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ORIGINAL ARTICLE

Acute effect of an intensified exercise program on subsequent sleep, dietary intake, and performance in junior rugby players

Oussama Saidi[1,2] · **Eric Doré**[1,2] · **Freddy Maso**[3] · **Damien Mack-Inocentio**[1,2] · **Stéphane Walrand**[2,4] · **Bruno Pereira**[5] · **Pascale Duché**[6]

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Abstract

The effect of exercise on sleep remains controversial in athletes especially in junior athletes. This study tested the acute effect of additional intense rugby training on sleep, next-day dietary intake, and physical performances in adolescent rugby players compared to a day with regular exercise. 17 male rugby players in the national under-17 category (age: 15.7 ± 1.1 years, height: 1.78 ± 0.1 m, weight: 84.4 ± 13.6 kg, BMI: 26.6 ± 3.8 kg/m^2, fat mass: 14.5 ± 3.4%, VO_{2max} Yo-Yo test: 52.1 ± 4.4 mL/min/kg, evening chronotype) took part in this study. The athletes completed two 36-h experimental sessions in random order: a regular exercise program (REP) vs. an intensified exercise program (IEP) at a 1-week interval. Physical activity and sleep data were collected using accelerometers. Performance tests were conducted the next morning after an ad libitum breakfast. Sleep improved during intensive training (TST: + 26 min, SL: − 4%, WASO: − 39%, SE: + 8.5%) with moderate effect size. There was no next-day difference in calorie intake from breakfast, but macronutrient composition shifted toward proteins (regular: 15.4 ± 6.1% vs. intensive: 18.9 ± 7.4%, ES = − 0.650 [− 1.13; − 0.18]). There were no significant differences in Wingate test performance or spatial awareness task time. However, performance in submaximal tests improved. Acute intensified training results in increased sleep duration and quality without disturbing next-day performance or dietary intake in young rugby players.

Keywords Sleep · Adolescent · Athlete · Physical performances · Nutritional behavior

Abbreviations

AC	Aerobic contribution
ESS	Epworth sleepiness scale
FI	Fatigue index
IEP	Intensified exercise program
LP	Low power
MEQ	Horne–Östberg morningness–eveningness questionnaire
PP	Peak power
PSQI	Pittsburgh sleep quality index
REP	Regular exercise program
SE	Sleep efficiency
SL	Sleep latency
TST	Total sleep time
TTB	Total time in bed
WASO	Wake after sleep onset
Yo-Yo IR1	Yo-Yo intermittent recovery test level 1

Introduction

Elite junior athletes have to contend with constraints of intensive sports practice on top of the physiological processes associated with adolescence. Training demands

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✉ Pascale Duché
pascale.duche@univ-tln.fr

[1] Laboratory of Adaptations to Exercise Under Physiological and Pathological Conditions (AME2P), Clermont Auvergne University, 63000 Clermont-Ferrand, France

[2] Center for Research in Human Nutrition Auvergne, 63000 Clermont-Ferrand, France

[3] Rugby Training Center of the Sportive Association Montferrandaise, 63100 Clermont-Ferrand, France

[4] INRA, Human Nutrition Unit, Clermont Auvergne University, 63000 Clermont-Ferrand, France

[5] Biostatistics Unit (DRCI), Clermont-Ferrand University Hospital, 63000 Clermont-Ferrand, France

[6] Laboratory of Impact of Physical Activity on Health (IAPS), Toulon University, 83000 Toulon, France

imposed on this population have considerably increased since the early 1990s, but recovery strategies have been lacking (Raglin and Wilson 2000). Although sleep is essential for the proper development of adolescents (Colrain and Baker 2011) and was proposed as the best available strategy for athletic recovery (Halson 2013), several recent studies suggest that young athletes are prone to insufficient sleep duration, poor sleep quality and circadian misalignment (Suppiah et al. 2015; von Rosen et al. 2016; Fowler et al. 2017). All these are implicated in non-functional overreaching, excessive diurnal fatigue, reduced physical and cognitive performance, and disturbed eating behavior (Fullagar et al. 2015).

Physical activity is incorporated into standard “sleep hygiene” advice and has been recognized to play a positive role on sleep in the general population, especially in those with sedentary lifestyles. A whole body of literature documents this fact in adolescents (Lang et al. 2016). However, a considerable number of recent studies report that highly intense training may compromise sleep in athletes, which may point to a threshold of positive effects of physical activity on sleep. For instance, intensified training for 9-day periods results in a decreased sleep efficiency, more frequent waking and an increased sleep fragmentation index (Killer et al. 2017). During training camps, studies report a decreased sleep duration and/or quality with an increase in training load in team sports such as soccer or rugby (Thornton et al. 2017). This was explained in part by physiological stimulus, muscle soreness, and increased heart rate at bedtime. Yet, others reported no differences in sleep between adolescent athletes, whose sport required high-intensity training compared to those in low-intensity training (Suppiah et al. 2016). In addition, some studies report that regular practice of elite sports does not seem to impair sleep in adolescents (Beltran-Valls et al. 2017; Lalor et al. 2018). Brand et al. (2009) even reported a favourable sleep pattern in adolescents engaged in football sport training compared to matched controls.

Given these conflicting results, the purpose of this study is to investigate the acute effect of an additional intense rugby training session on subsequent sleep, next-day dietary intake and physical performance. The hypothesis formulated was that at least in the short term, intensified exercise would result in better sleep among young athletes.

Methods

Subjects

Following an inclusion interview, 20 male adolescent rugby players in a good health (aged 14–17 years, Tanner stages 3–5) engaged in the under-17 national category were selected to take part in this study. The athletes’ characteristics were as follows, age: 15.7 ± 1.1 years, height: 1.78 ± 0.1 m, weight: 84.4 ± 13.6 kg, BMI: 26.6 ± 3.8 kg/m^2, fat mass: 14.5 ± 3.4%, $V\text{O}_{2\text{max}}$ Yo-Yo test: 52.1 ± 4.4 mL/min/kg. The athletes were enrolled in a regular fitness conditioning program (10 h per week) at their training center (Montferrand Sports Association-Rugby Section, France), and no cup matches or competitions were held during the study protocol. The athletes were informed about the study, and they agreed to take part with a parent’s written consent. The experiment was designed in accordance with the Declaration of Helsinki. Three athletes left the study owing to injury and missing data. They were not taken into account in the analysis.

Design

One week before the experimental sessions, the athletes underwent anthropometric, body composition, and Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) tests. Skinfold thickness was measured at four different right-hand-side locations (biceps, triceps, subscapular, and supra-iliac) by the same person using a Harpenden Skinfold Calliper. Relative fat mass was calculated using Siri equations amended by Weststrate and Deurenberg (1989). $V\text{O}_{2\text{max}}$ was estimated based on distance covered during the Yo-Yo IR1 test using the equation established by Bangsbo et al. (2008). The athletes were also asked to complete the Horne–Östberg morningness–eveningness questionnaire (MEQ), and the self-report Pittsburgh sleep quality index (PSQI) and Epworth sleepiness scale (ESS) questionnaires.

Experimental sessions

The athletes took part randomly in two 36-h programs held on the same days of two consecutive weeks (Fig. 1). They were equipped with a Sensewear Armband Pro (BodyMedia Inc., Pittsburgh, PA) to record their physical activity and sleep parameters. The regular exercise program (REP) comprised only habitual exercise (90 min starting from 9:30 a.m.), and during IEP additional intense training (90 min starting from 5:00 p.m.) was added in the afternoon. Dietary intake was matched for food and calories during the first day. On the second day, energy intake was measured by ad libitum breakfast. Half an hour later, performance tests were conducted. Athletes completed a submaximal rectangular test (5 min to 70% of the theoretical maximum heart rate), a Wingate test (30 s sprint on a Monark ergonometer), and a spatial awareness task (NeuroTracker).

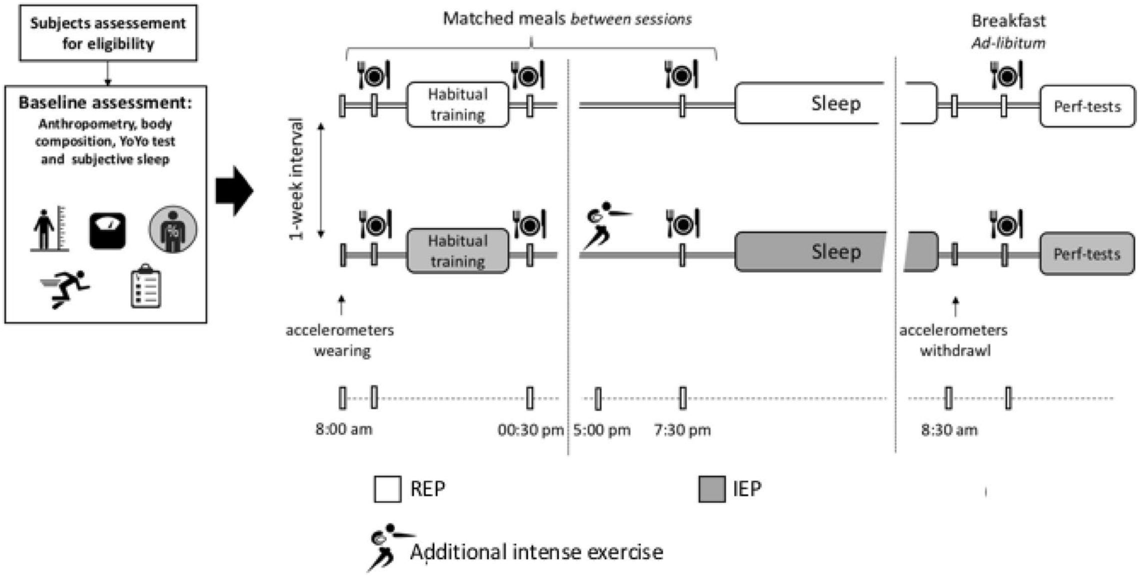

Fig. 1 Chronological presentation of the protocol

Regular and intensified exercise

Exercise during REP was done in the morning (9:30 a.m.) and involved a warm-up (~20 min) consisting of shuttle runs, jumping bouts, and dynamic stretches followed by body weight strength and power development circuits (~60 min). During IEP training similar to the REP session was conducted in the morning followed by additional intensive rugby training in the late afternoon (5:00 p.m.) for 90 min. All the athletes were equipped with a Polar-Pro Team2 heart rate monitor (Polar Electro Inc, Lake Success, NY) to control intensity of exercise. The device had been validated and used in previous studies to monitor heart rate during training, and percentage of training session spent in different HR ranges was measured.

Accelerometry measurements

The SenseWear Armband Pro (BodyMedia Inc., Pittsburgh, PA) was used to measure physical activity and sleep.

The number of steps was recorded and 24 h energy expenditure was estimated. The manufacturer's proprietary software (SenseWear 6.1) was used to analyze activity and energy expenditure data.

The athletes were permitted to go to bed whenever they wanted after the evening meal on the first day of each program (~9:00 pm), but wake-up time the next day was set at 7:00 am. In this way, total opportunity time for sleep was 10 h. The device gave an objective estimation of sleep duration and quality in adolescents (Roane et al. 2015). The specific sleep parameters assessed were total time in bed (TTB), total sleep time (TST), sleep latency (SL), wake after sleep onset (WASO), and sleep efficiency (SE) calculated according to the definition of Leeder et al. (2012). At the same time, the athletes were asked to keep a sleep diary (bedtime, wake time, and getting up from bed time) to verify Armband sensor-based estimated sleep duration.

Next-day measures

Ad libitum breakfast

Food intake was measured during the second day breakfast of each session by an ad libitum meal to quantify energy intake. The ad libitum buffet meal offered a variety of foods and beverages according to food questionnaire completed by the athletes in advance of the experimental sessions. Sufficient amounts of food and identical meals were offered for the two programs, and the athletes were asked to eat until they felt satiated. The weight of food consumed was recorded by investigators using a professional computerized nutrient analysis program (Bilnut 4.0 SCDA Nutrisoft software) and Ciqual tables (2016 version) to calculate energy intake and proportion of the energy derived from each class of macronutrient (carbohydrate, fat, and protein).

Submaximal rectangular test

The test involved pedaling for 6 min at a constant power (2 W/kg BM, equal power in IEP and REP) on a cycle ergometer with an electromagnetic brake (894th, Monark, Varberg, Sweden). Seat height was adjusted to fit each subject, and the footrest was used to prevent feet slipping from the pedals. After a warm-up, the subject cycled at a frequency of 60 rpm. Heart rate was measured using a standard transmitter (Polar. Inc-RS800CX Multi), and gas exchange was measured with a Metamax 3B portable gas analyzer (Cortex, Leipzig, Germany).

Wingate test

Following the rectangular test (after a 5-min recovery period), a Wingate test (WAnT: 30 s maximal sprint) was performed. The load was set at 0.087 kg per kg of BM. The athletes were given verbal encouragements during the test. Maximum power (peak power), minimum power (low power) and fatigue index were analyzed with the standard ergometer software. Respiratory gas exchange measurements were also made throughout the test. Oxygen consumption, used to assess aerobic contribution (AC), was converted into kJ using the conversion factor 20.92 kJ/L oxygen, assuming the metabolism to be 100% carbohydrate, since the respiratory quotient (RQ) for the Wingate test was 0.99. AC was then obtained by adjusting to 22% mechanical efficiency (ME).

Spatial awareness task

Spatial awareness was assessed using a NeuroTracker (CogniSens Athletic Inc., Montreal, Canada) 3D multiple object-tracking device. For the task, the athletes wore 3D glasses and sat in a 3D simulator bay, where they were asked to track object movements through space. The test consisted of 20 trials in which speed of object motion was adjusted for subsequent trials based on prior scoring until a threshold was determined. Threshold scores were derived based on object movement speeds in centimeters.

Statistical analysis

Statistical analyses were performed using Stata software version 13 (StataCorp, College Station, TX). A mixed model was used. Random-effects models for correlated data were run, rather than the usual statistical tests, which would have been inappropriate owing to an unverified assumption of independence. The subject was considered a random effect. The normality of the residuals from these models was checked using the Shapiro–Wilk test. When appropriate, the data were log-transformed to achieve normality of the dependent endpoint. A value of $p < 0.05$ was considered statistically significant. Effect size was calculated according to Cohen's recommendations (Cohen, 1988) defining effect size bounds as: small (ES: 0.2), medium (ES: 0.5) and large (ES: 0.8, "grossly perceptible and therefore large").

Results

According to the MEQ all the junior athletes presented an evening chronotype. Average PSQI score was 4.7 ± 3.1, with 23.5% of the athletes presenting scores > 5. This indicates severe sleep difficulties for at least two of the seven components, or moderate difficulties in more than three components. The population average ESS score was 12.9 ± 4.7, showing excessive daytime sleepiness.

Dietary intake during the first day was matched by food and energy intake between REP and IEP (3535.6 ± 799.5 kcal vs. 3438.3 ± 874.3 kcal). Energy expenditure increased during the IEP session compared to the REP session (2511.4 ± 395.0 kcal vs. 3065.7 ± 596.5 kcal, ES = − 1.860 [− 2.40; − 1.32]). Consequently, an energy deficit (~ 600 kcal) was obtained on the energy balance of IEP compared to RE (+ 944.3 ± 724.8 vs. + 330.0 ± 809.8 kcal). However, the athletes still had a status of net positive energy balance.

In IEP, percentages of the additional training session spent in different HR ranges were as follows: (17.0 ± 15.9% at 50–59% of HR_{max}, 25.1 ± 5.2% at 60–69% of HR_{max}, 33.6 ± 8.7% at 70–79% of HR_{max}, 22.2 ± 15.8% at 80–89% of HR_{max}, 2.2 ± 4.5% at 90–100% of HR_{max}), as shown in Table 1, the additional training during IEP resulted above all in a significant difference in the time spent on vigorous

Table 1 Comparison of means number of steps, sedentary activities, and physical activity (min) by intensity level expressed in metabolic equivalent of task (METs) during REP and IEP

	REP Mean ± SD	IEP Mean ± SD	ES	95% Conf. interval	*P*
Number of steps	14996 ± 2023	19397 ± 2428	− 2.417	− 2.96; − 1.87	< 0.001
Sedentary activities < 1.5 METs	798.38 ± 55.83	769.46 ± 64.60	0.665	0.12; 1.21	0.016
Light activities [1.5–3 METs]	168.92 ± 19.22	158.38 ± 24.04	0.555	0.01; 1.10	0.045
Moderate activities [3–6 METs]	421.61 ± 40.76	424.07 ± 48.96	− 0.039	− 0.58; 0.50	0.809
Vigorous activities [6 –9 METs]	46.69 ± 19.20	71.61 ± 17.50	− 1.663	− 2.21; − 1.12	< 0.001
Very vigorous activities > 9 METs	2.46 ± 2.40	15.46 ± 6.56	− 2.298	− 2.84; − 1.75	< 0.001

REP regular exercise program, *IEP* intensified exercise program and very vigorous activities compared to REP. Effect sizes were large for both vigorous and very vigorous activities. Although relatively moderate activities were not significantly different, a decrease in time spent on sedentary and light activities was noted. Effect sizes were small to moderate.

Objective sleep data are reported in Table 2. Despite a mild delay in bedtime and a reduced time spent in bed (non-significant), TST was higher during IEP than during REP (+26 min, ES=– 0.518 [– 0.99; 0.04]). In addition, SL decreased by 4%, ES=0.492 [0.02; 0.97], WASO decreased by 39%, ES=– 0.382 [– 0.09; 0.86], and SE increased by 8.5%, ES=– 0.793 [– 1.28; – 0.30]. Effect sizes were moderate for TST, SL, WASO and SE.

Dietary intake at the next-day ad libitum breakfast is reported in Fig. 2. There was no difference in calorie intake (912.0 ± 351.6 vs. 807.8 ± 431.4 kcal). However, there was a significant shift in macronutrient composition toward proteins (+3.5%, ES=– 0.650 [– 1.13; – 0.18]) with moderate effect size.

Results for the next-day performance tests are reported in Table 3. Mean power in the aerobic submaximal test was 168.8 ± 27.3 W. Percentage of $VO_{2\text{peak}}$ determined by indirect calorimetry increased (+11%, ES=– 0.752 [– 1.26; – 0.25]) and heart rate decreased during the IEP session (– 6.04%, ES=1.571 [1.07; 2.08]) with a large effect size. Anaerobic performance in WAnT showed no significant differences in peak power (%), fatigue index or aerobic contribution. The spatial awareness test showed no significant difference between REP and IEP.

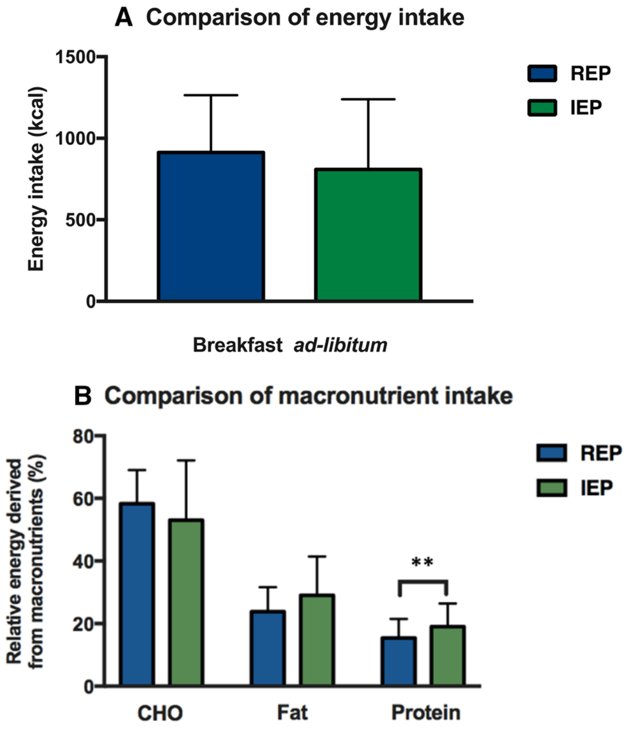

Fig. 2 Comparison between REP and IEP of energy intake (**a**) and macronutrients proportion at breakfast (**b**) (**$p < 0.01$)

Discussion

The purpose of this study was to evaluate the acute effect of additional intense rugby training on sleep and on next-day dietary intake and performance. The major finding was that acute intensified training improved subsequent sleep duration and quality. It reduced SL and WASO, and increased SE without disturbing bedtime, next-day food intake or physical performance compared to a day of regular training.

Subjective and objective measurements of sleep in both programs showed insufficient sleep duration and quality. This was consistent with the few outcomes described in the literature to date (Suppiah et al. 2015; von Rosen et al. 2016; Fowler et al. 2017). However, we underline that this problem is not exclusive to athletes, as several studies have reported a quantitative and qualitative impairment of sleep with excessive daytime sleepiness in the general adolescent population (Colrain and Baker 2011). Disturbed sleep patterns in junior athletes can be explained in part by factors related to adolescence including the reduced and delayed peak of melatonin from the onset of puberty, and exposure

Table 2 Armband sleep characteristics during REP and IEP

	REP Mean ± SD	IEP Mean ± SD	ES	95% Conf. interval	*P*
Bedtime (h:min)	23:24 ± 0:48	23:50 ± 1:04	– 0.368	– 0.86; 0.12	0.141
TTB (min)	482 ± 58	467 ± 58	0.422	– 0.05; 0.90	0.082
TST (min)	369 ± 66	395 ± 45	– 0.518	– 0.99; 0.04	0.033
SL (min)	15.0 ± 9.9	13.1 ± 8.4	0.492	0.02; 0.97	0.042
WASO (min)	89.7 ± 47.5	54.2 ± 35.0	– 0.382	– 0.09; 0.86	0.009
SE (%)	76.3 ± 9.3	84.8 ± 6.8	– 0.793	– 1.28; – 0.30	0.002

REP regular exercise program, *IEP* intensified exercise program, *TTB* total time in bed, *TST* total sleep time, *SL* sleep latency, *WASO* wake after sleep onset, *SE* sleep efficiency

Table 3 Physical condition and performances during each experimental program

	REP Mean ± SD	IEP Mean ± SD	ES	95% Conf. interval	*P*
Aerobic submaximal test					
Heart rate (bpm^{-1})	157.5 ± 8.5	148.0 ± 7.4	1.571	1.07; 2.08	< 0.001
% VO_{2peak} (Yo-Yo test)	75.2 ± 8.9	83.5 ± 7.8	− 0.752	− 1.26; − 0.25	0.004
Anaerobic Wingate test					
PP (w)	1076.2 ± 146.9	1068.2 ± 140.3	0.089	− 0.42; 0.60	0.730
LP (w)	440.1 ± 126.8	430.9 ± 145.7	0.048	− 0.46; 0.55	0.853
FI (%)	59.7 ± 12.9	59.2 ± 13.8	0.027	-0.48; 0.53	0.917
VO_2 (mL min^{-1} kg^{-1})	31.1 ± 8.0	34.2 ± 4.3	− 0.416	− 0.94; 0.08	0.096
AC (%)	23.0 ± 10.4	22.98 ± 4.2	0.015	− 0.55; 0.58	0.958
Spatial awareness test (Neurotracker)					
Score	0.49 ± 0.1	0.50 ± 0.1	− 0.089	− 0.56; 0.39	0.713

REP regular exercise program, *IEP* intensified exercise program, *PP* peak power, *LP* low power, *FI* fatigue index, *AC* aerobic contribution

to other factors related to the environment and lifestyle, such as exposure to evening artificial light, increased screen time and psychosocial pressures. However, athletes have in addition to face many constraints related to elite sport practice, such as strict schedules, competitions, travel, change in training environments, and high training demands.

As regards the acute effect of the additional training session on sleep, an improvement in sleep duration and quality was obtained. Although wake time was set in our protocol, the same wake-up time that these athletes had in everyday training was kept, giving them 10-h opportunity to sleep. These findings are at variance with previous studies claiming that intense exercise can alter sleep in elite athletes, at least in the short term, chiefly because in most of these studies, it was early-morning training sessions, strict schedules, change in sleep environment and pre-competitive stress that caused the disruption of sleep in athletes (Sargent et al. 2014a, b; Schaal et al. 2015; Kölling et al. 2016; Pitchford et al. 2017; Thornton et al. 2017). We assume that it is important to distinguish between intense exercise–sleep interaction and elite sport-sleep interaction, which takes on a broader dimension and includes other factors and commitments influencing sleep. For instance, the study by Schaal et al. (2015) took place just before the 2012 Olympic Games qualification tournament (Schaal et al. 2015), and the study by Kölling et al. (2016) took place during preparation for the World Rowing Cup (Kölling et al. 2016). In both cases, sleep parameters may have been further influenced by pre-competition anxiety and stress. It is further assumed that the disturbed sleep during camps may be partly due to the change in the sleep environment or opportunity time for sleep (Pitchford et al. 2017; Thornton et al. 2017). Pitchford et al. (2017) clearly demonstrated that a change in training environment adversely affects sleep quality (Pitchford et al. 2017).

The differences in the results could also be related to differences in dietary intakes and energy balance. Several recent studies indicate that diet quality affects sleep (St-Onge et al. 2016). Killer et al, (2017) even claimed that a high-carbohydrate diet preserves sleep quality during high-intensity exercise (Killer et al. 2017). Furthermore, it was shown that a negative energy balance could be implicated in sleep impairment during an intensive training period (Guezennec et al. 1994; von Rosen et al. 2016). It is important to note that although an extra energy cost due to increased energy expenditure was incurred in this study, energy intake was very high and sufficient to obtain a positive energy balance even allowing for the energy cost induced by the additional training, which is not always the case in other sports. To our knowledge, few studies have tested the effect of intensified training on sleep outside of elite sport commitments. Killer et al. (2017) found that high-intensity training disturbed sleep. However, energy balance data were not reported, and this study was conducted in adult athletes over a longer period.

We emphasize that it is quite possible that intensive training may have a gradient of effects between short-, medium- and long-term. However, a recent study by Thornton et al, (2018) during pre-season in rugby players supports our results, and shows that increased training load was associated with increased sleep efficiency and increased requirement for sleep.

Young elite rugby players tend to up-regulate their energy intake according to perceived exercise energy expenditure, according to our previous work (Thivel et al. 2015). However, energy intake at next-day breakfast remained unchanged. The intensified exercise–sleep interaction in this study may drive a different nutritional response than in prior studies that exclusively focused on the effect of acute exercise. The rise in percentage of calories from protein could be explained by increased protein requirement after IEP. However, further studies are needed to confirm nutritional adaptation to intensified exercise–sleep interaction over at least a 24-h period. Concerning physical performance, studies report reduced performance on incremental tests after a 9-day intensified training program (Killer et al. 2017), and reduced psychomotor skills after a week of intense training (Suppiah et al. 2016). Moreover, Guezennec et al. (1994) report that energy imbalance is associated with sleep disturbance, potentially leading to a decrease in the production of aerobic and anaerobic energy (Guezennec et al. 1994). However, in this study, neither sleep nor next-day performance were negatively affected by one day of intensified training. Instead, an improvement in aerobic submaximal test performance was noted. Overall, our results argue for a good recovery rate from acute intensified exercise among adolescent rugby players, with an improvement in sleep quality.

Limitations of this study

To our knowledge, this is the first study examining the short-term effects of intensified exercise on sleep in young high-performance athletes outside of sport commitments while controlling dietary intake and energy balance. However, this study presents several limitations. First, wake-up time was set in our protocol. Even though this could be considered as an influencing factor, being a part of sports commitments, we gave the athletes a total opportunity time for sleep of 10 h, which is much higher than that provided in other studies, particularly during training camps. Moreover, all participants in this study presented an evening chronotype: the results might have been different if participants had the other chronotype. Furthermore, armband measures are not very precise, especially for physical activity among athletes. However, this tool did enable us to collect data in an outpatient setting. Future studies using sleep EEG would be of great interest to obtain further information on sleep architecture and stage variation.

Conclusion

Young rugby players present disturbed sleep. The effect of intensified training on sleep remains controversial in the literature. However, our findings suggest that young athletes increase their sleep time and efficiency in response to 1 day of intensified exercise in their usual training environment, with enough opportunities for sleep and a positive energy balance. This suggests that short-term intensified exercise was associated with an increased sleep efficiency and an increased requirement for sleep in adolescent athletes. It is, nonetheless, possible that an increase in exercise intensity and duration higher than that reached in our protocol and / or repeated for a longer period might have a negative effect. Neither next-day dietary intake nor performance was adversely affected.

The training level corresponding to the threshold of positive effects on sleep quality in the medium- and long-term remains to be determined. Further work is also needed to clarify to what degree disturbed sleep patterns in adolescent athletes are primarily attributable to adolescence, to the constraints of elite sport, or to intense training.

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Compliance with ethical standards

Conflict of interest The authors report no conflict of interest.

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