Circadian countermeasures in the high arctic during summer

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IMPORTANT INFORMATIVE STATEMENTS

The data collected as part of this study was approved either by Defence Research and Development Canada's Human Research Ethics Board.

Abstract

Background: We have previously shown that the 24 hours of daily sunlight in the high Arctic during the summer provides a good environment for misaligning the physiological circadian pattern with the work-sleep schedule of the individual. As a result, there is a prevalence of sleep difficulty in the summer, with a general reduction in both the quantity and quality of sleep obtained among residents in the summer vs. the winter (Paul, M. A., Love, R. J., Hawton, A. M. et al. Melatonin production, sleep patterns and modeled performance effectiveness in subjects in the high Arctic. In. DRDC-RDDC-2014-R15, DRDC – Toronto Research Centre, 2014).

Methods: Subjects were 15 CAF personnel (11 males and four females, age range of 19 to 47 years, with mean age and standard deviation of 28.3 ± 8.3 years) who had arrived at CFS Alert at least one week prior to the study which encompassed 21 days from May 23rd to June 13th, 2014. During this period there were 24 hours of daylight. Subjects wore motion-detection devices (Actigraphs) to obtain objective sleep data, and completed questionnaires regarding sleep difficulty and psychosocial parameters at the beginning and end of the study. After a seven day period of baseline Actigraph data, salivary melatonin assays were collected two hourly for 24 hours while the subjects remained in dim light conditions. Based on the melatonin profiles and sleep questionnaire histories, 13 subjects were prescribed melatonin and given advice about light exposure. After a 10 day intervention period, a 24 hour melatonin profile was repeated under identical conditions. Treatment effects were evaluated using the questionnaire data, actigraphic data, and endogenous melatonin profiles.

Results: A small benefit of exogenous melatonin consumption was observed in 73% of the subjects. However, there was no statistically significant difference in the collective quantity or quality of sleep obtained by the subjects following the treatment. We believe that this was primarily because the subjects in this study all had normal melatonin rhythms, and generally obtained a good quantity of high quality sleep, which is in contrast to the results obtained in CFS Alert in June 2012, when sleep difficulty and irregular circadian rhythms were evident. The difference between research participants in June 2012 and June 2014 is attributed to reduced levels of nocturnal light exposure that are provocative to the human circadian rhythm. As compared to 2102, the Commanding Officer (CO) and Station Warrant Officer (SWO) in June 2014 were conservative in their permissible limits of off-station travel in effort to protect the health and safety of station personnel. In addition, the mess was closed by midnight at the latest.

Conclusion: These orders seem to limit the nocturnal light exposure that cause circadian rhythm misalignment and reduce associated insomnia or sleep difficulties among station personnel. These findings have important implications for military operations in the high arctic during summer.

Significance to defence and security

The study described herein found that regulating outdoor travel and unnecessary exposure to bright nocturnal light can have a positive impact on the sleep quality of Arctic residents. Given the small benefit that melatonin treatment had on several of the research subjects, the prescription of exogenous melatonin may be appropriate for individuals suffering from circadian rhythm misalignment and associated sleep difficulties arising from exposure to nocturnal light that is provocative to the human circadian system. While the improvement in sleep quality from melatonin treatment fell short of statistical significance, it is probable that restricted access to outdoor evening light resulted in relatively normal sleep in our current subjects. This is in stark contrast to the sleep hygiene of the subjects evaluated in June 2012. Improving sleep quality and minimizing insomnia among the military residents of the Arctic will have a significant positive impact on the cognitive effectiveness of these individuals.

Résumé

Contexte : Nous avons déjà démontré que dans l'Extrême-Arctique, en été, les journées de clarté de 24 heures constituent un milieu idéal pour causer un décalage du rythme circadien physiologique d'un individu par rapport à son horaire de travail et de sommeil. Conséquemment, on observe une prévalence de troubles du sommeil chez les résidents de cette région en été et, plus particulièrement, une réduction de la quantité et de la qualité du sommeil, comparativement à l'hiver (Paul, M. A., R.J. Love, A.M. Hawton et coll., *Melatonin production, sleep patterns and modeled performance effectiveness in subjects in the high Arctic*, dans DRDC-RDDC-2014-R15, Centre de recherches de RDDC Toronto, 2014).

Méthodes : Le groupe de sujets comportait 15 membres du personnel des FAC (11 hommes et 4 femmes dont l'âge variait de 19 à 47 ans, avec un âge moyen et un écart-type de 28,3 ± 8,3 ans), qui étaient arrivés à la SFC Alert au moins une semaine avant la période de l'étude de 21 jours (soit du 23 mai au 13 juin 2014). Les journées de cette période d'étude comptaient toutes 24 heures de clarté. Les sujets portaient des dispositifs de détection de mouvement (des actigraphes), qui permettent d'obtenir des données objectives sur le sommeil, et avaient rempli un questionnaire portant sur les troubles du sommeil et certains paramètres psychosociaux, et ce, au début et à la fin de l'étude. Après une période de 7 jours pendant laquelle des données de référence ont été recueillies à l'aide des actigraphes, des échantillons d'essai de mélatonine salivaire ont été prélevés au rythme de 2 à l'heure, pendant 24 heures, alors que les sujets étaient dans des conditions de faible éclairage. En se basant sur les profils de production de mélatonine et les données des questionnaires sur les troubles du sommeil, on a prescrit de la mélatonine à 13 des sujets et on leur a donné des conseils en matière d'exposition à la lumière. Après une période d'intervention de 10 jours, un profil de production de mélatonine a été de nouveau établi sur 24 heures, dans des conditions identiques aux précédentes. Les effets du traitement ont été évalués à l'aide des données du questionnaire, de celles des actigraphes et des profils de production de mélatonine endogène.

Résultats : Une légère amélioration de l'état du sujet, attribuable à la consommation de mélatonine exogène, a été observée dans 73 % des cas. Il n'y a toutefois aucune différence statistiquement significative, pour l'ensemble des sujets, en matière de quantité ou de qualité du sommeil après le traitement. Nous croyons que ces résultats sont en grande partie liés au fait que les sujets de l'étude avaient tous des rythmes normaux de production de mélatonine et qu'en général, ils pouvaient profiter d'une quantité adéquate de sommeil de haute qualité; les résultats contrastent avec ceux obtenus à la SFC Alert en juin 2012, lorsque les sujets ont clairement éprouvé des troubles du sommeil et présenté des rythmes circadiens irréguliers. On attribue la différence entre les résultats obtenus par les participants à l'étude de juin 2012 et ceux de l'étude de juin 2014 à la réduction de l'intensité d'exposition à la lumière nocturne, laquelle influe sur le rythme circadien des humains. Comparativement aux conditions de 2012, le commandant (cmdt) et l'adjudant de la station (adj Sta) en poste en juin 2014 ont adopté une approche prudente au chapitre des limites admissibles des déplacements hors station, et ce, afin d'assurer la santé et la sécurité du personnel de la station. De plus, le mess fermait, au plus tard, à minuit, durant cette période.

Conclusion : Les consignes susmentionnées semblent avoir pour effet de restreindre l'exposition à la lumière nocturne, laquelle entraîne un décalage du rythme circadien, et de réduire l'insomnie

connexe ou les troubles du sommeil chez le personnel de la station. Ces résultats ont d'importantes répercussions sur les opérations militaires effectuées dans l'Extrême-Arctique en été.

Importance pour la défense et la sécurité

Les résultats de l'étude décrite dans le présent document indiquent que la régulation des déplacements à l'extérieur et de l'exposition inutile à la lumière nocturne intense peut avoir des effets positifs sur la qualité du sommeil des résidents de l'Arctique. En tenant compte des légères améliorations ressenties par plusieurs des sujets de l'étude soumis au traitement à la mélatonine, la prescription de mélatonine exogène pourrait être adéquate dans le cas des personnes souffrant d'un décalage du rythme circadien et de troubles du sommeil connexes causés par l'exposition à la lumière nocturne, laquelle influe sur le rythme circadien des humains. Bien que l'amélioration de la qualité du sommeil attribuable au traitement à la mélatonine ne soit pas statistiquement significative, il est probable que les répercussions de l'accès restreint à l'éclairage extérieur, en soirée, comprennent le fait que les sujets de la présente étude ont profité d'un sommeil relativement normal. Ces faits contrastent nettement avec les données sur l'hygiène du sommeil des sujets évalués en juin 2012. L'amélioration de la qualité du sommeil des résidents militaires de l'Arctique et la réduction au minimum de leurs problèmes d'insomnie auront d'importantes retombées positives sur l'efficacité de leurs capacités cognitives.

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1 Background

Residents in extreme high and low latitudes have several significant environmental challenges that impact their health and wellbeing. In the summer, the lack of darkness can cause insomnia and/or problems regulating the human circadian rhythm, whereas, in the winter, extremes of temperature and lack of photoperiod make outdoor activities uncomfortable and dangerous, and can cause high levels of negative affect. Over the past three years, a research team from the Defence Research and Development Canada (DRDC) – Toronto Research Centre has been collecting circadian baselines in the Arctic, mainly at Canadian Forces Station (CFS) Alert, to assess the impact of the extremes in photoperiod during the Arctic summer and winter on the circadian physiology of military residents. We have found that residents of CFS Alert obtain less sleep during the summer compared to residents of CFS Alert during winter. As cognitive effectiveness is linked to amount of sleep, it is expected that cognitive effectiveness would be impacted more in the Arctic summer than in the Arctic winter. The seasonal differences in sleep have been attributed to a shifted circadian rhythm in a significant percentage of the military personnel in the summer due to provocative evening light exposure. Without deliberate intervention to control light exposure, the 24 hours of sunlight of the Arctic summer provides a perfect environment for misaligning the physiological circadian pattern with the work-sleep schedule of the individual.

The manipulation of human circadian rhythms using exogenous melatonin and appropriately timed light treatment has been highly studied by us [1-5] and others around the world [6-14]. Such control over human circadian rhythms allows for the deployment of personnel across several time zones without the usual impact on human performance caused by jet lag, and also creates the ability to treat insomnia caused by misalignment of an individual's circadian rhythm with their work/sleep schedule. In normal circumstances the pineal gland in the brain produces melatonin and releases it into the circulation in the late evening, which induces fatigue and facilitates sleep. This rhythm is driven by the endogenous circadian clock in the supra-chiasmatic nucleus of the hypothalamus: suitably timed light exposure of sufficient intensity and spectral composition maintains the appropriate circadian phase. In general morning light is the major factor determining circadian phase. The non-visual light receptors in the retina become less stimulated as the sun sets, thus removing the acute suppression of melatonin by evening light and resulting in the re-establishment of melatonin production. The time that melatonin is produced by the pineal gland and released in to the circulation is called melatonin onset. Since melatonin onset only occurs in dim light or dark environments, the time that the pineal gland naturally produces melatonin in the absence of light is called Dim Light Melatonin Onset (DLMO). Individuals who regularly go to bed between 2300 h and 2400 h, and sleep for seven to eight hours, will usually have a DLMO between 2000 h to 2200 h.

The timing of DLMO is affected by the times of sunrise and sunset, as well as exposure to ambient light. Evening exposure to sunlight during the Arctic summer phase delays the circadian system and prolongs the inhibition signal to the pineal gland, causing a delay in the production of melatonin by the pineal gland. The delayed production of melatonin subsequently leads to a delayed offset of melatonin if light conditions permit, which results in the individual feeling tired longer into the morning, and not becoming tired again until later that night. Over multiple days this can cause a significantly delayed circadian rhythm leading to difficulty sleeping at the desired bedtime.

Treating this sleep difficulty is achieved by realigning the individual's circadian rhythm with their work/sleep schedule. This is done by: (1) manipulating light with exposure to bright light upon awakening, and avoiding bright light exposure in the evening (which may include wearing sunglasses with specific wavelength filters); and (2) administration of low-dose exogenous melatonin administration in the evening. Furthermore, provocative light exposure in the evening is avoided by the individual donning sunglasses that block the blue and green wavelengths of light that stimulate the non-visual, chronobiotic retinal photoreceptors.

The work described here is our first attempt at implementing circadian countermeasures in the Arctic during the summer.

2   Methods

2.1   Subjects

Subjects were 15 Canadian Armed Forces (CAF) personnel (11 males and four females, age range of 19 to 47 years, with mean age and standard deviation of 28.3 ± 8.3 years) who had arrived at CFS Alert at least one week prior to the beginning of the study (May 24th, 2014). Subjects were volunteers recruited by the medical personnel in CFS Alert following emailed information advertising the study. Informed consent was obtained. Exclusion criteria included the use of beta-blockers, SSRIs, supplementary melatonin, or Circadian light treatment for at least 30 days prior to the study.

2.2   Protocol

The study covered a 23 day period from May 23 to June 13. During this time, there was 24 hours of daylight each day. Each subject wore an Actigraph for the duration of the study, and completed a daily sleep/activity log. The first week was a baseline sleep/wake assessment. On May 31, subjects underwent a 24 hour baseline salivary melatonin assessment to determine their individual DLMO (Dim Light Melatonin Onset). Based on the results of their baseline DLMO assessment and/or their baseline sleep questionnaires, subjects were prescribed melatonin and/or individual light therapy.

Thirteen subjects received a Circadian intervention consisting of melatonin (1mg sustained release combined with 0.5mg regular release) orally at 2200hrs, advice regarding light exposure (natural, or with light visor), and were advised to adhere to a specific 2300 bedtime (illustrated in Figure 1). Two subjects started melatonin but discontinued it because of morning drowsiness symptoms. Two other subjects did not receive any intervention.

Day	Date	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600
1	Mon. June 2					M								
2	Tues. June 3					M								
3	Wed, June 4					M								
4	Thurs, June 5					M								
5	Fri, June 6					M								
6	Sat, June 7					M								
7	Sun, June 8					M								
8	Mon, June 9					M								
9	Tues, Jun 10					M								
10	Wed, Jun 11					M								
11	Thurs, Jun 12													
		M = melatonin dosing time												

Figure 1: For treatment, Subjects 1-5, 7-12, 14, and 15 were told to take melatonin (1mg sustained Release + 0.5mg regular release) at 2200 h daily to improve sleep efficiency and reduce night time wakings. These subjects were also told to aim for a 2300 h bedtime.

Ten days later (June 13th), a repeat 24 hour salivary melatonin study was carried out on all subjects.

2.3   DLMO / salivary melatonin procedure

DLMO is determined by sampling melatonin concentration in blood or saliva at uniform intervals under dim light conditions (<10 lux; [15-18]). The time of the first sample that exceeds a prescribed threshold is designated as DLMO. In this study, saliva was collected in specialized test tubes (salivettes) and was analyzed for melatonin content at CFS Alert by DRDC – Toronto Research Centre staff using Enzyme-Linked ImmunoSorbent Assay (ELISA) kits from Bühlmann Laboratories AG (Schönenbuch, Switzerland). These salivary melatonin levels were used to calculate the timing of DLMO in each of the participating subjects. Based on our own data, a normal DLMO occurs 2.54 h ± 1.18 h before sleep onset [2-5]. A DLMO occurring after sleep onset or more than two SDs before mean sleep onset is considered abnormal.

During both pre- and post-treatment salivary melatonin profile assessments, subjects remained in a darkened room with illumination set to a maximum of 5 lux, as normal room lighting levels can suppress melatonin production. Based on our previous findings, a 5 lux light level does not suppress endogenous melatonin. All subjects were positioned on lounge chairs and remained in a semi-recumbent posture for at least 15 minutes immediately prior to each sampling of salivary melatonin, to avoid hemo-concentration of the melatonin that can occur across different postures [15]. The subjects were provided with water, and were served similar meals during both 24-hour assessments. They provided 13 saliva samples with one sample every 2 hours for the 24-hour period, starting and ending at 0900 h. The samples were collected by the study investigators and technicians from DRDC – Toronto Research Centre. Immediately prior to each saliva sample time, the subjects were handed a salivette (a small test tube which contains a cotton plug) by the data collectors. The subjects were instructed to drop the cotton plug from the salivette into their mouths without touching it with their hands, and to chew it for 45 seconds. The cotton plug was then held in their mouth for a further 45 seconds to ensure an adequate saliva sample was obtained. At the end of 90 seconds, the subjects deposited the cotton plug (now laden with saliva) back into the salivette. The salivettes were centrifuged to extract the saliva from the cotton plug. The subjects were allowed to arise from semi-recumbent posture to use an adjacent washroom (also kept at about 5 lux illumination), eat, and socialize as desired, except during the 15 minutes prior to a saliva sample. During this 24-hour period, subjects were allowed to relax in their lounge chairs watching a series of videos with the video monitor set at least 20 ft away from the subjects to keep the eye-level light from the monitor down to the level of ambient room lighting (i.e., max 5 lux). During the 24-h salivary melatonin sampling, the subjects were allowed to sleep between 2300 h and 0700 h, except when samples were being collected. Sleeping subjects were awakened five minutes prior to the time for each saliva sample. The subjects were required to remain awake between 0700 h and 2300 h.

The difference in timing of the pre-treatment to post-treatment DLMO provided the magnitude and direction (advance or delay) and thus the efficacy of the phase shift for those participants who received a treatment. Sleep questionnaires provided additional feedback on the efficacy of interventions.

2.4   Actigraph data

The wrist actigraph data files were downloaded and analysed together with sleep logs at CFS Alert by DRDC – Toronto Research Centre staff. The questionnaire data were linked to the Actigraph sleep findings and were analyzed using standard univariate data analysis.

Each subject's daily ambient light exposure was tracked (via the actigraph photocell) throughout all study days where the light exposure was captured in one-minute epochs, and then averaged for each hour across the 24-hr day for each day.

2.5   Questionnaires

Immediately prior to each of the pre- and post-treatment salivary melatonin profile assessments, all subjects completed several questionnaires to measure the psychological parameters of interest (depression symptoms, anxiety, sleep disturbance, negative and positive affect). A questionnaire to establish chronotype (i.e., morningness or eveningness) was completed prior to the first 24-hr salivery melatonin collection (i.e., the pre-treatment salivary melatonin collection). All questionnaires used in this study have undergone rigorous validation and are commonly used in the psychological literature.

Affect: Positive and negative affect were assessed using the Positive and Negative Affect Scales [16, 17]. Responses are summed or averaged separately for each subscale.

Symptoms of Depression and Anxiety: These were measured using items from the Patient Health Questionnaire [18]. Responses are summed separately for the depression and anxiety scales and higher scores indicate a greater degree of depression-, or anxiety-related symptomatology. Note that clinical assessment of the presence of depression or an anxiety disorder cannot be made with this instrument.

Sleep Disturbance: This is measured using the Sleep Disturbance subscale of the Pittsburgh Sleep Quality Index [19]. Responses are summed and higher scores are associated with greater degrees of sleep disturbance, and lower scores reflecting fewer sleeping problems.

Chronotype: To establish chronotype (i.e., morningness or eveningness) preference for each of our subjects, the Horne and Ostberg questionnaire [20] was used.

A wrist actigraph is a watch-like device worn on the wrist. The actigraph can discriminate a sleeping state from a waking state, and the associated software can quantify daily sleep to the nearest minute. Wrist actigraphs have been used in many previous studies [21].

During both pre- and post-treatment salivary melatonin profile assessments, subjects remained in a darkened room with illumination set to a maximum of 5 lux, as normal room lighting levels can suppress melatonin production. Based on our previous findings, a 5 lux light level does not suppress endogenous melatonin.. The subjects were provided with water, and were served similar meals during both 24-hour assessments. They provided 13 saliva samples with one sample every two hours for the 24-hour period, starting and ending at 0900 h. The samples were collected by the study investigators and technicians from DRDC – Toronto Research Centre. Immediately

prior to each saliva sample time, the subjects were handed a salivette (a small test tube which contains a cotton plug) by the data collectors. The subjects were instructed to drop the cotton plug from the salivette into their mouths without touching it with their hands, and to chew it for 45 seconds. The cotton plug was then held in their mouth for a further 45 seconds to ensure an adequate saliva sample was obtained. At the end of 90 seconds, the subjects deposited the cotton plug (now laden with saliva) back into the salivette. The salivettes were centrifuged to extract the saliva from the cotton plug. The subjects were allowed to arise from semi-recumbent posture to use an adjacent washroom (also kept at about 5 lux illumination), eat, and socialize as desired, except during the 15 minutes prior to a saliva sample. During this 24-hour period, subjects were allowed to relax in their lounge chairs watching a series of videos with the video monitor set at least 20 ft away from the subjects to keep the eye-level light from the monitor down to the level of ambient room lighting (i.e., max 5 lux). During the 24-h salivary melatonin sampling, the subjects were allowed to sleep between 2300 h and 0700 h, except when samples were being collected. Sleeping subjects were awakened 5 minutes prior to the time for each saliva sample. The subjects were required to remain awake between 0700 h and 2300 h.

3 Results

3.1 Individual effects of treatment

3.1.1 Treated subjects

3.1.1.1 Subject 1

Pre-treatment analysis of Subject 1's melatonin profile revealed that DLMO was 2102 h and the pineal gland was producing melatonin for approximately 12 hours each day (Figure 2, blue line). This is generally a normal melatonin rhythm, with an appropriate DLMO; however, Subject 1 reported some difficulty sleeping, and therefore melatonin was prescribed as a mechanism to improve sleep quality. Furthermore, a mid-day spike of melatonin was apparent from the pre-treatment saliva collection, and so this subject was advised to get one hour of light at 1300 h either outside of the station or with a light visor each day to reduce daytime sleepiness and reduce the daytime peak of melatonin. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).
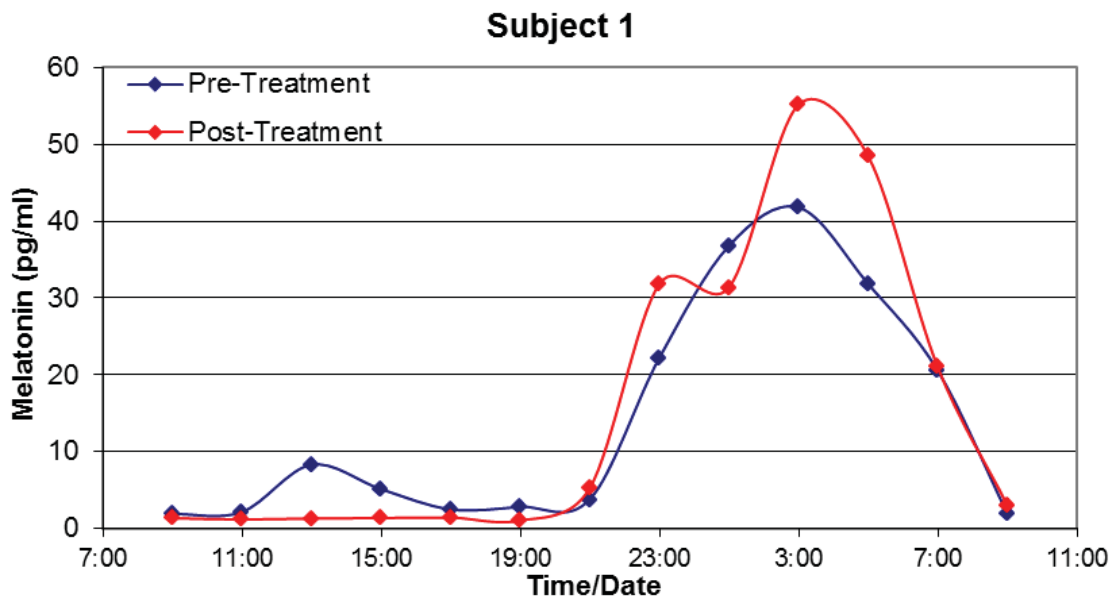
Figure 2: *Subject 1 pre- and post-treatment melatonin profiles.*

3.1.1.2   Subject 2

Pre-treatment analysis of Subject 2's melatonin profile revealed that DLMO was 2155 h, but the melatonin production throughout the night was low as the peak salivary melatonin concentration was only 6pg/ml (Figure 3, blue line). Furthermore, a mid-day spike of melatonin was evident. Since Subject 2 reported some subjective difficulty with sleeping, melatonin was prescribed to supplement the endogenous production and to support sleep. Quantitatively, Subject 2's quality of sleep was already quite high, as pre-treatment sleep efficiency was 96.7%. Light treatment was also prescribed for Subject 2 between 1400 and 1500 h each day to suppress the daytime production of melatonin. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).
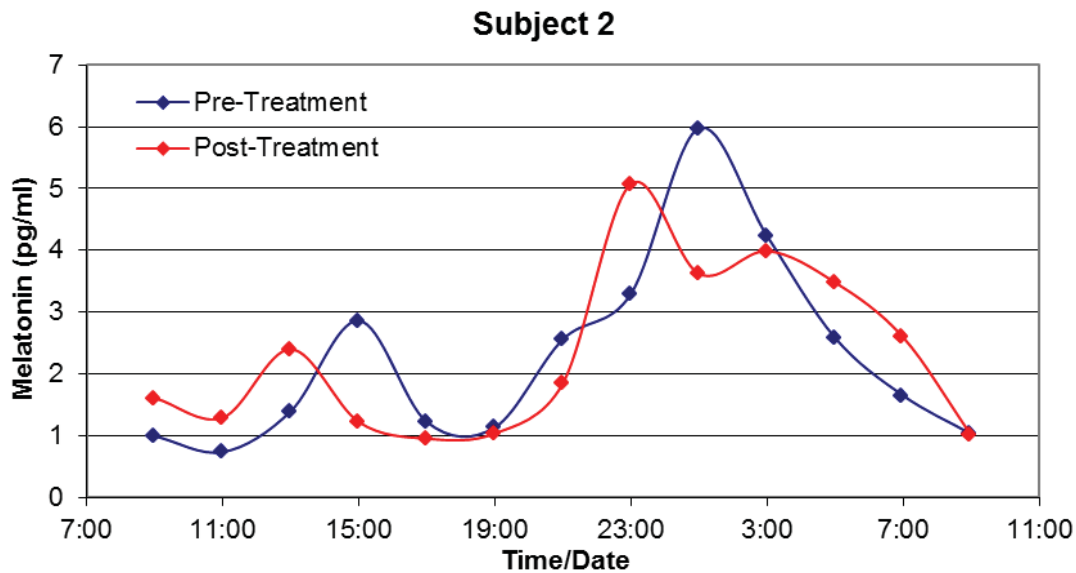
Figure 3: Subject 2 pre- and post-treatment melatonin profiles.

3.1.1.3   Subject 3

Pre-treatment analysis of Subject 3's melatonin profile revealed that DLMO was approximately 1954 h. Like Subject 2, the endogenous production of melatonin was quite low, only reaching a peak concentration of 7.7pg/ml during the pre-treatment data collection (Figure 4, blue line). Aside from the low amplitude, his melatonin rhythm was normal, with an appropriate DLMO and about 12 h of melatonin production from the pineal gland. Due to reported difficulty sleeping, melatonin was prescribed as a mechanism to improve sleep quality. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).

Figure 4: Subject 3 pre- and post-treatment melatonin profiles.

3.1.1.4   Subject 4

Pre-treatment analysis of Subject 4's melatonin profile revealed that DLMO was approximately 1907 h, which is early but not abnormal (Figure 5, blue line). Since Subject 4 reported some difficulty sleeping, melatonin was prescribed as a mechanism to improve sleep quality. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).

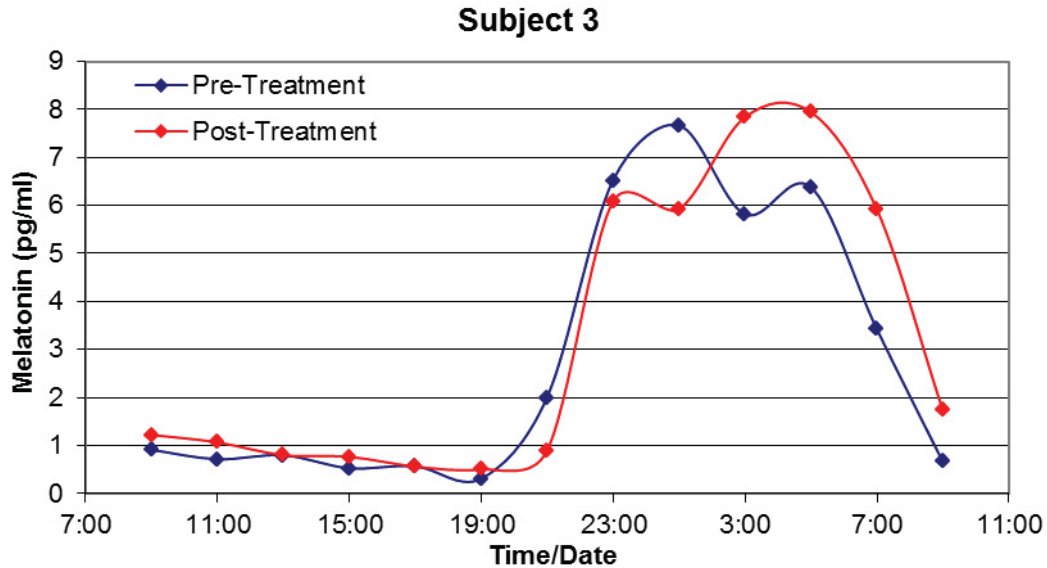*Figure 5:* Subject 4 pre- and post-treatment melatonin profiles.

3.1.1.5 Subject 5

Pre-treatment analysis of Subject 5's melatonin profile revealed that DLMO was 2123 h and the pineal gland sustained melatonin production for approximately 12 h (Figure 6, blue line). This is generally a normal melatonin rhythm, with an appropriate DLMO; however, Subject 5 reported some difficulty sleeping, and therefore melatonin was prescribed as a mechanism to improve sleep quality. Due to the mid-day spikes of melatonin at 1300 h and 1900 h, the subject was advised to get one hour of light at 1500 each day either outside of the station or with a light visor, to reduce daytime sleepiness and reduce the daytime peak of melatonin. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).

Figure 6: *Subject 5 pre- and post-treatment melatonin profiles.*
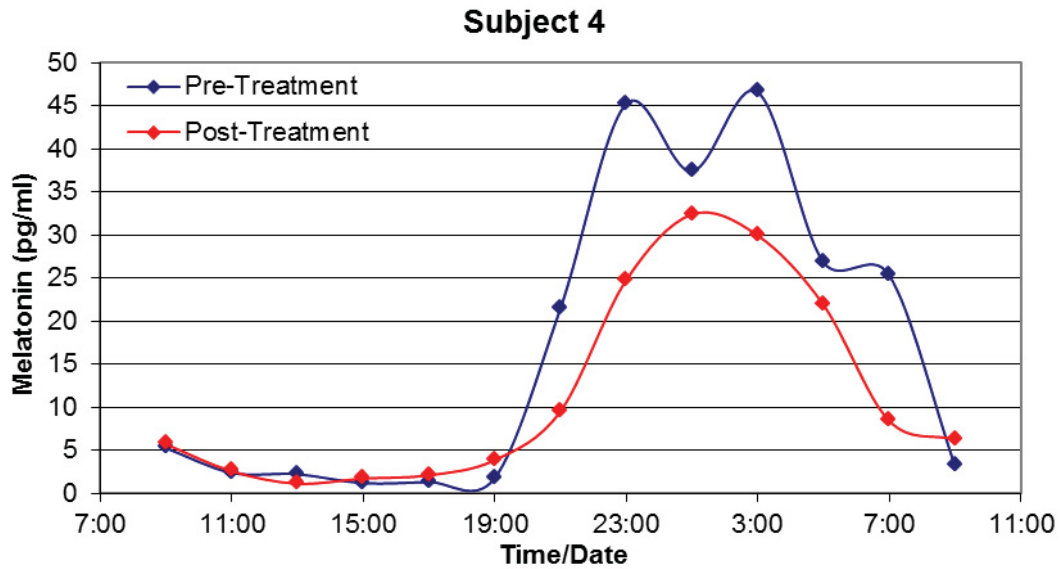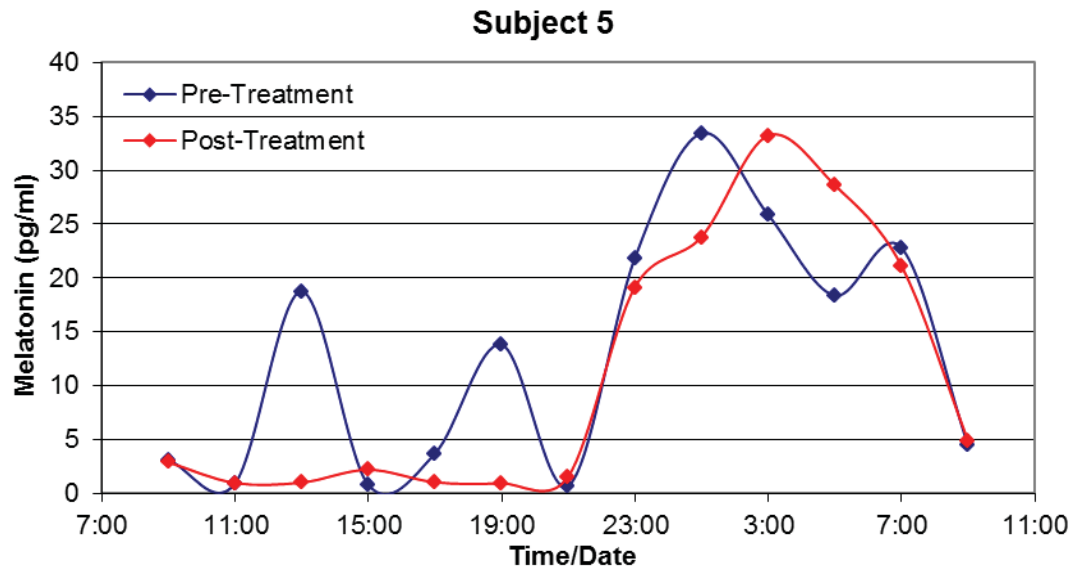
3.1.1.6 Subject 7

Pre-treatment analysis of Subject 7's melatonin profile revealed that DLMO was 2104 h and the pineal gland was producing melatonin for approximately 13.5 hours (Figure 7, blue line). This is generally a normal melatonin rhythm, with an appropriate DLMO; however, the subject was given the option of trying melatonin for the 10-day period to see if it helped his sleep at all, which he opted to try. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).

Notably, this subject's improvement of sleep quantity and quality is quite remarkable. Total number of sleep minutes increased by 1 h 2.8 min, and the efficiency with which he slept went up 7.1%.

Figure 7: *Subject 7 pre- and post-treatment melatonin profiles.*

3.1.1.7 Subject 9

Pre-treatment analysis of Subject 9's melatonin profile revealed that DLMO was 2102 h and his pineal gland was producing melatonin for approximately 12 hours each day (Figure 8, blue line). This is generally a normal melatonin rhythm, with an appropriate DLMO; however, Subject 9 reported some difficulty sleeping, and therefore melatonin was prescribed as a mechanism to improve sleep quality. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).
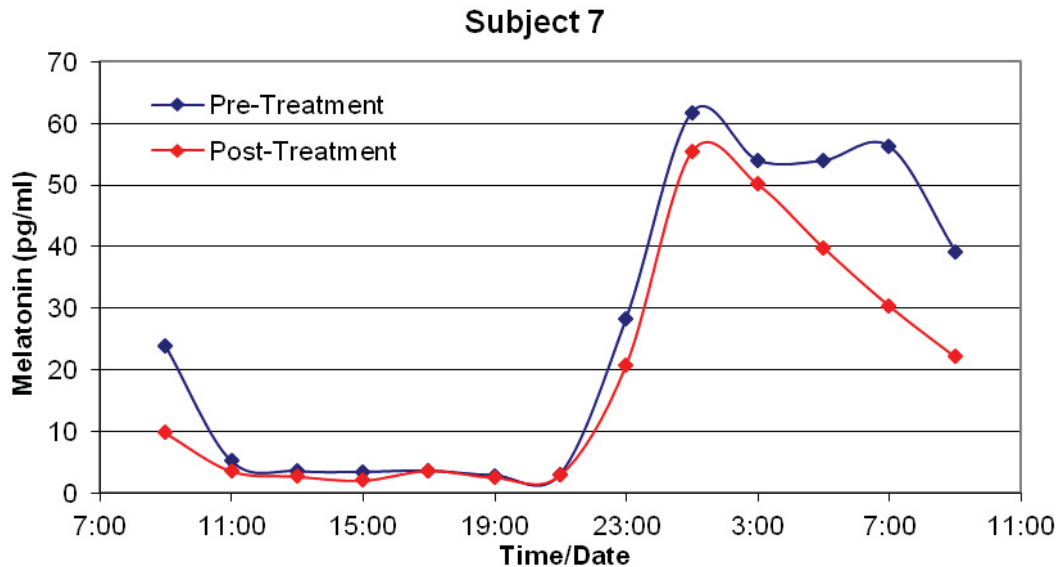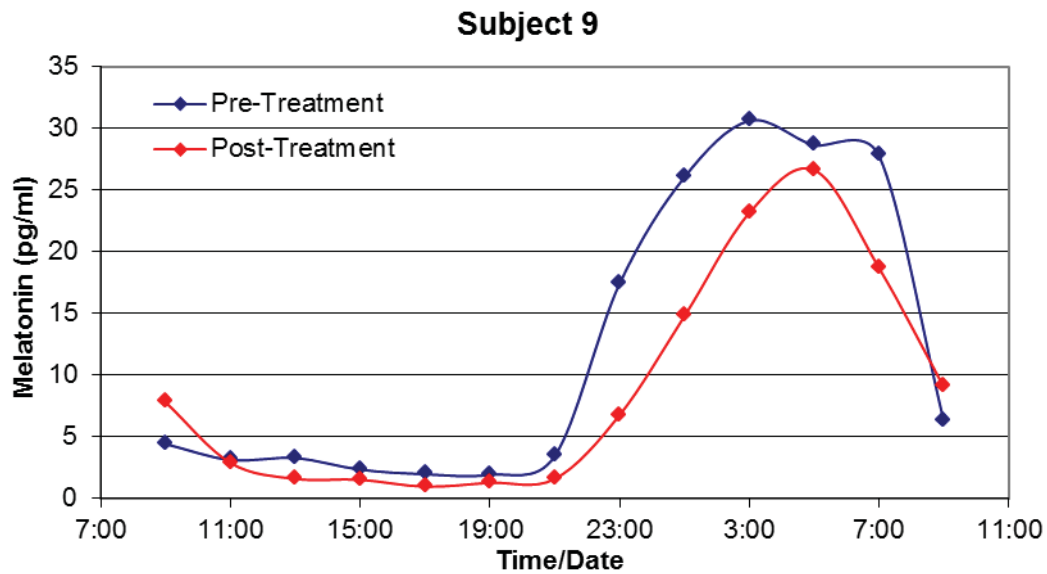

Figure 8: Subject 9 pre- and post-treatment melatonin profiles.

3.1.1.8   Subject 10

Pre-treatment analysis of Subject 10's melatonin profile revealed that DLMO was approximately 2113 h (Figure 9, blue line). The pre-treatment Pittsburgh sleep scale score was 13. Subject 10 obtained an average of 437.4 min of sleep each night, sleep efficiency was 97.4%, sleep latency was 14.4 min, and wake after sleep onset was 11.4 min. Due to the subjective difficulty with daytime sleepiness, low energy and occasional awakenings during the night, this subject was prescribed melatonin. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).
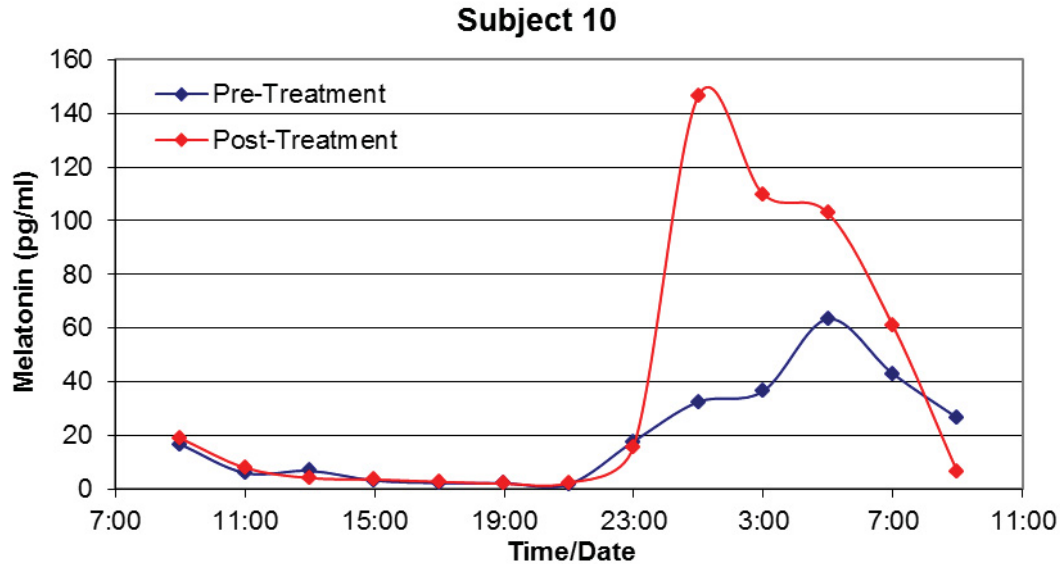
Figure 9: Subject 10 pre- and post-treatment melatonin profiles.

3.1.1.9   Subject 11

Subject 11's pre-treatment melatonin profile revealed that DLMO was 2136 h (Figure 10, blue line), which is normal. The pre-treatment Pittsburgh sleep scale score was 20 and this subject indicated trouble with daytime sleepiness, low energy, and significant problems falling and staying asleep. Subject 11 was therefore prescribed melatonin to improve these sleep quality issues. The average amount of sleep obtained by Subject 11 for the five days prior to pre-treatment melatonin assessment was 530.4 min, sleep efficiency was 91.8%, sleep latency was 17.4 min, and wake after sleep onset was 49.8 min. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).

Figure 10: Subject 11 pre- and post-treatment melatonin profiles.

3.1.1.10   Subject 14

Pre-treatment analysis of Subject 14's melatonin profile revealed that DLMO was 1905 h and pineal gland was producing melatonin for approximately 13.5 hours each day (Figure 11, blue line). This is generally a normal melatonin rhythm with an appropriate, if not slightly early DLMO; however, Subject 14 reported some trouble falling asleep three or more times per week and occasional waking during the night. The pre-treatment Pittsburgh sleep scale score was 17 and the average amount of sleep obtained by Subject 14 for the five days prior to pre-treatment melatonin assessment was 288.6 min. Sleep efficiency was 79.8%, sleep latency was 44.6 min, and wake after sleep onset was 74.8 min. Therefore melatonin was prescribed to improve sleep quality. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).
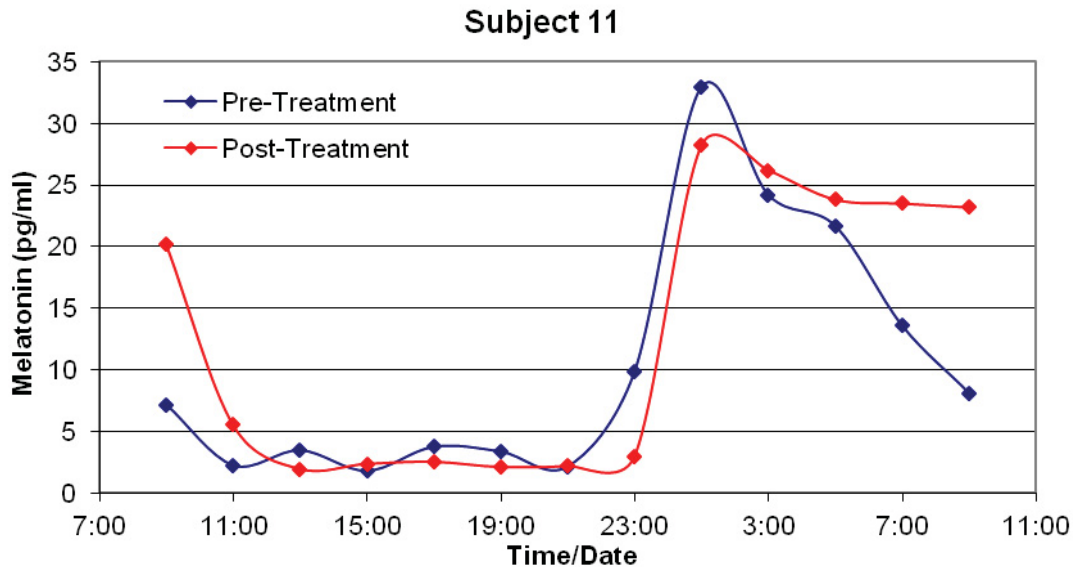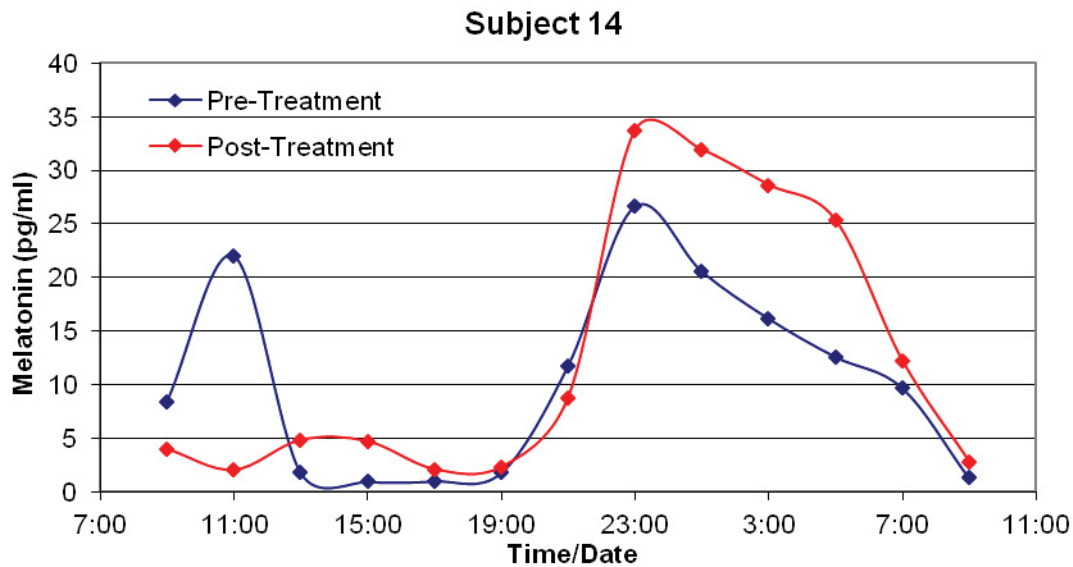

Figure 11: *Subject 14 pre- and post-treatment melatonin profiles.*

3.1.1.11   Subject 15

Subject 15's pre-treatment melatonin profile low melatonin production with a small nocturnal rise in melatonin. The DLMO was calculated to be 2137 h (Figure 12, blue line). This subject's pre-treatment Pittsburgh sleep scale score was 17, and the subject also indicated trouble with waking during the night 3 or more times per week. The average amount of sleep obtained by Subject 15 for the five days prior to pre-treatment melatonin assessment was 385 min, sleep efficiency was 88.5%, sleep latency was 26.8 min, and wake after sleep onset was 52.4 min. As a result of the low endogenous production of melatonin, and difficulty with waking, this Subject was prescribed melatonin. Since endogenous production is so low, the soporific effects of the 1.5 mg dose were expected to be more pronounced in this subject. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).

Figure 12: Subject 15 pre- and post-treatment melatonin profiles.

## 3.1.2 Subjects that discontinued treatment

3.1.2.1 Subject 8

Subject 8's melatonin profile from the pre-treatment saliva collection revealed that DLMO was 1910 h (Figure 13, blue line), which is slightly early but not abnormal. The average amount of sleep obtained by Subject 8 for the five days prior to pre-treatment melatonin assessment was 442.4 min, sleep efficiency was 91.5%, sleep latency was 5.2 min, and wake after sleep onset was 43.0 min. The pre-treatment Pittsburgh sleep scale score was 17 and they reported having trouble with waking during the night three or more times per week. Subject 8 was therefore prescribed melatonin in effort to keep them asleep during the night; however, after the first four days of treatment he was experiencing morning grogginess and his actigraphic sleep data indicated that his sleep efficiency had decreased. He was therefore advised to discontinue treatment. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).

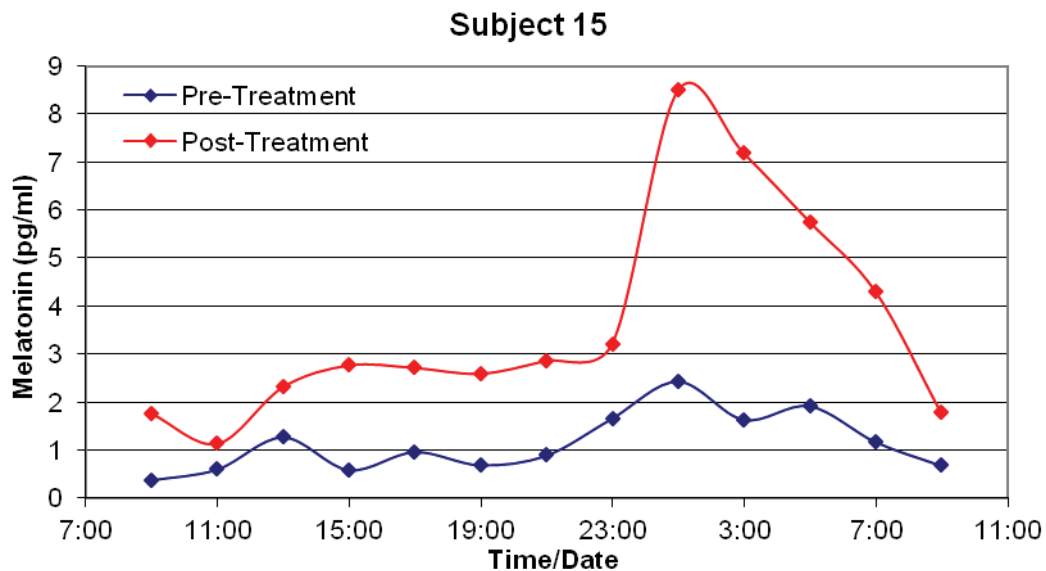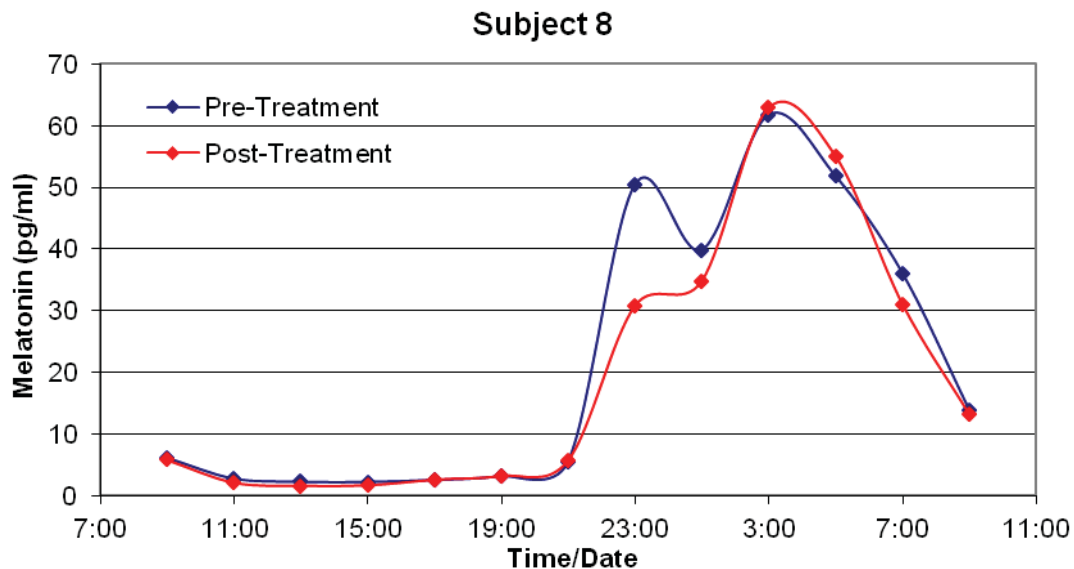*Figure 13: Subject 8 pre- and post-treatment melatonin profiles.*

3.1.2.2 Subject 12

Subject 12's pre-treatment melatonin profile revealed that DLMO was approximately 2132 h (Figure 14, blue line). This is generally a normal melatonin rhythm, with an appropriate DLMO; however, the subject reported problems with waking in the night once or twice per week and melatonin was prescribed as a mechanism to reduce awakenings. This subject's pre-treatment Pittsburgh sleep scale score was 18. The average amount of sleep obtained by Subject 12 for the five days prior to pre-treatment melatonin assessment was 375.6 min, sleep efficiency was 96.2%, sleep latency was 7.6 min, and wake after sleep onset was 14.8 min. The high sleep efficiency is notable, and indicates that he was really having very little difficulty with sleeping. It is therefore not surprising that this Subject chose to discontinue treatment after the first four days. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).
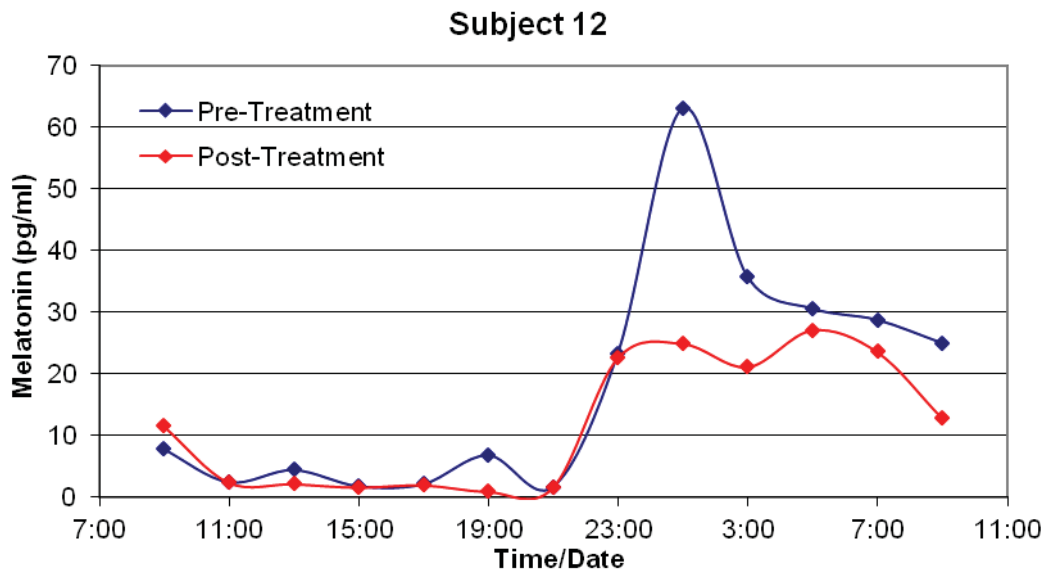
Figure 14: *Subject 12 pre- and post-treatment melatonin profiles.*

3.1.3 Non-treated subjects

3.1.3.1 Subject 6

Pre-treatment analysis of Subject 6's melatonin profile revealed that DLMO was 2111 h and the pineal gland was producing melatonin for approximately 12 hours each day (Figure 15, blue line). This is generally a normal melatonin rhythm, with an appropriate DLMO. This subject's pre-treatment Pittsburgh sleep scale score was nine, which is the lowest possible score and indicates that he had no subjective difficulty with sleeping. The average amount of sleep obtained by Subject 6 for the five days prior to pre-treatment melatonin assessment was 411.2 min, sleep efficiency was 93.8%, sleep latency was 11.4 min, and wake after sleep onset was 26.4 min. Due to the high sleep efficiency, sufficient quantity of sleep and the low (good) sleep scale score, this subject was not given a treatment. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).
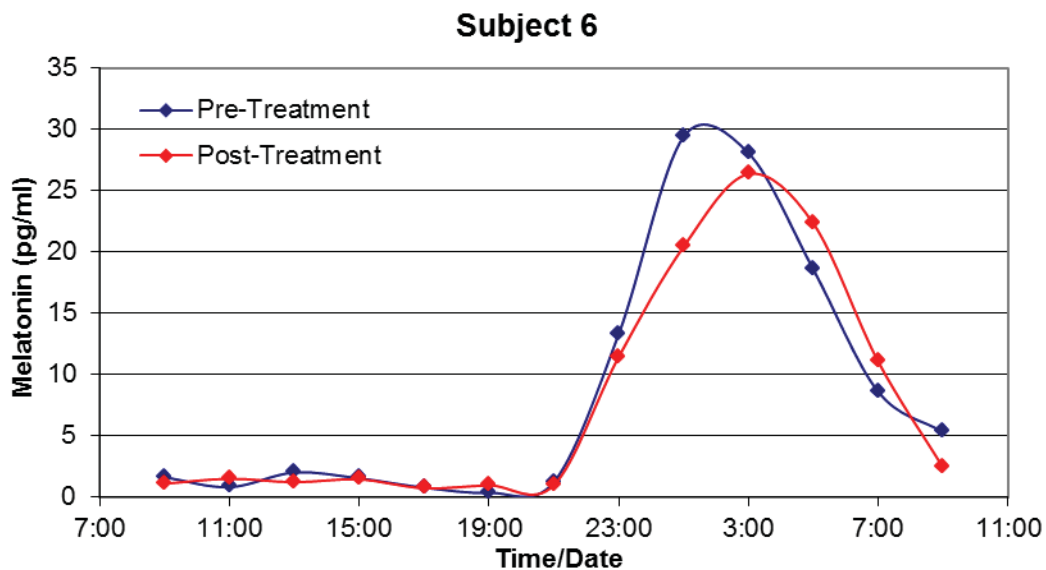
Figure 15: *Subject 6 pre- and post-treatment melatonin profiles.*

3.1.3.2   Subject 13

Pre-treatment analysis of Subject 13's melatonin profile revealed that DLMO was 1948 h (Figure 16, blue line). His melatonin production was lower than normal, with a peak concentration of only 13 pg/ml. However, his pre-treatment Pittsburgh sleep scale score was 10, which indicates that he was having little or no difficulty sleeping. Furthermore, his average nightly duration of sleep for the five days prior to pre-treatment melatonin assessment was 357.8 min, his sleep efficiency was 96.3%, his sleep latency was 19.4 min, and his wake after sleep onset was 13.6 min. Due to the high sleep efficiency Subject 13 was not prescribed a treatment plan, but there was an option to try melatonin for the 10-day treatment period, which this subject chose to decline. A summary of pre- and post-treatment DLMO and is provided in Table 1 (pg. 22).
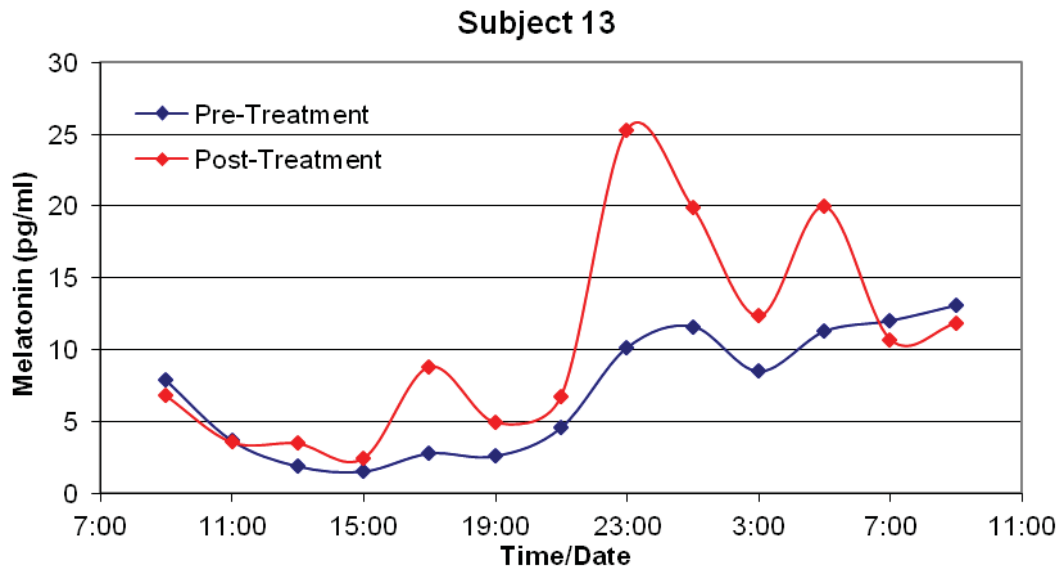
Figure 16: Subject 13 pre- and post-treatment melatonin profiles.

Table 1: Summary of DLMO and sleep data.

SUBJ	TREAT	DLMO			WASO			Sleep (mins)			PSS			SE			SL		
#	Y/N	PRE	POST	Δ	PRE	POST	Δ	PRE	PST	Δ	PRE	PST	Δ	PRE	POST	Δ	PRE	POST	Δ
1	Yes	2102	1915	-77	35.4	35.6	0	479	491	+12	14	13	-1	93.3	93.3	0	9.4	11.2	+1.8
2	Yes	2155	2108	-47	13.8	9.8	-5	437	400	-37	15	12	-3	96.7	97.5	+0.8	7.2	8.6	+1.4
3	Yes	1954	2111	+77	50.6	42.6	-8	419	385	-34	16	12	-4	89.3	90	-0.7	9.2	10.4	+1.2
4	Yes	1907	1910	+3	11.2	30.8	+20	334	376	+42	10	9	-1	96.7	93.5	-3.2	9.4	14.2	+4.8
5	Yes	2123	2105	-18	41.6	48.4	+7	427	458	+31	15	15	0	91.0	90.6	-0.4	12.4	6.6	-5.8
7	Yes	2104	2107	+3	41.6	8	-34	407	470	+63	9	9	0	91.2	98.3	+7.1	32	5.8	-25.2
9	Yes	2102	2108	+6	110	74	-36	362	370	+8	24	19	-5	79.0	79.8	+0.8	41.8	101.4	+60
10	Yes	2113	2114	+1	11.4	10	-1.4	437	492	+55	13	10	-3	97.4	98.0	+0.6	14.4	6.0	-8.4
11	Yes	2136	2301	+85	50	27	-23	530	472	-58	20	20	0	91.8	94.8	+3.0	17.4	15.6	-1.8
14	Yes	1905	1902	-3	74.8	17.8	-57	289	384	+95	17	14	-3	79.8	95.6	+15.8	44.6	7.4	-37.2
15	Yes	2137	2119	-18	52	33	-19	385	411	26	17	18	+1	88.5	92.6	+4.1	26.8	7.4	-19.4
8	Stop	1910	1918	+8	43	36.4	-6.6	442	463	+21	17	15	-2	91.5	92.8	+1.3	5.2	23.6	+18.4
12	Stop	2132	2107	-25	14.8	39.8	+25	376	406	+31	18	17	-1	96.2	91	-5.2	7.6	5.4	-2.2
6	No	2111	2108	-3	26.4	51.8	+25	411	398	-13	9	11	2	93.8	88.6	-5.2	11.4	13	+1.6
13	No	1948	1948	0	13.6	9.4	-4.2	358	410	+52	10	10	0	96.3	97.9	+1.6	19.4	8.2	-11.2

DLMO – Dim Light Melatonin Onset (24 hour clock time)
WASO – Wake After Sleep Onset (minutes spent awake after falling asleep)
PSS – Pittsburg Sleepiness Score (lower scores reflect improved sleep; 9 is optimal)
SE- Sleep Efficiency (Total Sleep Time-WASO/Total Sleep TIme)
SL – Sleep Latency (time in minutes before falling asleep)

## 3.2 Treatment efficacy – pre- vs. post- treatment

To compare the efficacy of the treatment, pre- and post- treatment, each of the sleep parameters derived from the actigraph data was analyzed by repeated measure Analysis of Variance (ANOVA) for the subjects that received the full treatment. The results of these analyses are provided below in sections 3.2.1 – 3.2.3. We have only used the final five days of treatment for two reasons: (1) On a daily basis treatment effects can be small, but will generally accumulate over time. Therefore, the greatest impact of treatment is expected to be at the end of the treatment period. (2) The five last days of treatment match the only five days we have for the pre-treatment period. Therefore, to properly perform a repeated measure ANOVA, we have balanced the number of days for main dependent variable (i.e., pre/post-treatment).

The subjective Pittsburgh sleep scale scores were assessed with a paired two-tail t-test, and the results are illustrated in Figure 20 under section 3.2.4.

3.2.1 Daily main sleep minutes

The data illustrated in Figure 17 were analysed by repeated-measures ANOVA (two levels of Pre- vs. Post-treatment x five days). The main effect of pre-post $F_{(1,11)} = 1.632$, $p = 0.23$ is not significant. The main effect of days $F_{(4,44)} = 0.683$, $p = 0.61$ is not significant. However the pre-post x days interaction $(F_{4,44}) = 3.150$, $p < 0.023$ is significant. Post hoc analysis of the interaction indicates that on Day 5, the subjects obtained more sleep post-treatment relative to their pre-treatment condition.
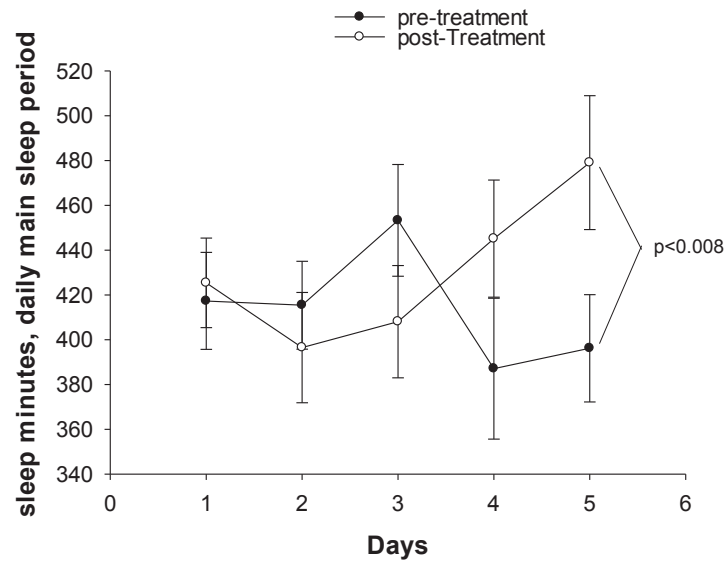
Figure 17: *Daily main sleep minutes pre- and post-treatment. Values are means ± s.e.m.*

3.2.2 WASO, daily main sleep

The data illustrated in Figure 18 were analysed by the same 2 x 5 repeated-measures ANOVA as listed immediately above. There were no significant findings in Figure 18 (Pre vs. Post treatment $F(1.11) = 2.194$, $p = 0.167$, main effect of days $F(4,44) = 0.592$, $p = 0.67$, Pre-post x days interaction $F(4,44) = 0.295$, $p = 0.880$).
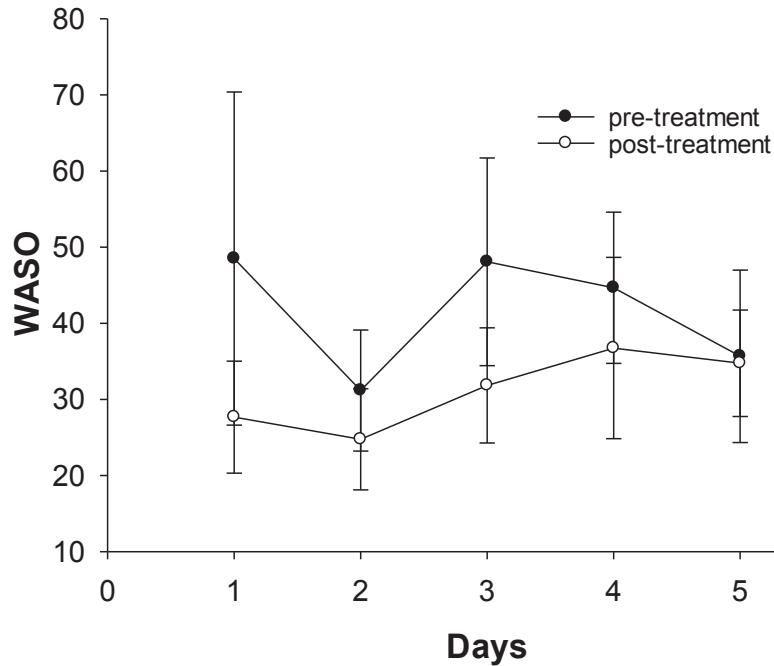
Figure 18: *WASO, daily main sleep minutes pre- and post-treatment. Values are means ±s.e.m.*

3.2.3 Sleep efficiency, daily main sleep data

Similar to the WASO (Figure 18) sleep efficiency (Figure 19) yielded no significant findings (Pre vs. Post-treatment $F(1,11) = 1.456$, $p = 0.253$, main effect of days $F(4,44) = 0.625$, $p = 0.647$, Pre-post x days interaction $F(4,44) = 0.084$, $p = 0.987$).
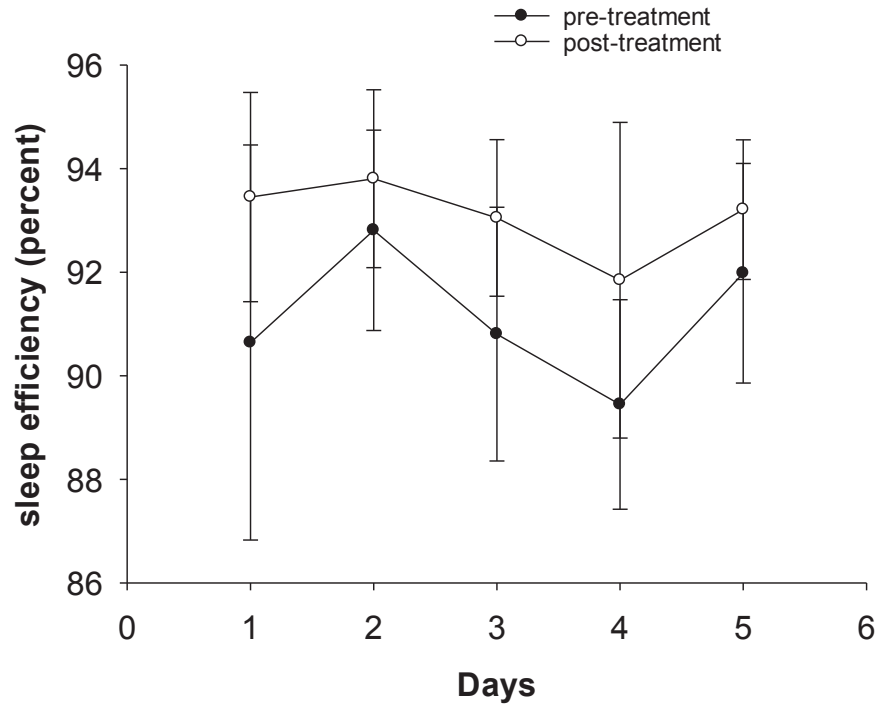
Figure 19: *Sleep efficiency, daily main sleep minutes pre- and post-treatment.*
Values are means ± s.e.m.

3.2.4   Pittsburgh sleep scale scores

The subjects who took melatonin for the full 10 days reported significantly less difficulty sleeping following the treatment phase of the protocol according to their Pittsburgh sleep scale scores ($p = 0.015$, Figure 20).
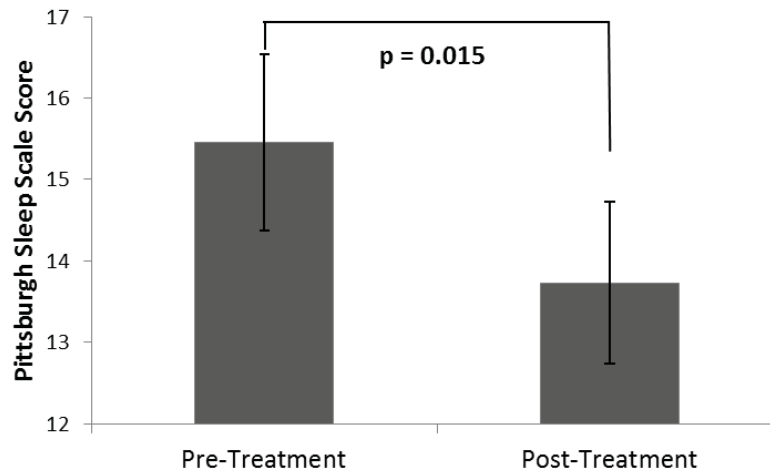
Figure 20: *A comparison of the pre- and post-treatment Pittsburgh sleep scale scores*
for the 11 subjects that completed the treatment.

In summary, apart from some singular subjects (e.g., Subject 7), there was minimal improvement in sleep patterns and melatonin profiles in the 2014 cohort of subjects. The reason for this is revealed in Section 3.3.

3.3   June 2012 vs. June 2014

Following the collection of the pre-treatment actigraph, melatonin, and subjective survey data, the research team noted that there was a striking difference in the sleep patterns and physiological circadian rhythms of the current (June 2014) station personnel compared to the station personnel that completed our study in June 2012. That is, the sleep patterns and physiological circadian rhythms of station personnel in our recent trial were mostly normal, which meant that there was very little room for improvement from the treatment from the outset of the study. We have compared the participants from our recent June 2014 study with those that completed our study in June 2012. That analysis is provided below in Sections 3.3.1 – 3.3.5, and discussed in Section 4.

3.3.1   Differences in sleep quantity and quality

3.3.1.1   Subjective difficulty sleeping – Pittsburgh sleep scale scores

The mean pre-treatment Pittsburgh sleep scale score for the entire subject population (treated and non-treated) from the June 2014 study was 15. In June 2012 the mean Pittsburgh sleep scale score was 18.8. An unpaired 2-tail t-test between the June 2012 participant scores and the June 2014 pre-treatment scores revealed that the 2012 participants reported significantly more difficulty sleeping compared to the June 2014 participants ($p<0.01$, Figure 21).
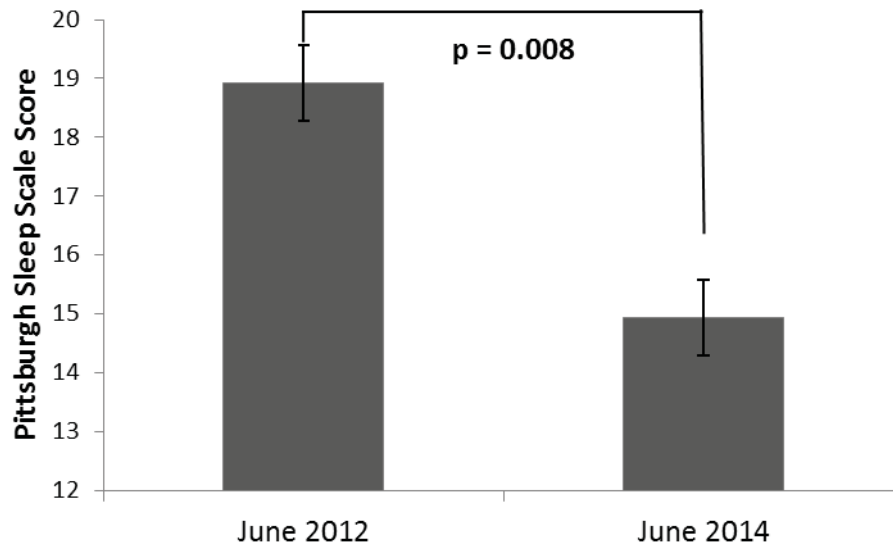
Figure 21: *Comparison of the Pittsburgh sleep scale scores from June 2012 and June 2014. For the June 2014 scores, all 15 subjects (treated and non-treated) are included in the analysis.*

3.3.2 Differences in light exposure

To determine the underlying cause for the differences in sleep between June 2012 and June 2014, we turned to the light exposure data. We have previously highlighted that a major factor for the poor quality and insufficient quantity of sleep obtained by some of our subjects in June 2012 was due to their shifted circadian rhythms caused by exposure to provocative nocturnal light. As a result of their shifted circadian rhythms but stable work and meal schedule, some of these subjects were going to bed before their DLMO, which led to poor sleep quality (more segmented, less efficient, and more time spent awake after sleep onset [WASO]) and a reduction in the quantity of sleep that they obtained each night. We were therefore interested to examine whether the reason the June 2014 subjects slept significantly better was due to a reduced exposure to provocative nocturnal light.

3.3.2.1 Mean 24-hour light exposure in 1-hour bins

The graph of mean hourly light exposure shown below in Figure 22 illustrates the differences in light exposure between our subjects in June 2012 and June 2014. A particular focus should be given to the night time light exposure levels as these are particularly effective at suppressing endogenous melatonin and shifting the human circadian rhythm.
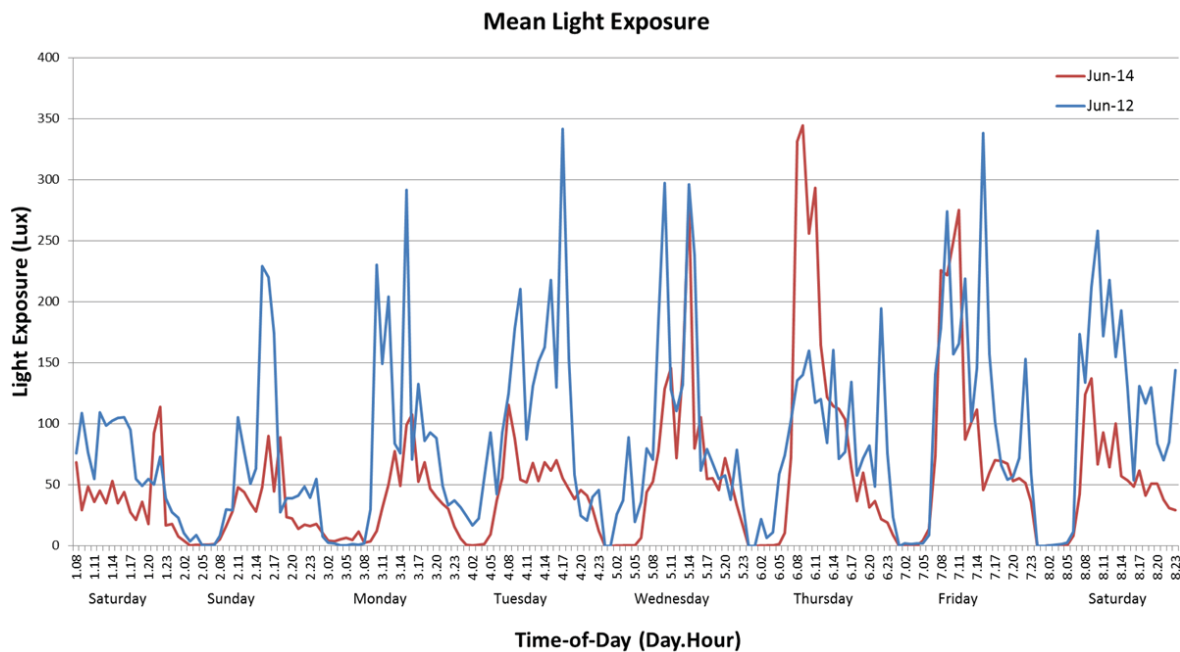
Figure 22: *Mean hourly light exposure for the week prior to salivary melatonin collection in June 2012 and 2014.*

3.3.2.2   Mean light exposure for five days prior to melatonin assessment

The mean light exposure for the five days prior to the initial melatonin assessment in June 2012 and June 2014, as shown in Figure 23, highlights the differences in light that the different groups were exposed to. The data illustrated in Figure 23 was analysed by an ANOVA (two levels of year x five days). The main effect of year $F(1,11) = 3.7245$, $p = 0.08$ was not significant. The main effect of days $F(4,44) = 1.9688$, $p = 0.11596$ was also not significant. However the year x days interaction $(F4,44) = 4.5184$, $p<0.004$ was significant. Post hoc analysis of the interaction indicates that on days 1 and 5, the subjects in June 2012 were exposed to significantly more light compared to the June 2014 subjects. It should be noted however, that mean light exposure only provides a glimpse of the photic environment that our subjects experienced. The light exposure that is provocative to the human circadian system has also been assessed for both groups and is shown below in Figure 24.
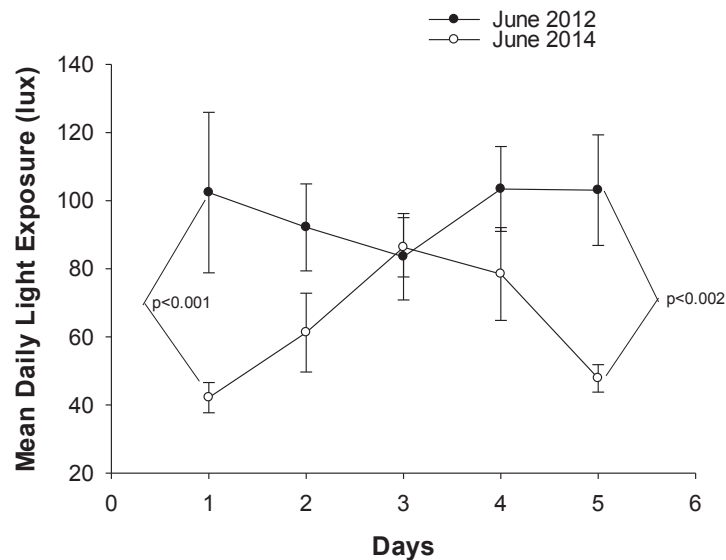
Figure 23: *Mean daily light exposure from June 2012 participants and the pre-treatment phase of the June 2014 study. There was no significant main effect of 'year' [F(1,11) = 3.7245, p = 0.08], but there was a significant interaction between 'year' and 'days' [(F4,44) = 4.5184, p<0.004]. Values are means ±s.e.m.*

3.3.2.3 Mean nocturnal light for five days prior to melatonin assessment

The graphs of mean nocturnal light exposure, shown below in Figures 24 and 25, highlight the differences between the June 2012 subjects and June 2014 subjects in their exposure to light that was provocative to the human circadian system.
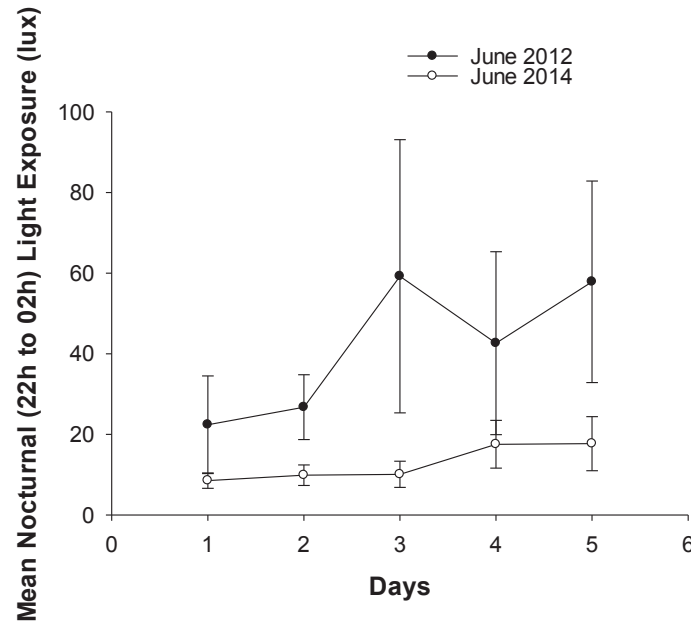
Figure 24: *Mean nocturnal light exposure (22h to 02h) each day for the June 2012 participants and during the pre-treatment phase of the June 2014 study. Values are means ±s.e.m.*
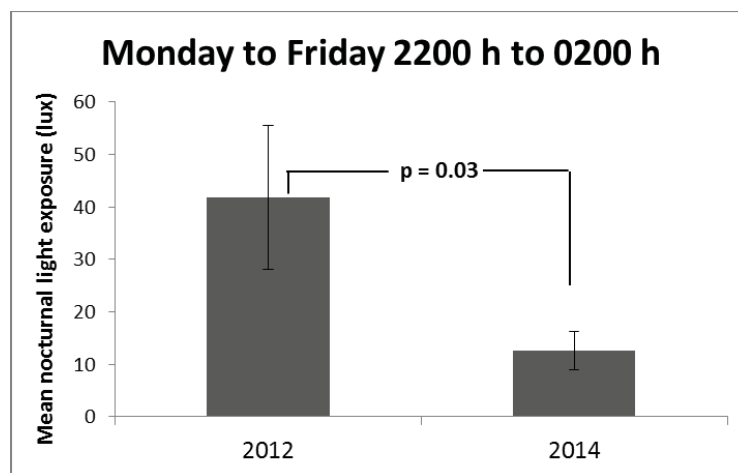
Figure 25: *Main effect of year for nocturnal light exposure. Average light exposure from 2200 h to 0200 h for the week (Monday to Friday) prior to pre-treatment salivary melatonin assessment in June 2012 and June 2014.*

4   Discussion

A small benefit to sleep was seen in many of the subjects following the treatment phase of the protocol. However, the improvement in several of the quality measures of sleep fell short of statistical significance meaning that the numerically superior sleep quality following treatment could be due to chance. As with our past studies at CFS Alert, due to the low numbers of potential subjects at CFS Alert for this study, the failure to reject the null hypothesis may be a case of type two statistical error. Nevertheless, the comparison of the pre-treatment sleep statistics with our data from June 2012 reveals that there was a statistically significant difference in the quantity and quality of sleep that was being obtained prior to this trial, which are likely due to the differences in rules imposed by the Commanding Officer (CO) and Station Warrant Officer (SWO) regarding the permitted times and boundaries when venturing off station for work or leisure. From our experience, the CO and SWO in June 2014 were more conservative than their 2012 counterparts in their permissible limits of off-station travel in effort to protect the health and safety of station personnel. Specifically, venturing off-station was prohibited after 2000 h. These orders had the unintended effect of helping to control excessive and provocative nighttime light exposure that station personnel may otherwise receive. In addition, the CO and SWO are responsible for setting mess hours, and ordered the mess closed at 2300 h on most weeknights, and 2400 h on weekends. As a result, the sleep patterns and physiological circadian rhythms of station personnel in our recent trial were mostly normal. In contrast, during our 2012 summer trial at CFS Alert we found that night-time exposure to light caused delayed circadian rhythms and significant sleep difficulties among a substantial subset of our research participants [22]. Night-time exposure to light is known to shift circadian rhythms and suppress melatonin, which can result in delayed circadian rhythms and insomnia. Avoidance of such light exposure has been shown to increase the amount of sleep an individual obtains each night, and may also impact the quality of sleep he/she obtains.

The treatment that was provided to the subjects was prescribed on the basis of subjective sleep difficulties, which were significantly improved by the treatment. Some minor, though not statistically significant, improvements to several of the quantitative sleep parameters were observed; however, there was very limited room for improvement to begin with, and without statistical significance, we cannot definitively say the exogenous melatonin was effective at improving sleep. Still, many of the subjects seemed to benefit from the treatment such that their quality of sleep improved. The subjects that seemed to benefit most from the treatment were Subjects 7 and 14, who both saw marked improvement in the quality as well as the quantity of sleep that was obtained each night. Overall, improvement in sleep quality was observed in 8 of the 11 treated s (73% of cases; improved sleep quality observed in Subjects 2, 3, 7, 9, 10, 11, 14 and 15).

In summary, the exogenous melatonin treatment given to the subjects was not significantly effective at improving their quality of sleep; however, this is primarily because there was such little room for improvement to begin with. The subjects in this study all had normal melatonin rhythms, and generally obtained a good quantity of high quality sleep. These results are in contrast with the results obtained in CFS Alert in June 2012, in which sleep difficulty and irregular circadian rhythms were evident. The main differences between these two studies were the rules of the station imposed by the Commanding Officer and Station Warrant Officer in spring/summer 2014 vs. the lack of such rules in spring/summer 2012. We therefore recommend

that future CO's and SWO's of CFS Alert similarly prohibit venturing off-station after 2000 h, and closing the bars at a reasonable time (e.g., 2300 h on weeknights, and 2400 h on weekends), as the unintended consequence of this is the maintenance of a regular sleep-wake/work schedule among Station personnel.

5 Conclusions

The pertinent findings from this study are as follows:

1. After initial arrival in the high Arctic summer, there is a period of acclimatization during which personnel may not obtain adequate sleep and so have degraded performance,

2. The most effective measure for Circadian optimization (and resulting personnel performance) in the high Arctic summer is Command and Control of personnel with regard to light exposure, by enforcing limitation of evening light exposure and enforcing a regular sleep-wake schedule.

These findings have important implications for all military personnel operating in the high arctic during the summer, and not only personnel at CFS Alert.

References

[1]   Paul, M.A., G.W. Gray, H.R. Lieberman, R.J. Love, J.C. Miller, and J. Arendt. *Management of Circadian Desynchrony (Jetlag and Shiftlag) in CF Air Operations*. 2010, TR 2010-002, DRDC Toronto. p. 48.

[2]   Paul, M.A., G.W. Gray, H.R. Lieberman, R.J. Love, J.C. Miller, M. Trouborst, and J. Arendt. Phase advance with separate and combined melatonin and light treatment. *Psychopharmacology*, 2011. **214**: p. 515-523.

[3]   Paul, M.A., J.C. Miller, G.W. Gray, F. Buick, S. Blazeski, and J. Arendt. Circadian Phase Delay Induce by Phototherapeutic devices. *Aviat. Space Environ. Med*, 2007. **78**: p. 645-652.

[4]   Paul, M.A., J.C. Miller, G.W. Gray, R.J. Love, H.R. Lieberman, and J. Arendt, Melatonin treatment for eastward and westward travel preparation. *Psychopharmacology (Berl)*, 2010. **208**(3): p. 377-387.

[5]   Paul, M.A., J.C. Miller, R.J. Love, H.R. Lieberman, S. Blazeski, and J. Arendt. Timing Light Treatment for Eastward and Westward Travel Preparation. *Chronobiology International*, 2009. **26**(5): p. 867-890.

[6]   Burgess, H.J., V.L. Revell, and C.I. Eastman. A three pulse phase response curve to three milligrams of melatonin in humans. *J Physiol*, 2008. **586.2**: p. 639-647.

[7]   Burgess, H.J., V.L. Revell, T.A. Molina, and C.I. Eastman. Human Phase Response Curves to 3 Days of Daily Melatonin: 0.5 mg versus 3.0 mg. *Journal of Clinical Endocrinlology and Metabolism*, 2010. **doi:10.1210/jc.2009-2590**.

[8]   Khalsa, S.B., M.E. Jewett, C. Cajochen, and C.A. Czeisler. A phase response curve to single bright light pulses in human subjects. *J Physiol,* 2003. **549**(Pt 3): p. 945-952.

[9]   Lewy, A.J., V.K. Bauer, S. Ahmed, K.H. Thomas, N.L. Cutler, C.M. Singer, M.T. Moffit, and R.L. Sack. The human phase response curve (PRC) to melatonin is about 12 hours out of phase with the PRC to light. *Chronobiol Int*, 1998. **15**(1): p. 71-83.

[10]   Minors, D.S., J.M. Waterhouse, and A. Wirzjustice. A Human Phase Response Curve to Light. *Neuroscience Letters*, 1991. **133**(1): p. 36-40.

[11]   Zaidan, R., M. Geoffriau, J. Brun, J. Taillard, C. Bureau, G. Chazot, and B. Claustrat. Melatonin is able to influence its secretion in humans: description of a phase response curve. *Neuroendocrinology*, 1994. **60**(1): p. 105-112.

[12]   Burgess, H.J., S.J. Crowley, C.J. Gazda, L.F. Fogg, and C.I. Eastman. Preflight adjustment to eastward travel: 3 days of advancing sleep with and without morning bright light. *J Biol Rhythms*, 2003. **18**(4): p. 318-328.

[13]   Eastman, C.I. and H.J. Burgess. How to Travel the World Without Jetlag. *Sleep Medicine Clinics*, 2009. **4(2)**: p. 241-255.

[14]   Revell, V.L., H.J. Burgess, C.J. Gazda, M.R. Smith, L.F. Fogg, and C.I. Eastman. Advancing human circadian rhythms with afternoon melatonin and morning intermittent bright light. *J Clin Endocrinol Metab*, 2006. **91**(1): p. 54-59.

[15]   Deacon, S. and J. Arendt. Posture influences melatonin concentrations in plasma and saliva in humans. *Neuroscience Letters*, 1994. **167**: p. 191-194.

[16]   Watson, D. and J.W. Pennebaker. Health complaints, stress, and distress: exploring the central role of negative affectivity. *Psychological Review*, 1989. **96**(2): p. 234-54.

[17]   Watson, D., L.A. Clark, and A. Tellegen. Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, 1988. **54**(6): p. 1063-70.

[18]   Spitzer, R.L., K. Kroenke, J.B.W. Williams. Validation and utility of a self-report version of PRIME-MD - The PHQ primary care study. *Jama-Journal of the American Medical Association,* 1999. **282**(18): p. 1737-1744.

[19]   Buysse, D.J., C.F. Reynolds, 3rd, T.H. Monk, S.R. Berman, and D.J. Kupfer. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research*, 1989. **28**(2): p. 193-213.

[20]   Horne, J.A. and O. Ostberg. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International journal of chronobiology*, 1976. **4**(2): p. 97-110.

[21]   Paul, M.A., R.A. Pigeau, and H. Weinberg. CC130 Pilot Fatigue during Re-supply Missions to Former Yugoslavia. *Aviat Space Environ Med*, 2001. **72**(11): p. 965-73.

[22]   Paul, M.A., R.J. Love, A.M. Hawton, D. Ebisuzaki, J. McHarg, W.G. Burfitt, T.P. Harris, K.S. Luomala, R.N. Watson, and J. Arendt. *Melatonin production, sleep patterns and modeled performance effectiveness in subjects in the high Arctic*. 2014, DRDC Toronto, DRDC-RDDC-2014-R15, 62 pages.

List of symbols/abbreviations/acronyms/initialisms

ANOVA	ANalysis Of VariAnce
CAF	Canadian Armed Forces
CFS	Canadian Forces Station
DLMO	Dim Light Melatonin Onset
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DSTKIM	Director Science and Technology Knowledge and Information Management
ELISA	Enzyme-Linked ImmunoSorbent Assay
R&D	Research & Development
SWO	Station Warrant Officer
WASO	Wake After Sleep Onset

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Background. We have previously shown that the 24 hours of daily sunlight in the high Arctic during the summer provides a good environment for misaligning the physiological circadian pattern with the work-sleep schedule of the individual. As a result, there is a prevalence of sleep difficulty in the summer, with a general reduction in both the quantity and quality of sleep obtained among residents in the summer vs. the winter (Paul, M. A., Love, R. J., Hawton, A. M. et al. Melatonin production, sleep patterns and modeled performance effectiveness in subjects in the high Arctic. In. DRDC-RDDC-2014-R15, DRDC – Toronto Research Centre, 2014).

Methods. Subjects were 15 CAF personnel (11 males and 4 females, age range of 19 to 47 years, with mean age and standard deviation of 28.3 ± 8.3 years) who had arrived at CFS Alert at least one week prior to the study which encompassed 21 days from May 23rd to June 13th, 2014. During this period there were 24 hours of daylight. Subjects wore motion-detection devices (Actigraphs) to obtain objective sleep data, and completed questionnaires regarding sleep difficulty and psychosocial parameters at the beginning and end of the study. After a 7 day period of baseline Actigraph data, salivary melatonin assays were collected 2 hourly for 24 hours while the subjects remained in dim light conditions. Based on the melatonin profiles and sleep questionnaire histories, 13 subjects were prescribed melatonin and given advice about light exposure. After a 10 day intervention period, a 24 hour melatonin profile was repeated under identical conditions. Treatment effects were evaluated using the questionnaire data, actigraphic data, and endogenous melatonin profiles.

Results. A small benefit of exogenous melatonin consumption was observed in 73% of the subjects. However, there was no statistically significant difference in the collective quantity or quality of sleep obtained by the subjects following the treatment. We believe that this was primarily because the subjects in this study all had normal melatonin rhythms, and generally obtained a good quantity of high quality sleep, which is in contrast to the results obtained in CFS Alert in June 2012, when sleep difficulty and irregular circadian rhythms were evident. The difference between research participants in June 2012 and June 2014 is attributed to reduced levels of nocturnal light exposure that are provocative to the human circadian rhythm. As compared to 2102, the Commanding Officer (CO) and Station Warrant Officer (SWO) in June 2014 were conservative in their permissible limits of off-station travel in effort to protect the health and safety of station personnel. In addition, the mess was closed by midnight at the latest.

Conclusion. These orders seem to limit the nocturnal light exposure that cause circadian rhythm misalignment and reduce associated insomnia or sleep difficulties among station personnel. These findings have important implications for military operations in the high arctic during summer.

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endogenous melatonin, circadian desynchrony, fatigue, sleep hygiene, modeled cognitive effectiveness