.0 min vs. 97.0 min vs. 74.6 min, respectively) (Table 4).

### 3.10. Sleep quantity and quality in relation to sports type

The majority of the included articles studied participants in purely aerobic or mixed sports, whereas only 2 studies<sup>9,31</sup> included participants in sports that require mostly power/explosiveness. According to this categorization, SOL was longer in power/explosiveness sports compared to other sports, with a large SD ( $24.2 \pm 31.3$  min). According to sleep architecture, athletes in anaerobic sports had slightly less REM sleep compared with athletes in aerobic or mixed sports (103.0 min vs. 111.8 min vs. 107.9 min, respectively). N3 “deep sleep” was longer in athletes in mixed sports than in athletes in aerobic sports, and over 2-fold longer than athletes in power/explosiveness sports (139.5 min vs. 78.2 min vs. 61.0 min, respectively). Comparing individual and team sports, no great differences were present, except for N3 sleep, which was longer in athletes participating in team sports than for athletes participating in individual sports (Table 4).

### 3.11. Sleep during ultra-endurance competitions

The majority of the studies used actigraphic devices to evaluate sleep after ultra-endurance competitions. During multi-day ultra-endurance competitions, mean TST ranged from  $7.0 \pm 0.9$  h to  $7.7 \pm 2.0$  h, with SE ranging from  $83.0 \pm 6.0$  h to  $85.1\% \pm 5.9\%$ . In case of extreme ultra-endurance team-sport races such as roparun, athletes obtained a mean of  $2.2 \pm 0.3$  h of TST with  $83.0\% \pm 6.0\%$  SE. According to sleep architecture, no longitudinal EEG data were available for multi-day ultra-endurance events. Nevertheless, it was shown that immediately after an ultra-triathlon race, REM sleep decreased, wakefulness increased, and slow wave sleep, corresponding to N3 sleep stage, was not different compared to a no-exercise scenario.

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## 4. Discussion

The current review aimed to summarize objectively measured sleep data from a wide range of athletic populations in order to (1) develop an integrative perspective of athletes' sleep, (2) identify potential sleep issues or related risk factors, and (3) reveal possible gaps in current knowledge. Since norms and recommendations for athletes' sleep have not been established yet, this review points toward a general depiction of athletes' sleep. The current review reveals that sleep quantity of athletes is reduced and potentially insufficient according to the general consensus of the AASM for non-athlete healthy adults.<sup>32</sup> Thus, overall sleep quality appears inadequate, which highlights the need for sleep-optimizing interventions, especially for children and adolescent athletes, for which specific guidelines are not available. Furthermore, periods of heavy training load were identified as being more sensitive to potential alterations in sleep quality, while sleep architecture may be modified during pre-season.

### 4.1. Sleep quantity

Evidence suggests that sleep duration in athletes is limited to 7.2 h/night, across all investigated categories. All studies reported TST mean values shorter than 8 h/night, which is considered to be at the lowest values of the cut-off point of 7 h according to the guidelines of AASM for healthy

adults.<sup>32</sup> Notably, the shortest mean TST was 6.3 h, which was reported in children and adolescents,<sup>33</sup> in contrast with the current AASM guidelines for the pediatric population, which suggest 8–12 h/night.<sup>21</sup> In early adulthood, average sleep duration was marginally within the suggested >7 h of sleep per night.<sup>32</sup> In contrast, in middle-aged athletes, TST was below this recommended cut-off. However, these suggested limits for a healthy population may underestimate sleep needs in athletes, since the recovery demand in sports is increased.<sup>34</sup> This fact is supported by studies that found improvements in sports performance when sleep was extended up to approximately 2 h.<sup>3,4</sup>

The prevalence of insufficient sleep duration in elite athletes is well documented in the literature.<sup>35</sup> In most cases athletes appear to obtain less than 8 h of sleep per night.<sup>36</sup> This issue is also highlighted in young athletes.<sup>33,37</sup> Student-athletes were found to sleep less than their non-athletic counterpart population.<sup>38</sup> Similarly, adolescent athletes had less sleep than senior athletes.<sup>39</sup> However, these studies included mainly athletes of Asian origin; hence, these results could have been influenced by the habits of this specific ethnic group.

Several factors, such as training or competition, have been shown to consistently correlate with athletes' sleep quantity.<sup>14</sup> An athlete's training schedule impairs sleep duration because it reduces the time available for sleep.<sup>40,41</sup> For young athletes, their daily schedule, including school attendance, may be a key factor in reducing sleep quantity. Furthermore, reduced sleep duration is often observed during training camps,<sup>42,43</sup> where not only training schedules, but also training volume and intensity are increased. It has been previously shown that sleep duration is impaired in endurance athletes who experienced overreaching due to high training volume<sup>28,44</sup> and that high-intensity training requires sufficient sleep time since recovery demands are elevated.<sup>45</sup> For example, during multiple-day ultra-endurance competitions, such as roparun (a non-stop relay run between Rotterdam and Paris), athletes sleep is considerably reduced to 2.2 h.<sup>29</sup>

Because sleep is a key restorative factor for daytime-induced fatigue, insufficient sleep duration may be a risk factor for several hormonal imbalances that suppress muscle growth<sup>46</sup> and may result in unfavorable body composition.<sup>47</sup> Inadequate sleep quantity in athletes extends its consequences to sports performance. In contrast, benefits derived from adequate sleep duration translated into higher team rankings in a netball tournament.<sup>48</sup> Overall, variation in sleep quantity affects mostly psychomotor vigilance.<sup>49</sup> Because adolescent athletes tend to sleep more over the weekends to counterbalance their weekday sleep debt, their psychomotor vigilance time was found to be shorter on Monday than on Tuesday or Friday.<sup>50</sup> Additionally, in a study by Choi and colleagues,<sup>33</sup> longer sleep duration correlated with improved shuttle bouncing performance in junior badminton players.

#### 4.2. Sleep quality

A key finding of the present review is that reduced sleep quality is reported among athletes. In the reviewed athletic sample, children and adolescents, independently of athletic expertise, exhibited a notably low SE (80.3%). However, SE alone cannot recognize short episodes of wakefulness; therefore, examination of SOL and WASO is important. In the present review, no significant differences were reported for SOL, but WASO was longer among children and adolescents (74.0

min). This fact may be indicative of long or frequent wake bouts during nocturnal sleep. Furthermore, low SE and elevated WASO was more noticeable in pre-season training compared with in-season and off-season (Table 4).

Overall, there seems to be an interrelation among several sleep quality parameters such as SOL, WASO, and SE.<sup>9</sup> As shown in elite young athletes/rowers, falling asleep quickly (reduced SOL) was related to more restful sleep and fewer awakenings.<sup>37</sup> However, overall SE was shown to be lower in elite athletes compared to the age- and sex-matched non-athletic population.<sup>9</sup>

As with sleep quantity, sleep quality is affected by training and competition.<sup>51</sup> A short period of intensified training results in progressive decrements in sleep quality among cyclists and triathletes.<sup>44,52</sup> Extending this period—for example, during training camps<sup>42</sup> or during a cycling grand tour<sup>28</sup>—may also impair SE. Overall, Wall and colleagues<sup>53</sup> suggested that SE may be an objective predictor of overreaching in swimmers.

In regards to other health issues, low SE values are indicative of the development or establishment of health problems such as increases in systolic blood pressure<sup>2</sup> or lower cognitive function.<sup>54</sup> Also, Choi and colleagues<sup>33</sup> showed that higher SE was related with better shuttle bouncing performance in young badminton players.

#### 4.3. Sleep architecture

The data we reviewed on sleep architecture showed that athletes of both sexes spend approximately 114.1 min of their sleep time in the REM stage, 47.9 min in N1 stage, 240.5 min in N2 stage, and 91.5 min in N3 stage. Converting these sleep stages from minutes to percentages of TST, the following distribution is obtained: 23.1% REM, 9.7% N1, 48.7% N2, and 18.5% N3 sleep stage. In comparison, a typical non-athletic adult spends approximately 25% of sleep time in REM stage, 5% in N1 stage, 50% in N2 stage, and 20% in N3 stage.<sup>8</sup> Early studies showed that athletes tended to spend more time in non-REM sleep and less time in REM sleep compared to non-athletic controls.<sup>55</sup> However, ultra-endurance competition changes athletes' sleep architecture by increasing REM sleep stage, while N3 sleep stage is not affected.<sup>26</sup>

A factor that was identified as being associated with alterations in sleep architecture in athletes was pre-season training period. It was observed that during the pre-season period the amount of sleep in the N3 sleep stage is extended. However, these data were calculated from a limited number of studies, and generalized assumptions should be made with caution.

Findings based on training volume and sleep architecture show that after endurance races, REM proportion is reduced and N3 stage sleep may increase.<sup>26,56</sup> Driver and colleagues<sup>26</sup> found that the REM stage was a more sensitive indicator of exercise-induced stress than N3, since REM changed only after 15.0 km and 42.2 km runs. Sapiro and colleagues<sup>56</sup> showed that after a 92-km road race, REM proportion was decreased and N3 stage sleep was increased. During pre-season and peak

training period, N3 sleep has also been found to increase.<sup>57</sup> Recent data show that N3 stage sleep increases in response to higher physiological restorative demand in athletes (as indicated by higher resting heart rate and lower heart rate variability).<sup>58</sup> Trinder et al.<sup>31</sup> found that, according to the type of sport, N3 was higher in athletes practicing an aerobic sport compared to an anaerobic sport.

#### 4.4. Sleep optimization interventions

Several interventions have been implemented in order to improve athletes' sleep, such as bright-light exposure,<sup>59</sup> cold-water immersion,<sup>60</sup> napping,<sup>61</sup> nutritional interventions,<sup>3</sup> and sleep hygiene education.<sup>62</sup> Some interventions may improve sleep in the short term, but these improvements are not sustained in the long term.<sup>62</sup> Some factors that were thought to negatively affect sleep, such as the use of electronic devices in the evening, should perhaps be reconsidered before relevant interventions are established.<sup>63</sup> Thus, awareness should be raised when investigating easily applicable and targeted sleep optimization interventions.

Supplementing nocturnal sleep with daily naps has shown mixed results. In adolescent athletes, daily naps showed varying effects on sports-specific performance. For example, 20-m run performance improved but no effect was observed in shooting performance.<sup>64</sup> Furthermore, after travel, napping showed no significant benefit in Wingate performance.<sup>61</sup> On the other hand, Blanchfield and colleagues<sup>65</sup> reported benefits in endurance performance after nap supplementation of nocturnal sleep among athletes with a TST of <7 h. Similarly, Waterhouse and colleagues<sup>66</sup> showed that post-lunch napping improved alertness and sprint performance in sleep-deprived subjects.

More promising results were found in studies that tried to prolong nocturnal sleep duration. In basketball players, extension of TST correlated with improvements in athletic performance.<sup>4</sup> In a recent study, extension of sleep duration induced by a meal containing high glycemic index carbohydrates was related to faster reaction time the following morning.<sup>3</sup> Notably, sleep quantity and quality were modified by administering a post-exercise meal containing high glycemic index carbohydrates, thus underlining the need for easily applicable sleep-optimizing interventions. For example, tart cherry juice was found to be an effective nutrition intervention for improving sleep duration and quality in healthy individuals.<sup>67</sup> Nutritional interventions should be used with caution, however, as they may result in improved athletic performance but still have a negative effect on sleep. For example, a study by Miller and colleagues<sup>68</sup> showed that caffeine supplementation lead to improvements in endurance sports performance but impaired sleep duration in athletes.

#### 4.5. Other factors that may affect sleep in athletes

Sleep is a multidimensional construct that alters throughout the human life span according to an individual's habits, such as electronic device use.<sup>69</sup> Due to the nature of both their training and competition, athletes are exposed to several additional risk factors that may alter sleep patterns and induce sleep deprivation. For instance, environmental factors that influence sleep include traveling across different time zones,<sup>70</sup> training in heat,<sup>60</sup> conditions that lead to hypoxia,<sup>71,72</sup> and psychological issues derived from competition stress.<sup>73</sup>



Practicing a sport since adolescence seems to alter sleep quantity. It has been shown that sleep onset and wake time differ between athletes and non-athletes, with young athletes going to sleep earlier and waking earlier compared to controls who are training recreationally or are sedentary.<sup>74</sup> Because training schedules demand that student athletes wake up early in the morning, electronic device usage may contribute considerably to the reduced sleep of adolescent athletes. For example, the use of smartphones after lights out may impair athletes' sleep,<sup>69</sup> and unrestricted Internet access appears to be related to fewer hours of sleep among young athletes.<sup>75</sup> On the other hand, some recent studies have shown that electronic device use does not necessarily affect sleep quantity and quality in young adults.<sup>6,63</sup>

Recently, Fowler and colleagues<sup>70</sup> showed that professional rugby players who travelled from Australia to the UK needed on average of 5 days to restore their sleep-wake patterns. Waterhouse and colleagues<sup>76</sup> showed that appropriate itinerary arrangements might reduce some of the negative effects of jet lag. In contrast, one study showed that interstate travel did not affect sleep patterns in athletes on the night before a game.<sup>77</sup>

Pedlar and colleagues<sup>71</sup> found that sleep duration was not impaired when training was performed at high altitude and that sleeping in a normobaric hypoxic tent led to impaired duration of stage N1 and N2 sleep but led to no significant changes in deep sleep or REM sleep. Sleeping at high altitude showed that REM sleep initially falls acutely but afterwards rises gradually from Day 1 to Day 15.<sup>78,79</sup> In contrast, deep sleep was shown to decline gradually during exposure to altitude.<sup>79</sup> Similarly, sleep disturbances as a response to high altitude have also been observed in female middle distance runners and young soccer players of various levels.<sup>78,80,81</sup> Ambient temperature is an additional environmental parameter that may impair sleep. As shown by Skein and colleagues,<sup>60</sup> 5 consecutive days of training in the heat can impair sleep quality.

Another factor that has been investigated for its effect on athletes' sleep is chronotype. It is proposed that chronotype not only affects ratings of perceived exertion and fatigue scores and performance,<sup>16</sup> but it also affects sleep quality following exercise training.<sup>82</sup> In regard to chronobiology and circadian rhythm, it was recently shown that rest–activity circadian rhythms vary among different sport disciplines,<sup>18</sup> and this has an impact on sleep onset and wake times.<sup>18</sup>

#### 4.6. Methodological issues and future research directions

The current study aimed to analyze athletes' sleep intra-variability using only objectively measured sleep-related data while excluding extreme environmental factors that could affect sleep. Objectively measured data was used because it is well documented that subjective measures, such as sleep logs, often overestimate athlete sleep duration.<sup>5,6</sup> Likewise, commercially available wearable devices also show poor accuracy and reliability for sleep tracking.<sup>83,84</sup> In athletic populations, wearable devices may overestimate TST, providing questionable results.<sup>10</sup> Nevertheless, wearables are practical, user-friendly, non-invasive devices that, after adequate validation, could be useful for coaches and sports scientists to use in longitudinally monitoring athletes' sleep.

Analyzing only objectively measured data revealed gaps in current methodologies and existing literature. When comparing data across studies, differences in the way each sleep variable was calculated may significantly affect the outcomes. For example, in some studies,  $27.81$  SE was artificially higher because its calculation did not include the SOL measure. Regarding sleep-related measures, data were scarce for certain categories of participants, and especially for sleep architecture measures. Sleep stages of female athletes, at both the elite and semi-elite levels, were not presented separately. Sleep architecture data were also understudied for elite male athletes and middle-aged adult athletes. No data were retrieved in the literature search for masters athletes or athletes in late adulthood.

Thus, it is difficult to measure sleep architecture in elite athletes across all ranges of the human lifespan. Therefore, additional studies are needed to investigate sleep stages and their relations to various physiological measures in athletes. Future studies should also focus on sleep evaluation of female athletes. An important outcome of this review is that athletes, especially children and adolescents, present overall poor sleep quality and quantity. Thus, easily applicable interventions should be investigated to optimize sleep and sleep-related parameters in junior athletes.

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## 5. Conclusion

The current systematic review showed that athletes slept on average  $7.2$  h/night with  $86.3\%$  SE. Notably, athletes in junior categories demonstrated low SE ( $80.3\%$ ), with no significant increases in SOL, but with long WASO. Several exercise- and sports-related parameters that can potentially influence sleep quantity and architecture were analyzed, such as athletic expertise, training season, and sports type. Data were lacking for certain age- and sex-specific categories, such as females and masters athletes. Therefore, more studies should be conducted to evaluate sleep architecture among these categories of athletes. Further research is needed to establish sleep recommendations for athletes and promote sleep-optimizing interventions, especially for children and adolescent athletes.

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## Authors' contributions

AV performed the literature review and data extraction and wrote the first draft of the manuscript; CDG performed the literature review and data extraction and wrote and revised the first draft of the manuscript; GA, GCB, GKS, and EA revised the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

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## Competing interests

The authors declare that they have no competing interests.

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Footnotes

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Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jshs.2020.03.006.

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Appendix. Supplementary materials

Click here to view.(64K, docx)Image, application 1

Click here to view.(15M, mp4)Image, video 2

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