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Original Article

The relationship between body composition and sleep architecture in athletes

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ABSTRACT

Sleep is essential for athletes to recover physical fitness. It has been suggested that sleep is affected by muscle volume. Compared to female athletes, male athletes with greater muscle volume may have inferior objective sleep quality. This study aimed to assess the relationship between body composition and objective sleep parameters in male and female athletes. The body composition of 17 male and 19 female collegiate athletes were measured, and they underwent overnight home sleep monitoring. Compared with female athletes, male athletes had more muscle mass and less fat mass. Moreover, male athletes had lower sleep efficiency, longer sleep onset latency, higher arousal index, less rapid eye movement (REM) sleep, and lower percentage of slow-wave (N3) sleep in the initial non-REM sleep. Furthermore, the percentage of muscle mass was inversely related, whereas fat mass or percentage of fat mass was directly related to the percentage of N3 sleep in the initial non-REM sleep. Overall, there were no significant association between sex and sleep parameters. However, a significant correlation was found within both subgroups. Objective sleep quality was suggested to be worse in male athletes than in female athletes, implying that sleep architecture may be related to the muscle volume.

1. Introduction

Sleep is a fundamental requirement for human health, and it plays an essential role in the athlete's ability to recover physical fitness due to its physiological and psychological restorative effects [1,2]. Therefore, understanding sleep architecture and improving sleep quality are essential for condition management in athletes [3].

In general, subjective sleep quality is more impaired in females than in males [4,5]; this is also true for athletes [6,7]. However, the results were better in females when sleep quality was assessed objectively on electroencephalography (EEG)-based sleep monitoring [8–11]. However, the sex-related differences in objective sleep quality among athletes remain clear.

There are physiological differences between male and female athletes, and one of these factors is physique. The relationship between body composition, including muscle volume, and objective sleep quality is of interest, especially when considering the sleep quality of athletes who are likely to have a greater muscle volume than non-athletes. Indeed, one study suggested that in males, greater the muscle mass, as assessed by lean body mass,

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index; EEG, electroencephalography; N3, slow-wave; PAT, peripheral arterial tonometry; REM, rapid eye movement; SDB, sleep-disordered breathing; SOL, Sleep onset latency; SE, Sleep efficiency; TST, Total sleep time; WASO, Wake after sleep onset.

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worse the sleep quality [12]. This was more prominent in athletes than in non-athletes [12]. However, no female subjects were included in this study.

Considering the inverse relationship between muscle mass and sleep quality in males [12], we hypothesized that we might find a relationship between muscle mass and sleep quality if female athletes who are likely to have less muscle mass are included in the study, and that female athletes may have better objective sleep quality than male athletes because of their lower muscle mass. To test this hypothesis, we assessed the relationship between body composition and objective sleep parameters in both male and female collegiate athletes. Inter-sex variations in objective sleep architecture and body composition were assessed.

2. Materials and methods

2.1. Participants

Healthy male and female athletes were recruited from basketball and track-and-field collegiate teams from the Juntendo University School of Health and Sports Science. Athletes with any known sleep disorders and/or mental disorders, any drug use, or pathologies that may interfere with sleep patterns including recent injuries, shift work, and transmeridian travel within the past three months and during study periods were excluded. All participants were asked whether they had trouble sleeping due to any pain one or more times a week in the previous one month. This study was approved by the Research Ethics Committee of the Juntendo University. Informed consent was obtained from all participants.

2.2. Body compositions

The body composition of all participants was measured using a tetrapolar bioimpedance instrument (InBody 430; InBody Japan, Tokyo, Japan). These body composition analyzers adopted a tetrapolar, eight-point tactile electrode system. Before measurement, participants wiped the bottom of their feet with electrolyte tissue. Then, they were instructed to stand on the scale while holding the handrails with metal grip electrodes, thereby providing contact with a total of eight electrodes (two for each foot and hand). The participants fully extended their arms at an abduction angle of approximately 20° laterally. The components included in body composition were height, weight, body mass index (BMI), muscle mass, percent muscle mass, fat mass, and percent fat mass.

2.3. Electroencephalography-based sleep monitoring

All participants underwent overnight home sleep monitoring for two consecutive nights using a two-channel portable EEG device (ZA-9. Proassist Ltd., Osaka, Japan) [13]. The device consists of two pairs of electrodes connected to a transmitter and a receiver and provides EEG, an electrooculogram, and a submental electromyogram. The participants set up the portable EEG themselves at home. Sleep parameters using this device were validated by polysomnography [14]. All data were manually scored by an experienced sleep technologist based on widely used criteria [15]. Total sleep time (TST) was calculated as the total sleep period minus the time spent awake during the sleep period. Sleep onset latency (SOL) was defined as the time from bedtime to sleep onset. Sleep efficiency (SE) was evaluated as the TST as a percentage of the total time in bed. Wake after sleep onset (WASO) was calculated as the total wakefulness time between the initial sleep onset and final sleep offset. For sleep stages, the percentages of rapid eye movement (REM) sleep (ie, stage R) and slow-wave sleep (ie, stage N3) per TST were determined. In addition, we assessed the percentage of N3 sleep during the interval from sleep onset to initial REM sleep (ie, percentage of N3 sleep in initial non-REM sleep) because this is important for athletes in terms of growth hormone secretion [16]. Arousal index was calculated as the number of microarousals per hour of sleep.

The first night was just to adapt to the EEG device, and the obtained data were not scored or used. Data from the second night were used for analyses. For female athletes, sleep monitoring was performed at night between the seventh and 10th nights after menses onset. This was chosen because we wanted to exclude the effects of menses on objective sleep parameters suggested in our previous study [13], and because it is generally easy to capture this phase. We asked all participants to perform each EEG monitoring during the training season.

2.4. Screening for the sleep-disordered breathing

Screening for sleep-disordered breathing (SDB) was performed using a portable polygraphy device (WatchPAT 200; Itamar Medical, Caesarea, Israel) at subjects' homes one night before the first night for EEG-based sleep monitoring. The device is worn around the wrist and has one finger probe including a peripheral arterial tonometry (PAT) sensor and an oximetry sensor. Arterial pulsatile volume changes of the finger in association with sympathetic nervous activation due to respiratory events were determined using a PAT sensor. A reduction in PAT amplitude accompanied by an increase in pulse rate and desaturation at the termination of respiratory events was scored as a respiratory event. Many studies, including a study from a Japanese population, have demonstrated that the apnea-hypopnea index (AHI) determined by a PAT-based device is well correlated with those determined by formal polysomnography [17,18]. In this study, all data downloaded from the device were analyzed automatically in an offline application (Zzz PAT version 4.4.64.p; Itamar Medical), and SDB was defined as AHI $\geq$5/h [19].

2.5. Statistical analysis

Continuous variables are summarized as mean ± SD or median [interquartile range], and categorical variables are shown as percentages. Variables were compared between males and females using Student's *t*-test or the Mann–Whitney *U* test (if the variables were non-normally distributed) for continuous variables, and Fisher's exact test for categorical variables. Correlations between body composition and EEG parameters were assessed using Pearson or Spearman correlation coefficients. To compare the correlation slopes between males and females, relationships between variables were analyzed with the interaction between sexes. Two-tailed P-values <0.05 were considered significant. All analyses were conducted using SPSS version 27 (IBM, Armonk, NY).

3. Results

3.1. Characteristics and body compositions of participants

Overall, 40 collegiate athletes (20 male and 20 females) were enrolled. The data of three males and one female could not be used because they could not complete the EEG monitoring for personal reasons. Thus, 17 male and 19 female athletes were included in the analysis. Their characteristics and body composition are summarized in Table 1. There were no significant differences in age, training time on the EEG monitoring day, or BMI between the sexes. Female athletes were selected from a mixture of players from the basketball and track-and-field teams, whereas all male athletes were basketball players. Three male athletes had very mild

Table 1
Characteristics of male and female athletes.

	All N = 36	Males N = 17	Females N = 19	P
Age, years	21.0 ± 0.9	21.0 ± 0.9	21.1 ± 0.8	0.860
Type of sport (basketball, %)	27 (75.0)	17 (100.0)	10 (52.6)	0.001
Training time, min	116.6 ± 32.7	113.4 ± 26.2	119.5 ± 38.0	0.579
Height, cm	169.1 ± 8.3	173.7 ± 8.7	165.0 ± 5.4	<0.001
Weight, kg	64.4 ± 7.8	68.1 ± 7.8	61.0 ± 6.4	0.005
BMI, kg/m^2	22.5 ± 1.9	22.5 ± 1.3	22.4 ± 2.3	0.920
Muscle mass, kg	51.4 ± 6.8	56.1 ± 6.6	47.3 ± 3.6	<0.001
Percent muscle mass, %	80.0 ± 5.2	82.4 ± 2.3	77.9 ± 6.1	0.008
Fat mass, kg	10.7 ± 3.6	8.6 ± 2.0	12.5 ± 3.9	<0.001
Percent fat mass, %	16.7 ± 5.2	12.7 ± 2.4	20.2 ± 4.5	<0.001
SDB, n (%)	3 (0.8)	3 (17.6)	0 (0)	0.227
AHI, events/h of sleep	2.1 [3.0]	2.6 [4.1]	1.7 [2.2]	0.438

Continuous variables were summarized using mean ± SD or median [interquartile range].
AHI, apnea-hypopnea index; BMI, body mass index; SDB, sleep-disordered breathing.

obstructive sleep apnea (AHI: 5.7, 6.3, and 6.9), but there were no significant differences in the prevalence or AHI between sexes. Male athletes were taller and heavier and had more muscle mass than female athletes, whereas female athletes had more fat mass than male athletes. Five participants (13.9%) had trouble sleeping due to pain one or more times a week in the previous one month, but this had no sex predilection (3 males [17.6%] and 2 females [10.5%], P = 0.650).

3.2. EEG parameters

SE was greater, SOL was shorter, and arousal index was lower in females than in males. There was a sex-related difference in the percentage of REM sleep in TST, where male athletes spent less time in REM sleep than female athletes. Although the percentage of N3 sleep in TST was similar, the percentage of N3 sleep in initial non-REM sleep was significantly lower in male athletes than in female athletes (Table 2).

3.3. Relationship between body compositions and EEG parameters

Although no significant relationship was observed between most body composition and EEG parameters, there were significant inverse relationships between the percentage of N3 sleep in initial non-REM sleep and percentage of muscle mass, and a direct relationship between percentage of N3 sleep in initial non-REM sleep and fat mass or percentage of fat mass (Fig. 1). There were no significant interactions between sexes and these relationships (Fig. 1). Nevertheless, we performed subgroup analyses by sex and found significant inverse relationships between percentage of N3 sleep in initial non-REM sleep and percentage of muscle mass in both the male and female subgroups (Fig. 1), and a direct relationship between percentage of N3 sleep in initial non-REM sleep and fat mass or percentage of fat mass in both the male and female subgroups (Fig. 1).

4. Discussion

Or study findings provide several insights into sleep quality in athletes. First, despite having similar BMI, male athletes were taller and heavier and had more muscle mass than female athletes. Female athletes had more fat mass than male athletes. In terms of EEG monitoring, female athletes were more likely to fall asleep easily (ie, shorter SOL) and to have more consolidated sleep (ie, better SE and fewer arousals) with a greater percentage of REM sleep than male athletes, suggesting that the objective sleep quality of female athletes was better. Second, in both male and female athletes body composition parameters and percentage of N3 sleep in initial non-REM sleep were correlated: greater the muscle volume, lower the N3 sleep in the initial non-REM sleep; greater the fat mass or percentage fat mass, greater the N3 sleep in initial non-REM sleep. Third, no sex-related differences were observed in the relationship between body composition parameters and the percentage of N3 sleep in the initial non-REM sleep. These findings suggest that sex itself may not be a main factor in determining objective sleep architecture in athletes and sex-related differences in sleep architecture may be explained by differences in muscle and/or fat volume.

We previously reported that subjective sleep quality was impaired more in female athletes than in male athletes [5,6].

Table 2
Electroencephalography parameters of male and female athletes.

	All N = 36	Males N = 17	Females N = 19	P
TIB, min	392.2 ± 49.7	393.0 ± 46.8	391.5 ± 52.1	0.928
TST, min	355.3 [57.1]	356.0 [46.2]	354.5 [62.5]	0.428
WASO, min	14.50 ± 13.2	19.1 ± 16.8	10.4 ± 6.6	0.052
SE, %	89.3 ± 7.0	86.5 ± 8.8	91.9 ± 2.9	0.018
SOL, min	23.4 ± 17.6	30.1 ± 22.0	17.5 ± 8.6	0.031
Arousal index, events/h	8.3 ± 2.7	9.2 ± 2.5	7.5 ± 2.5	0.047
% of REM sleep in TST, %	24.1 [6.2]	21.1 [5.9]	26.2 [5.8]	0.008
% of N3 in TST, %	23.7 [7.0]	24.4 [6.3]	23.0 [6.0]	0.568
% of N3 in the initial non-REM sleep, %	50.3 ± 19.1	42.9 ± 16.2	56.9 ± 19.1	0.028

Continuous variables were summarized using mean ± SD or median [interquartile range].
N3, slow-wave sleep; REM, rapid eye movement; SE, sleep efficiency; SOL, sleep onset latency; SPT, sleep period time; TIB, total time in bed; TST, total sleep time; WASO, wake after sleep onset.

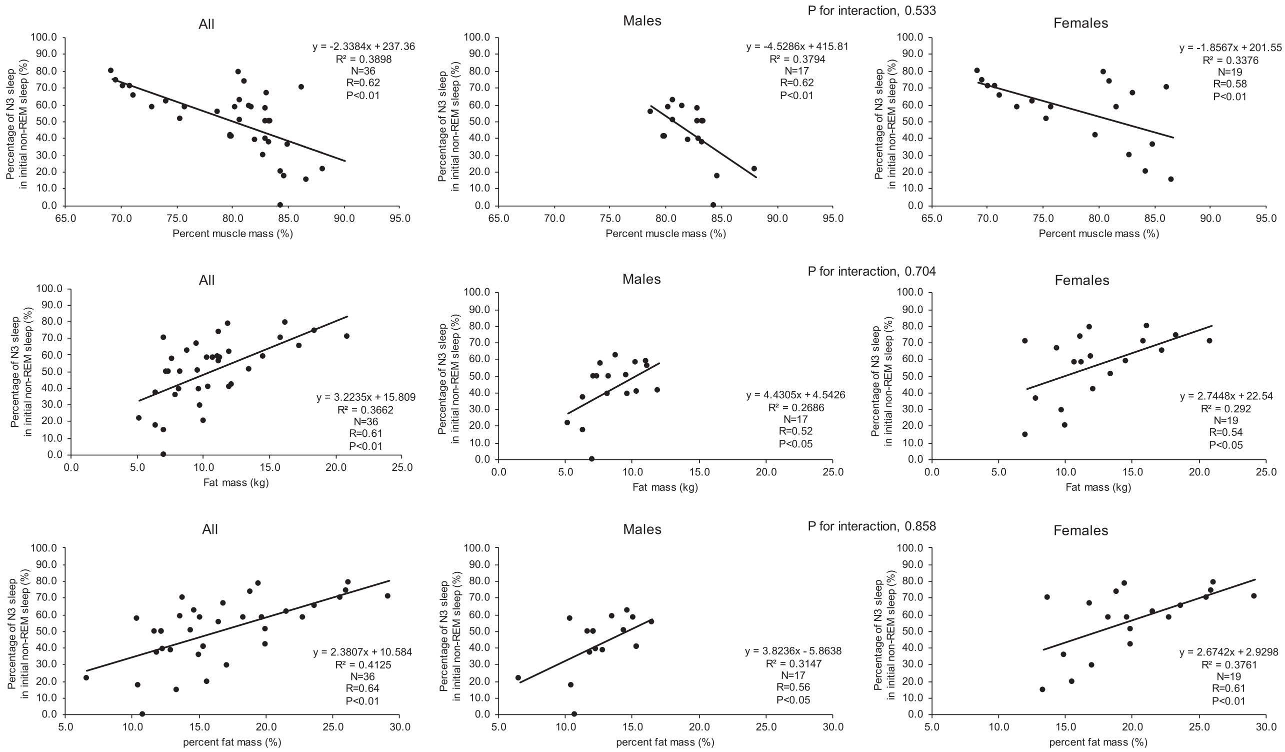

Fig. 1. Relationships between percentage of N3 sleep in REM sleep latency and body compositions. Percent N3 sleep in REM sleep latency was correlated with percent muscle mass, fat mass, and percent fat mass. These absolute values of the regression coefficients were more significant in male athletes than in female athletes. N3, deep non-REM sleep.

However, such sex-related differences in subjective sleep quality were either not identified or favorable to females when objective sleep quality was assessed using EEG-based sleep monitoring [8–11]. In athletes, there is no clear view of sex-related differences in objective sleep quality. In a previous study by Carter et al., actigraphy was used as an objective measure of sleep in athletes [20], and they found that female athletes had greater SE, less WASO, and shorter SOL, which is consistent with the findings of the present study. Some parameters such as sleep quality, which were agreed upon by experts' panels, were SOL, number of awakenings >5 min, WASO, and SE [21]. Our study suggested that objective sleep quality was better in female athletes than in male athletes.

Although no sex-related difference in the percentage of N3 sleep in TST was detected, the present study is the first to compare sleep architecture between male and female athletes. The study presents a novel finding that female athletes spend more time in N3 sleep in the initial non-REM sleep than male athletes. A previous study by Paxon and colleagues reported that in males, greater the muscle volume, as assessed by lean body mass, lesser the time spent in slow-wave sleep, and such an inverse relationship between muscle volume and sleep quality was more prominent in athletes than in non-athletes [12]. In contrast, there were direct relationships between fat mass, percent fat mass, and percent N3 sleep in the initial non-REM sleep. This may be just a mirror image of the inverse relationship between muscle volume and percent N3 sleep in the initial non-REM sleep. We infer that the relationship between muscle volume, fat mass, and sleep quality can be mediated by thermoregulation. The first reason is that sleep is initiated in association with the maximal decline rate in core body temperature [22,23], and after sleep onset, consolidated sleep with increased slow-wave sleep is derived from the low minimum core body temperature [24,25]. Another reason is that an increase in peripheral muscle volume may prevent core body temperature from lowering [26,27]. However, these are only speculations, and it will be necessary to measure core body temperature for these verifications as a future plan.

This study had some limitations. First, only basketball and track-and-field athletes were examined. It should be noted that the body composition of athletes differs according to sport, and the results may be different in athletes with different distributions of muscle volume. Second, detailed information on lifestyle and sleep environments was not collected. Factors other than body composition may be related to an objective decline in sleep quality. Finally, we did not assess athletic performance based on differences in sleep architecture. Considering data from the study by Mah et al., which reported that prolonged sleep duration in athletes contributes to improved performance [28], it is plausible that improved sleep quality contributes to improved performance.

5. Conclusions

Objective sleep quality was found to be worse in male athletes than in female athletes. Sleep architecture may be related to the muscle volume. Thus, it is necessary to be sensitive to their complaints of poor sleep and intervene in sleep management according to body composition that changes depending on time; for example, during season and off-season. Furthermore, different approaches may be needed considering the variations in muscle volume.

Author contribution

Eri Kitamura: Conceptualization, Formal analysis, Investigation, Writing-original draft, **Yu Kawasaki:** Formal analysis, Investigation, Writing-original draft, **Takatoshi Kasai:** Conceptualization, Methodology, Formal analysis, Writing-original draft, Supervision, Project administration, **Itsuki Midorikawa:** Investigation, Validation,

Nanako Shiroshita: Formal analysis, Investigation, **Fusae Kawana:** Formal analysis, Investigation, **Etsuko Ogasawara:** Writing-review & editing, **Mari Kitade:** Writing-review & editing, **Atsuo Itakura:** Writing-review & editing, **Natsue Koikawa:** Conceptualization, Methodology, Investigation, Writing-review & editing, **Takao Matsuda:** Conceptualization, Writing-review & editing.

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Conflict of interest

Takatoshi Kasai and Fusae Kawana are affiliated with a department endowed by Philips Respironics, ResMed, and Fukuda Denshi. Takatoshi Kasai and Nanako Shiroshita are affiliated with a department endowed by Paramount Bed. The other authors report no conflicts of interest.

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