Original Article

Sleep deficits in the High Arctic summer in relation to light exposure and behaviour: use of melatonin as a countermeasure

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A B S T R A C T

Background: There are conflicting reports regarding seasonal sleep difficulties in polar regions. Herein we report differences in actigraphic sleep measures between two summer trials (collected at Canadian Forces Station Alert, 82.5°N, in 2012 and 2014) and evaluate exogenous melatonin for preventing/treating circadian phase delay due to nocturnal light exposure.

Methods: Subjects wore actigraphs continuously to obtain sleep data. Following seven days of actigraphic recording the subjects filled out questionnaires regarding sleep difficulty and psychosocial parameters and subsequently remained in dim light conditions for 24 hours, during which saliva was collected bihourly to measure melatonin. During Trial 2, individuals who reported difficulty sleeping were prescribed melatonin, and a second saliva collection was conducted to evaluate the effect of melatonin on the circadian system.

Results: Trial 1 subjects collectively had late dim light melatonin onsets and difficulty sleeping; however, the Trial 2 subjects had normally timed melatonin rhythms, and obtained a good quantity of high-quality sleep. Nocturnal light exposure was significantly different between the trials, with Trial 1 subjects exposed to significantly more light between 2200 and 0200h. Melatonin treatment during Trial 2 led to an improvement in the subjective sleep difficulty between the pre- and post-treatment surveys; however there were no significant differences in the objective measures of sleep.

Conclusions: The difference in sleep and melatonin rhythms between research participants in June 2012 and June 2014 is attributed to the higher levels of nocturnal light exposure in 2012. The avoidance of nocturnal light is likely to improve sleep during the Arctic summer.

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1. Introduction

In extreme high and low latitudes, the spring and summer months experience 24 hours of daylight, or the ‘midnight sun’ (October to March in the Antarctic, and April to September in the Arctic). Such nocturnal daylight has a major effect on the human circadian system [1,2] and can cause insomnia and/or circadian rhythm misalignment [3]. Over the past three years, a research team from Defence Research and Development Canada in Toronto has studied circadian rhythms, fatigue, and sleep difficulties in the high Arctic, mainly at Canadian Forces Station (CFS) Alert (the most northerly manned-outpost in the world; 82.5°N). Among other things, we have found that residents of CFS Alert obtained less sleep during the summer of 2012 compared to residents of CFS Alert during winter of 2012 [4]. Cognitive effectiveness models of these two groups of subjects indicated that summer performance was compromised compared with winter performance [5]. These seasonal differences in sleep have been attributed to a shifted circadian rhythm in a significant percentage of the military personnel in the summer, which resulted from evening light exposure [5]. Evening exposure to sunlight during the Arctic summer phase delays the circadian system [6–9] and prolongs the inhibition signal to the pineal gland, causing a delay in the onset of melatonin production by the pineal gland [10]. This delayed onset of melatonin subsequently leads to a delayed offset of melatonin if light conditions permit, and is associated with the individual feeling tired longer into the morning, and not feeling tired again until later that night [11]. Over multiple days this can cause significantly delayed circadian rhythms [10] leading to difficulty sleeping at the desired bedtime.

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Shifting the human circadian system with appropriately timed light-treatment and exogenous melatonin has been highly studied and several phase response curves (PRCs) have been developed [7,12–14]. This control over the circadian system enables the treatment of insomnia caused by a misalignment with the work/sleep schedule. Low-dose exogenous melatonin administered in the evening, combined with exposure to light upon awakening in the morning can be an effective stimulus for realigning an individual’s circadian rhythm with their work/sleep schedule [12,15–18]. The problematic nocturnal light exposure in the evening can be minimized by the individual donning sunglasses that block the blue and green wavelengths of light which are the major stimuli to the non-visual retinal photoreceptors influencing circadian rhythms [18–25]. Given our 2012 findings that subjects obtained less sleep in summer relative to winter, we hypothesized that shifting/anchoring Dim Light melatonin onset (DLMO) to approximately 2100 h with an evening dose of exogenous melatonin would significantly improve sleep quantity and quality. Based on a composite of our own data collected in Toronto, Canada, a normal DLMO occurs 2.5±1.8 h (mean±SD) before sleep onset [9,26–28]. Therefore, an individual that goes to bed at 2330 h should have their DLMO at approximately 2100 h.

We now report a comparison of nocturnal light exposure, sleep and melatonin rhythms between summer 2012 and summer 2014, together with the use of melatonin in summer as a possible countermeasure to the sleep difficulties noted in 2012.

2. Materials and methods

2.1. Subject inclusion/exclusion criteria, age/gender demographics, and environment

A baseline experiment was conducted at CFS Alert from June 8th to 17th, 2012. The trial (hereafter referred to as Trial 1) included 12 subjects, eight men and four women, with an age range from 22 to 47 years. The mean age and standard deviation of the participants was 31.2±2.8 years. Data collection for Trial 2 occurred from May 24th–June 15th, 2014 at CFS Alert and included 15 subjects (11 males and four females, age range of 19 to 47 years, with mean age and standard deviation of 28.3±8.3 years). To qualify for either trial, the subjects had to have been at CFS Alert for at least two weeks. In both trials there were approximately 25 potential volunteers. Anyone taking beta-blockers, selective serotonin reuptake inhibitors, hypnotics, stimulants, or supplementary melatonin was excluded from the study. The subjects provided written informed consent prior to their participation in the protocol. The protocol and consent form was approved by the DRDC Human Research Ethics Committee and met the ethical standards of the Declaration of Helsinki. Subjects were compensated for their participation in accordance with Canadian Government Guidelines for experimental stress allowance.

The subjects in both trials were free to go about their routines as they normally would including taking a nap during the day if their work schedule allowed. Meals were served three times per day in hour-long windows (Breakfast = 7–8 h, Lunch = 12–13 h, Dinner = 17–18 h), and work was generally performed between 0800 h and 1600 h. Some participants, especially in Trial 1, would go outside or spend the time before they went to bed in well-lit common areas. During Trial 1 (June 8th to 17th, 2012) the lowest daily sun angle (angle above the horizon; 0000 h solar time) was 15.4° on June 8th and 15.9° on June 17th, and the highest daily sun angle (1200 h solar time) was 30.4° on June 8th and 30.9° on June 17th. At the start of Trial 2 (May 24th, 2014), the sun angle varied between 13.2° (0000 h solar time) and 28.3° (1200 h solar time) above the horizon. At the end of Trial 2 (June 15th, 2104, the sun angle varied between 15.8° (0000 h solar time) and 30.8° (1200 h solar time) above the horizon.

All bedrooms were dark as the windows were able to be covered with a well-fitting hinged door and dark curtains.

There were some major differences in the station rules between 2012 and 2014 that should be noted, as these differences may have impacted our results. In June 2014, venturing off-station was prohibited after 2000 h and social activities were concluded at 2300 h on most weeknights, and 2400 h on weekends. These differences may have limited nocturnal light exposure that Station members experienced in 2014 as they transitioned from their social activities to their accommodations.

2.2. Data collection protocol

All subjects wore actigraphs (Motionlogger, version 14.000, Ambulatory Monitoring Inc., Amherst, NY, USA) during each trial. The actigraphs were used to record various measures of sleep including time of sleep onset, total duration of sleep, sleep efficiency, rise time, and total wake minutes after sleep onset. To help score the actigraph data, the subjects also maintained a sleep log. After a week of wearing the actigraph, all subjects underwent a 24-hour salivary melatonin assessment profile by providing 13 samples (one sample every two hours for 24 hours). For the salivary melatonin assessment, the subjects arrived at the Station gymnasium at 0830 h. They were assigned lounge chairs for the 24-h saliva collection period. The gymnasium lights were turned off but supplementary lighting (to a maximum of 5 lux) was positioned around the gymnasium and in the washrooms. A large monitor was setup approximately 20 feet in front of the line of subjects (in their lounge chairs) to provide the subjects with movies during the 24-h period, with eye-level ambient light from the monitor measuring less than 5 lux for all subjects. The subjects were allowed to get up from their chairs to go to the washrooms or socialize for about 100 minutes of each 2-hour block, but remained in areas with ambient light of less than 5 lux. The subjects returned to a semi-recumbent posture in their lounge chairs for the 15 minutes prior to each sample. The subjects were required to remain awake from 0900 h until 2300 h, after which they were permitted to sleep but were awakened in the 15 minutes prior to each sample. The subjects were released on Sunday morning after the 0900 h sample.

The saliva was collected in test tubes configured for that purpose (Salivette®, Sarstedt Inc., Montreal, QC). During sample collection, the subjects chewed the cotton swab for 45 seconds, and then let the swab remain in their mouth to absorb saliva for another 45 seconds. The cotton swab was then replaced in the Salivettes® collection device and the samples were centrifuged for five minutes to extract the saliva. The cotton swab was then discarded and the samples were either frozen at –20 °C (Trial 1) or refrigerated at 4 °C (Trial 2).

Following Trial 1, the saliva samples were analyzed by a laboratory at the University of Toronto (Toronto, Canada). The analysis was performed using a radioimmunoassay (RIA) from Bühmann Laboratories AG (Schönenuch, Switzerland). The reported intra- and inter-assay coefficients of variation (CVs) for the RIA kits were 7.9% and 9.8%, respectively, and the limit of detection (analytical sensitivity) was 0.2 µg/ml. The assays were run such that all samples from a given subject were analyzed in duplicate on the same RIA plate.

During Trial 2, melatonin content was analyzed at CFS Alert by DRDC, Toronto Research Center Staff immediately following collection of the final pre/post-treatment sample. Enzyme-linked immunosorbent assay (ELISA) kits, which have been highly characterized and validated against their RIA kits, were purchased from Bühmann Laboratories AG (Schönenuch, Switzerland) and utilize the same Kennaway G280 anti-melatonin antibody as in the RIA kits. As in Trial 1, all samples from a given subject were analyzed in duplicate on the same ELISA plate. The reported intra- and inter-assay CVs for the kits were 12.6% and 22.9%, respectively, and the
limit of detection (analytical sensitivity) was 0.5 pg/ml. Dim light melatonin onset (DLMO) was calculated by linear interpolation of the samples that straddled the threshold, which was defined as 2 standard deviations above the baseline for the individual melatonin profile.

Immediately prior to the salivary melatonin profile assessments, all subjects completed several questionnaires to measure the psychological parameters of interest (Patient Health Questionnaire, Depression and Anxiety Symptoms Scales, Pittsburgh Sleep Quality Index, Positive and Negative Affect Scale). A questionnaire to establish chronotype (ie, Morningness or Eveningness) was also completed prior to the first 24-hr salivary melatonin collection. All questionnaires used in this study have undergone rigorous validation and are commonly used in the psychological literature.

Subjects who reported difficulty sleeping on the Pittsburgh Sleep Quality Index following the pre-treatment saliva data collection for Trial 2 were prescribed treatment consisting of exogenous melatonin. The daily exogenous melatonin treatment included a 1.0 mg sustained-release (SR) tablet (Now Foods, Bloomingdale, IL) and a 0.5 mg quick-release (QR) capsule (Life Extension, Ft. Lauderdale, FL). Subjects were instructed to take both pills daily at 2200 h and go to bed within the hour. The treatment started two days following the pre-treatment saliva data collection (Tuesday), and continued for 10 days, such that there was approximately 35 hours for the exogenous melatonin to clear from the participant’s body before the post-treatment saliva data collection. At the start of the treatment phase of the Trial 2 protocol 13 subjects started taking melatonin. Midway through the trial two males discontinued the treatment because they experienced no subjective improvement to their sleep. Therefore, 11 subjects completed the treatment phase of the trial and are included in the analysis of pre- and during-treatment sleep quantity and quality.

2.3. Calculation of daily sleep quantity and quality

The quantity of total daily sleep and indices of sleep quality for the five days prior to each saliva data collection were calculated from the wrist activity monitors worn by the subjects. The actigraphy data was collected in Zero Crossing Mode with one-minute epochs. Sleep periods were marked using the manufacturer’s software (ActionW version 2.6, Ambulatory Monitoring Inc., Amherst, NY, USA) with the help of sleep logs, and scored using the Cole-Kripke algorithm [29]. The sleep quality parameters generated by the actigraphy data, and calculated by the manufacturer’s software were: Percent Sleep (percentage of time spent sleeping after going to bed), Sleep Efficiency (percentage of time spent sleeping after initial sleep onset), Wake After Sleep Onset, and the number of sleep episodes (per total sleep period). The validity of these sleep quality parameters against Electroencephalography (EEG) has been assessed by de Souza and colleagues [30]. A review of the role and validity of activity monitoring in sleep and circadian rhythm research has been published by Ancoli-Israel and colleagues [31].

Despite collecting at least seven days of actigraphy prior to each saliva data collection, we focused only on the five days prior to each saliva data collection, as were primarily interested in the alertness/fatigue during working days. During weekends, workers were generally permitted to sleep when they wished (ie, take long naps, ‘sleep-in’, etc.) as they did not have to report to work. As the effect of any treatment for the circadian system is cumulative, (ie, the benefit builds overtime) the data from the last five days prior to saliva data collection allows us to see the largest effect of treatment.

2.4. Analysis of light data

The light data was collected using an integrated light sensor within the actigraphs, and was captured in one minute epochs. The epochs were averaged by the hour (eg. 0900 – 0959), and subsequently averaged for the day. The subjects in the studies were encouraged to wear the actigraph on top of their clothing, but there is a possibility that clothing was occasionally covering the light sensor.

2.5. Statistics

Statistical differences were assessed using ANOVA (Statistica, StatSoft Inc., Tulsa, OK) when and where appropriate and significant main effects and interactions were assessed by Fisher’s Least Significant Difference post hoc test. Details on the type of ANOVA and the layout of the data used for analysis are provided in the description of the statistical results below. For trial 2 a significance level of $p = 0.05$, effect size $= 1 SD, n = 11$ treated subjects, test, re-test reliability in repeated measures of $r = 0.5$, the power of this design is 88%. Paired t-tests were performed for several of the quantitative and qualitative sleep quality measures to evaluate differences between pre- and post-treatment.

3. Results

3.1. A comparison of the sleep obtained by participants between two data collections at CFS alert

Actigraphic sleep data from Trial 1 and Trial 2 was compared using a between-subjects repeated measures ANOVA. A significant main effect of year was found for daily sleep minutes $[F(1.11) = 6.19, p = 0.03]$, indicating that the subjects obtained more sleep during Trial 2 (2014) compared with Trial 1 (2012) (Fig. 1A). However, there were no statistical differences between groups for Sleep Efficiency (see Fig. 1B), Wake-After-Sleep-Onset (Fig. 1C), or Sleep Latency (data not shown). The Pittsburgh Sleep Quality Index scores were significantly higher in June 2012 (correlated unpaired t-test, $p = 0.008$), indicating that the group in 2012 also subjectively experienced more difficulty sleeping (Fig. 1D). Bed-time, arise time, sleep duration, and the Pittsburgh Sleep Quality Index scores for each subject in Trial 1 and Trial 2 have been included in Table 1.

3.2. Mean light exposure in CFS alert and the associated mean DLMO for each trial

Light exposure was averaged for each hour during the trials, and is graphed in Fig. 2A. The weekday light exposure was then averaged and subjected to a between-subjects repeated-measures ANOVA [Year (2012 vs. 2014) × Days (5 days)]. The main effect of ‘Year’ was not statistically significant $[F(1,11) = 3.72, p = 0.08]$, but there was a significant interaction between ‘Year’ and ‘Days’ $[F(4,44) = 4.52, p = 0.004]$, and subsequent post-hoc analysis revealed that there were statistically significant differences between the groups for light exposure on the first Monday and Friday of each trial (Days 1 and 5 respectively, $p = 0.001$ and $p = 0.002$; see Fig. 2B). We then looked at only weekday nocturnal light exposure between the groups using a correlated unpaired t-test, and found that there was a significant difference between the years ($p = 0.03$; see Fig. 2C), indicating that the 2012 subjects received significantly more nocturnal light exposure which is known to affect the human circadian system. Because of the high levels of nocturnal light exposure in 2012, we looked at the differences in DLMO between the two syndicates and found that the groups were not significantly different even though the Trial 2 DLMO was later compared to Trial 1 (see Fig. 2D, $p = 0.08$, raw DLMO data provided in Table 1). As reported in Table 1, the DLMO of Subject 6 (Trial 1) was substantially later compared to the rest of the subjects in the trial. Therefore, we re-analyzed the DLMO differences between the
syndicates with and without Subject 6 from Trial 1. By removing Subject 6, the mean DLMO in Trial 1 was 2143 h (from 2240 h with Subject 6 included), and the difference in mean DLMO between Trial 1 and Trial 2 was 60 minutes (p = 0.14).

3.3. Sleep quality and quantity before and during melatonin treatment (trial 2, 2014)

The quantity of sleep obtained daily during the main sleep period was evaluated using a 2-factor, within-subjects repeated-measures ANOVA [Treatment (2 levels, pre- and post-treatment) × Days (last 5 days of treatment)]. There was no significant main effect of treatment [mean Pre-Post difference = 18.5 ± 44.5; F(1,10) = 1.318, p = 0.28], nor was there a significant main effect of Days [F(4,40) = 0.719, p = 0.58]. A significant interaction between Days and Treatment was found [F(4,40) = 3.177, p = 0.023] (see Fig. 3A). Wake-After-Sleep-Onset did not change significantly due to the prescribed treatment [mean difference = 14.2 ± 21.1; F(1,10) = 1.958, p = 0.192], and neither the factor of Days, nor the interaction between Treatment and Days were significant [see Fig. 3B; F(4,40) = 0.654 (p = 0.627), and F(4,40) = 0.859 (p = 0.497), respectively]. There was also no significant effect for Sleep Efficiency [see Fig. 3C; mean difference = 22.3 ± 4.9; Main effect of Treatment: F(1,10) = 1.294, p = 0.282; Main effect of Days: F(4,40) = 0.886, p = 0.481; and the interaction between Days and Treatment: F(4,40) = 0.365, p = 0.832]. However, scores on the Pittsburgh Sleep Quality Index improved significantly following treatment (Fig. 3D; mean difference = 1.7 ± 1.8), indicating that the subjects who took melatonin for the full 10-day treatment period reported significantly less difficulty sleeping (paired 2-tailed t-test, p = 0.015).

4. Discussion

The light data from the two research trials highlights the substantial difference between the groups, especially with respect to nocturnal light exposure, despite being comparable in demographics. Our experience on the Station during both trials leads us to suspect that Station rules played a very significant role in the different light exposure levels. Specifically, the rules imposed by the Commanding Officer and Station Warrant Officer in June 2014 regarding the permitted times and boundaries when venturing off station for work or leisure were more conservative than the 2012
trial. These rules had the unintended effect of helping to control excessive and undesirable nighttime light exposure that station personnel may have otherwise received. We believe that as a result of this the sleep patterns and physiological circadian rhythms of station personnel in our recent trial were mostly normal. Probably due to the lower nocturnal light exposure levels in 2014 compared to 2012, DLMO from the June 2014 research participants was at a more appropriate clock time. In summary, the comparison of the 2014 study with the previous 2012 results underlines the real significance of scheduled activity and controlled light exposure in these circumstances.

Consequently, participants commenced our June 2014 trial while displaying relatively little difficulty with sleeping as compared to participants from our initial June 2012 trial. This limited our ability to fully evaluate the efficacy of the 1.5 mg melatonin dose for use in the Canadian High Arctic as a sleep aid and zeitgeber during the spring/summer periods when there is 24/7 sunlight. We have therefore decided to flip his entire sleep wake schedule to handle his work requirement.

Technician must start reporting weather at 0300. This individual had provided to the flight crew at frequent intervals starting three hours prior to departure of the aircraft from its current location. Generally, this means that one or two days a week, the Meteorology Technician must start reporting weather at 0300. This individual had therefore decided to flip his entire sleep wake schedule to handle that work requirement.

5. Conclusions

In conclusion, we have shown that misalignment of the circadian system with the work/sleep schedule of the individual living in the Arctic/Antarctic summer, along with the associated difficulty sleeping and daytime fatigue, appears to be mitigated simply by avoiding nocturnal light. Melatonin treatment was not effective at improving actigraphic measures of sleep quality/quantity; however, the treated subjects all had normal melatonin rhythms and generally obtained enough high-quality sleep.

Table 1
Demographics, sleep and circadian phase.

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Note 1: Bedtime, Arise Time, Sleep Duration, and Sleep Efficiency reflect the mean of the 5 days prior to each saliva data collection.

Note 2: Pre and Post refer to Pre-Treatment and Post-Treatment respectively.

PSS, Pittsburgh Sleep Scale; DLMO, Dim Light Melatonin Onset.

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Fig. 2. Light exposure and DLMO for the 2012 and 2014 pre-treatment syndicates (N = 12 and 15, respectively). A. Mean hourly light exposure for each day of the syndicates. The numbers on the abcissa indicate the day of the experiment (eg, Day 1–8) followed by the hour of each day (ie, 0–24 hrs; right of the decimal). B. Mean Daily Light Exposure for the syndicates for the 5 days prior to melatonin assessment (Day 1 = Monday, Day 5 = Friday). C. Nocturnal (22h to 02h) Light Exposure averaged for the 5 days prior to melatonin assessment for each trial. D. Dim light melatonin onset (DLMO) calculated for the 2012 and 2014 syndicates using the threshold of mean baseline +2 SD for each subject. The 2014 bar reflects the mean pre-treatment DLMO.
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.2014.12.012.

Appendix: Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.sleep.2014.12.012.

References


