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Original Article

# Effects of one night of induced night-wakings versus sleep restriction on sustained attention and mood: a pilot study

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ABSTRACT

*Objective:* Despite their high prevalence in daily life, repeated night-wakings and their cognitive and emotional consequences have received less research attention compared to other types of sleep disturbances. Our aim was to experimentally compare the effects of one night of induced infrequent night-wakings (of ~15 min, each requiring a purposeful response) and sleep restriction on sustained attention and mood in young adults.

*Methods:* In a within-between subjects counterbalanced design, 61 healthy adults (40 females; aged 20–29 years) underwent home assessments of sustained attention and self-reported mood at two times: after a normal (control) sleep night, and after a night of either sleep restriction (4 h in bed) or induced night-wakings (four prolonged awakenings across 8 h in bed). Sleep was monitored using actigraphy and sleep diaries. Sustained attention was assessed using an online continuous performance test (OCPT), and mood was reported online using the Profile of Mood States (POMS).

*Results:* Actigraphic data revealed good compliance with experimental sleep requirements. Induced night-wakings and sleep restriction both resulted in more OCPT omission and commission errors, and in increased depression, fatigue and confusion levels and reduced vigor compared to the normal sleep night. Moreover, there were no significant differences between the consequences of induced awakenings and sleep restriction.

*Conclusions:* Our pilot study indicates that, similar to sleep restriction, one night of life-like repeated night-wakings negatively affects mood and sustained attention.

## 1. Introduction

Night-wakings are ubiquitous throughout the life cycle. In adults, night-wakings often result from nocturnal child-care needs, occupational requirements, environmental disturbance, bladder pressure, and many other physiological, psychological and medical conditions [1–5]. Surprisingly, although there is a wide recognition of the potential detrimental effects of nocturnal awakenings, these effects have rarely been systematically studied using experimental designs. The purpose of this study was to address this neglected area of research.

Decades of sleep research have yielded evidence as to the detrimental effects of sleep loss and disruptions on various aspects of human functioning [6,7]. Specifically, sleep restriction (also referred to as partial sleep deprivation) has been shown to compromise several neurobehavioral and cognitive domains [8,9]. One of the cognitive functions that seem to be particularly sensitive to sleep restriction is sustained attention. Studies have repeatedly demonstrated that sleep loss is associated with poorer sustained attention, as measured by continuous performance tests (CPT) and the psychomotor vigilance test (PVT) [10–14]. This literature suggests that sleep restriction leads to a general slowing of response times, an increase in the number and duration of attentional lapses, and an increase in errors of commission or false alarms. Moreover, the loss of sleep extensively intensifies the gradual deterioration of performance with sustained focus throughout a cognitive task, known as the 'time-on-task effect' [11].

Compared to these cognitive effects, the emotional consequences of sleep restriction have received less attention in the literature [15]. Nevertheless, a meta-analytic review revealed that mood is negatively affected by sleep deprivation, more so than cognitive performance [16]. There is evidence suggesting a consistent decline in mood during sleep restriction [10,17]. Healthy sleep-deprived individuals tend to report more general distress and negative mood scores, as well as more symptoms of depression, anxiety and somatic complaints [18,19].

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Sleep fragmentation is another form of sleep loss that has been shown to adversely affect cognitive performance and mood. A number of studies have used experimental manipulations that are meant to briefly and repetitively interrupt sleep, creating electroencephalographic (EEG) arousals that mimic the arousals characteristic of obstructive sleep apnea or periodic limb movements [20]. Such empirical studies typically use tones to repeatedly disturb sleep or change its architecture, and some target specific sleep stages [21]. This type of sleep fragmentation has been found to hinder performance on tasks that involve vigilant attention [22–24], and to result in more reports of negative mood and depressive symptoms [25–27].

Despite its high prevalence, the fragmentation of sleep by recurrent full nocturnal awakenings has received very little research attention. This type of sleep disturbance may be less analogous to the abnormalities seen in sleep fragmentation related to breathing disorders or seizures, yet it bears relevance to a great many of the general public. Vast proportions of the population experience night-wakings regularly due to occupational demands, environmental circumstances or the very common parental need to tend to a child during the night. Such ‘disturbances’ often involve awakenings that require prolonged behavioral activity (eg giving advice when on call, or soothing a crying baby). If we consider, for example, parents of infants and young children, data based on a cross-cultural study of close to 30,000 parents in 11 countries indicate that 24.5% report an average of two night-wakings in their 0–3-year-old children [28]. An additional 19.5% of the parents report an average of three or more night-wakings. These high rates increase if only the first year of life is considered (28.5% and 27.6%, respectively). These rates demonstrate the ubiquitous nature of night-wakings in adults caring for young children and the need to explore the effects of sleep fragmentation of this nature. Correlative studies have associated such awakenings with reduced neurobehavioral performance, as well as with more negative mood and depressive symptoms in mothers of young children [2,29,30]. To our knowledge, no experimental studies have been conducted to investigate the cognitive and emotional consequences of this type of sleep disruption. Due to the vast prevalence of this phenomenon, experimental examination of the consequences of sleep repeatedly interrupted by prolonged full awakenings appears to be of great importance.

Direct experimental comparisons of different types of sleep disruption and their cognitive and emotional impact are also relatively scarce. To our knowledge, the cognitive consequences of partial sleep restriction and sleep fragmentation caused by prolonged night-wakings (designed to simulate nocturnal awakenings experienced by parents of young infants for instance) have not yet been scientifically compared. Moreover, the effects of different forms of sleep disruption on measures of mood have yet to be compared within the same experiment. The potential value of such comparison studies is considerable, since they may help establish direct links between different forms of sleep loss or disruption and their outcomes [20].

With regard to methodology, sleep deprivation, restriction, and fragmentation studies have traditionally been conducted in laboratory settings to maximize control over sleep schedules and measurement. However, recent studies have demonstrated the feasibility of conducting naturalistic studies investigating the effects of sleep disruptions, using actigraphy to monitor compliance with prescribed sleep schedules [13,31–33]. For example, in a pilot study of anesthetists, sleep disruption caused by on-call work, as measured using actigraphy, was associated with deteriorated vigilance performance [34]. Recent evidence has also confirmed the feasibility of conducting online tests of sustained attention, suitable for home-based experimental use [35,36]. These are important, in light of recent findings concerning the potential negative cognitive and emotional impact of the laboratory environment itself [37,38]. Moreover, the ecological value of naturalistic studies such as these is substantial, because they allow measurement of sleep patterns and related outcomes in participants’ natural settings.

To the best of our knowledge, the cognitive and emotional consequences of different types of sleep disruptions have not yet been experimentally compared in a home-based naturalistic setting. In this pilot study, we used a sleep schedule consisting of induced prolonged awakenings (of at least 10 min) in an effort to simulate the sleep of populations that experience such fragmentation due to demands of their life circumstances. The goal of the study was to evaluate the effects of sleep restriction compared to induced prolonged night-wakings (meant to simulate the phenomena of recurrent awakenings that require a behavioral response, commonly experienced by parents, on-call residents, etc.) on sustained attention and mood of young adults in their natural home environment. We hypothesized that, in comparison to normal sleep, both night of sleep restriction and night of induced night-wakings would lead to compromised performance on a sustained attention task and would have a negative impact on participants’ mood.

## 2. Methods

### 2.1. Participants

Sixty-one undergraduate students (40 females) participated in this study (mean age = 23.08 years; SD = 1.64; range = 20–29). Participants received research credit hours according to their academic requirements. Due to software compatibility problems, 13 participants failed to complete all online continuous performance tests (OCPTs), and were excluded from the relevant analyses. Additionally, sleep data of three participants were incomplete due to technical problems, and these were excluded from the relevant analyses. All participants reported good health and being free of prescription medications for health problems.

### 2.2. Measures

### 2.2.1. Sleep assessment

Activity-based sleep monitoring (actigraphy) and sleep diaries were used to monitor compliance with the sleep requirements. Actigraphy has been established as a non-intrusive reliable method for naturalistic studies of sleep–wake patterns in infants, children and adults [31,39,40]. The actigraph is a miniature wristwatch-like device that enables continuous recording of movements, which are later translated to valid sleep–wake measures. Participants were given actigraphs (Mini Motionlogger, Ambulatory Monitoring, Inc., Ardsley, NY, USA), with amplifier setting 18 and 1 min epoch interval according to the standard working mode for sleep–wake scoring. Actigraphic raw data were then translated into sleep measures [41].

Actigraphic sleep measures used in this study included: (i) true sleep time: sleep time excluding all periods of wakefulness during the sleep period; and (ii) number of long waking episodes: night-wakings lasting a minimum of 5 min. Daily sleep logs were completed by the participants and included information on sleep schedule and subjective sleep quality. The diary data were used to corroborate the actigraphic data, and to detect and correct any potential artifacts of these data.

### 2.2.2. Online continuous performance test

Sustained attention was assessed using the OCPT (eAgnosis Inc., Newark, DE, USA), which is a standard CPT designed and programmed for delivery over the Internet. It uses two geometric stimuli: equilateral triangles and circles, both presented in the middle of the screen within a rectangle that is presented constantly throughout the task. Each trial consists of a presentation of one geometric shape for 100 ms followed by a 1900 ms inter-trial interval. Participants are instructed to respond to the triangle shape (target) as fast as possible, and to inhibit responses to the circle shape (non-target).

The task contains two conditions: low target frequency and high target frequency. The first half of the test (low target frequency) consists of 224 trials (56 targets, 168 non-targets) with a target to non-target ratio of 1:3. In this half, the task is boring and fatiguing. In the second half of the test (high target frequency), the target to non-target ratio is reversed and is set to 3:1 (168 targets, 56 non-targets). In this half of the test, the participants are expected to respond most of the time, but occasionally must inhibit the tendency to respond. These two conditions were chosen because they reflect a conceptual distinction in the attention/CPT literature between a condition that taxes sustained attention and attention focusing in a dull and boring environment (low target frequency), and a condition that taxes primarily the ability to inhibit a prepotent response (high target frequency) [42].

Throughout the task the geometric shapes are presented in a fixed, pseudo-random sequence. To minimize practice effects, each half of the task is preceded by a 2 min practice phase reflecting the target to non-target ratios of the actual test to follow. Subjects are not informed about the practice nature of these 2 min sessions and consider these parts of the test. Total net test time (including the two practice sessions) is 19 min. Three breaks are allowed (following the first and second practice sessions and following the low target frequency session). Participants are instructed not to exceed 2 min of break time.

Responses with RTs that are faster than 150 ms are considered anticipatory and are removed from analyses. When a participant presses the spacebar more than once per stimulus presentation, only the data from the first response are included in the analysis. Two primary measures were extracted for analyses: (i) omission errors: failures to respond to the target; and (ii) commission errors: responding inappropriately to the non-target.

The OCPT has been validated against in-office administration of traditional CPT tasks [36]. Reliability and validity of the OCPT have been shown to be satisfactory among young adults. Furthermore, the OCPT has demonstrated sensitivity to sleep restriction to 4 h in comparison to 8 h of sleep [35].

### *2.2.3. Profile of Mood States (POMS)*

Mood was measured using the POMS, a well-validated self-report measure of mood states [43]. The original English version consists of 65 items, consisting of adjectives which are rated with regard to the participant's current mood on a six-point Likert scale ranging from 0 (not at all) to 5 (extremely). Answers provide standardized scores for six identified subscales: anger–hostility, confusion–bewilderment, depression–dejection, fatigue–inertia, tension–anxiety, and vigor–activity. Higher scores indicate more negative mood states, except for vigor–activity for which lower scores denote a more negative mood state. The POMS has high internal consistency, as well as predictive and constructive validity [44]. The Hebrew version consists of 64 items [45]. Measures of internal consistency (Cronbach's $\alpha$) for each subscale of the Hebrew version were computed and found adequate ($\alpha$ ranged from 0.78 to 0.95). An electronic version of the translated questionnaire was created so that the participants could complete their reports subsequent to sleeping in their natural environment.

## *2.3. Procedure*

This study was approved by the local ethics committee, and written informed consent was obtained from all participants. Participants were provided with actigraphs and instructed to wear them during five subsequent days. During these days, participants were instructed to complete daily sleep logs every evening prior to sleep and every morning upon waking. They were also instructed to avoid napping throughout the days of the experiment.

Participants were then randomly assigned to one of two groups: (a) sleep restriction: participants in this group ($n = 30$) were instructed to sleep no more than 4 h (from 03:00 to 07:00) on the experimentally manipulated night. To confirm wakefulness, participants were instructed to call the experimenters every hour, on which occasion they were sent a 10 min task via email and were asked to complete the task and e-mail it back to the experimenter; and (b) induced night-wakings: participants in this group ($n = 31$) were instructed to spend 8 h in bed on the experimentally manipulated night, and they were awakened four times (every 90 min) by telephone calls from the experimenters. Upon each of these four night-wakings, participants were sent a 10 min task via e-mail and were asked to complete the task and e-mail it back to the experimenter before resuming sleep.

Each participant was tested using an online computerized attention test and reported mood on two occasions: once following an experimentally manipulated night (sleep restriction night/induced wakings night), and once after a night of regular sleep, in which participants were instructed to spend at least 8 h in bed (see Fig. 1). To control for potential order effects, participants in each sleep condition were randomly assigned to one of two groups. One group was instructed to obtain 8 h of sleep during the first night of the protocol and to perform the OCPT and complete the POMS on the following morning. They were asked to complete these tasks 1 h after rise time to minimize sleep inertia effects. These participants were instructed to sleep their regular sleep schedule on the following nights, and their sleep was disrupted (either restricted or fragmented by awakenings) on the fourth night of the protocol. They were again asked to perform the OCPT and complete the POMS on the subsequent morning. The other group received the same instruction, the only difference being that the first night was the disrupted sleep night and the fourth night was a regular 8 h night.

While performing the OCPT, participants were instructed to avoid any distractions including phone calls, television, or other media or interpersonal stimulation. They were also instructed to shut down all other active windows or programs on the personal computer used to perform the test.

## 3. Results

The data analysis plan was aimed at assessing: (a) compliance of the participants with the experimentally imposed sleep schedule; (b) the effects of sleep restriction and induced night-wakings on cognitive performance as measured by the OCPT; and (c) the effects of sleep restriction and induced night-wakings on subjective mood variables, as measured by the POMS.

To control for order effects, a repeated measures ANOVA was conducted with day of experimentally manipulated sleep (first or fourth day of protocol) and night (normal sleep night or manipulated sleep night) as the independent variables and each of the sleep, mood and sustained attention measures as the dependent variables. No significant order effects were found, thus the order factor was excluded from further analyses.

### *3.1. Compliance with experimental sleep schedule*

To assess compliance with experimental sleep requirements we examined actual sleep time and long waking episodes (defined as wakings longer than 5 min), as monitored by actigraphy following the nights of prescribed 4 h, 8 h or fragmented 8 h of sleep (see

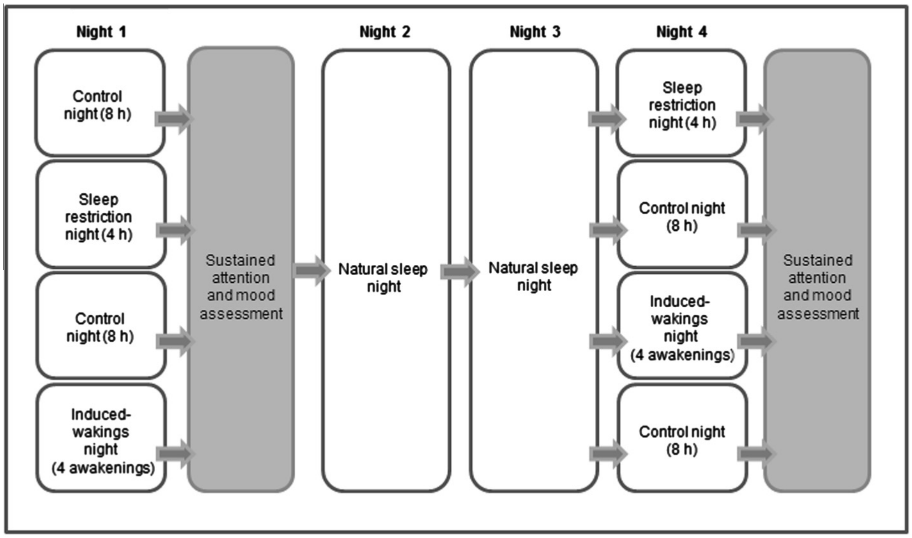

**Fig. 1.** Sleep schedule time-line in each of the four experimental conditions.

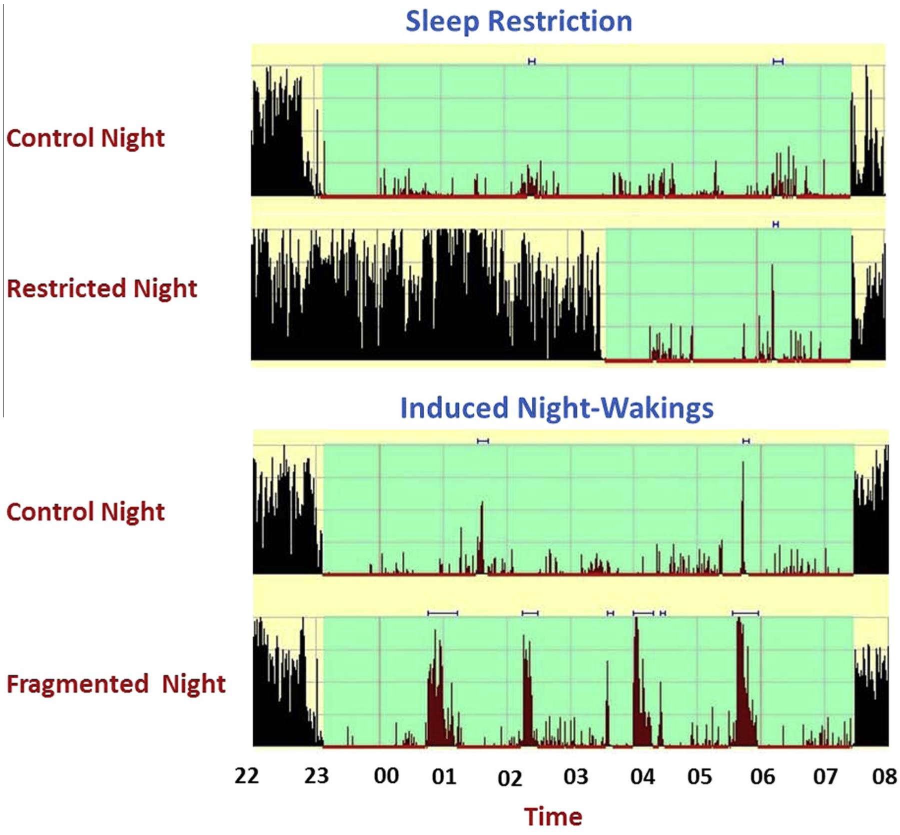

**Fig. 2.** Examples of raw activity data of (i) two nights of a participant in the sleep restriction condition (upper) and (ii) two nights of a participant in the induced night-wakings condition (lower). Each black line represents the subject's activity level in a given epoch. Areas with condensed tall black lines indicate wake periods or awakenings. In these examples, both subjects were given an 8 h sleep opportunity on the first night of the experiment (control night), and their sleep was manipulated (restricted or fragmented) on the fourth night; however, the order of these sleep schedules was randomized and counterbalanced in the study with half of the participants having their manipulated night on the first day and their control night on the fourth day.

Figs. 2 and 3). Three participants were excluded from sleep analyses due to incomplete sleep data, thus these analyses were computed with $n = 58$.

Two repeated measures ANOVAs with type of sleep manipulation (sleep restriction or induced night-wakings) and night (normal sleep night or sleep disruption night) as independent measures, and either true sleep time or long waking episodes as the dependent measures were computed.

As expected, a significant night effect was found for true sleep time [$F(1, 54) = 262.43$; $P < 0.0001$], as well as for long waking episodes [$F(1, 54) = 6.95$; $P < 0.01$]. Additionally, a significant night by manipulation type interaction effect was found for true sleep time

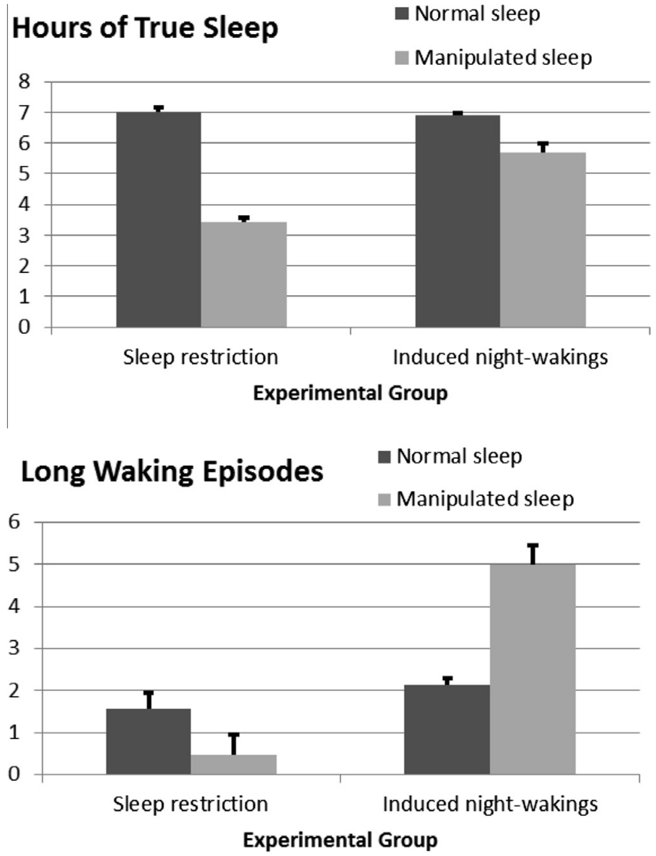

**Fig. 3.** Means and standard error bars for actigraphic true sleep time (upper) and long waking episodes (lower) in each group according to sleep requirements on the night of manipulated sleep (restriction or induced night-wakings) compared to the normal sleep night. On the normal sleep night, participants in both groups were instructed to spend at least 8 h in bed.

[$F(1, 54) = 55.89$; $P < 0.0001$], and for long waking episodes [$F(1, 54) = 35.36$; $P < 0.0001$].

### *3.2. Effects of induced night-wakings and sleep restriction on sustained attention*

Each participant completed the OCPT on two occasions: once after a night of normal sleep and once after a night of manipulated sleep (restriction/induced night-wakings). Due to software compatibility problems only 48 participants completed the OCPT on both occasions, thus these analyses were computed with $n = 48$. Also, outliers (one or two on each measure) were recoded using a winsorizing procedure so that values higher or lower than three standard deviations (SD) above average were coded as the compatible value for 3 SD [46].

Repeated measures ANOVA was conducted with type of sleep manipulation (sleep restriction or induced night-wakings) as a between-subject independent variable, night (normal sleep night or sleep disruption night) as a within-subject independent variable, and OCPT measures as the dependent variables.

A significant night effect on the general number of OCPT errors was revealed [$F(1, 44) = 15.82$; $P < 0.0003$], indicating that performance was significantly poorer following the night of initiated sleep disturbance compared to the normal sleep night. A significant night effect was also recorded for overall omission errors [$F(1, 44) = 17.33$; $P < 0.0001$], as well as for overall commission errors [$F(1, 44) = 4.28$; $P < 0.04$] (see Fig. 4). No type of sleep manipulation by night interaction effects were found for any of the OCPT errors, indicating that sleep restriction and induced night-wakings did not differ significantly in their effect on OCPT measures.

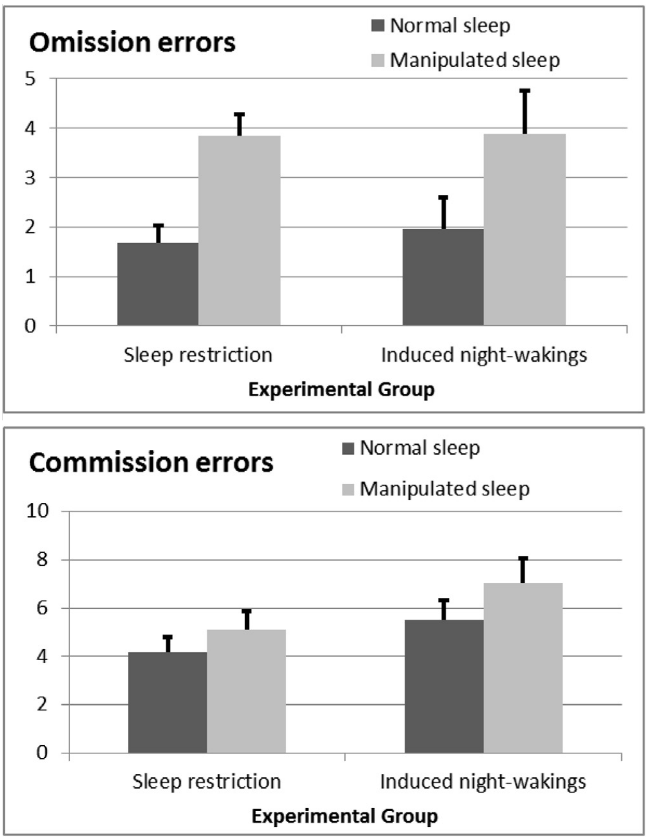

**Fig. 4.** Means and standard error bars for omission (upper) and commission (lower) errors in the online continuous performance test (OCPT). Comparison of performance following normal sleep versus sleep manipulation night (sleep restriction or induced night-wakings). No significant type of sleep manipulation by night interaction effects were found.

**Table 1**
Subjective mood measures following normal and manipulated sleep conditions.

| POMS subscale | Normal sleep (mean ± SD) | Manipulated sleep (mean ± SD) | $F$(1,57) Night |
|---|---|---|---|
| Anger–hostility | 0.47 ± 0.62 | 0.61 ± 0.73 | 3.65 |
| Confusion–bewilderment | 0.84 ± 0.68 | 1.08 ± 0.71 | 5.54$^{*}$ |
| Depression–dejection | 0.70 ± 0.52 | 0.99 ± 0.66 | 14.88$^{***}$ |
| Fatigue–inertia | 1.77 ± 0.77 | 2.20 ± 0.91 | 13.07$^{**}$ |
| Tension–anxiety | 0.65 ± 0.54 | 0.79 ± 0.62 | 2.37 |
| Vigor–activity | 1.92 ± 0.76 | 1.59 ± 0.85 | 14.82$^{***}$ |

POMS, Profile of Mood States.
*F*-values are related to the night effect (normal sleep compared to experimental sleep manipulation) beyond the type of sleep manipulation (sleep restriction compared to induced night-wakings). No significant type of sleep manipulation by night interaction effects were found.
$^{*}$ $P < 0.05$.
$^{**}$ $P < 0.005$.
$^{***}$ $P < 0.0005$.

### *3.3. Effects of induced night-wakings and sleep restriction on reported mood*

Both sleep restriction and induced night-wakings resulted in impaired subjective mood relative to the control sleep condition (see Table 1). Repeated measures ANOVA revealed significant night effects for the depression–dejection, vigor–activity, fatigue–inertia, and confusion–bewilderment subscales [respectively

$F(1, 57) = 14.88$, $P < 0.0003$; $F(1, 57) = 14.82$, $P < 0.0003$; $F(1, 57) = 13.07$, $P < 0.0006$; $F(1, 57) = 5.54$, $P < 0.02$]. These effects indicate that following the night of restricted sleep or sleep fragmented by awakenings, participants reported elevated depression, fatigue and confusion levels, and reduced vigor compared to their mood ratings following the night of normal sleep. No significant type-of-sleep manipulation by night interaction effects were found for the POMS subscales, indicating that mood was not differentially affected by sleep restriction and induced night-wakings. Significant night effects were not found for the anger–hostility and tension–anxiety subscales.

## 4. Discussion

To the best of our knowledge, this study is the first to experimentally compare the cognitive and emotional consequences of sleep fragmented by induced night-wakings with sleep restriction in a home-based naturalistic setting. Whereas most previous sleep fragmentation studies examined the effects of EEG arousals or very brief awakenings, we investigated the effects of full prolonged awakenings (of ~15 min), that we consider similar to the daily (or rather nightly) life experiences of a considerable portion of the population. The present results buttress the feasibility of conducting experimentally imposed sleep loss studies outside the laboratory, using actigraphy for sleep monitoring and online testing of mood and sustained attention. Actigraphic measures demonstrated acceptable compliance with the experimental sleep schedules. Sleep time was significantly reduced on the sleep restriction night compared to the normal sleep night. In addition, a significant increase in night-wakings was shown on the night of induced wakings, whereas the sleep restriction manipulation resulted in a decrease in night-wakings. This finding is not surprising in light of the relatively short sleep opportunity on the sleep restriction night, as well as earlier findings demonstrating increased sleep efficiency on nights following experimental sleep restriction [47]. There was no significant main effect for order. These findings are consistent with previous evidence as to the feasibility of conducting experimental sleep manipulation studies in home settings in young adults [35], as well as children and adolescents [13,32,33].

Taken together, our results suggest that a night of induced life-like nocturnal awakenings (consisting of at least four prolonged purposeful awakenings throughout the night) leads to significant negative effects on mood and sustained attention, which are indistinguishable from those resulting from sleep restriction of 4 h per night. The OCPT data revealed that induced night-wakings and sleep restriction both resulted in more omission and commission errors compared to a normal sleep night. Moreover, both forms of sleep disruption had similar effects on performance in the sustained attention task, as indicated by the absence of significant type-of-sleep manipulation by night interaction effects. These results are consistent with earlier findings regarding the adverse effects of partial sleep deprivation on sustained attention and general cognitive performance [8,12,13,48]. They also dovetail well with findings regarding the negative cognitive consequences of sleep that is fragmented by micro-arousals [22–24]. In one of the rare studies comparing the cognitive consequences of total sleep deprivation and sleep fragmentation, Bonnet [21] found no difference in vigilance hit rates following the two types of sleep loss. In line with this finding, our results demonstrate the detrimental cognitive effects of induced prolonged awakenings that fragment sleep, and suggest that such fragmentation has a significant adverse effect on the restorative function of sleep, that is comparable to sleep restriction to 4 h of sleep.

As hypothesized, subjective mood was also negatively affected by sleep restriction and by repeated induced night-wakings compared to normal sleep. Following a night of sleep restriction or prolonged awakenings, the participants reported significantly higher depression, fatigue and confusion levels and reduced vigor compared to their reports of mood following their control sleep night. Furthermore, as in the case of cognitive effects, there were no significant differences between the effects of sleep restriction and induced night-wakings on mood, as indicated by the lack of significant type-of-sleep manipulation by night interaction effects for any of the POMS subscales. This is consonant with studies that have found mood to be negatively affected by total and partial sleep deprivation [17–19,49], as well as by different forms of sleep fragmentation [23,25,27,50]. Our findings extend previous research, suggesting that the effects of 4 h sleep restriction and four recurring night-wakings on mood are significant and indistinguishable. Correspondingly, Bonnet and Arand [20] conclude their review of the clinical effects of sleep deprivation, restriction and fragmentation by stating that their consequences depend more on the degree rather than on the type of sleep disturbance. Fragmented sleep thus could be more, less or equally damaging in comparison to sleep restriction, depending on the extent of disruption. Further studies experimentally comparing the dose–response effects of these different types of sleep disruptions are needed to deepen the knowledge about the costs of these widespread phenomena. These investigations could also compare the cumulative (rather than single-night) effects of sleep fragmented by induced wakings, sleep restriction and total deprivation.

In this study, no significant effects of sleep disruption were found with regard to the anger–hostility and tension–anxiety subscales. Previous investigations have yielded inconsistent results as to the effects of sleep loss on these specific emotional aspects. Several studies have demonstrated significant increases in anxiety and anger following total or partial sleep deprivation [19,51], whereas others have failed to show evidence of such influence [52–54]. These features of mood seem to be less sensitive to the effects of sleep loss and disruption compared to others (such as depression and vigor). Hence, the lack of influence may be explained by the relatively less demanding sleep schedules that were used in the present study, compared to paradigms used in previous investigations (eg total sleep deprivation). Future studies could examine the effects of more demanding sleep loss schedules on subsequent anxiety and hostility.

In interpreting the results of the present study, several limitations merit consideration. First, compared to laboratory-based studies, monitoring of participants' behavior and environment in this study was limited. Specifically, the use of alertness-promoting agents (eg caffeine) was not directly controlled, potentially affecting some of the results. Second, due to software compatibility problems, the OCPT could not be completed by 13 participants, thus sample size was somewhat reduced in the analyses of cognitive outcomes. Third, the design used in this study was a mixed within- and between-subjects design, that holds more power to detect differences between the baseline and the manipulated sleep night (within-subject comparison), compared to differences between the two types of sleep manipulations (between-subject comparison). This choice of design may have influenced the sensitivity of this study to reflect differences between the experimental manipulations (group-related differences). Alternative designs should be used in future investigations to compare the effects of sleep restriction and induced night-wakings.

Finally, in natural settings the fragmentation of sleep by night-wakings entails a certain loss of true sleep time, particularly when awakenings are full and require a behavioral response, as in the paradigm used in this study. Total sleep time was not controlled in the present study, thus on the night of induced wakings participants slept about an hour less on average compared to their normal sleep night. One might suggest that this reduction in total sleep time may in itself explain the deterioration in cognitive performance and mood following the fragmented sleep night. This claim may be supported by previous studies that found no significant differences between differing amounts of sleep restriction after a single night [9,55]. However, studies have repeatedly demonstrated the dose-dependent effects of sleep restriction on cognitive performance and mood, indicating that the extent of negative outcomes is a function of the magnitude of sleep restriction [9,56,57]. Interestingly, even relatively severe sleep restriction (eg time in bed = 3 h) does not always produce significant impact on sustained attention after the first night [17,55]. Therefore, it is less likely that a reduction of 71 min of sleep for a single night would, in itself, result in significant effects on attention and mood. It is more probable that deficits following the induced-wakings night were due to the combined effect of the fragmentation by awakenings and mild restriction of sleep. Further research should focus on the effects of sleep restriction and sleep fragmented by induced awakenings when total sleep time is controlled for. Yet, real-life recurrent night-wakings involve some extent of sleep loss as an inevitable part of the picture; thus, exploring the costs of the phenomenon as a whole is essential in the effort to sustain ecological validity.

This pilot study is one of the first to explore the effects of induced nocturnal awakenings requiring a purposeful response on later functioning. Since this area of research is still in its infancy, the present study was aimed to examine the potential impact of the pervasive phenomenon of a small number of night-wakings requiring purposeful behavior during the night. Future studies are needed to explore issues such as: (a) differences between spontaneous and induced awakenings; (b) differences between night-wakings requiring engagement in purposeful behaviors vs night-wakings with no special behavioral demands; (c) dose-related effects (eg 4 h of sleep restriction vs 4 h of wakefulness due to extended night-wakings); and (d) the impact of night-wakings on subsequent sleep and its restorative function. These studies could facilitate the understanding of the impact of night-wakings, underlying mechanisms, as well as dose-related issues.

Notwithstanding these issues, the results of the present study call attention to the potential adverse consequences of life-like sleep fragmentation caused by repeated night-wakings. Fragmented sleep (consisting of at least four full prolonged awakenings) and restricted sleep (to a night of no more than 4 h of sleep) were found to be similarly detrimental in their effects on sustained attention and mood. Our findings bear relevance to substantial portions of the population, whose sleep is regularly fragmented including medical residents, shift workers, military personnel, and parents. They shed light on correlative data indicating that child sleep disruptions are associated with more maternal fatigue, stress and depressive symptoms [2,58]. Their implications are substantial for debates regarding reduction of risk in the workplace. For example, recommendations on resident physician safety typically refer to the minimal length of sleep opportunity, and to the risks involved in sleep deprivation, as opposed to recurrent externally induced awakenings [59]. Professionals as well as the general public should be aware of the detrimental effects of the various kinds of disruptions in sleep on daily functioning and mood, and consider countermeasures to minimize their consequences.

## Financial sources

None.

## Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2014.03.016.

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