TITLE: EVIDENCE OF DISTURBED SLEEP AND INCREASED ILLNESS IN OVERREACHED ENDURANCE ATHLETES.

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Running title: Overreaching, sleep and illness

Disclosure funding received for this work: We received funding for research on which this article is based from the French Anti Doping Agency. The authors report no conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

ABSTRACT

Purpose: To examine whether i) objective markers of sleep quantity and quality are altered in endurance athletes experiencing overreaching in response to an overload training program and ii) whether potential reduced sleep quality would be accompanied with higher prevalence of upper respiratory tract infections in this population.

Methods: Twenty seven trained male triathletes were randomly assigned to either overload (*n*=18) or normal (CTL, *n*=9) training groups. Respective training programs included a 1-week moderate training phase, followed by a 3-week period of overload or normal training, respectively and then a subsequent 2-week taper. Maximal aerobic power and oxygen uptake ($\dot{V}O_{2max}$) from incremental cycle ergometry were measured after each phase, whilst mood states and incidences of illness were determined from questionnaires. Sleep was monitored every night of the 6 weeks using wristwatch actigraphy.

Results: Nine of the 18 overload training group subjects were diagnosed as functionally overreached (F-OR) after the overload period, as based on declines in performance and $\dot{V}O_{2max}$ with concomitant high perceived fatigue ($p<0.05$), whilst the nine other overload subjects showed no decline in performance (AF, $p>0.05$). There was a significant time × group interaction for sleep duration (SD), sleep efficiency (SE) and immobile time (IT). Only the F-OR group demonstrated a decrease in these three parameters (-5.4±5.3%, -2.1±2.0% and -5.7±5.0%, for SD, SE and IT, respectively, $p<0.05$), which was reversed during the subsequent taper phase. Higher prevalence of upper respiratory tract infections were also reported in F-OR (67%, 22%, 11% incidence rate, for F-OR, AF and CTL, respectively).

Conclusion: This study confirms sleep disturbances and increased illness in endurance athletes who present with symptoms of F-OR during periods of high volume training.

Keywords: fatigue; overtraining; endurance training; recovery; immunity

INTRODUCTION

Paragraph 1. Increases in training intensity or volume are typically undertaken by athletes in an attempt to enhance physiological adaptation and improve physical performance. However, when the balance between appropriate training stress and adequate recovery is disrupted, an abnormal training response may occur and a state of short-term "overreaching" (functional OR, F-OR) (23) may develop, resulting in a decline in performance. Even though the F-OR state is generally reversed when an appropriate period of recovery is provided (~1-3 weeks) (18, 23), it can compromise competition outcomes in the short term, particularly when insufficient recovery is available prior to competition. However, critical reviews of existing scientific literature continue to conclude that the underlying causes of F-OR in endurance athletes remain uncertain (11, 23, 26, 36).

Paragraph 2. One of the most commonly reported methods for managing fatigue and enhancing recovery is obtaining adequate passive rest and sufficient sleep (25, 31). The restorative qualities of sleep for maintaining optimal bodily function are well recognized. The recovery of cognitive processes and metabolic functions, both of which are important contributors to exercise performance, can be affected by the quality and quantity of sleep (31). Despite health-based survey research reporting associations between regular moderate physical activity and better sleep (5), few studies have reported alterations in sleep quality in response to highly demanding training programs (19, 35). Taylor et al. (35) measured sleep via polysomnography during the ‘onset of training’, ‘heavy training’ and during the ‘pre-competition taper’ in elite female swimmers. Sleep onset latency, time awake after sleep onset, total sleep time, rapid eye movement and sleep times were similar at all three training phases but the number of movements during sleep was significantly higher (6%) during higher training volumes, suggesting some alteration to sleep. Nevertheless, the improvement in performance time and low levels of tension and anger at peak training suggests that the swimmers were not F-OR. Recently, Fietze et al. (7) used wrist actigraphy during a 67-day period of high physical and mental stress to study sleep patterns in 24 classical ballet dancers before a ballet premiere performance. They found small but significant reduction in sleep duration (-6%), in sleep efficiency (-

2%), in time in bed (-3%) and an increase in wakefulness after sleep onset (+3%). Sleep onset latency did not change. Nevertheless, these authors did not report changes in physical performance in response to the prescribed overload program, making clear conclusions for sleep disruption in OR athletes difficult. However, studies during which sleep was monitored in athletes who demonstrated clear signs of OR (i.e. high perceived fatigue and decreased performance), remain few and involve self-reporting of reduced perceived subjective sleep quality (13, 14). Given such equivocal findings, a recent joint consensus statement led Meeusen et al. (23) to recommend additional research to determine the relationship between F-OR and altered sleep patterns.

Paragraph 3. Past research showed that aspects of both innate and adaptive immunity are depressed during sustained periods of heavy training (for review, (38)). An imbalance between training loads and recovery has been shown as a major contributor to illness (38). These abnormalities share similarities with impairment in immune function observed after moderate sleep deprivation (33). Vgontzas et al. studied the effects of modest sleep restriction from 8 to 6h per night for 1 week in 25 young, healthy, normal sleepers for 12 consecutive nights in a sleep laboratory (37). Their results showed that modest sleep loss is associated with significant increased secretion of pro-inflammatory cytokines, suggesting a link between the recuperative processes of sleep and the immune system. Similarly, Cohen et al. (4) showed that insufficient sleep volume over consecutive days can impair immune function, and increase the risk of developing upper respiratory tract infections. These authors reported that participants with less than 7 hours of sleep were 2.94 times more likely to develop a ‘cold’ than those with 8 hours or more of sleep once administered nasal drops containing a rhinovirus and monitored for ensuing development of a clinical cold. The association with sleep efficiency was also graded, with participants reporting <92% sleep efficiency 5.5 times more likely to develop a cold than those with >98% efficiency. Taken together, these results have led some authors to suggest that the potential immunosuppressive effects of overreaching may act through sleep disturbances (38). However, no scientific investigation to date provides evidence of this relationship to substantiate this argument.

Paragraph 4. The aim of the present study was therefore to determine whether changes in objective sleep parameters were evident between an experimental group of triathletes developing F-OR compared to a control group. After one week of light training (baseline), the experimental group completed a 3-week overload period followed by a 2-week taper. By programming intensified training over a large population of endurance athletes (n = 28), we hypothesized that some participants would demonstrated signs of F-OR (*i.e.* transient reduced performance). By this way, the present research gave us also the opportunity to determine whether sleep disturbances would be observed during an overload period in participants led to F-OR. In the light of past literature, we hypothesized that the development of F-OR would be accompanied by a decline in sleep quality and sleep quantity. Furthermore, we investigated whether potential presence of F-OR and reduced sleep quality in F-OR athletes would be accompanied with higher prevalence of upper respiratory tract infections (URTI).

MATERIAL AND METHODS

Subjects

Paragraph 5. Forty well-trained triathletes volunteered to participate in this study. All subjects had been competing for 3 years and were training a minimum of 7 times per week. During the experimental period, 7 subjects did not follow the protocol due to injury or personal obligations and were excluded from subsequent analyzes. Additionally, 5 participants, who worked at night with irregular schedules were excluded from subsequent analyzes. One subject was also excluded due to technical problems with equipment. The final sample size included in analysis was n = 27. The experimental design of the study was approved by the Ethical Committee of Saint-Germain-en-Laye (acceptance no. 12048) and was conducted in accordance with the Declaration of Helsinki. Prior to participation, subjects underwent medical assessment with a cardiologist to ensure normal electrocardiograph patterns and obtain a general medical clearance. All subjects were free from chronic diseases and were not taking prescribed medication at the commencement of the study. After comprehensive verbal and written explanations of the study, all subjects gave their written informed consent to participate.

Study design

Paragraph 6. An overview of the study design is shown in Figure 1. The subjects were randomly assigned to either the control group (*n* = 9) or the overload training group (*n* = 18) according to a matched group experimental design based on maximal aerobic power, habitual training volume and years of past experience in endurance sports. All subjects had regularly competed in triathlons for at least three years and were training a minimum of 10 $h \cdot wk^{-1}$. The training of each triathlete was monitored for a period of 9 weeks in total, which was divided into a pre-testing phase and then three distinct experimental phases. Both the pre-testing phase and the first phase were the same for for all groups. The pre-testing phase consisted of 3 weeks during which the subjects completed their usual training regime without any study intervention (*i.e.* normal training load). The first experimental phase (Baseline) consisted of one week of moderate training load during which the subjects were asked to reduce their habitual training volume by ~50% while maintaining the training intensity. This mini-taper was selected according to the guidelines for optimal tapering in endurance sports (2). During the second experimental period (overloading phase), the overload group completed a 3-week overload program designed to deliberately overreach the subjects. The duration of each training session of the normal (pre-testing) training period was increased by 30% (*e.g.* a 1 hour run including 8 repetitions of 400 m at the maximal aerobic running speed was converted into a 80 min run including 11 repetitions of 400 m at the maximal aerobic running speed). As particualr subjects were unable to accommodate such prolonged -duration cycling sessions (≥ 5 hours) into their routines, these specific sessions were split (*e.g.* a 5 h cycling session was converted into two sessions of 2h30). The participants reproduced the same training program during each week of the overload period, so that both the content and the weekly distribution of the training sessions remained consistent. The control group repeated its habitual training program during this period. Next, all the participants completed a two-week taper period (third experimental phase, Taper), where their normal training load was decreased by 50% each week (*e.g.* a 1 hour run including 8 repetitions of 400 m at the maximal aerobic running speed was converted into a ~30 min run including 4 repetitions of 400 m at the maximal aerobic running speed). All training sessions were performed by the triathletes in their own training structure according to the training program established by the same sport scientist. Throughout the entire study, the same sport scientist was responsible for coaching and controlling the training loads of all subjects. To avoid injuries, particular attention was devoted to daily feedback obtained from the triathletes. Before the beginning of the experimental period, the subject reported once to the laboratory to become familiarized with the maximal incremental cycling test (described below) and the daily testing used during the protocol (sleep actigraphy and questionnaires). Testing was perfromed on 3 occasions (Figure 1), including Pre (ie. after baseline phase), Post (after overload phase) and Taper (after taper phase), respectively.To ensure that performance variations during the maximal incremental cycling tests were due to the training regimen and not to the training session(s) performed the day before each test, the subjects respected a 24 h rest period before each laboratory session.

Training monitoring

Paragraph 7. Training volume and intensity were calculated and controlled on the basis of heart rate (HR) measurement (Polar, Kempele, Finland). For all subjects, HR was measured every 5 s during each training session over the entire protocol. The distribution of HR into training zones was subsequently calculated using three HR zones: (1) ≤ HR at 2 mmol.L^{-1}, (2) between HR at 2 mmol.L^{-1} and HR at lactate threshold and (3) HR values superior to HR at lactate threshold. Given that the relationship between blood lactate accumulation and HR values at exercise can be influenced by a heavy training load program (17), these reference HR values were reassessed after each maximal incremental cycling test.

Laboratory testing

Paragraph 8. During the 48 h prior to each maximal incremental cycling test, the subjects received specific nutirtional guidelines in order to ensure muscle glycogen stores were replenished. Specifically, they were instructed to eat until satiety was reached during each lunch. Breakfast consisted of a variety of macronutrients from both solid and liquid energy sources. The selected foods included an assortment of cereals, bread, fruit, yogurt, milk, juice, ham and cheese. For lunch and dinner, the subjects consumed a mixed salad as starter, then white meat during lunch and fish during dinner. The side plate consisted of a mixed of 50% carbohydrates (i.e., pasta, nice, noodles) and 50% of vegetables (i.e., green beans, broccoli, tomatoes). One piece of fruit and tub of yogurt were added as dessert, at both lunch and dinner. To ensure the subjects were well-hydrated on each testing day, they were instructed to ensure the maintenance of a well-hydrated state.

Paragraph 9. *Profile of mood state.* Before exercise testing, subjects were asked to complete the profile of mood state (POMS) questionnaire to assess overall mood disturbance (21). The POMS questionnaire is a 65-item Likert scale questionnaire, which provides measures of six specific mood states: vigor, depression, fatigue, anger, anxiety, and confusion.

Paragraph 10. *Performance and* $\dot{V}O_{2max}$. Maximum oxygen uptake (V̇O2max) was assessed on an electronically braked cycle ergometer (Excalibur Sport, Lode®, Groningen, The Netherlands) equipped with standard 170-mm cranks and the athletes used their own shoes. Positions of the handlebars and seat height were adjusted to the measures used by the athletes on their own bike and replicated between sessions. The test was performed until complete exhaustion to estimate $\dot{V}O_2$max and maximal aerobic power. This exercise protocol started with a warm-up of 5 min at a workload of 100 W, followed by 5 min at 150 W and 5 min at 200 W. Thereafter, further increments of 25 W were added every 2 min until volitional exhaustion. Subjects wore a face mask covering their mouth and nose for breath collection (Hans Rudolph, Kansas City, MO, USA), and oxygen and carbon dioxide concentration in the expired gas was continuously measured and monitored as breath-by-breath values

(Quark, Cosmed®, Rome, Italy). The gas analyzers and the flowmeter of the applied spirometer were calibrated prior to each test.

Paragraph 11. After the test, breath-by-breath values were visually inspected and averaged over 30 s. The highest 30-s average value was used as $\dot{V}O_{2max}$. Performance (Wmax) was calculated as Wmax = Wcompl + 25 × (t/120); Wcompl is the last completed workload, and t is the number of seconds in Wcompl.

Paragraph 12. *Perceived exertion*. The rating of perceived exertion (RPE) was measured verbally using the Borg 6-20 scale (1) immediately at the end of the maximal incremental cycling test. The subjects completed standard anchoring procedures with the scale at the start of the study and were reminded of its correct use before each maximal incremental cycling test throughout the experiment.

Sleep monitoring

Paragraph 13. All subjects were monitored continuously using an Actiwatch worn on the non-dominant wrist (Cambridge Neurotechnology Ltd. UK), with the epoch length set to 1 minute. Athletes were monitored in the home environment every day at baseline (7 days), during overloading (21 days) and during the taper (14 days) (see Figure 1). Mean behavioural activity over the whole recording period was automatically calculated using the Sleepwatch software (Actiwatch activity and sleep analysis version 5.28, Cambridge Neurotechnology Ltd., UK). Wristwatch Actigraphy is a non-intrusive, cost-effective tool used to estimate sleep quantity and quality which has been compared to polysomnography, showing an accuracy of up to 80% in sleep disordered patients for total sleep time and sleep efficiency (16) and as such is widely used in the sleep literature (24, 34). In a recent review on the role and the validity of actigraphy in sleep medicine, Sadeh concluded that according to most studies, actigraphy has reasonable validity and reliability in normal individuals with relatively good sleep patterns (29).

Paragraph 14. Eloquent sleep-wake scoring can be reliably obtained only with additional information provided in manually completed sleep logs (7). All participants were therefore requested to complete daily sleep diaries. The subjects were asked to record the times of going to bed, falling asleep, waking up, and leaving the bed. Additionally, the subjects were asked to mark the time of switching off the light to sleep and wake-up time with a push of the button on the face of the actiwatch.

Paragraph 15. Individual nights of sleep were analyzed for the following range of variables: time in bed, bedtime, get-up time, sleep latency, actual sleep time, percent time sleeping whilst in bed (sleep efficiency), and sleep restlessness (fragmentation index) and immobile minutes. The following dependent variables were derived from the sleep diary and activity monitor data:

- Time in bed (h): the amount of time spent in bed attempting to sleep between bedtime and get-up time.
- Bedtime (hh:mm): the self-reported clock time at which a participant went to bed to attempt to sleep.
- Get-up time (hh:mm): the self-reported clock time at which a participant got out of bed and stopped attempting to sleep.
- Sleep onset latency (min): the period of time between bedtime and sleep start.
- Actual sleep time (h:min): The time asleep from sleep start to sleep end.
- Sleep efficiency (%): sleep duration expressed as a percentage of time in bed.
- Fragmentation index: A measure of restlessness during sleep, using the percentage of epochs where activity is > 0.
- Immobile time (min): The actual time spent immobile during time in bed.

Paragraph 16. The term ‘sleep quality’ in this investigation is determined by wrist actigraphy by measures of sleep efficiency and fragmentation index, however this is different from ascertaining sleep quality from sleep stages measured by polysomnography.

Paragraph 17. In order to quantify how the training weeks affected the perceived sleep quality, the participants reported their perceived feelings on a 7-point scale, ranging from ‘very very good’ to ‘very very poor’ after waking up each morning. Additionally, the effect of the training regimen on perceived fatigue?? was recorded each week and? on the morning before the maximal incremental cycling test via a visual 0-100 analog scale (from "no fatigue" to "maximum fatigue").

Illness symptoms

Paragraph 18. During the 6-week experimental period, the subjects were required to complete a health questionnaire (URTI symptoms and gastrointestinal-discomfort symptoms) on a weekly basis, as performed in previous studies (8, 9). They were not required to abstain from medication when they were suffering from illness symptoms, but they were required, on a weekly basis, to report any unprescribed medication taken, visits to the doctor, and any prescribed medications. The illness symptoms listed on the questionnaire were sore throat, inflammation in the throat, runny nose, cough, repetitive sneezing, fever, joint aches and pains and headache. Two usual items of URTI diagnosis (*i.e.* muscle soreness and loss of sleep) were not included given that they could be potentially influenced by training overloading and not necessarily the signs of illness. The numerical ratings of light, moderate and severe (L, M, or S, respectively) were scored as 1, 2, and 3, respectively. In any given week of total symptom score ≥ 12 was taken to indicate that a URTI was present. This score was chosen in previous studies (8, 9) because to achieve it a subject would have to record at least three moderate symptoms lasting for 2 days or two moderate symptoms lasting for at least 3 days in a given week. A single URTI episode was defined as a period during which the weekly total symptom score was ≥ 12 and separated by at least 1 week from another week with a total symptom score ≥ 12. Subjects were also asked to rate the impact of illness symptoms on their ability to train (normal training maintained, training reduced, or training discontinued; L, M, or S, respectively). The gastrointestinal-discomfort symptoms listed on the questionnaire were loss of appetite, stomach upset, vomiting, abdominal pain, and diarrhea. These symptoms were rated and scored the same way as the illness symptoms (8, 9).

Data analysis

Paragraph 19. As per the methods of previous research (17), the subjects in the OR group were distributed into two subgroups according to their response to the overload period and during the subsequent taper. The triathletes who demonstrated decreased performance (vs. Pre) and high perceived fatigue ("very tired" to "extremely tired" on the POMS scale) at Post with subsequent performance restoration or supercompensation were diagnosed as functionally overreached (F-OR group). The remaining subjects in the overload group who maintained or increased their performance after the overload period, despite increased perceived fatigue, were considered acutely fatigued (AF, 21). Additionally, because extended monitoring reduces the inherent measurement errors in actigraphy and increases reliability (29), subsequent analyses were conducted using the mean value of each sleep parameter over each training phase (*i.e.* baseline, overload, taper).

Statistical analysis

Paragraph 20. Normality of data was tested using a Kolmogorov–Smirnov test. Values at baseline for age, weight, height, past experience in endurance sport, MAP and $\dot{V}O_{2max}$ were compared between groups (*i.e.*, CTL, AF, F-OR) using a one-way analysis of variance (ANOVA). Two-way (group × time) ANOVAs were used to examine differences in dependent variables (*i.e.*, $\dot{V}O_{2max}$, RPE, POMS items, perceived sleep quality and actimetry data during sleep) between group means at each time point. When the sphericity assumption in repeated-measures ANOVAs was violated (Mauchly's test), a Geisser–Greenhouse correction was used. If a significant main effect was found, pairwise comparisons were conducted using Duncan's *post hoc* analysis. These statistical tests were conducted using Statistica (Version 7.0, StatSoft, Tulsa, OK) and the data are presented as means and standard deviation (SD).

Paragraph 21. The magnitude of the within-group changes in performance were expressed as standardized mean differences (Cohen's *d*), which were calculated using the pooled standard deviations (3) in modified statistical spreadsheets (12). The magnitude of the percentage change in time was interpreted by using values of 0.3, 0.9, 1.6, 2.5 and 4.0 of the within-athlete variation (coefficient of variation) as thresholds for *small*, *moderate*, *large*, *very large* and *extremely large* differences in the change in performance between the trials. The typical variation (CV) for performance during the maximal incremental cycling test was established using the values collected in CTL group during the protocol.

RESULTS

Paragraph 22. Changes in weekly mean training volume, the distribution of the relative training time spent in the intensity zones and the number of training sessions per week in the three groups during each respective training phase are presented in Table 1. The results demonstrated that the three experimental groups successfully adhered to the prescribed training program, and that the respective OR groups increased training volume substantially more than the CTL group ($p<0.001$).

Assessment of the OR syndrome.

Paragraph 23. At Pre, all subjects reported low perceived fatigue at rest (*i.e.* all subjects responded "not at all" or "a little" on the POMS fatigue item), confirming that they were not already in an OR state. Nine of the 18 overloaded subjects demonstrated a *moderate* to *very large* decrease in performance (- 10 ± 4 W) at Post followed by a *small* to *large* performance restoration or supercompensation effect at the end of the Taper (5 ± 5 W, Table 2). This reduced performance was systematically associated with a concomitant high fatigue score at Post (*i.e.* "quite bit" to "extremely" on the POMS fatigue item, Table 2). On the basis of this analysis, these 9 triathletes were considered as "functionally OR", the short term form of OR (F-OR) (23). The 9 other subjects in the overload training group demonstrated higher perceived fatigued but no reduction in performance. According to the nomenclature of Meeusen et al. (21), they were not diagnosed as OR and instead considered acutely fatigued (AF). Thus, the subsequent results are presented for 9 F-OR subjects (F-OR group), 9 AF subjects (AF group) and 9 control subjects (CTL group). Mean (±SD) age, height and weight were 37 ± 6 years, 182 ± 6 cm, 72 ± 9 kg for the CTL group, 35 ± 8 years, 179 ± 9 cm, 73 ± 8 kg for the AF group 35 ± 5 years, 180 ± 5 cm, 72 ± 9 kg for the F-OR group. There were no differences between groups for these descriptive parameters (P>0.05)???

Perceived sleep quality and sleep actigraphy data

Paragraph 24. Measures of sleep data for the three experimental groups are presented in Tables 3. There was no significant time × group interaction in perceived sleep quality (p = 0.11), time in bed (p = 0.09), bedtime (p = 0.77), get-up time (p = 0.42), sleep latency (p = 0.33) and fragmentation index (p = 0.35). A significant interaction effect was observed for actual sleep time (p = 0.006), sleep efficiency (p = 0.003) and immobile time (p = 0.004). A progressive decrease of these three parameters was systematically observed only in the F-OR group during the overload period compared to baseline (actual sleep time, p = 0.01, sleep efficiency, p = 0.05; immobile time, p = 0.005, during the last week of the overload period). All of these parameters were progressively restored to baseline values during the ensuing taper.

Infection-Symptom Incidence

Paragraph 25. Analysis of illness questionnaires indicated that 8 subjects reported at least one episode of URTI during the training overload and/or tapering periods. The occurrence of URTI symptoms during the protocol is presented in Table 4. The proportion of subjects who experienced symptoms of infection was higher in the F-OR group (n = 6, 67% of total infection cases) than in AF (n = 2, 22%) and CTL groups (n = 1, 11%). No subjects reported symptoms of gastrointestinal-discomfort during any phase of the training program.

DISCUSSION

Paragraph 26. In the present study, we studied nocturnal actimetry in a group of trained triathletes who completed an overload training program followed by a two week taper period and developed symptoms of F-OR in comparison to control counterparts without signs of training intolerance. The most important finding indicated a progressive decrease in the indices of sleep quality, alongside small reductions in sleep quantity, during the overload period in the F-OR athletes, which was progressively reversed during the subsequent taper. Furthermore, higher prevalence of upper respiratory tract infections was also reported in this F-OR group.

Paragraph 27. Signs of decreased sleep quality in overreached or overtrained endurance athletes have been reported by previous researches. Jurimaë et al. (13) monitored the recovery-stress state in competitive male rowers over a six-day training camp in response to an average increase in training load by approximately 100% compared to average weekly loads. Using the Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport) (15), these authors showed decreased levels of perceived sleep quality, suggesting that recovery may not have been adequate during this training camp, leading to performance impairment and genesis of high perceived fatigue (*i.e.* overreaching). However, given the lack of objective markers of sleep actimetry, the reliance on perception of sleep quality is problematic to then associate sleep disruption with overloading. In a similar vein, Matos et al. (22) recently reported frequent perceived sleep problems was one of the most reported physical symptoms by athletes who had experienced persistent daily fatigue and a significant decrement in performance that lasted for long periods of time. Altogether, these results suggest that heavy load training may exert a negative effect on sleep quality, but to date limited literature provides objectively measured changes in sleep characteristics during periods of confirmed F-OR.

Paragraph 28. The novelty of the present research provides objective measures of sleep in a group of trained athletes demonstrating differentiated performance responses (*i.e.* acute fatigue vs. functional overreaching, 21) during a 6-week training program involving periodic high training load.

Time in bed and sleep latency were not different at any period of the training program in the F-OR group; however, these subjects demonstrated a progressive decrease in actual sleep duration, sleep efficiency and immobile time during the overload period, suggesting substantial sleep disturbances. This finding was reported in at least 7 of the 9 F-OR athletes for each parameter. During the same period, mean sleep values remained unchanged in the control and in the AF groups. To the best of our knowledge, this study is the first to show such alterations in objective markers of sleep quality during a period of intensified training that resulted in overreaching. Whilst causation is not inferred, it is possible the sleep disturbance may have been related to mild muscle fatigue or soreness resulting from the high training loads. Certainly given neither bed time, sleep latency or time spent in bed were altered, the reduction in sleep duration may result from the lowered efficiency due to difficulty in remaining immobile during sleep. However, despite such measured sleep disruption, subjective quality of sleep remained unaltered; suggesting some disconnect in actual and perceived measures of sleep. Indeed, despite 8 of the F-OR athletes reporting reduced scores for perceived sleep quality, the magnitude in change was insufficient to reach statistical significance.

Paragraph 29. Although the results suggest that F-OR athletes demonstrated a modest decrease in quality and quantity of sleep during the overload period, it remained considerably better than that experienced by sleep disorder patients (30), extreme sleep deprivation (32) or by athletes in response to jet lag (20) or hypoxic exposure (27). Additionally, Halson et al. (10) reported larger sleep deficiency during the period leading to overtraining (< 6 hours per night) in a talented female sprint cyclist who developed signs of overtraining (*i.e.* persistent feeling fatigued and underperforming over months). The actual sleep time in the F-OR subjects during the overload training period remained higher than the values reported by Leeder et al. (19) in a cohort of elite athletes under normal training conditions. Nevertheless, we cannot exclude that the moderate changes observed in the F-OR during the present experiment would not unduly affect performance in elite athletes, where very small differences in performance can have large impact on the competition issue. It remains also unclear during the present study whether sleep disturbance was an etiological mechanism of overreaching, or simply just a symptom. Regardless, it is acknowledged that the reduction in sleep duration during F-

OR was small in the spectrum of sleep disturbances, and may suggest that sleep monitoring to detect F-OR may require extended periods of data collection. Further research is required to determine the relationship of sleep with training tolerance and adaptation, especially in athletes developing training maladaptations (*i.e.* overreaching, overtraining).

Paragraph 30. Given the purported relationship between prolonged reductions in sleep quality and quantity with increased risk of illness, it was interesting to observe a higher infection rate in the F-OR subjects during the present experiment. Of the 9 F-OR athletes, 5 reported increased URTI symptoms during the overload period and concurrent to the noted sleep disturbances, while only two cases were observed in the AF and CTL groups during the same period. Interestingly, this illness prevalence was the highest during the last week of the overload period, which is temporally aligned to when sleep disturbances reached their highest magnitude during the study, perhaps implying an accumulative effect. The observed decrease in sleep and increase in URTI during F-OR is in accordance with several previous studies reporting both innate and adaptive immunity are depressed during sustained periods of heavy training (38). This association suggests there is a link between the recuperative processes of sleep and the immune system (28). The current study provides supporting evidence that high volume training periods may result in increased URTI, alongside reduced sleep quality. However, again whether sleep disturbance was an etiological mechanism of URTI development as a result of overreaching, or simply coincidental symptoms remains to be elucidated, particularly given the relatively small reductions in sleep durations reported.

Paragraph 31. In conclusion, F-OR athletes showed objective signs of moderate sleep disturbances and higher prevalence of infections in the present study. These results were in contrast with control counterparts, who did not demonstrate any symptoms of training intolerance during the protocol. Whether poor sleep was a consequence of increased training causing the development of overreaching, or whether sleep disturbances were simply symptoms of OR remain unclear. Whatever the causative link between F-OR and sleep, we suggest that endurance athletes should be encouraged to ensure ideal sleeping environment (quiet, cool, and dark) and to implement short post-lunchtime naps, when they are exposed to high training load (6). The ability to nap for short periods during the day may be a useful skill for athletes to compensate the potential decline in sleep quality associated with development of F-OR. Further investigations are required to investigate the importance of sleep and its relationship with overreaching.

ACKNOWLEDGMENTS

This study was made possible by technical support from the French Federation of Triathlon. The authors are especially grateful to Frank Bignet and Benjamin Maze for their help and cooperation. We received funding for research on which this article is based from the French Ministry of Sport and the French National Institute of Sport, Expertise and Performance (Paris). The authors report no conflict of interest.

The authors report no conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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FIGURE 1. Schematic representation of the experimental protocol. Bicycle symbols represent maximal incremental cycling tests. Note that 9 subjects of the overload group developed symptoms of functional overreaching at Post (decreased performance vs. Pre associated with high perceived fatigue, F-OR group). The nine other overloaded subjects were only acutely fatigued (AF group).

FIGURE 2. Change in mean weekly sleep parameters from baseline values during the overload and taper phase in the three experimental groups. CTL: control; AF: acute fatigue; F-OR: functionally overreached. Gray areas and dashed lines represent 1xCV and 2xCV of the considered parameter during the 6-week protocol in the control group. *, significantly different from Baseline at $P < 0.05$; †, significantly different from the third week of the Overload period at $P < 0.05$.