Melatonin production, sleep patterns and modeled performance effectiveness in subjects in the high Arctic

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Abstract

Background. Previous research conducted by DRDC Toronto shows that human circadian rhythms can be manipulated using appropriately-timed treatments of light and/or supplementary melatonin. The seasonal extremes of photoperiod in the high Arctic places pArcticular strain on the human circadian system, which may lead to Seasonal Affective Disorder (SAD) in the winter months and difficulty obtaining sufficient sleep in the summer months. The goal of the work reported here was to study the circadian rhythms of personnel deployed to the high Arctic by tracking the melatonin produced by the body and identifying the timing of daily onset of melatonin production (DLMO, or Dim Light Melatonin Onset). This will permit follow-up work and recommendations for the treatment of discordant human circadian rhythms and associated conditions with the aforementioned countermeasures. **Methods.** Three research trials were conducted, two in the built environment of CFS Alert, and one on land during the SARTech Arctic Survival Course. During all three trials, subjects wore motion logging devices (Actigraphs), which measure ambient light as well as motion. Sleep data obtained from the Actigraphs was used to model the cognitive effectiveness of each subject. Furthermore, saliva was collected at regular intervals to measure melatonin and assess DLMO. **Results.** In general, sleep duration was found to be significantly different between the January and June data collections at CFS Alert, with subjects in June sleeping an average of 46 minutes less than their January counterparts each day. Sleep duration was also found to fall significantly from Sunday to Monday for subjects in both January and June, resulting in reduced cognitive effectiveness in many of the subjects through the week. Circadian stress and poor cognitive effectiveness was most pronounced in the meteorology technicians that we studied, which we attribute to their variable work schedules. **Conclusions.** The Arctic summer represents a parcticularly challenging environment for obtaining sufficient sleep, which affects cognitive performance of staff during work hours. A reduction of total melatonin production and a reduced duration of melatonin production in the Arctic summer are contributing factors to the reduced desire to sleep in CFS Alert during the summer months.

Significance to defence and security

This report documents the impact of the winter and summer extremes of Arctic photoperiod (read daylight) on circadian physiology. Operating in the Arctic during winter can lead to mood disorders, whereas the main circadian impact during Arctic summer is difficulty obtaining significant sleep. The information in this report will serve as baseline information to be used in the crafting of circadian countermeasures (in the follow-on countermeasure phase of this project) to improve Operational Readiness in the Arctic.

Résumé

Contexte. Des recherches antérieures menées par RDDC Toronto indiquent que le rythme circadien humain peut être modifié à l'aide de séances de photothérapie administrées au bon moment et/ou de suppléments de mélatonine. Les variations extrêmes de la photopériode liées aux saisons dans le Haut Arctique exercent une pression particulièrement forte sur le rythme circadien humain, ce qui peut entraîner un trouble affectif saisonnier (TAS) dans les mois d'hiver et une difficulté à dormir suffisamment durant les mois d'été. L'objectif des travaux décrits était d'étudier le rythme circadien du personnel envoyé dans le Haut Arctique en mesurant régulièrement la mélatonine fabriquée par l'organisme et en déterminant le moment où elle est produite quotidiennement (début de la production de mélatonine dans des conditions de faible luminosité). Cette surveillance permettra de faire un travail de suivi et de formuler des recommandations sur le traitement des perturbations du rythme circadien humain et des affections associées au moyen des contre mesures susmentionnées. **Méthodes.** On a procédé à trois essais de recherche, soit deux dans l'environnement aménagé de la station des Forces canadiennes (SFC) Alert et un autre sur le terrain durant le cours de survie en Arctique destiné aux Tech SAR. Lors des trois essais, les sujets portaient un dispositif d'enregistrement du mouvement (ActiGraph), qui mesure la lumière ambiante et le mouvement. Les données sur le sommeil obtenues grâce aux dispositifs Actigraph ont servi à modéliser l'efficacité cognitive de chacun des sujets. En outre, de la salive a été recueillie à intervalles réguliers pour mesurer la quantité de mélatonine et déterminer le début de la production de mélatonine dans des conditions de faible luminosité. **Résultats.** En général, selon les données recueillies à la SFC Alert, la durée du sommeil était nettement différente entre janvier et juin, les sujets dormant en moyenne 46 minutes de moins par jour en juin que leurs homologues en janvier. Nous avons aussi constaté que la durée du sommeil des sujets diminuait considérablement du dimanche au lundi tant en janvier qu'en juin, ce qui entraînait une baisse de l'efficacité cognitive chez de nombreux sujets toute la semaine durant. Le stress imposé par les variations du rythme circadien et la baisse d'efficacité cognitive étaient plus prononcés chez les techniciens en météorologie évalués, phénomène que nous avons attribué à leurs horaires de travail variables. **Conclusions.** Il est particulièrement difficile de dormir suffisamment pendant l'été en Arctique, et le manque de sommeil a des répercussions sur la performance cognitive du personnel pendant les heures de travail. La baisse de la production totale de mélatonine et la plus courte période de production de la substance en été dans l'Arctique sont des facteurs qui réduisent l'envie de dormir à la SFC Alert pendant les mois d'été

Importance pour la défense et la sécurité

Ce rapport documente les effets des variations extrêmes de la photopériode (durée du jour) entre l'hiver et l'été en Arctique sur la régulation de la physiologie par le rythme circadien. Le fait de travailler en Arctique pendant l'hiver peut entraîner des troubles de l'humeur, tandis qu'en été, la principale conséquence sur le rythme circadien est la difficulté à dormir suffisamment. Le présent rapport fournit des données sur lesquelles on pourra s'appuyer pour élaborer des contre mesures destinées à réguler le rythme circadien (dans la phase sur les contre mesures à venir de ce projet) qui permettront d'améliorer l'état de préparation opérationnelle dans l'Arctique.

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1 Background

DRDC Toronto has recently completed a 4-year project to optimize the ability of the Canadian Armed Forces (CAF) to advance or delay circadian rhythms using appropriately-timed ingestion of exogenous (supplementary) melatonin [1, 2]; and appropriately-timed light treatment [3-5] which suppresses the manufacture and release of endogenous (made by the body) melatonin. This capability to manipulate circadian rhythms allows us to mitigate the circadian desynchrony that is inherent in jetlag and shiftlag. The CAF now has the ability to treat military personnel prior to deployment such that they arrive in a new time zone without jetlag, and the same knowledge can be used to adapt military personnel to various nocturnal work schedules.

DRDC Toronto exploited this new capability to address seasonal extremes of the Arctic photoperiod (Arctic winter with 24/7 darkness for several months, and Arctic summer with 24/7 daylight for several months). There is evidence of increases in the level and duration of endogenous melatonin produced during winter in the high latitudes [6-9] which may result in symptoms such as daytime sleepiness, or Seasonal Affective Disorder (SAD) which is sometimes referred to as Winter Depression. SAD [10] which was first discovered in 1984 can occur in the middle latitudes (e.g., Halifax, Quebec, Ottawa, Toronto, Winnipeg, Calgary and Vancouver), and has the potential to be especially severe in the polar regions (Arctic and Antarctic) during winter. During the extreme photoperiod of the Arctic summer, exposure to bright light is possible throughout 24h day, which suppresses endogenous melatonin, causes difficulty obtaining sufficient sleep, and results in disruptions to mood and cognitive functioning. Our work to address seasonal extremes in the high Arctic will occur in two phases; 1) determine how the endogenous circadian rhythm of melatonin changes during the seasonal extremes and 2) evaluate countermeasures (exogenous melatonin, potentially useful during both winter and summer), light treatment (winter), and special eye-glasses (which filter out the blue and green light energy wavelengths which can otherwise suppress the body's ability to manufacture and release melatonin into the circulation) especially while living and conducting operations out on the land during Arctic summer.

The work reported here covers the first phase of this project (i.e., the seasonal extremes of the endogenous melatonin rhythm during each of Arctic winter and Arctic summer). The goal of the work reported here was to document the endogenous melatonin rhythm (i.e., melatonin produced by the body) of personnel deployed to the high Arctic, especially the timing of daily onset of melatonin (DLMO, or Dim Light Melatonin Onset). Based on our own data, a normal DLMO occurs 2.54 ± 1.18 h (mean ± SD) before sleep onset [2, 4, 5, 11]. A DLMO occurring after sleep onset or more than 2 SDs before mean sleep onset will be considered abnormal. The knowledge of the impact that seasonal extremes have on the timing of DLMO is an important pre-requisite to circadian countermeasures, since the optimum timing of circadian countermeasures with light and melatonin are a function of the timing of DLMO [1, 2, 5, 11-14].

2 Methodology

2.1 Dim Light Melatonin Onset (DLMO)

DLMO is found by sampling melatonin concentration in blood or saliva at uniform intervals under dim light conditions (<10 lux; [15-18]), where the first sample that exceeds a prescribed threshold is designated as DLMO.

2.2 Subject inclusion/exclusion criteria/age/gender demographics

The report covers three high Arctic data collections as follows:

1. From January 5th to 13th 2012, Chrystal City (Resolute) SARTech Arctic Survival Course (out on the land).

2. From January 14th to 22nd 2012, CFS Alert (built environment).

3. From June 8th to 17th 2012, CFS Alert (built environment).

For data collections 2 and 3, subjects had to have been at CFS Alert continuously for at least 1 month.

For data collection 1, since the SARTechs were only in the Arctic for their 7-day Arctic survival course, the requirement to have been in the Arctic for at least a month prior to data collection was waived. The ages of the 12 male subjects ranged from 24 to 47 years, with a mean age and standard deviation of 30.4 ± 2.4. Eleven of the subjects were regular force SARtech candidates and 1 subject was a civilian instructor.

For data collection 2, the ages of the 14 subjects ranged from 21 to 56 years, with a mean age and standard deviation of 36.9 ± 2.9. There were 9 regular force males, 4 regular force females and 1 female class B reservist.

For Data collection 3, the ages of the 12 subjects ranged from 22 to 47 years, with a mean age and standard deviation of 31.2 ± 2.8. Of the 8 male subjects, 7 were regular force and 1 was a class A reservist. All four female subjects were from the regular force.

The protocol for each data collection was approved by the DRDC-Toronto Human Research Ethics Committee. All subjects provided written informed consent prior to participating and were free to discontinue the study at any point in time.

2.3 Procedures

2.3.1 Data collection 1 (SARTechs in arctic survival course), Jan 5-13 2012 (out on the land)

Subjects wore a wrist actigraph from January 5th until the data collection was completed at 0600 h on January 13th to record their daily sleep. This sleep data was used to generate models of cognitive effectiveness with FAST™ (Fatigue Avoidance Scheduling Tool) software. The subjects also maintained a sleep log to cover for the possibility of actigraph failure. The subjects arrived in Resolute Bay at 2345 h on January 5th and slept at the Narwahl Inn for 3 nights. On January 8th at 0800 they arrived at Chrystal City, a remote area about 5 km from Resolute Bay where they subjects underwent survival training for the following 4 days. The first night in Chrystal City was spent in Arctic tents. By 1800 h, the following day (January 9th) the subjects had built either igloos or snow caves and moved into those accommodations for the balance of the survival course. With temperatures ranging from -20C to -40C actigraphs often froze-up and stopped functioning. Thus some subjects were re-issued functioning actigraphs several times during the data collection. When actigraph sleep data was not available, sleep and wake times were taken from sleep log data for generation of FAST models.

Given the reality of the austere environment and the requirement for us not to impact on the conduct of the survival course, concessions were made to the normal procedures (fixed semi-recumbent posture in the 15 minutes prior to each sample) for collection of the 24-hr saliva samples during the Arctic survival course). At 0600 h on Thursday January 12th, our staff commenced collection of the 24-hr saliva samples. The 0600 h and 0800 h samples were collected while subjects were in snow caves or igloos. The Kudlik (a small Inuit light and source of heat) was set up in all igloos and snow caves (the ambient light in the igloos and snow caves was less than 5 lux). The 1000 h samples could not be collected due to higher priority activity in the survival course. The saliva sampling resumed at 1320 h (outside of the igloos and snow caves) and was repeated at 1420 h. At about 1600 h the subjects trekked from Chrystal City arriving at the Narwhal Inn shortly after 1700 h. A saliva sample was taken from all subjects at 1720 h in the Narwahl Inn in their darkened rooms (less than 5 lux). Some subjects were not available for the 1850 h sample. All subjects provided saliva samples for the balance of the 24-hr collection (2000 h, 2200 h, 2400 h, 0200 h, 0400 h and 0600 h) in their respective darkened rooms.

2.3.2 Data collection 2 (CFS Alert Staff), Jan 14-22, 2012 (built environment)

The subjects donned their actigraphs on January 14th and wore them until the end of the data collection at 0900 on Sunday January 22nd. They also maintained a sleep log during this period to cover for possible actigraph failure. On Saturday Jan 21st, the subjects arrived at the Station gymnasium for 0830 h. They were assigned lounge chairs for the 24-h saliva collection period. The gymnasium lights were turned off but supplementary lighting (to 5 lux) was stationed around the gymnasium and in the washrooms. A large monitor was setup about 20 feet in front of the line of subjects (in their lounge chairs) to provide the subjects with movies during the 24-h period. Eye-level ambient light from the monitor was 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 1hr 40 minutes out of each 2-hour sampling block, but remained in areas with ambient light of less than 5 lux.

The subjects had to be back in semi-recumbent posture in their lounge chairs in the 15 minutes prior to each sample. The subjects were required to remain awake from 0900 h until 2300 h, after which they could sleep but were awakened in the 15 minutes prior to each sample. The subjects were released Sunday morning after the 0900 h sample.

2.3.3 Data collection 3 (CFS Alert Staff), June 8-17, 2012 (built environment)

The procedures for data collection 3 were identical to those for data collection 2.

2.4 Overview of the features of FAST^{TM} model graphs

- The vertical axis on the left side of the FAST^{TM} graphs represents human cognitive effectiveness as a percentage of optimal performance (100%). The oscillating line in the diagram represents the subjects average performance (cognitive effectiveness) as determined by time of day, the predicted state of their biological rhythms, time spent awake in the preceding 24 hours, and the amount of time spent asleep in the preceding 24 hours.
- The dotted line which is below the cognitive effectiveness curve and follows a similar oscillating pattern as the cognitive effectiveness, represents the lower 10th percentile of the subjects predicted cognitive effectiveness.
- The green band (from 90% to 100%) represents acceptable cognitive performance effectiveness for workers conducting safety sensitive jobs (flying, driving, weapons operation, command and control, etc).
- The yellow performance band (from 65% to 90% cognitive effectiveness) indicates caution. Personnel engaged in skilled performance activities such as aviation should not be allowed to operate in this performance band.
- The area from the horizontal dotted line to the pink area represents the cognitive effectiveness equivalent to the circadian nadir and a 2nd day without sleep.
- The pink performance band (below 65% modelled performance effectiveness) represents significantly reduced performance with anticipated performance compromise on any task.
- The vertical axis on the right side of FAST^{TM} graphs represents the Blood Alcohol Content (BAC) equivalency throughout the spectrum of cognitive effectiveness. A value of 77.5% cognitive effectiveness corresponds to a blood alcohol content of 0.05% (legally impaired in some jurisdictions). A value of 70% cognitive effectiveness corresponds to a blood alcohol content of 0.08% (legally impaired in most jurisdictions). The BAC equivalency levels associated with sleep deprivation/fatigue are based on three important studies [19-21].

3 Results

3.1 Individual subject data – SARTechs

For each of the subjects listed below, a FAST® model of their cognitive effectiveness is presented and is based on their Actigraph sleep/wake data. Where sleep data is not available, sleep log data was used. The FAST® model is followed by a plot of individual salivary melatonin data from their 24 hour samples.

The salivary melatonin graphs shown below illustrate the timing of melatonin production. The times shown are in digital 24-hr time, for example 23.06 h is equivalent to 11:04 PM. Mean sleep (slp) time is the time of sleep onset (ie. the time the subjects fell asleep). DLMO is the calculated time (by linear interpolation) of dim-light melatonin onset based on the time point where melatonin concentration exceeded the prescribed threshold of 2.7 pg/ml of saliva.

3.1.1 Subject 3

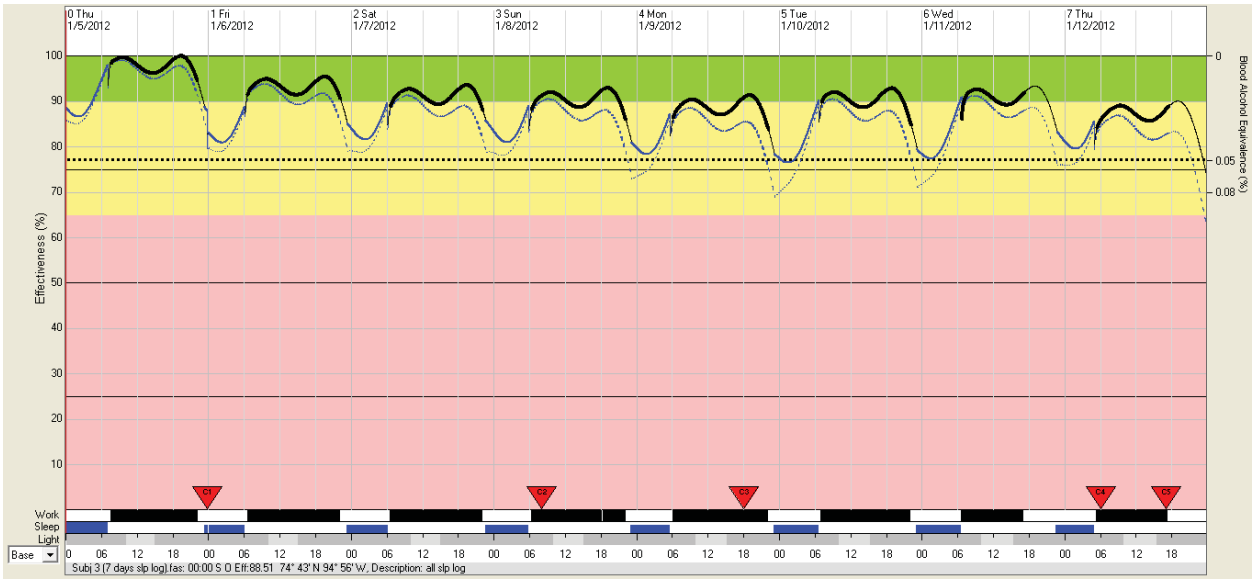

Figure 1. *FAST™ model showing cognitive effectiveness for subject 3. Subject 3 shows some deterioration in cognitive effectiveness over time, but given the extreme circumstances this subject is sleeping well and performing well. The red triangles along the abscissa represents 5 events as follows; C1 = subjects arrive from Comox in Resolute Bay, C2 = subjects have departed Narwhal Inn and arrive at Chrystal City (site of the survival course) and spend the first night in Arctic tents, C3 = subjects move into the snow caves or igloos they have built, C4 = 24-h saliva collection commences in snow caves and igloos at 0600 h January 12th, C5 = 24-h saliva collection ends at Narwahl Inn at 0600 January 13th.*

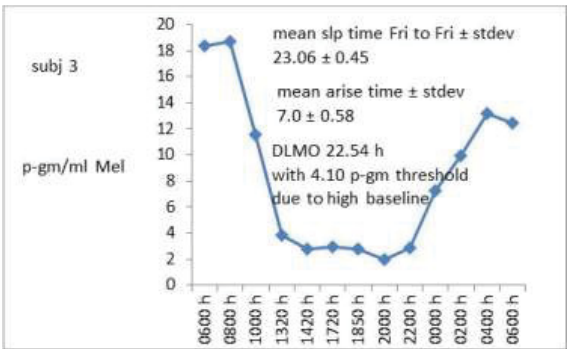

Figure 2. *Salivary melatonin (p-gm/mL) for subject 3, plotted over 24-hours. Subject 3 has a normal bedtime, arise time, and a relatively late DLMO. An insufficient amount of light data was obtained to display graphically.*

3.1.2 Subject 4

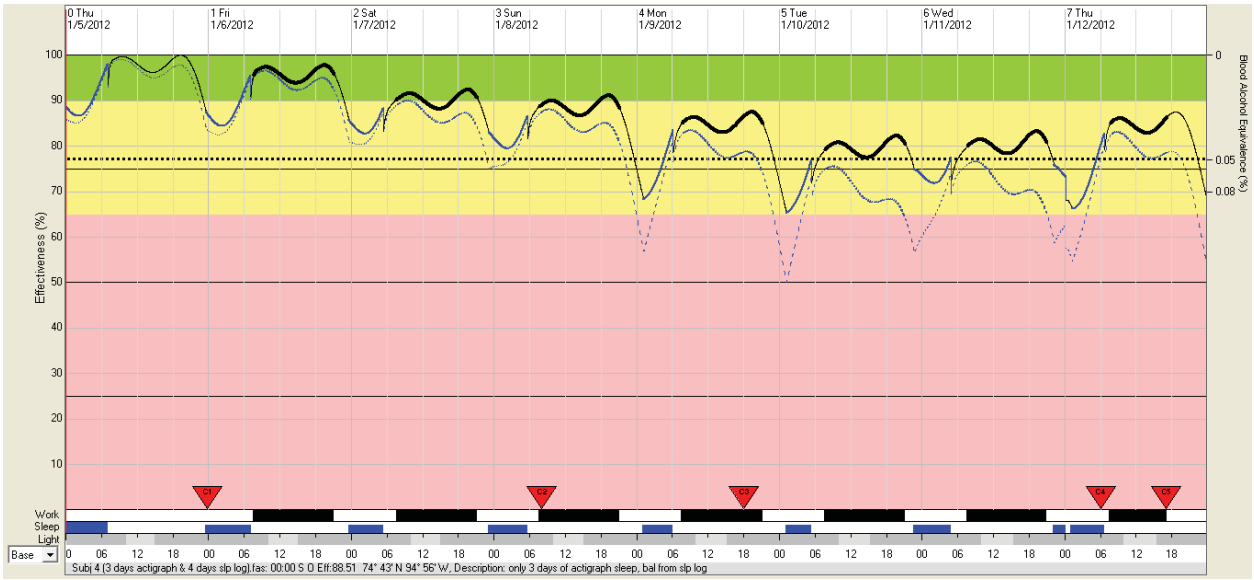

Figure 3. *FAST™ model showing cognitive effectiveness for subject 4. Subject 4 shows detioration in cognitive effectiveness over time. The nadir of his performance occurs after the first sleep in his snow shelter (igloo or snow cave) on Tuesday Jan 10th.*

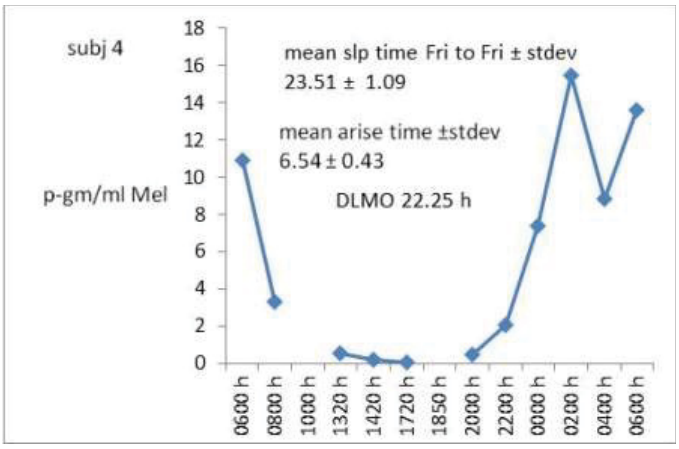

Figure 4. *Salivary melatonin (p-gm/mL) for subject 4, plotted over 24-hours. Subject 4 has a normal bedtime, arise time, and a slightly late, normal DLMO. An insufficient amount of light data was obtained to display graphically.*

3.1.3 Subject 5

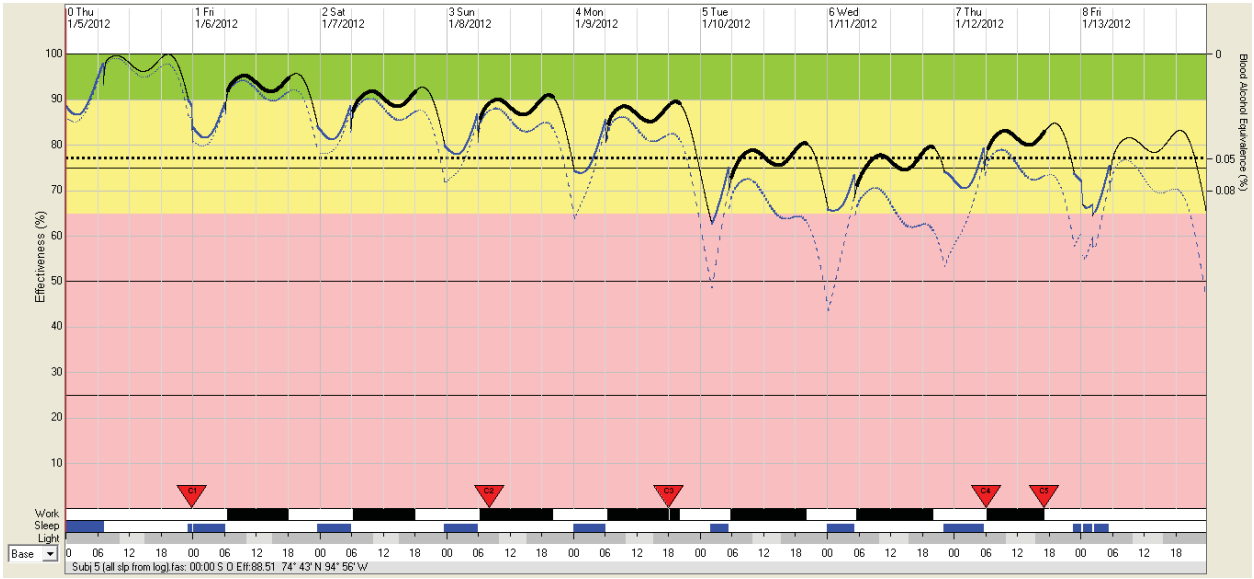

Figure 5. *FAST™ model showing cognitive effectiveness for subject 5. Subject 5 also shows detioration in cognitive effectiveness over time. The nadir of his performance occurs after the first sleep/inadequate sleep in his snow shelter (igloo or snow cave) on Tuesday January 10th and shows some recovery during the 24-hr saliva collection.*

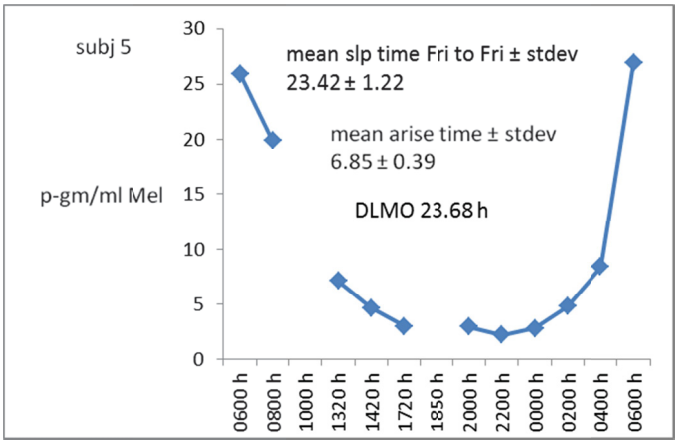

Figure 6. *Salivary melatonin (p-gm/mL) for subject 5, plotted over 24-hours. Subject 5 has a normal bedtime and arise time but his DLMO is retarded and actually occurs just after his bedtime. An insufficient amount of light data was obtained to display graphically.*

3.1.4 Subject 6

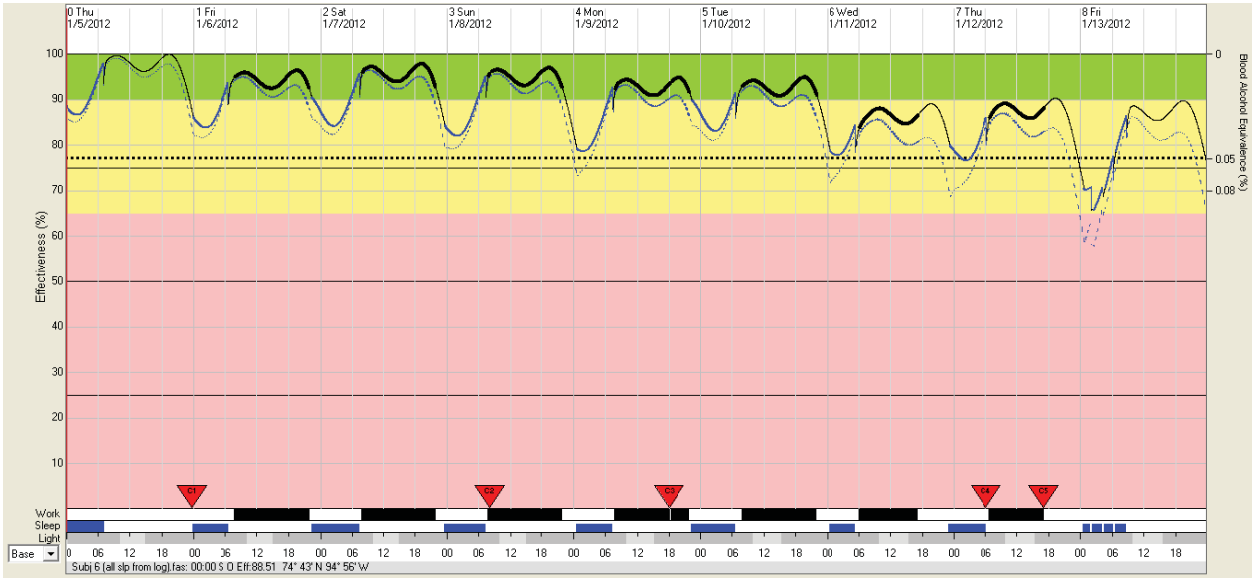

Figure 7. *FAST^{TM} model showing cognitive effectiveness for subject 6. Subject 6 shows good cognitive effectiveness (in the green band) which falls into the yellow band on January 11th after limited sleep during the 2nd night in his snow shelter. The cognitive effectivness remains in the yellow band for the rest of the data collection.*

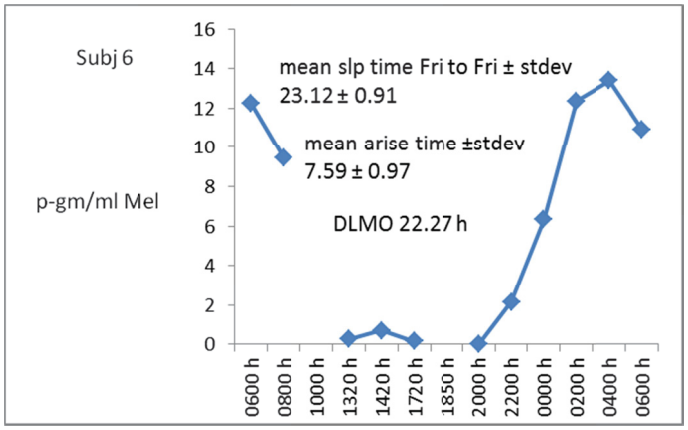

Figure 8. *Salivary melatonin (p-gm/mL) for subject 6, plotted over 24-hours. Subject 6 has normal sleep and arise times and a normal DLMO since it occurs about an hour prior to the average bedtime. An insufficient amount of light data was obtained to display graphically.*

3.1.5 Subject 7

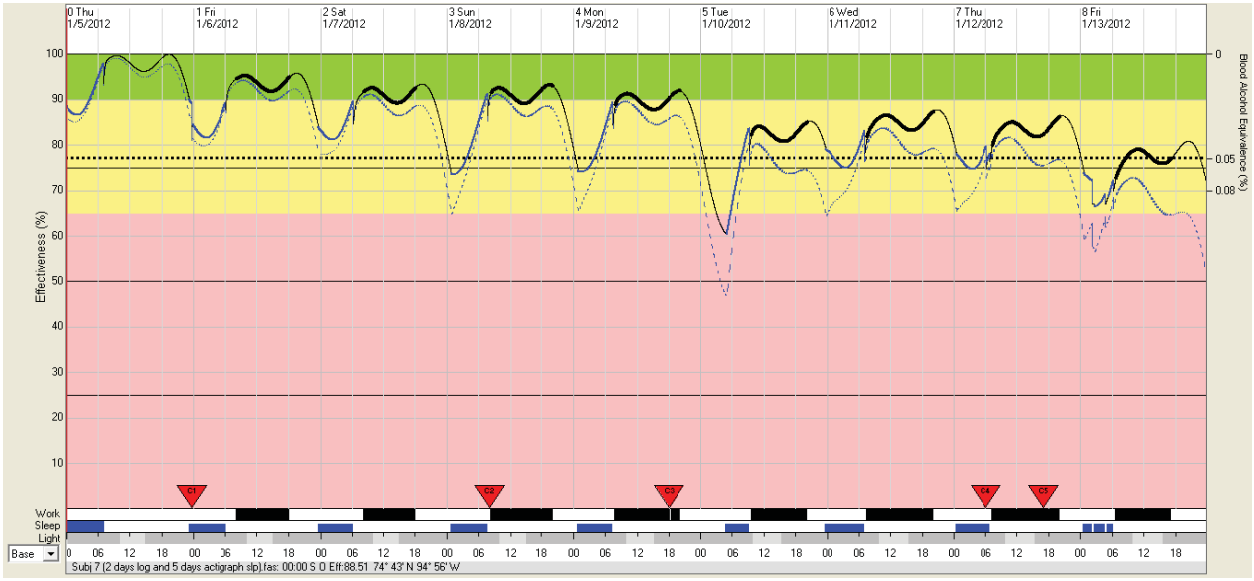

Figure 9. *FAST^{TM} model showing cognitive effectiveness for subject 7. Subject 7 shows good cognitive effectiveness (in the green band) over the first few days. After limited sleep in his snow shelter his cognitive effectiveness falls into the yellow band on January 10th and remains there for the balance of the data collection, reaching equivalence to Blood Alcohol Content 0.05% on the last day.*

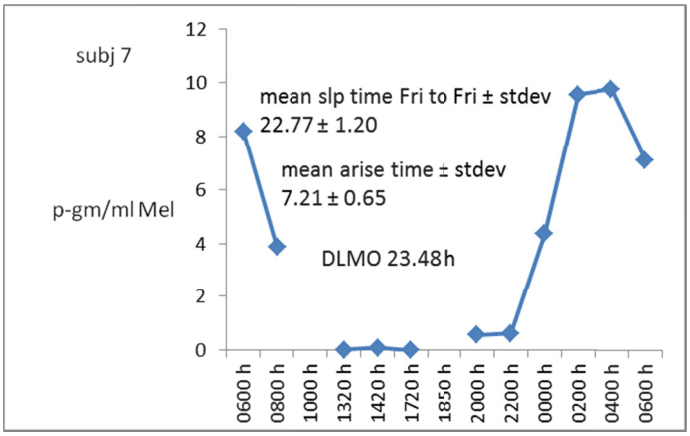

Figure 10. *Salivary melatonin (p-gm/mL) for subject 7, plotted over 24-hours. Subject 7 has normal sleep and arise times. His DLMO is retarded since it occurs after sleep onset rather before bedtime. An insufficient amount of light data was obtained to display graphically.*

3.1.6 Subject 8

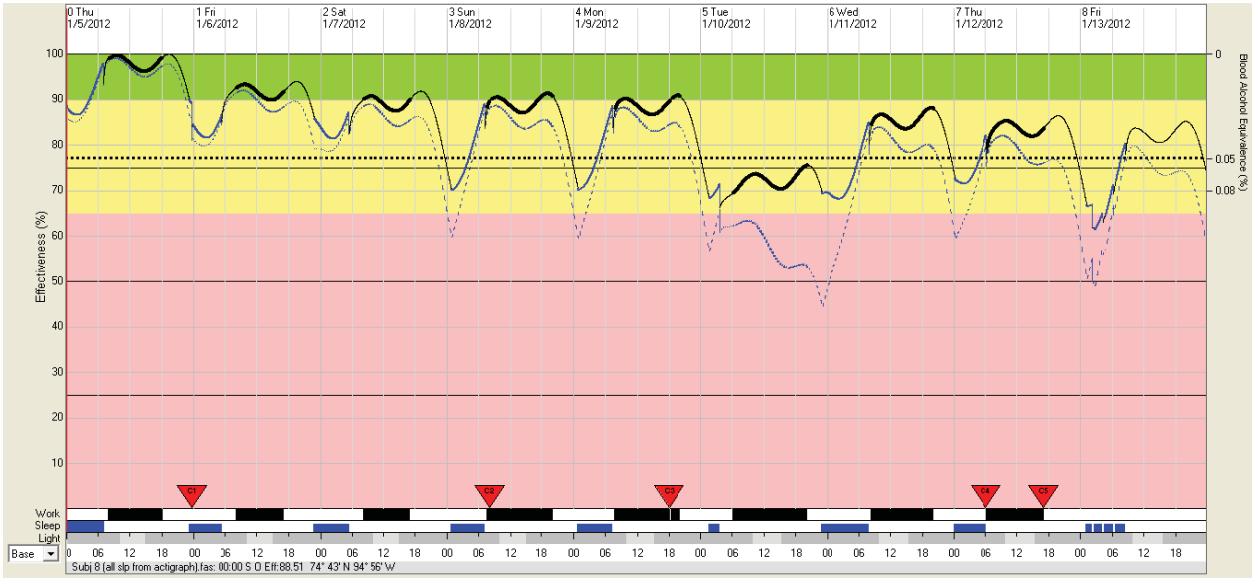

Figure 11. *FAST™ model showing cognitive effectiveness for subject 8. Subject 8 shows good cognitive effectiveness (in the green band) prior to moving into his snow shelter. After limited sleep in his snow shelter his cognitive effectiveness on January 10th falls to equivalence of BAC 0.08% and recovers somewhat over the next 2 days.*

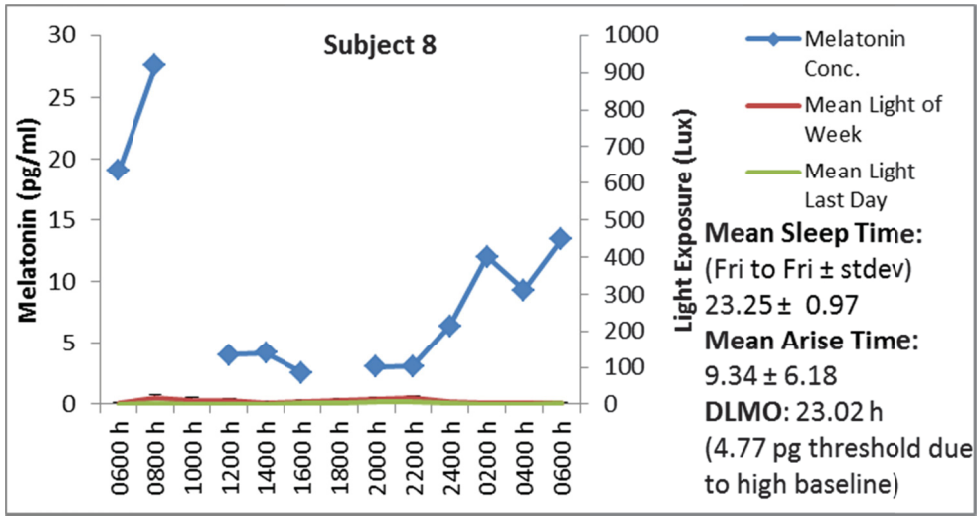

Figure 12. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 8, plotted over 24-hours. Subject 8 has a normal average bedtime and a late average arise time. However, he has a late DLMO.*

3.1.7 Subject 9

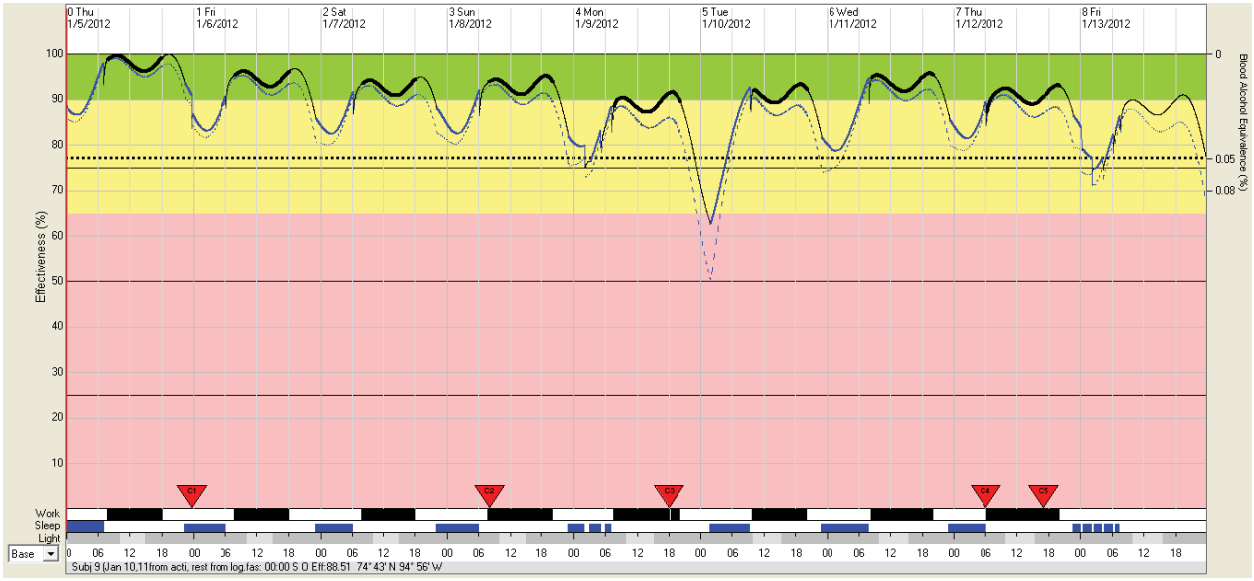

Figure 13. *FAST™ model showing cognitive effectiveness for subject 9. Subject 9 shows good cognitive effectiveness (in the green band) prior to moving into his snow shelter. In spite of intermittent sleep in the Arctic tent (the night prior to moving into his snow shelter) probably due to firewatch duties his drop in cognitive effectiveness on Jan 9th wasn't too pronounced. He appears to have slept well in his snow shelter and consequently has relative good cognitive effectiveness during his stay in the snow shelter.*

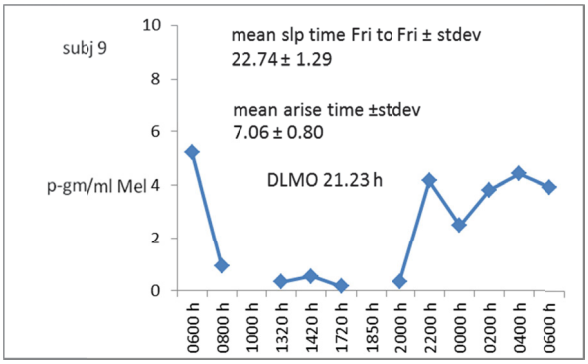

Figure 14. *Salivary melatonin (p-gm/mL) for subject 9, plotted over 24-hours. Subject 9 has normal average bedtime and arise times and a very normal DLMO, although his peak melatonin production (0600 h at the beginning of the salivary melatonin profile) is rather low at less than 6 p-gm/mL. An insufficient amount of light data was obtained to display graphically.*

3.1.8 Subject 11

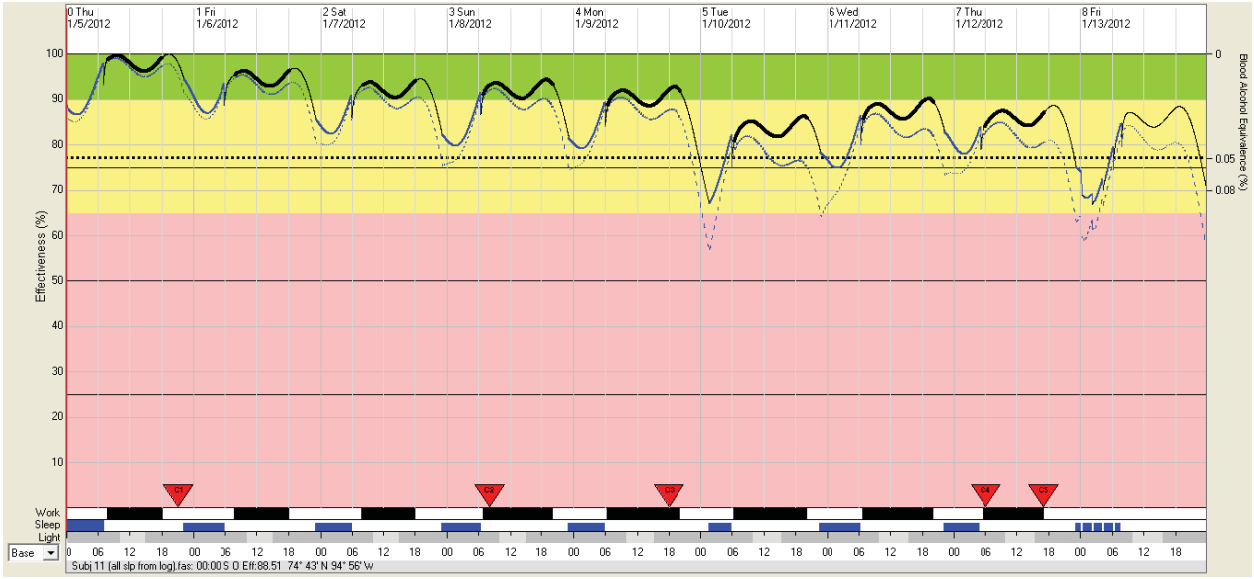

Figure 15. *FAST™ model showing cognitive effectiveness for subject 11. Subject 11 shows good cognitive effectiveness (in the green band) prior to moving into his snow shelter. His limited sleep the first night in the snow cave leads to a drop in modeled cognitive effectiveness the following day. Cognitive effectiveness improves somewhat over the next 2 days.*

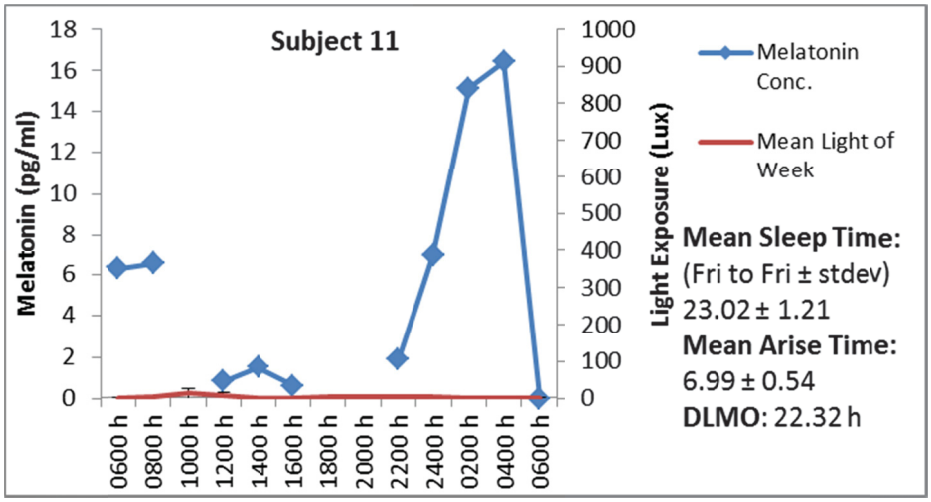

Figure 16. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 11, plotted over 24-hours. Subject 11 has normal average bedtimes and arise times, and a normal DLMO. The light meter on the subject's actigraph was not functional the day prior to saliva collection.*

3.1.9 Subject 12

There was insufficient actigraph and sleep log data to develop a FAST^{TM} model for subject 12.

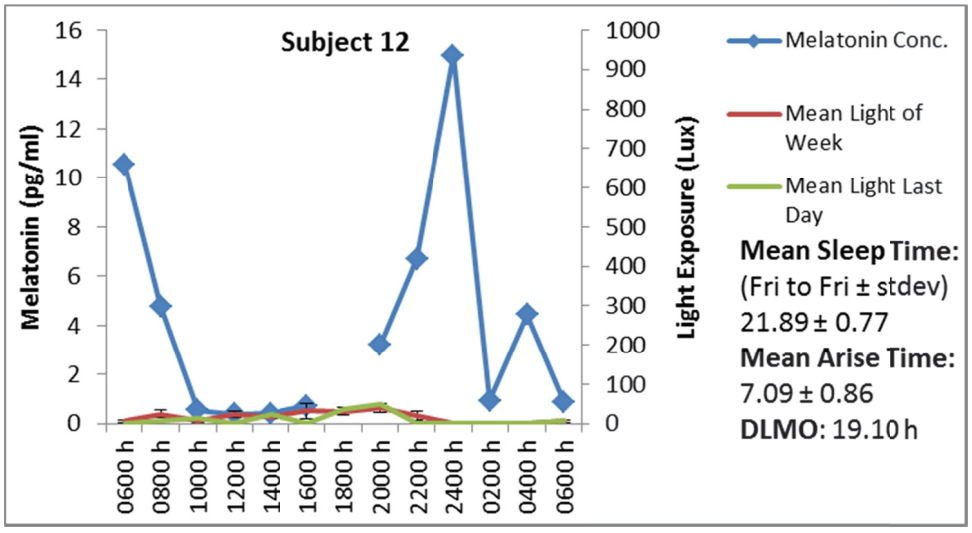

Figure 17. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 12, plotted over 24-hours. Subject 12 has an early average bedtime, a normal arise time, and an early DLMO.*

3.1.10 Subject 14

There was insufficient actigraph and sleep log data to develop a FAST™ model for subject 14.

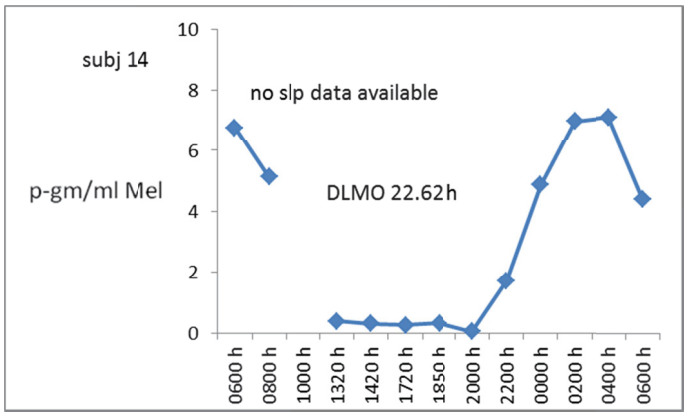

Figure 18. *Salivary melatonin (p-gm/mL) for subject 14, plotted over 24-hours. Subject 14 has a relatively normal DLMO. An insufficient amount of light data was obtained to display graphically.*

3.1.11 Subject 15

There was insufficient actigraph and sleep log data to develop a FAST™ model for subject 15.

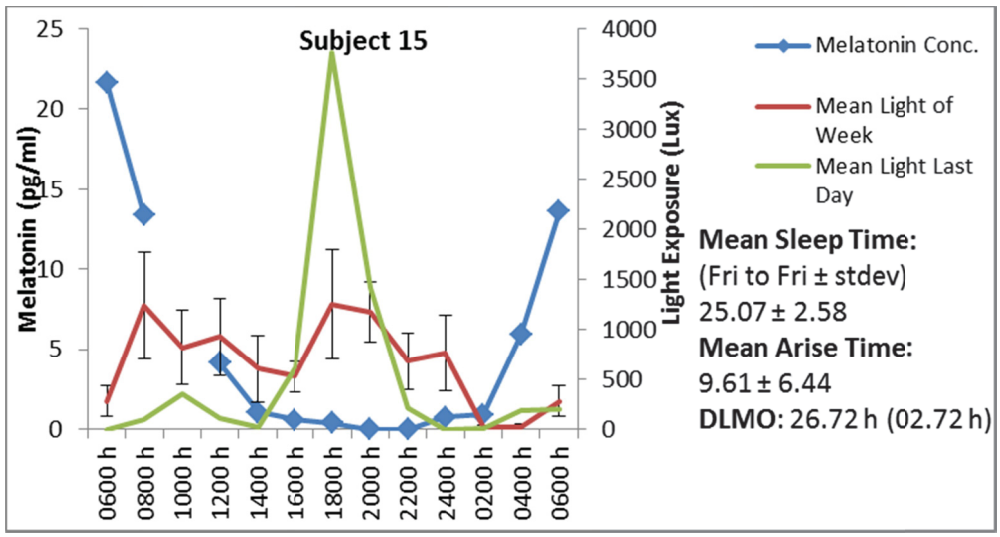

Figure 19. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 15, plotted over 24-hours. Subject 15 has a late average bedtime and a late average rise time and an especially late DLMO which occurs after the average bedtime.*

3.1.12 Subject 17

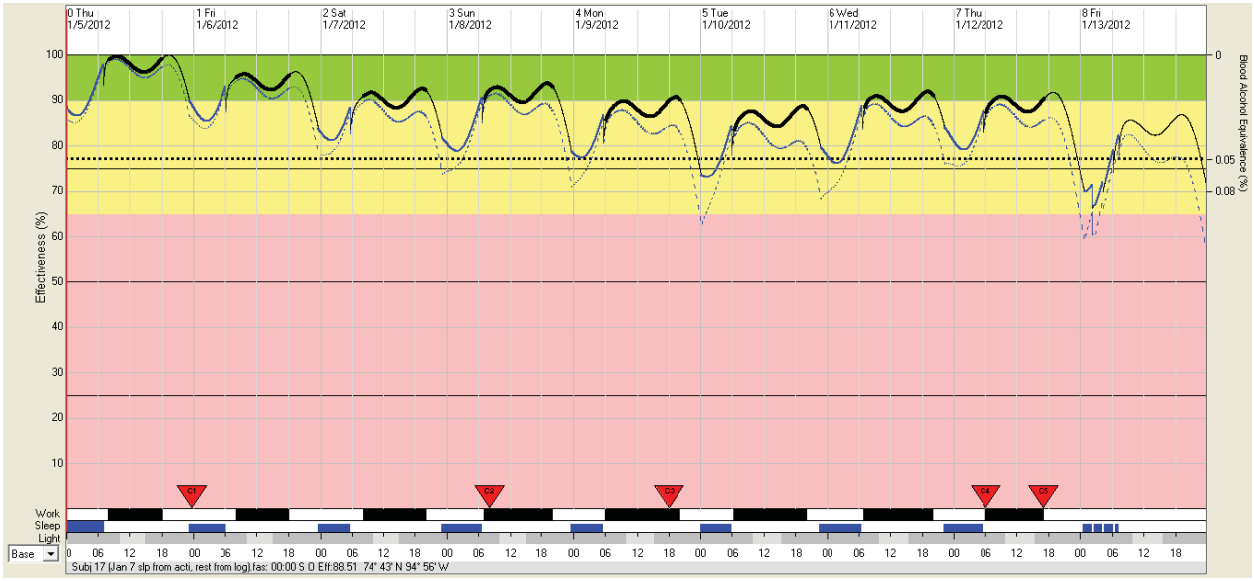

Figure 20. *FAST™ model showing cognitive effectiveness for subject 17. Subject 17 shows good cognitive effectiveness (in the green band) prior to moving into his snow shelter. His cognitive effectivness falls somewhat after sleeping in the Arctic tent and after the first night in his snow shelter. Cognitive effectiveness improves over the last 2 days.*

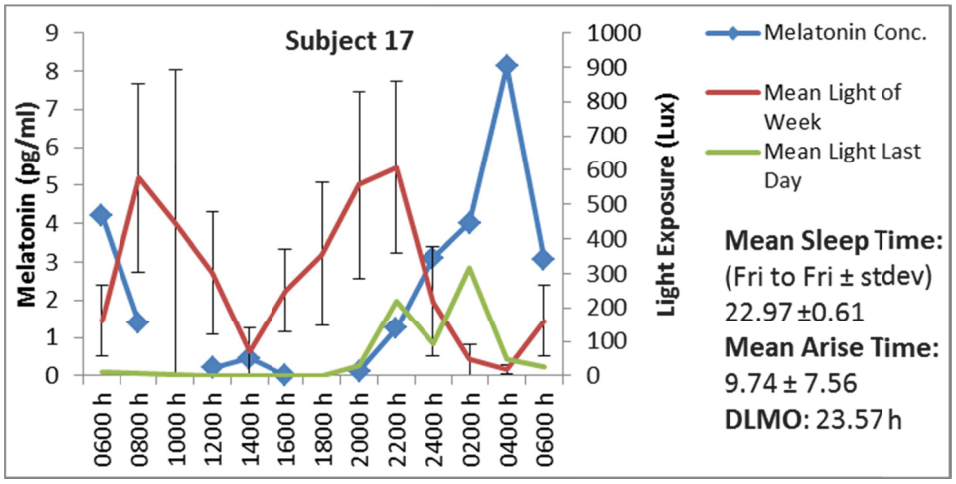

Figure 21. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 17, plotted over 24-hours. Subject 17 has normal average bedtimes and arise times and retarded DLMO which occurs after bedtime rather than prior to bedtime.*

3.2 Individual subject data – Alert-based winter subjects

3.2.1 Subject 21

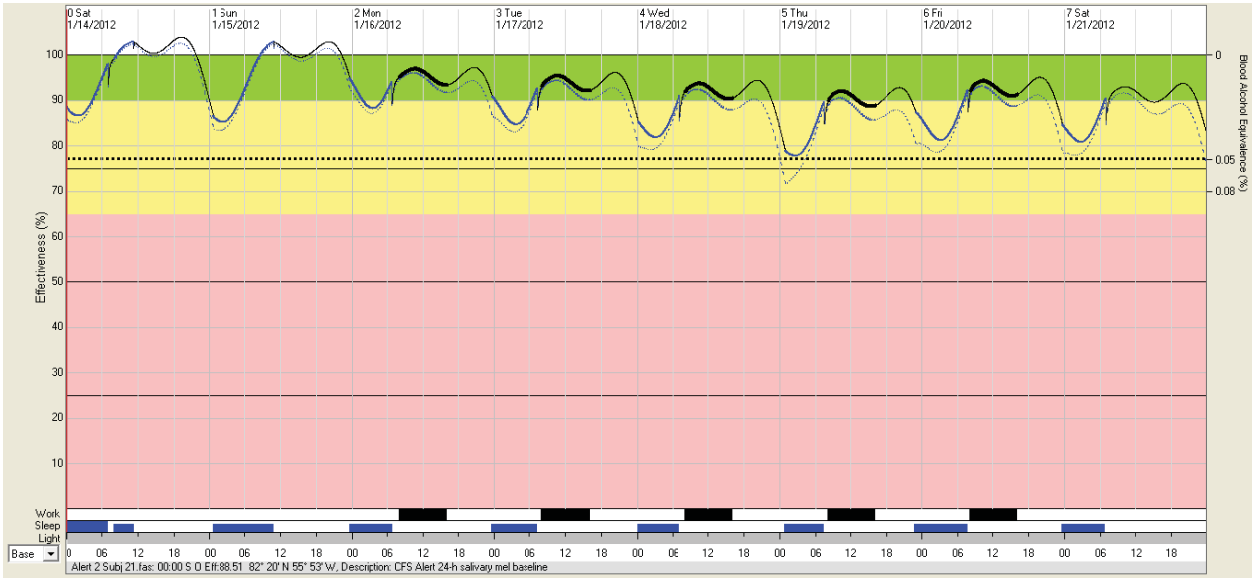

Figure 22. *FAST™ model showing cognitive effectiveness for subject 21. Subject 21 shows good cognitive effectiveness (in the green band) over the 5 days prior to his 24-h salivary melatonin collection in the CFS Alert Gymnasium from 0900h Saturday January 21st to 0900 h Sunday January 22nd.*

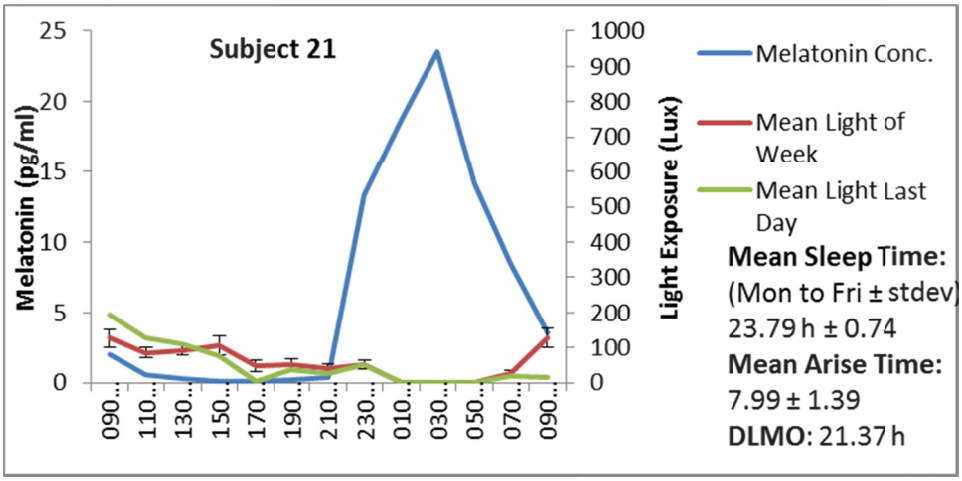

Figure 23. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 21, plotted over 24-hours. Subject 21 has normal average bedtimes and arise times and a normal DLMO.*

3.2.2 Subject 22

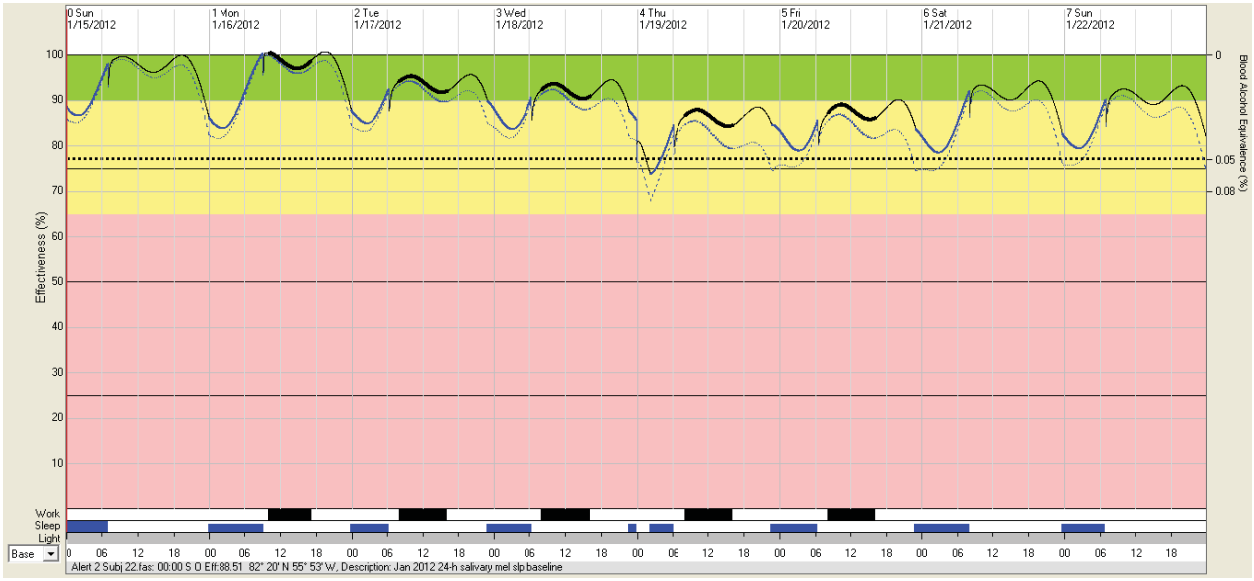

Figure 24. *FAST^{TM} model showing cognitive effectiveness for subject 22. Subject 22 shows a pattern of decreasing cognitive effectivneness subsequent to limited sleep on Tuesday, Wednesday and Thursday (January 17th -19th). His sleep and cognitivue effectiveness start to recover on Friday January 20th and is restored to norml at the beginning of the 24-h salivary melatonin collection in the CFS Alert Gymnasium.*

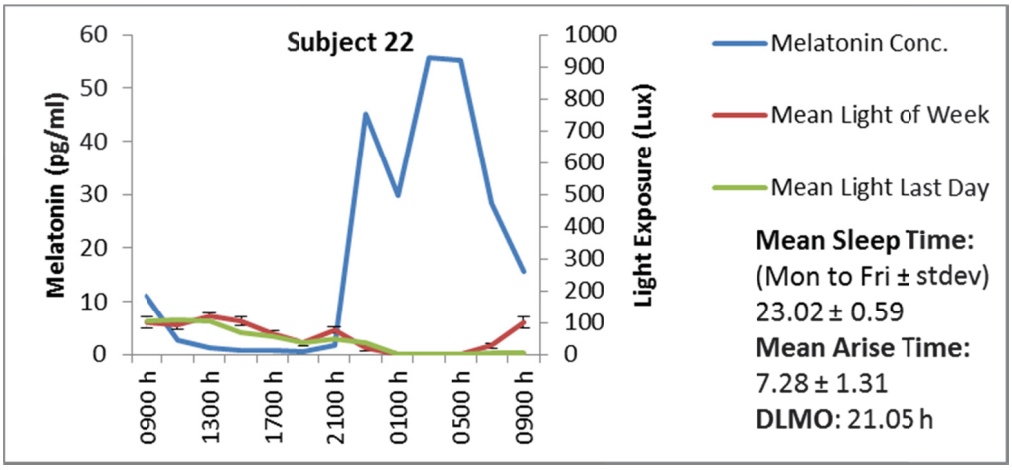

Figure 25. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 22, plotted over 24-hours. Subject 22 has normal average bedtimes and arise times and a normal DLMO.*

3.2.3 Subject 23

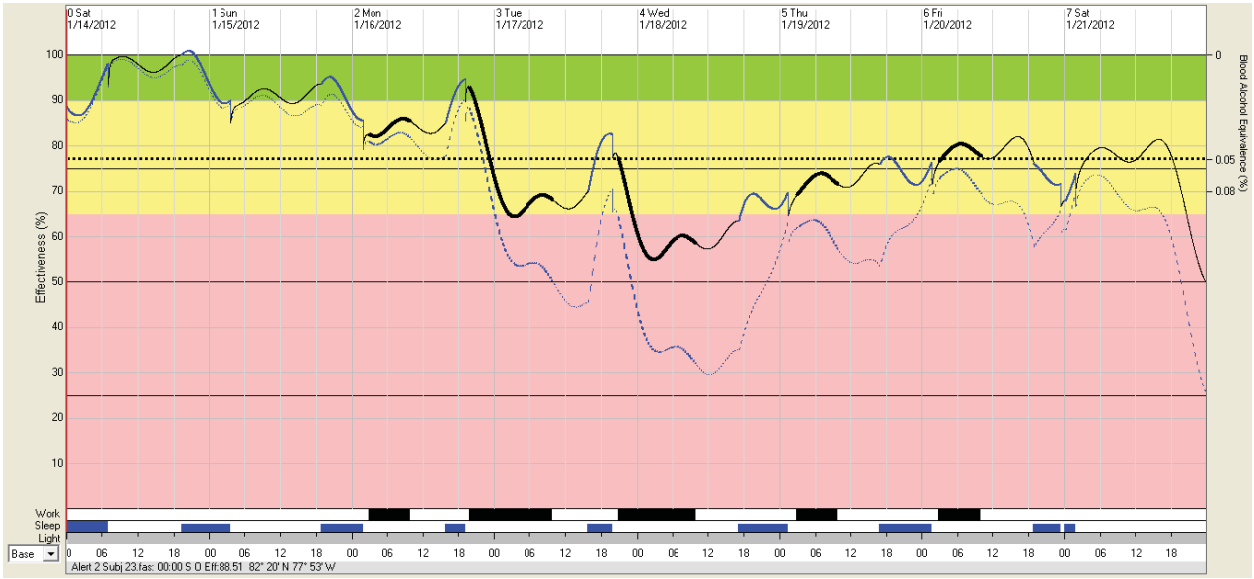

Figure 26. *FAST™ model showing cognitive effectiveness for subject 23. Subject 23 is a meteorology technician and has to report to the control tower for night duty to broadcost meteorological data to incoming re-supply aircraft. This person generally works day but has to immediately revert to night work whenever an aircraft is inbound to CFS Alert. This dictates a widely fluctuating sleep pattern as well as extremes of poor cognitive effectiveness, especially during night work as can be seen on Tuesday and Wednesday (January 17-18) where performance drops to the pink zone where no one can function well on any task.*

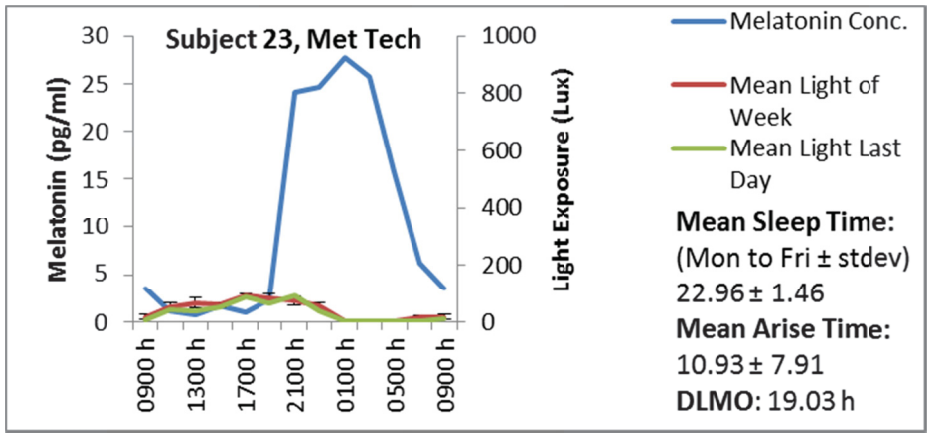

Figure 27. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 23, plotted over 24-hours. In spite of the extremes of this individual's bedtimes and arise times, the average bedtime is normal. However, the average arise time is late. The DLMO is surprisingly early given the issues of this person's sleep hygiene reality.*

3.2.4 Subject 24

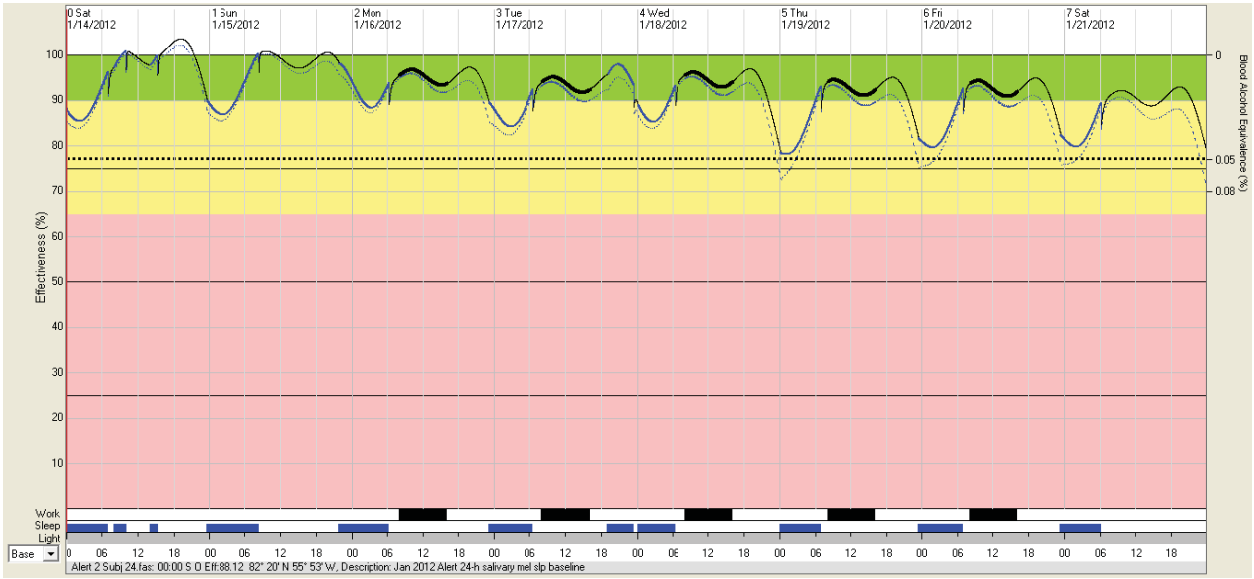

Figure 28. *FAST™ model showing cognitive effectiveness for subject 24. Subject 24 has good sleep and correspondingly good modeled cognitive effectvieness.*

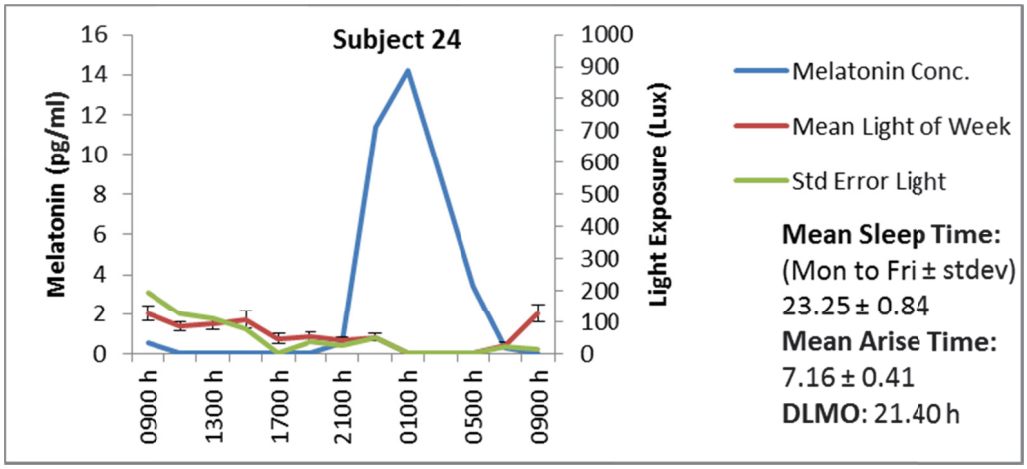

Figure 29. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 24, plotted over 24-hours. Subject 24 has normal average bedtimes and arise times and a normal DLMO.*

3.2.5 Subject 25

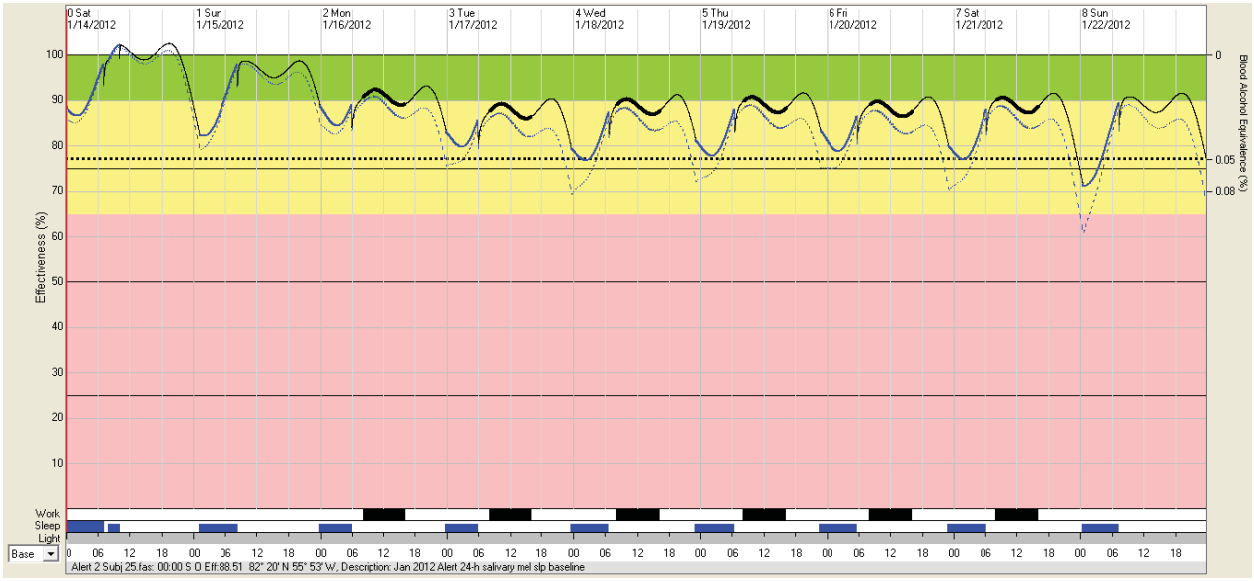

Figure 30. *FAST™ model showing cognitive effectiveness for subject 25. Subject 25 has slightly less than optimal cognitive effectiveness, operating mainly in the yellow perfromance band rather than the green performance band.*

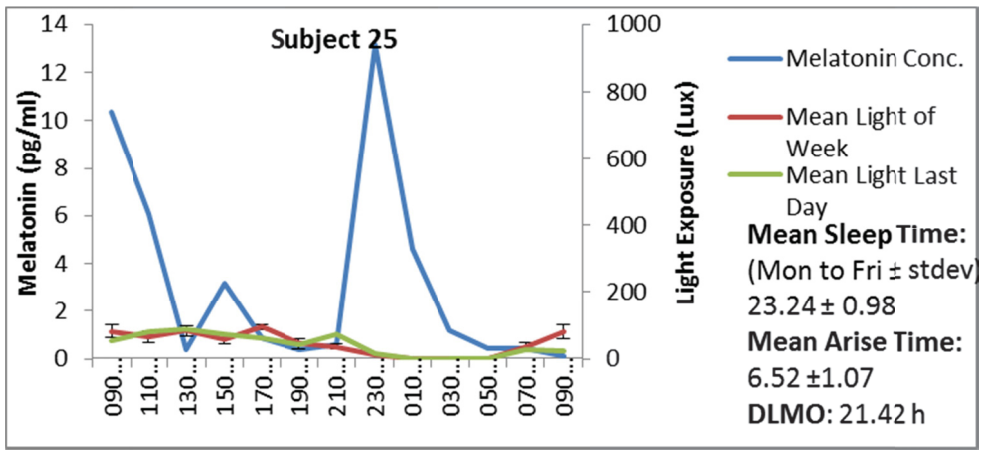

Figure 31. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 25, plotted over 24-hours. Subject 25 has normal average bedtimes and arise times and a normal DLMO.*

3.2.6 Subject 26

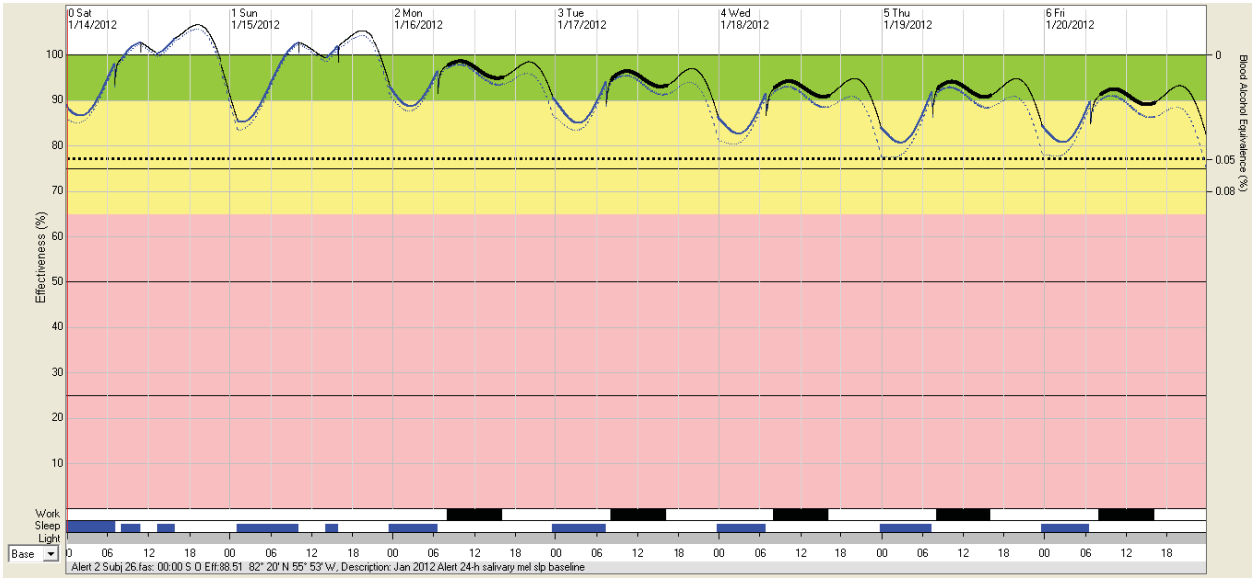

Figure 32. *FAST™ model showing cognitive effectiveness for subject 26. Subject 26 has good sleep and correspondingly good modeled cognitive effectvieness.*

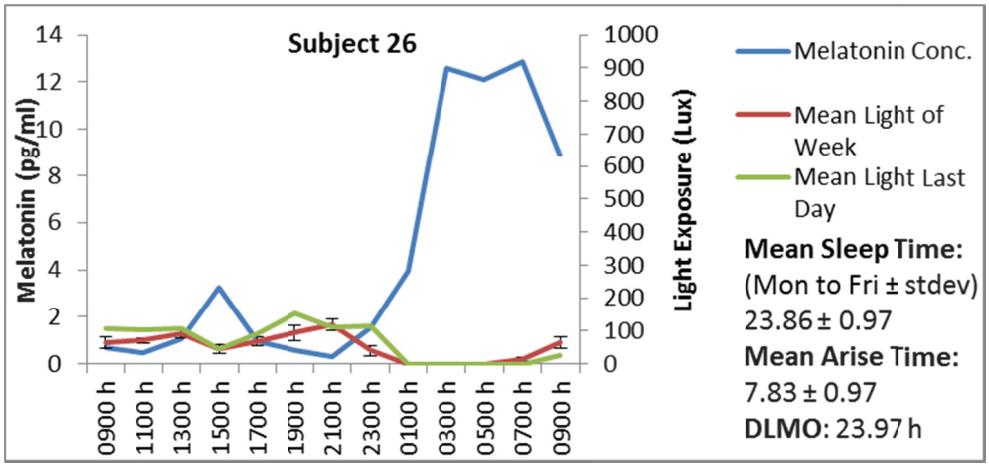

Figure 33. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 26, plotted over 24-hours. Subject 26 has normal average bedtimes and sleep times but his DLMO occurs just after sleep time and is thus abnormally delayed.*

3.2.7 Subject 27

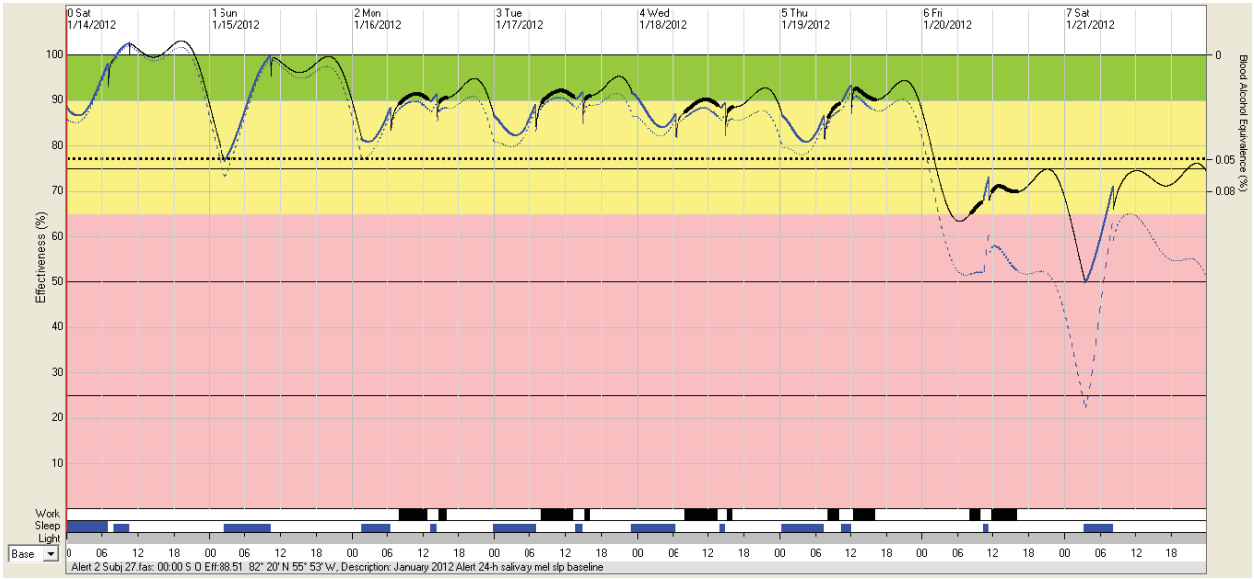

Figure 34. *FAST™ model showing cognitive effectiveness for subject 27. Subject 27 has an aproximate 1-hour nap during his workday and maintaines moderate but sub-optimal modeled cognitive effectiveness Monday through Friday but misses sleep on Thursday/Friday night resulting in very poor modeled cognitive effectiveness (well in excess of BAC 0.08%) on Friday.*

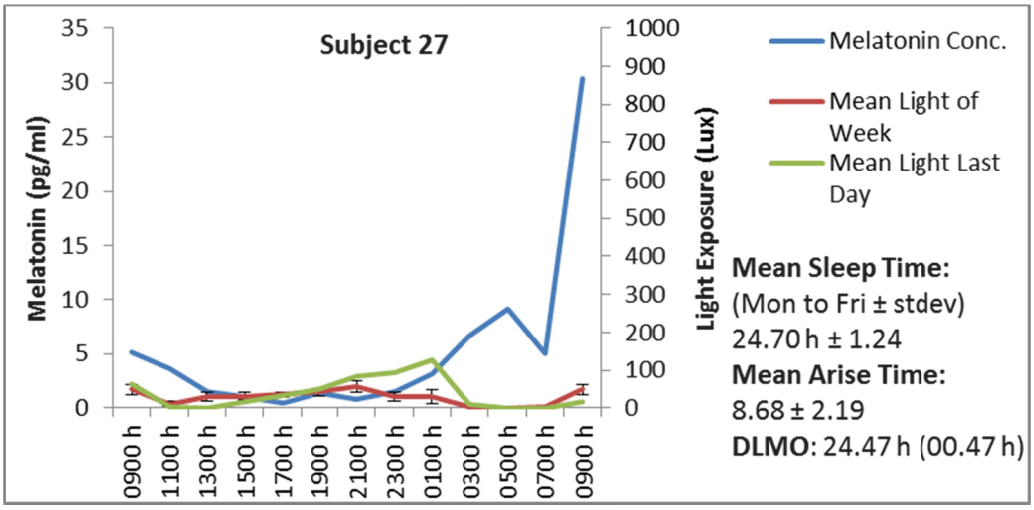

Figure 35. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 27, plotted over 24-hours. Subject 27 has a late average bedtimes and arise times. His DLMO occurs just before bedtime and is thus occurring later than his bedtimes/arise times would suggest.*

3.2.8 Subject 28

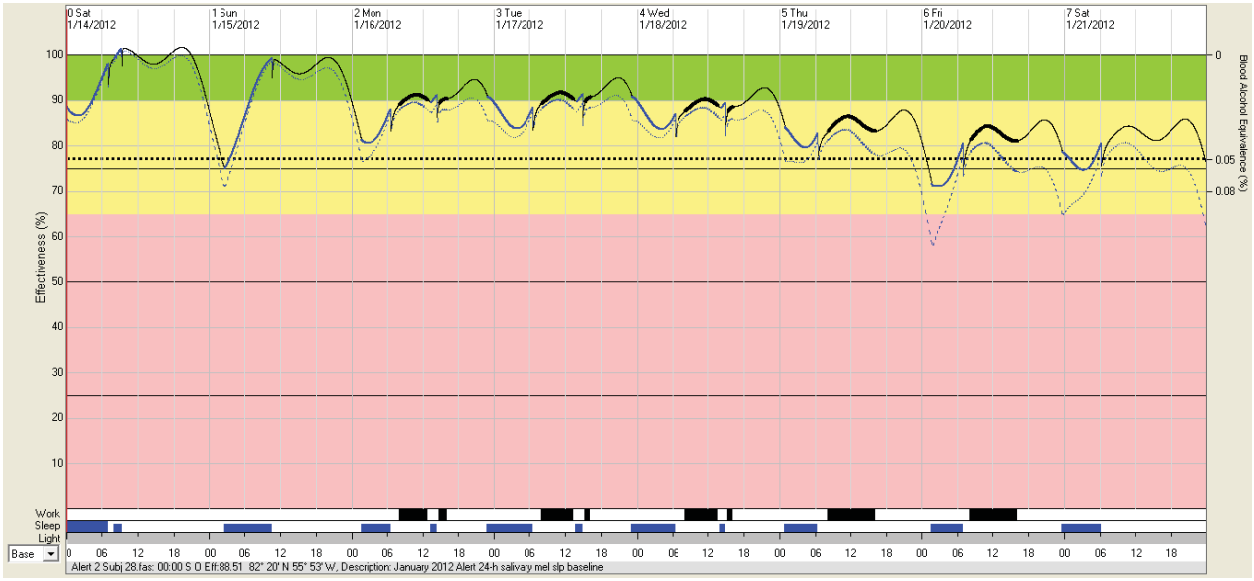

Figure 36. *FAST™ model showing cognitive effectiveness for subject 28. On several nights, Subject 28 has insufficient sleep. On Saturday, Monday, Tuesday and Wednesday he has approximately 1-hour naps in the early afternoon. His cognitive effectiveness on Monoday, Tuesday and Wednesday is less than ideal (i.e., at the junction of the greeen and yellow bands) and falls further on Thursday and Friday.*

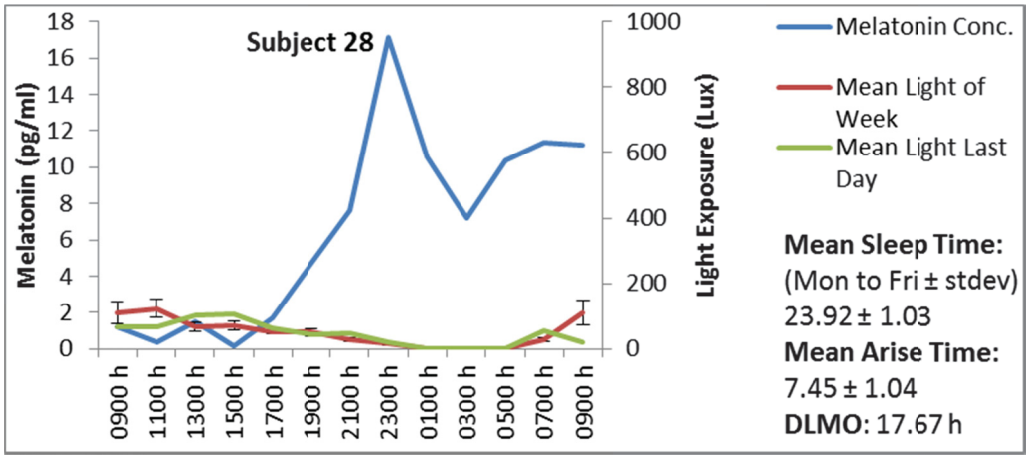

Figure 37. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 28, plotted over 24-hours. Subject 28 has normal bedtimes and sleep times but has an abnormally early DLMO. Based on figure 36 above (FAST model for this subject), the Saturday, Monday, Tuesday, and Wednesday naps may have advanced his circadian system causing the early DLMO (17.67 h).*

3.2.9 Subject 29

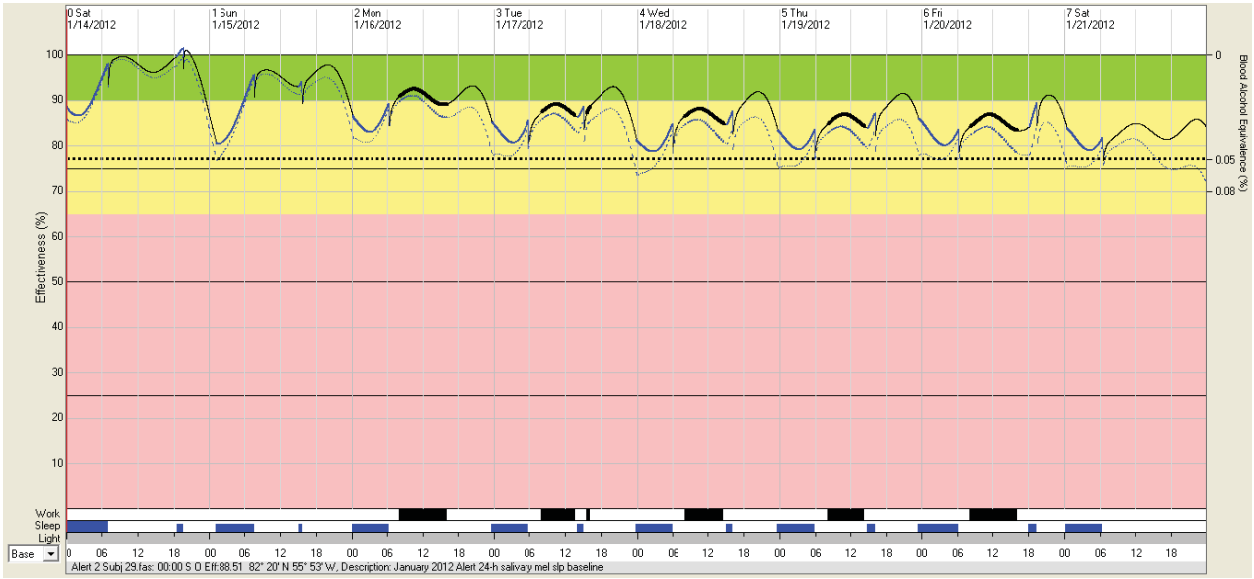

Figure 38. *FAST™ model showing cognitive effectiveness for subject 29. Subject 29 has a daily mid afternoon nap to supplment approximately 6 to 7 hour nocturnal sleep periods. On Monday, this subject is operating in the green (good) performance band. His performance falls into the yellow (caution) band the next day and continues to slowly fall over the next several days.*

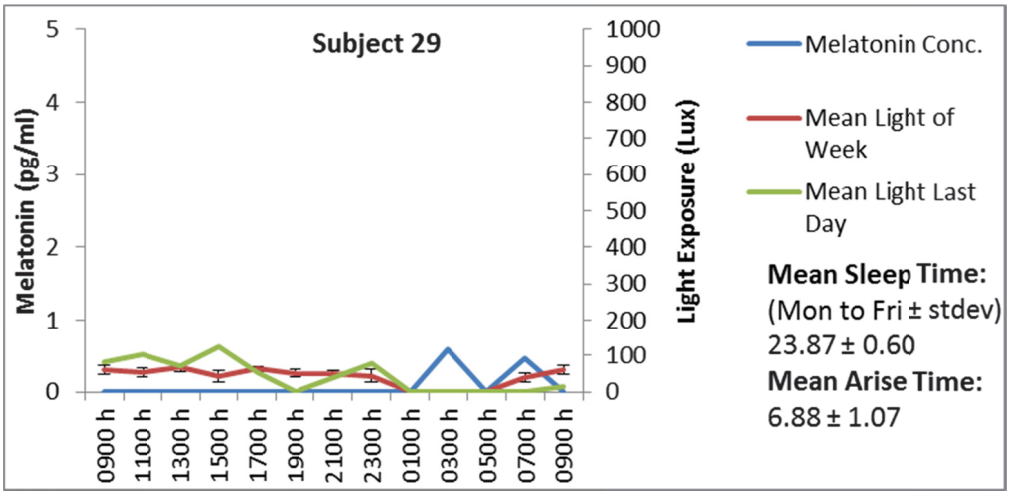

Figure 39. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 29, plotted over 24-hours. Subject 29 has normal average bedtimes and arise times but doesn't produce any melatonin and thus has no DLMO.*

3.2.10 Subject 30

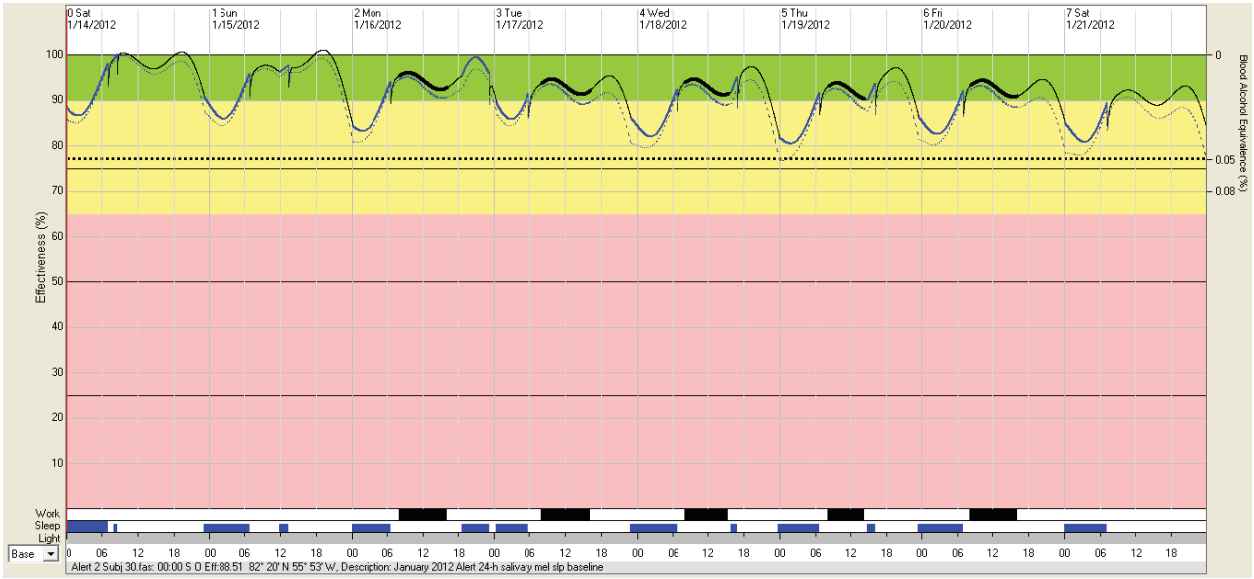

Figure 40. *FAST™ model showing cognitive effectiveness for subject 30. Subject 30 is continuously operating in the green (good) perfomrance band. When he has insufficient sleep he augments his regular sleep with an afternoon nap.*

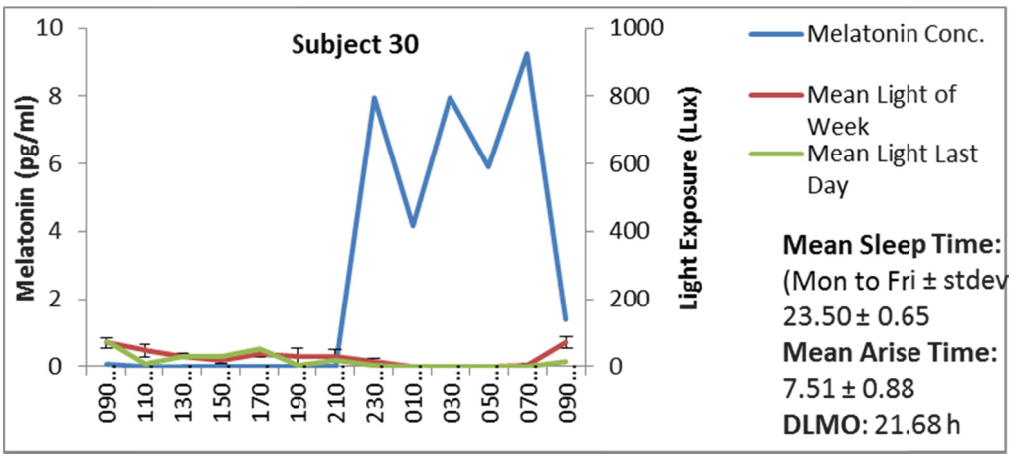

Figure 41. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 30, plotted over 24-hours. Subject 30 has normal average bedtimes and arise times and a normal DLMO.*

3.2.11 Subject 31

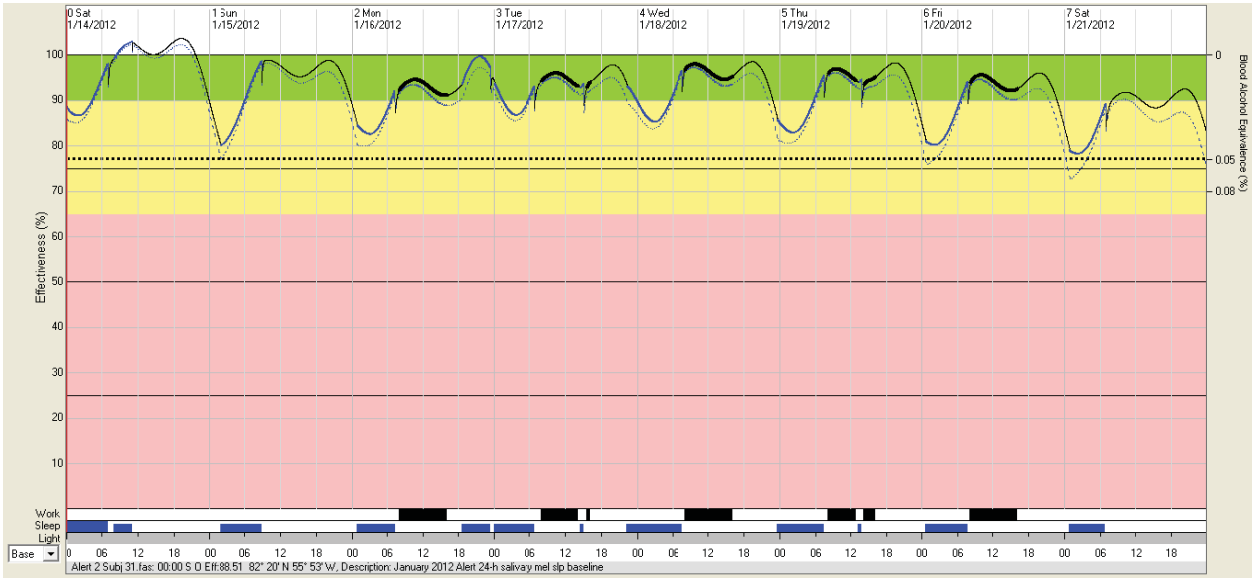

Figure 42. *FAST™ model showing cognitive effectiveness for subject 31. Subject 31 continuously operates in the green (good) performance band. His sleep quantity varies from night to night. He uses an afternoon nap on Tuesday and Thursday to augment his normal sleep.*

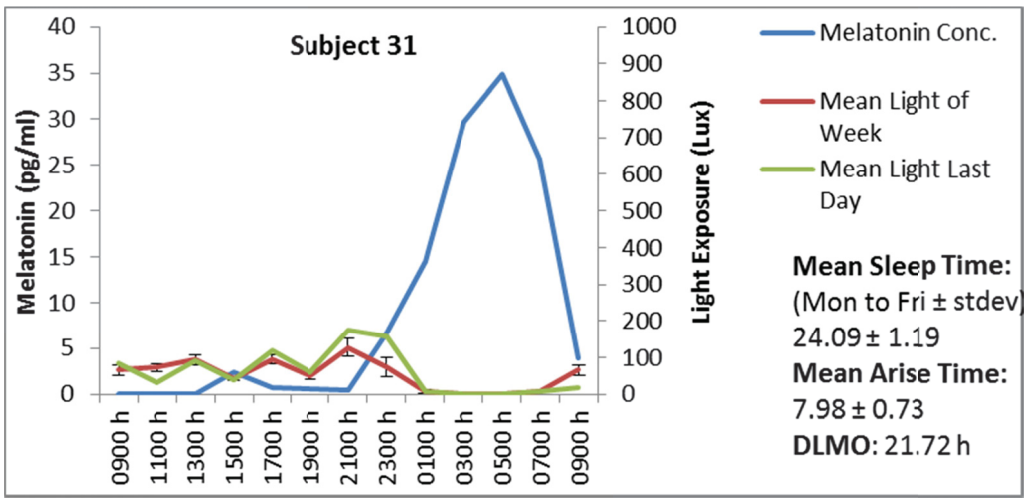

Figure 43. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 31, plotted over 24-hours. Subject 31 has normal bedtimes and arise times and a normal DLMO.*

3.2.12 Subject 32

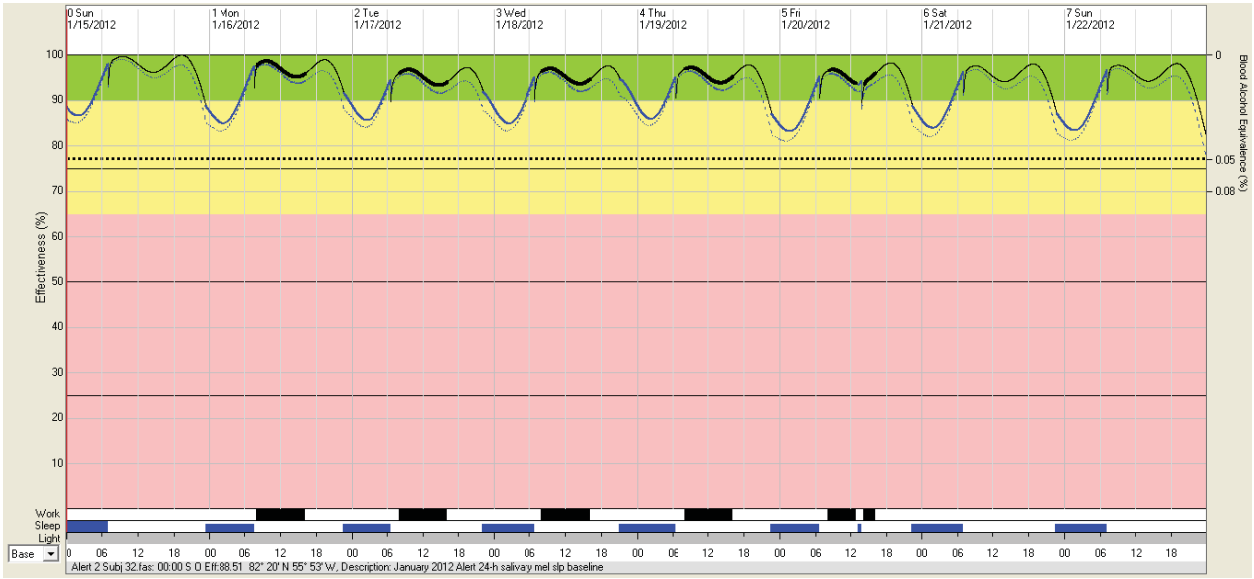

Figure 44. *FAST™ model showing cognitive effectiveness for subject 32. Given his excellent sleep, subject 32 continuously operates in the green (good) performance band.*

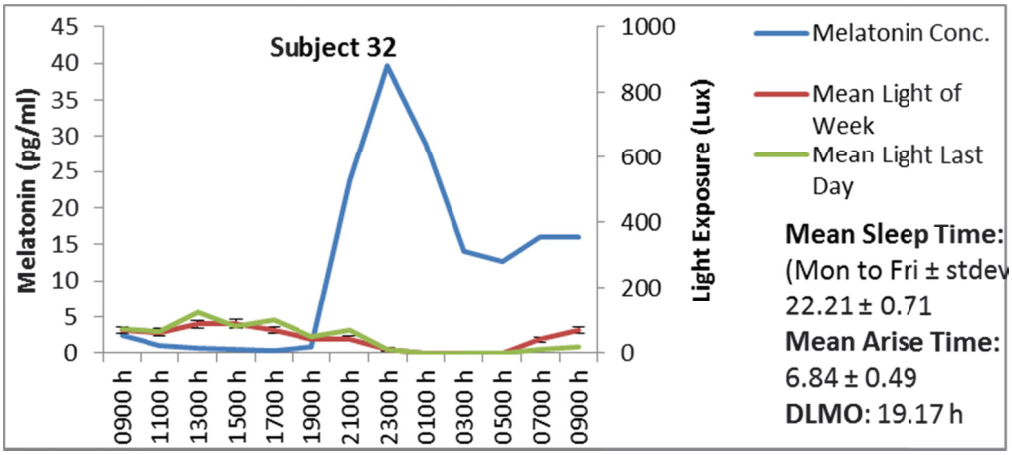

Figure 45. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 32, plotted over 24-hours. Subject 32 moderately early average bedtimes and arise times and a corresponding early but normal DLMO.*

3.2.13 Subject 33

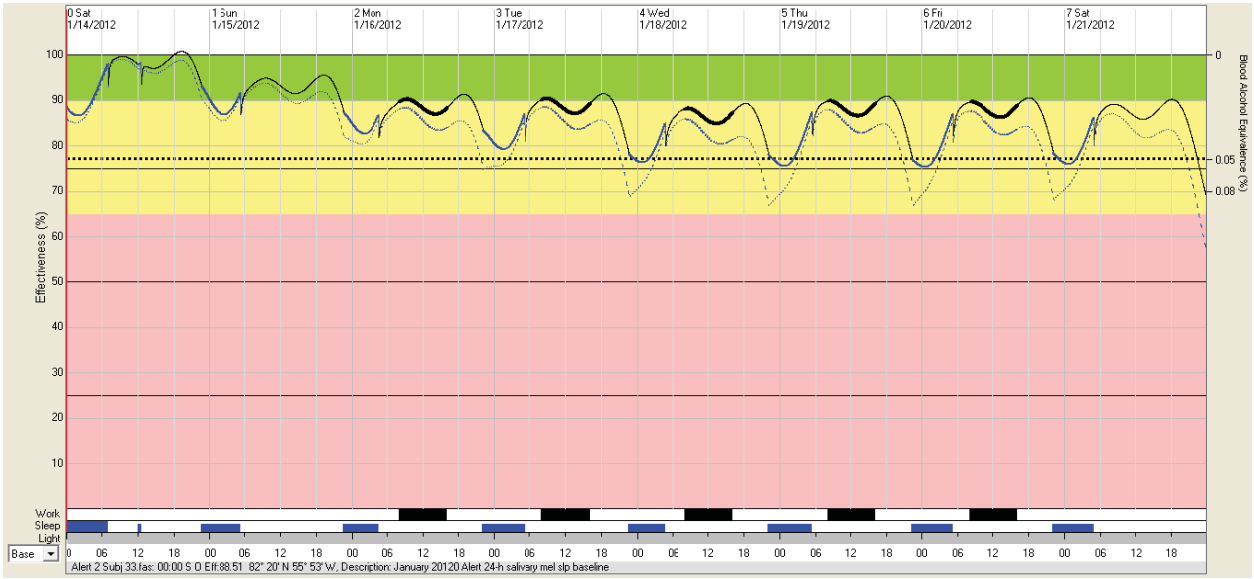

Figure 46. *FAST™ model showing cognitive effectiveness for subject 33. Subject 33 has consistent but insufficient sleep to operate in the green (good) band.*

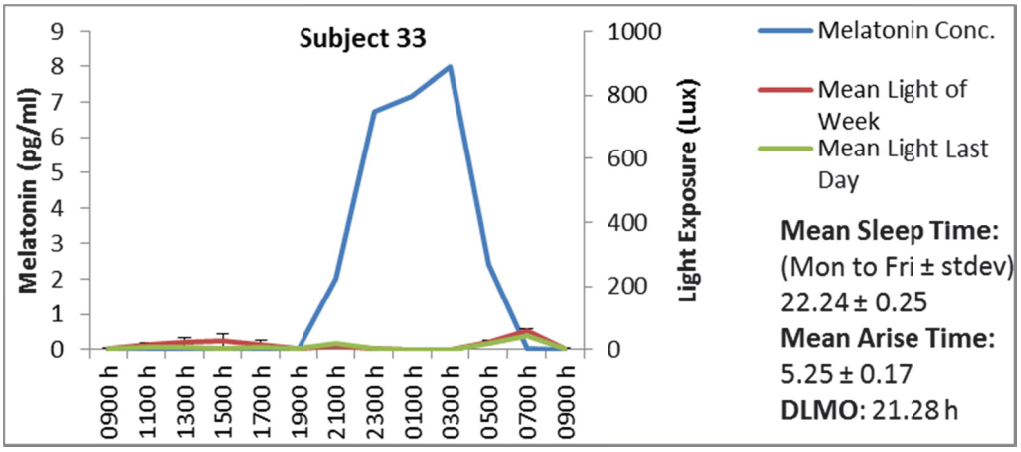

Figure 47. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 33, plotted over 24-hours. Subject 33 has slightly early average bedtimes and quite early arise times but still has a normal DLMO.*

3.2.14 Subject 34

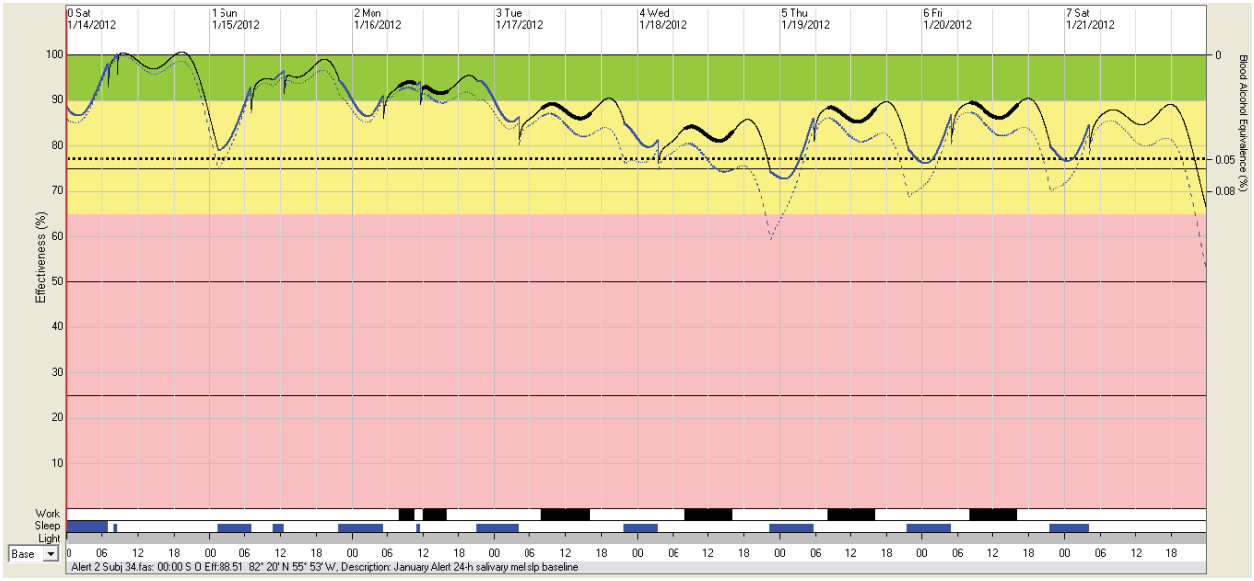

Figure 48. *FAST™ model showing cognitive effectiveness for subject 34. On Monday, subject 34 is operating in the green (good) performance band but secondary to inadequate sleep his performance falls on Tuesday and Wednesday before recovering somewhat on Thursday and Friday.*

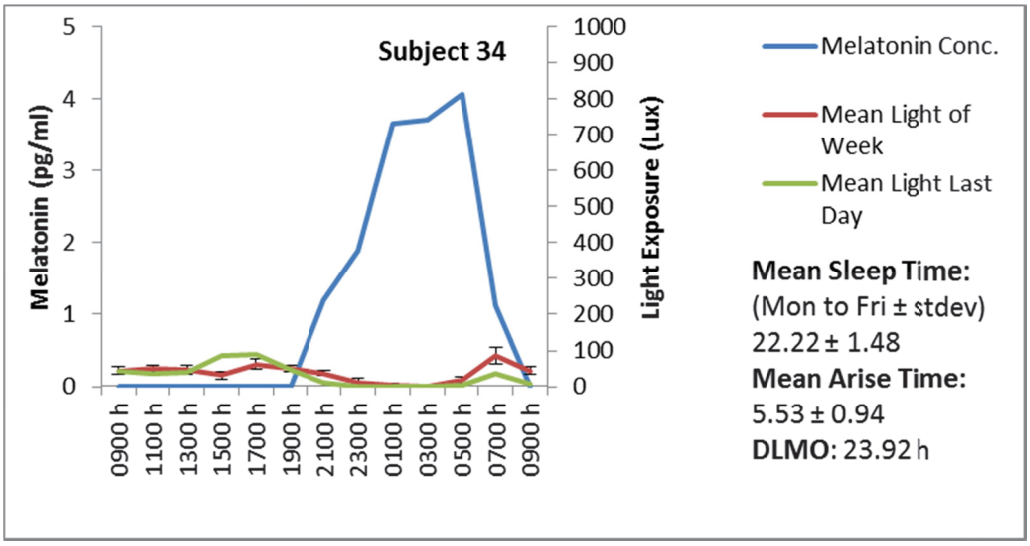

Figure 49. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 34, plotted over 24-hours. Subject 34 has somewhat early average betimes and arise times but has an abnormally late DLMO since it occurs after sleep onset.*

3.3 Individual subject data – Alert-based summer subjects

3.3.1 Subject 1

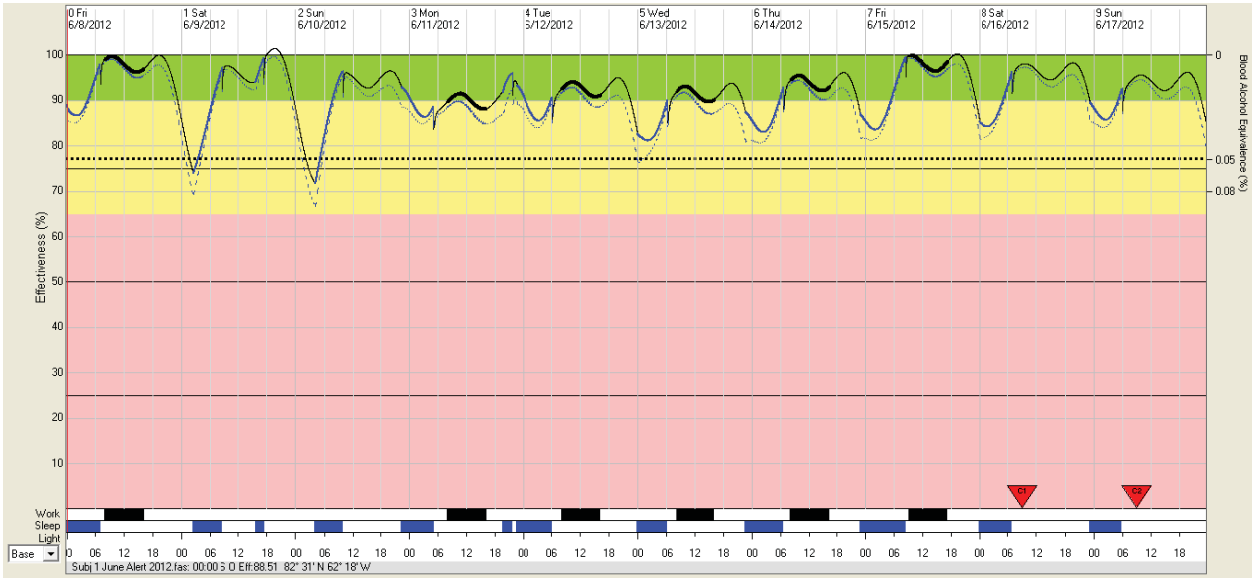

Figure 50. *FAST™ model showing cognitive effectiveness for subject 1, data collection 3. Subject 1 has inadequate sleep during the weekend. On Monday his performance is the lowest of the week but steadily improves, reaching the highest level by Friday.*

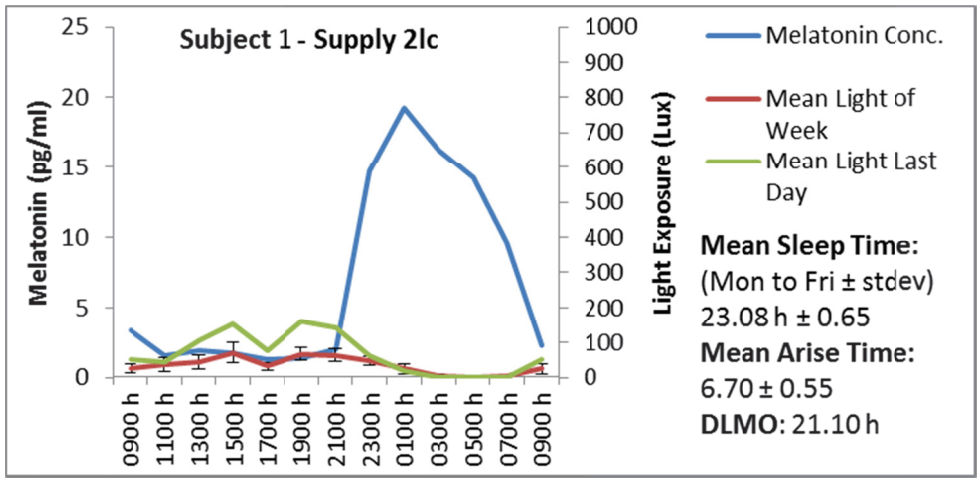

Figure 51. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 1 (data collection 3), plotted over 24-hours. Subject 1 has normal average bedtimes and arises times and a normal DLMO.*

3.3.2 Subject 2

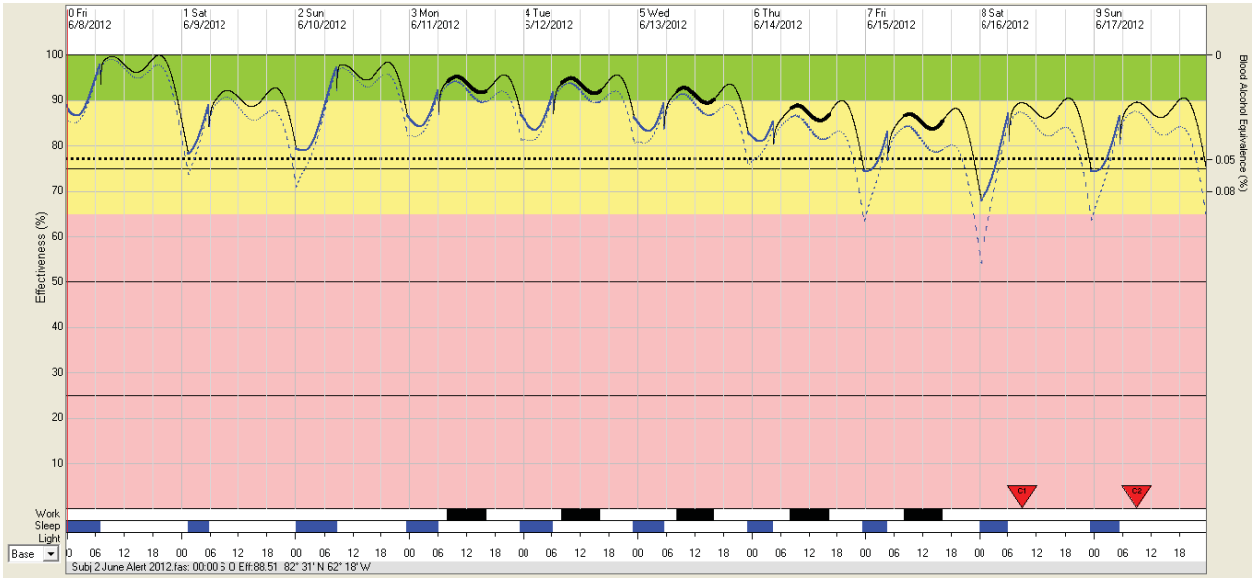

Figure 52. *FAST™ model showing cognitive effectiveness for subject 2, data collection 3. Modeled performance for subject 2 is good on Monday and Tuesday but falls progressively from Wednesday to Friday, secondary to inadequate sleep.*

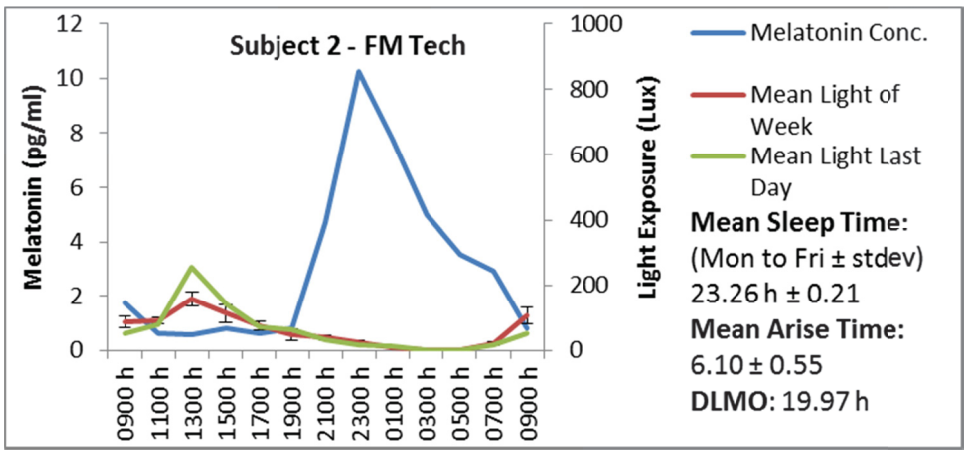

Figure 53. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 2 (data collection 3), plotted over 24-hours. Subject 2 has normal average bedtimes and arise times and a normal DLMO.*

3.3.3 Subject 3

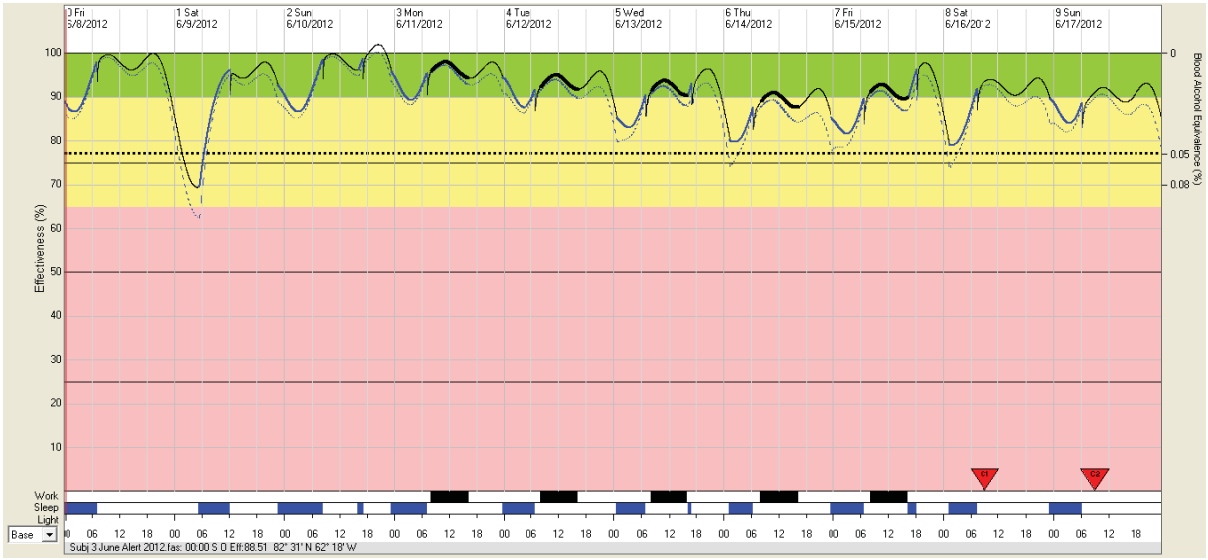

Figure 54. *FAST™ model showing cognitive effectiveness for subject 3, data collection 3. Modeled performance for subject 3 starts out well on Monday but falls progressivelly over the next 2 days and improves slightly on Friday.*

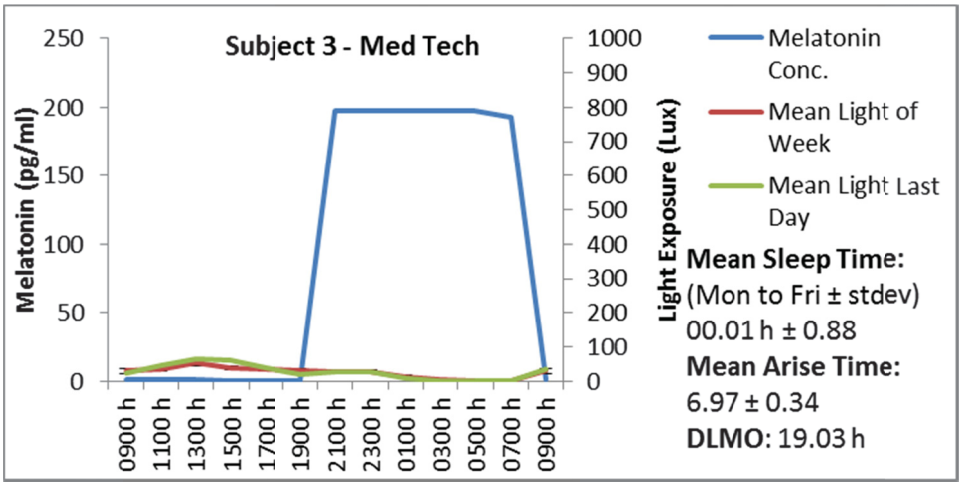

Figure 55. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 3 (data collection 3), plotted over 24-hours. Subject 3 has normal average bedtimes and arise times. Due to an error in bioassay of the saliva samples, the data are insufficiently reliable for calculating DLMO.*

3.3.4 Subject 4

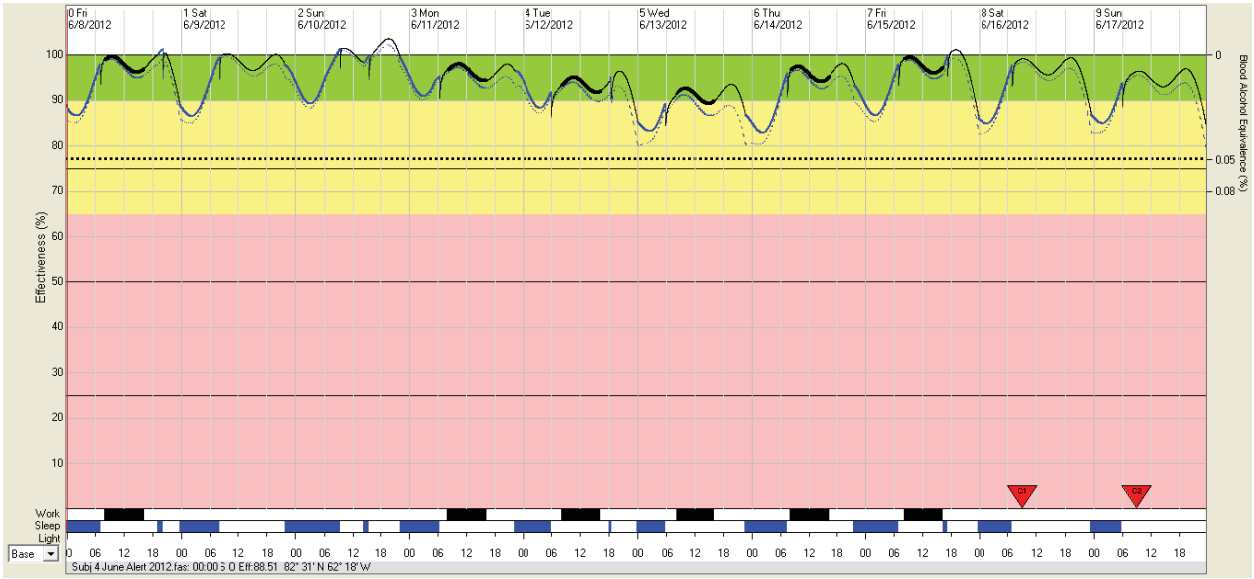

Figure 56. *FAST™ model showing cognitive effectiveness for subject 4, data collection 3. Cognitive effectiveness for subject 4 is high on Monday and in response to less sleep on Tuesday evening, modeled performance reaches a weekly low on Wednesday, after which performance increases on Thursday and Friday.*

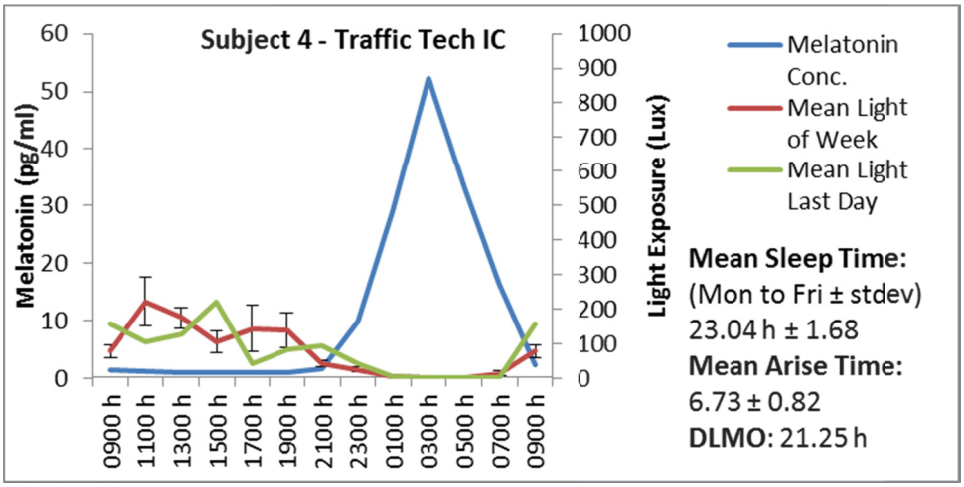

Figure 57. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 4 (data collection 3), plotted over 24-hours. Subject 4 has normal average bedtimes and arise times as well as a normal DLMO.*

3.3.5 Subject 5

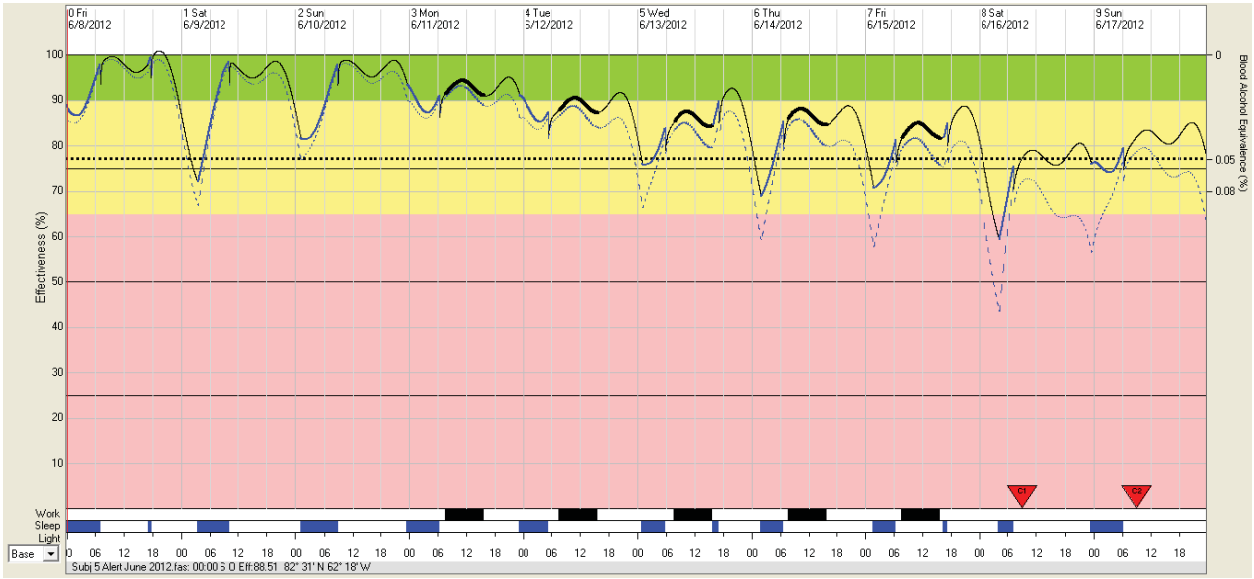

Figure 58. *FAST™ model showing cognitive effectiveness for subject 5, data collection 3. In response to decreasing sleep during the work week, cognitive effectiveness falls steadily from Monday (green performance band) reaching the lowest performance on Friday in the yellow performance band.*

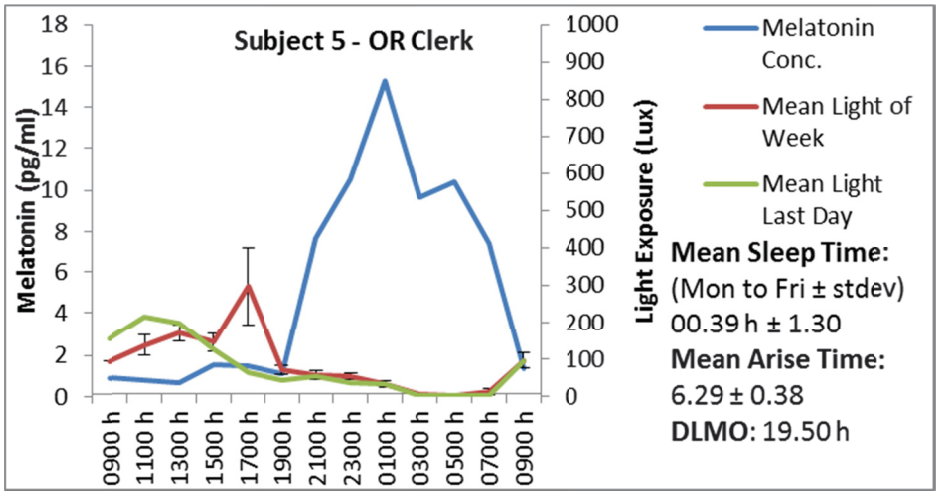

Figure 59. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 5 (data collection 3), plotted over 24-hours. Subject 5 has widely fluctuating bedtimes (i.e., stdev ± 1.30) and early normal arise times with a relatively early DLMO.*

3.3.6 Subject 6

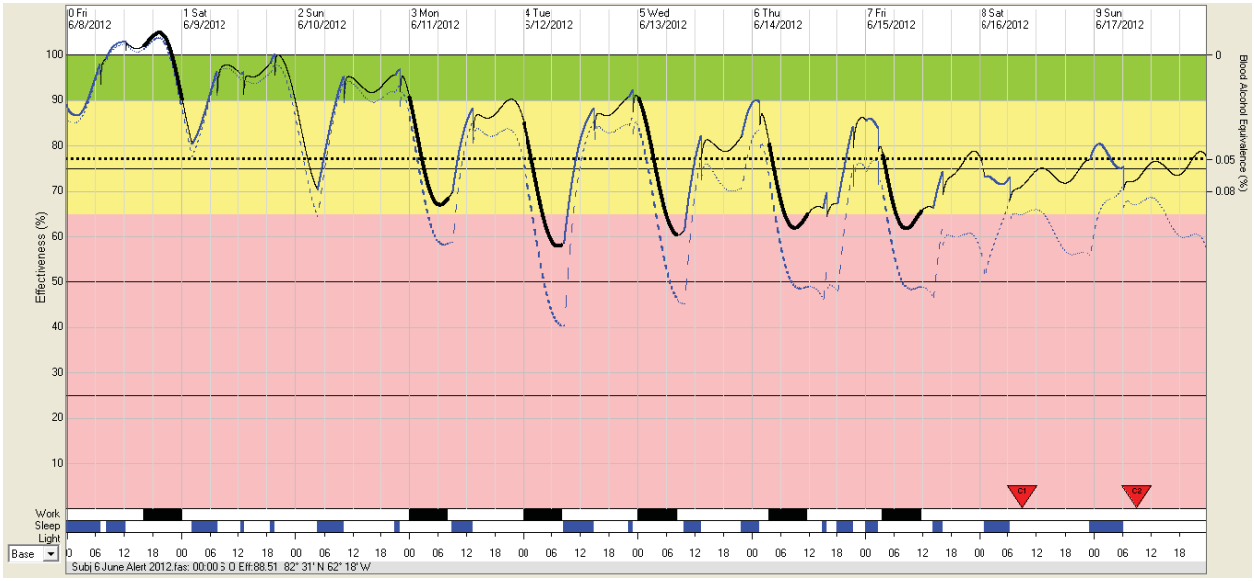

Figure 60. *FAST™ model showing cognitive effectiveness for subject 6, data collection 3. Subject 6 (Meteorology Tech) has an obligation to work nights on an irregular basis (broadcasting Met reports for incoming re-supply aircraft. In the January data collection the Met tech had similar sleep and performance issues. No one can operate well on any task in the pink performance band, especially 4 days in a row.*

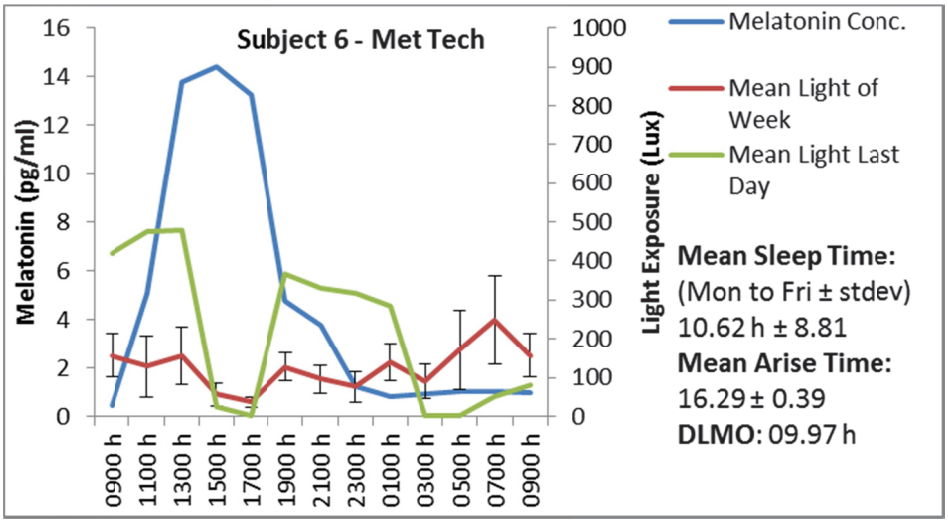

Figure 61. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 6 (data collection 3), plotted over 24-hours. As a consequence of the variable nocturnally oriented work schedule, the Met Tech has a morning average bedtime and an afternoon arise time. Her DLMO occurs about 40 minutes prior to sleep. From a chronobiological point of view, this DLMO indicates a good adaptation to the work timing imperative. Nevertheless, performance is worrisome during those nocturnal work periods.*

3.3.7 Subject 7

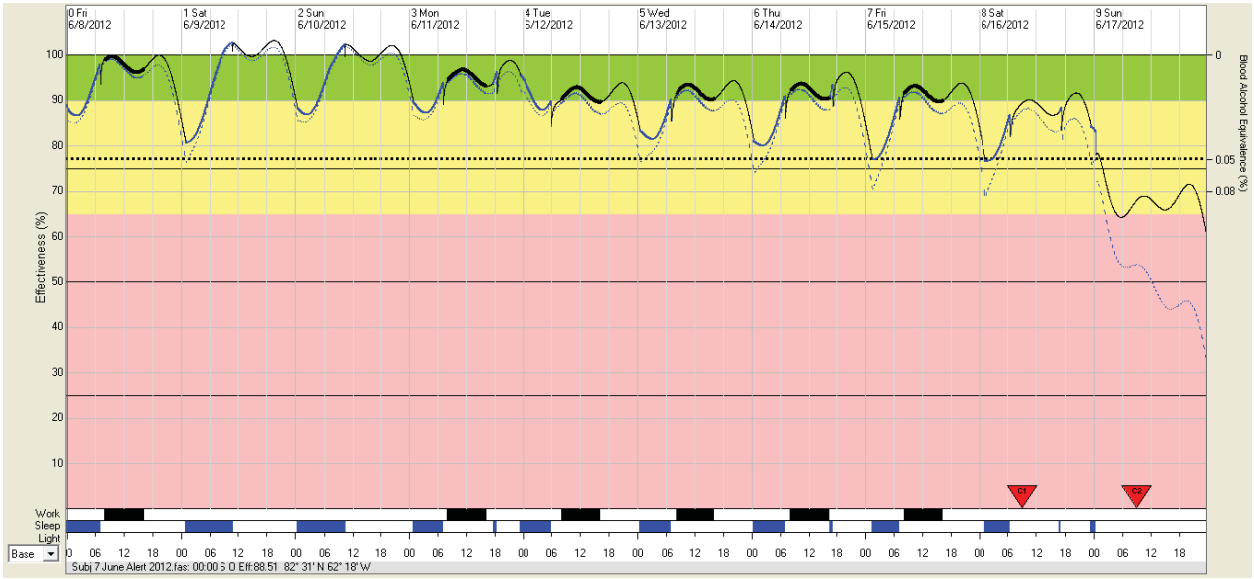

Figure 62. *FAST™ model showing cognitive effectiveness for subject 7, data collection 3. This model indicates that while Subject 7 had slowly decreasing cognitive effectiveness across his 5-day work week, his performance remained in the green (good performance) band.*

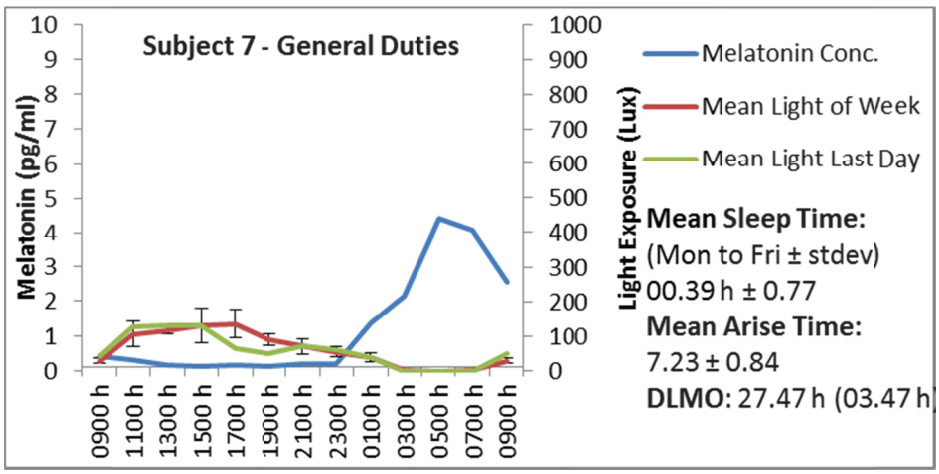

Figure 63. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 7 (data collection 3), plotted over 24-hours. Subject 7 has a somewhat late average bedtime and a normal arise time. However, the DLMO is very abnormal occurring more than 3 hours after bedtime.*

3.3.8 Subject 8

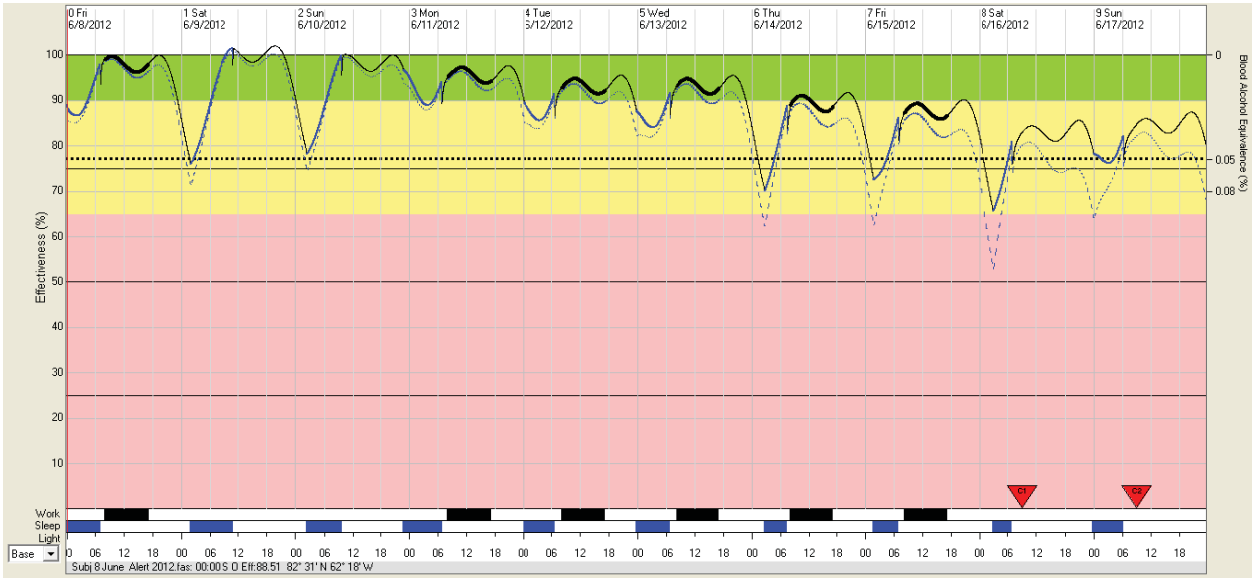

Figure 64. *FAST™ model showing cognitive effectiveness for subject 8, data collection 3. During the 5-day work week, subject 8 is performing in the green (good performance band) Monday through Wednesday but limited sleep Wednesday and Thursday nights decreases performance on Thursday and Friday to the yellow (caution) band.*

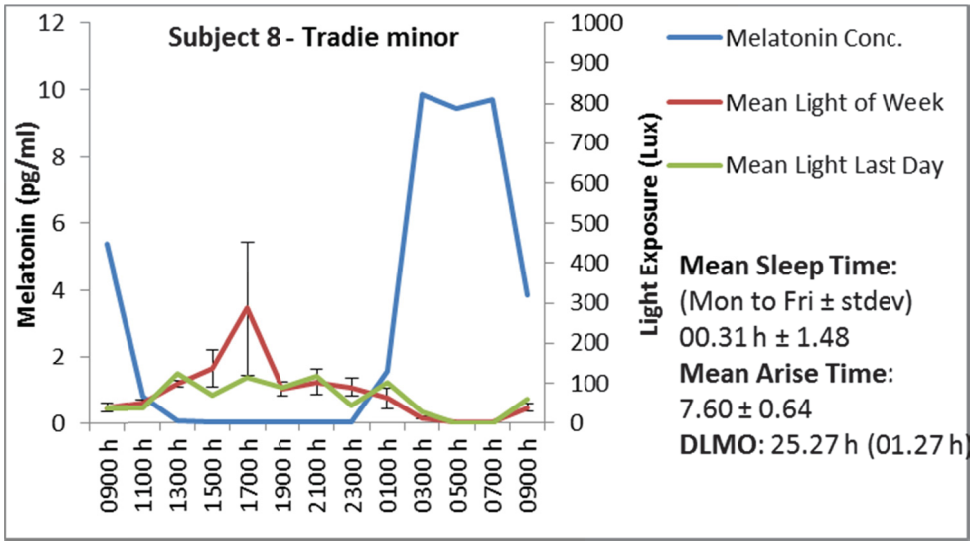

Figure 65. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 8 (data collection 3), plotted over 24-hours. Subject 8 has a late average bedtime time and a normal arise time. However, the DLMO is abnormal occurring an hour after bedtime.*

3.3.9 Subject 9

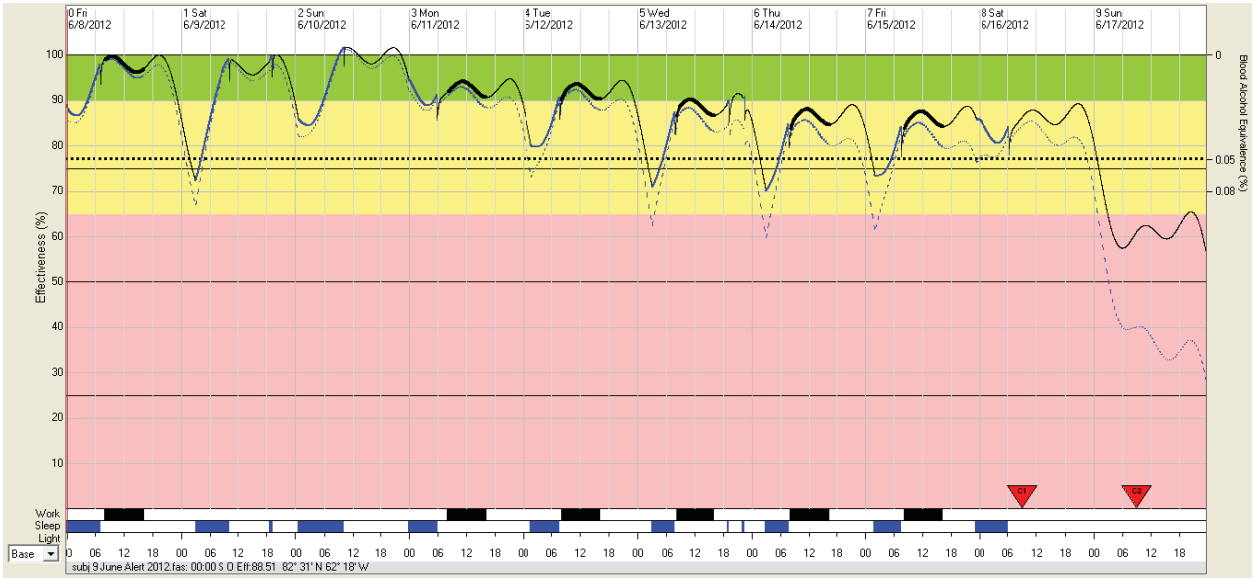

Figure 66. *FAST™ model showing cognitive effectiveness for subject 9, data collection 3. During the work week, on Monday and Tuesday subject 9 is performing in the green (good performance) band but due to limited sleep over the subsequent 3 nights, performance falls into the yellow (caution) band over the next 3 days.*

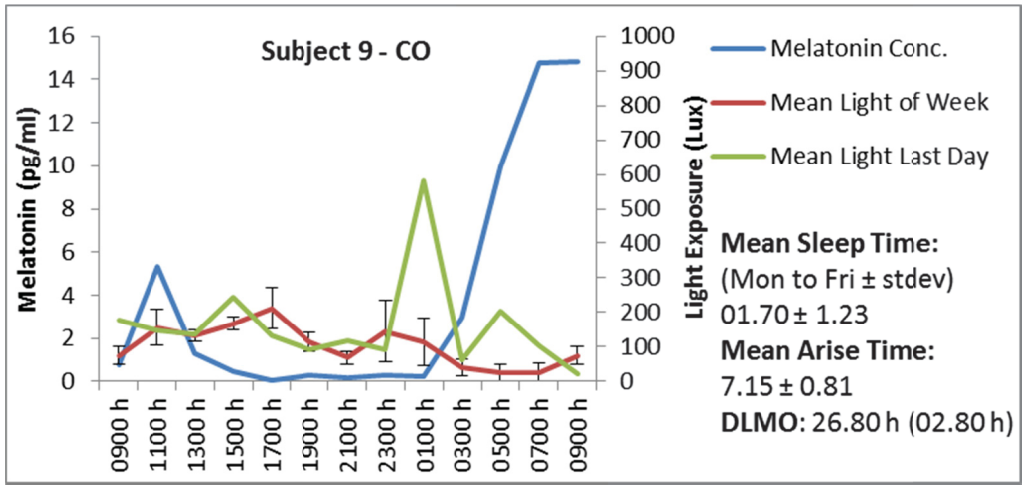

Figure 67. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 9 (data collection 3), plotted over 24-hours. Subject 9 has a late bedtime and a normal arise time. His DLMO is abnormal in that it occurs more than an hour after bedtime.*

3.3.10 Subject 10

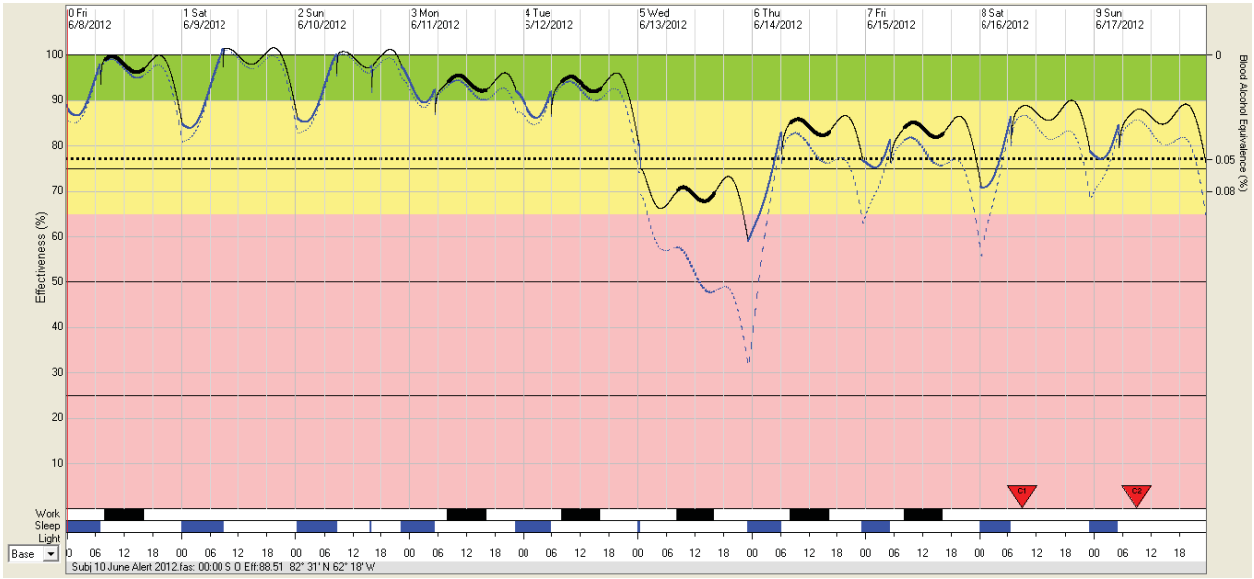

Figure 68. *FAST™ model showing cognitive effectiveness for subject 10, data collection 3. For the first 2 days of the work week (Monday and Tuesday) subject 10 is performing in the green (good performance) band. After only 75 minutes of sleep on Tuesday night, his performance falls drastically on Wednesday to levels equivalent to Blood Alcohol Content (BAC) in excess of 0.08%. Over the next two nights, this improves as well as his cognitive effectiveness reaching a range from 82% to 85% (a level of performance where there is no impairment with equivalance to significant BAC).*

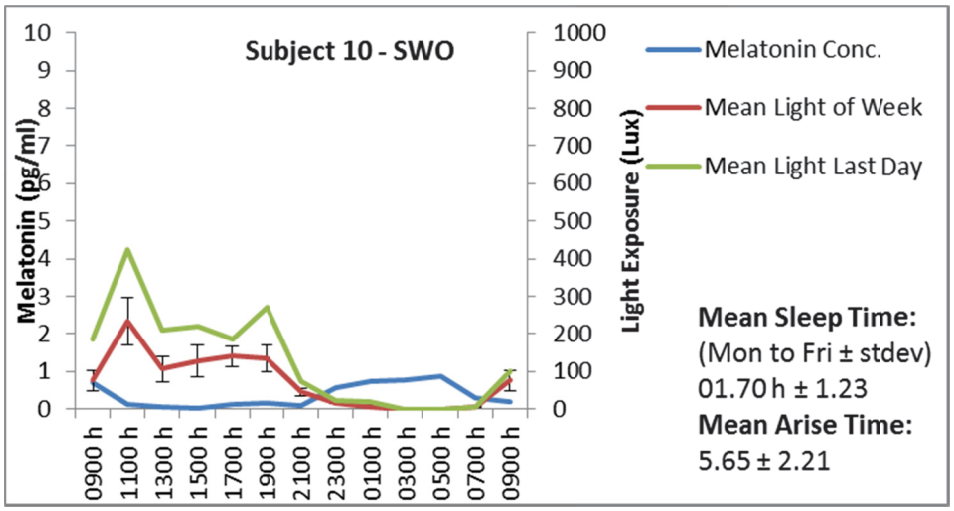

Figure 69. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 10 (data collection 3), plotted over 24-hours. Subject 10 has a late average bedtime and an early average arise time suggesting his average sleep time is just under 5 hours. Further, he is not producing any melatonin and thus has no measurable DLMO.*

3.3.11 Subject 11

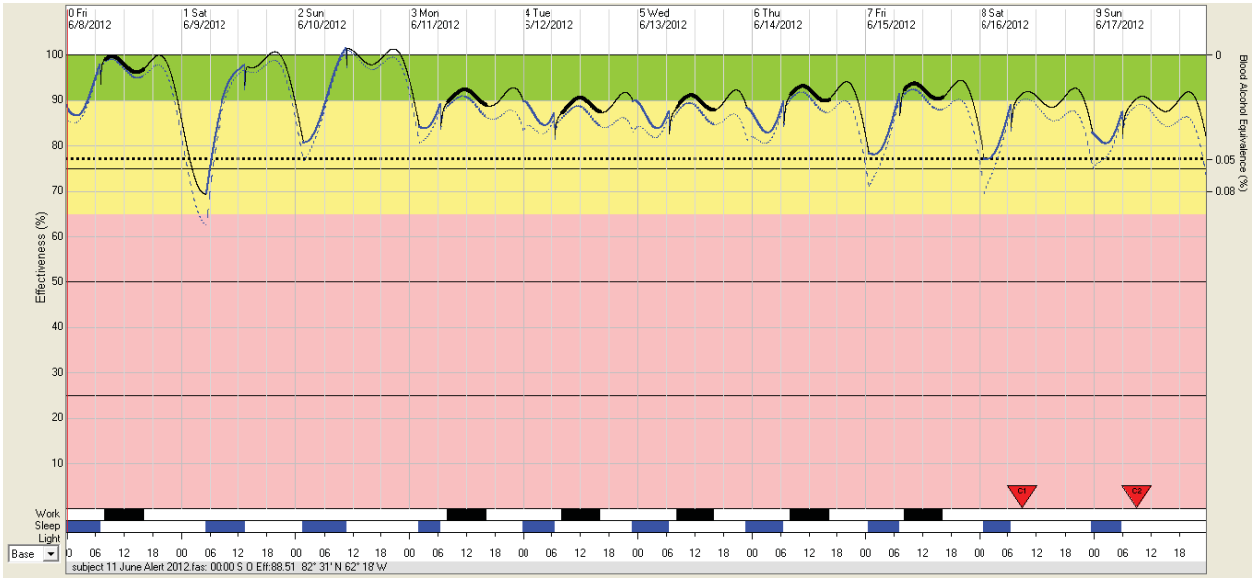

Figure 70. *FAST™ model showing cognitive effectiveness for subject 11, data collection 3. During the work week, Subject 11 has performance straddling the upper limit of the yellow band and the lower limit of the green band, with performance on Thursday and Friday better than Monday through Wednesday.*

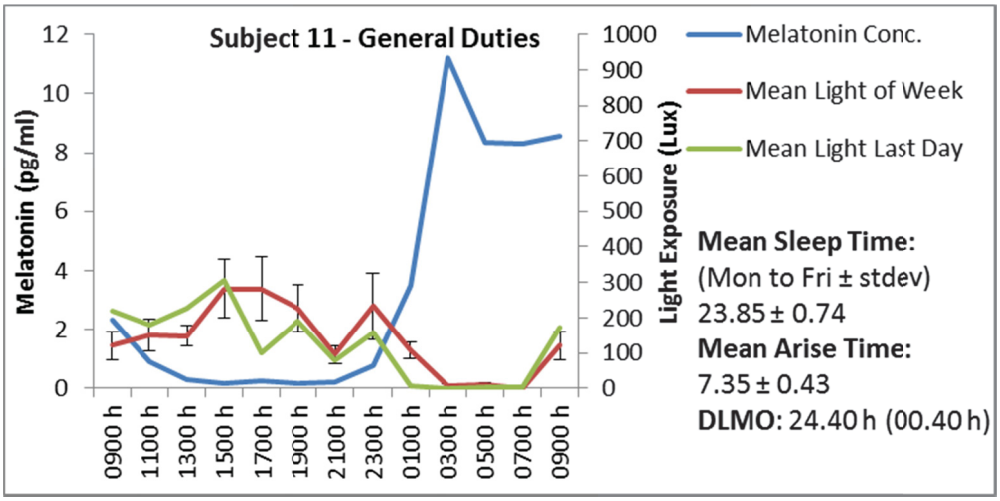

Figure 71. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 11 (data collection 3), plotted over 24-hours. Subject 11 has normal average bedtimes and arise times. However his DLMO is abnormal given that it occurs after bedtime.*

3.3.12 Subject 12

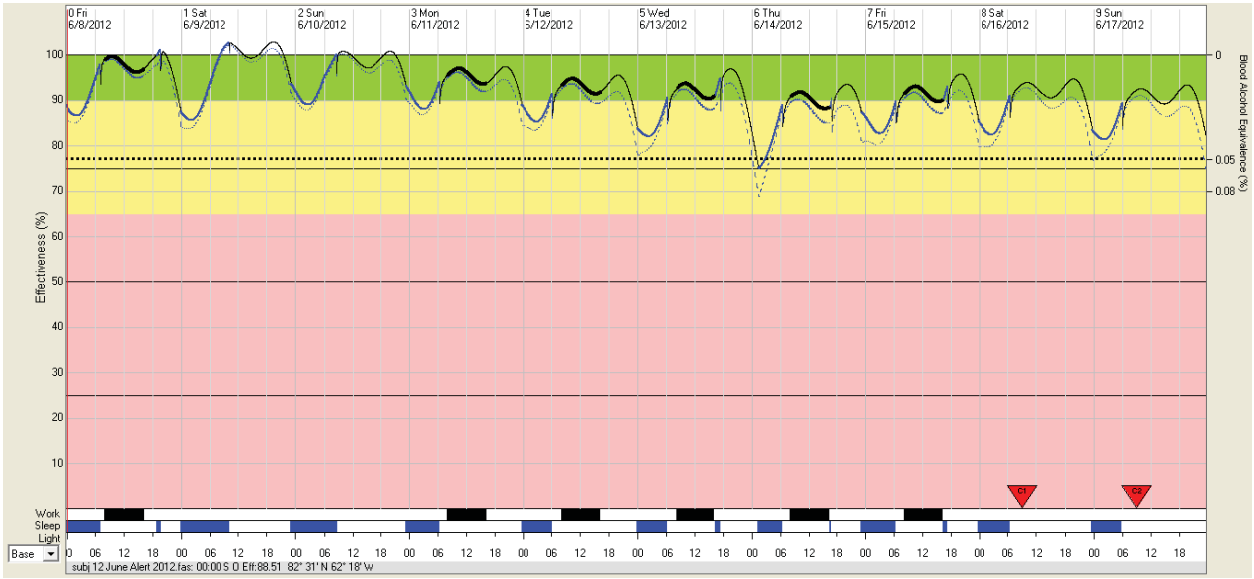

Figure 72. *FAST™ model showing cognitive effectiveness for subject 12, data collection 3. The performance of subject 12 starts out in the upper half of the green (good performance) band and falls slightly each day due to limited sleep, reaching a nadir on Thursday (into the yellow (caution) band and a small improvement on Friday.*

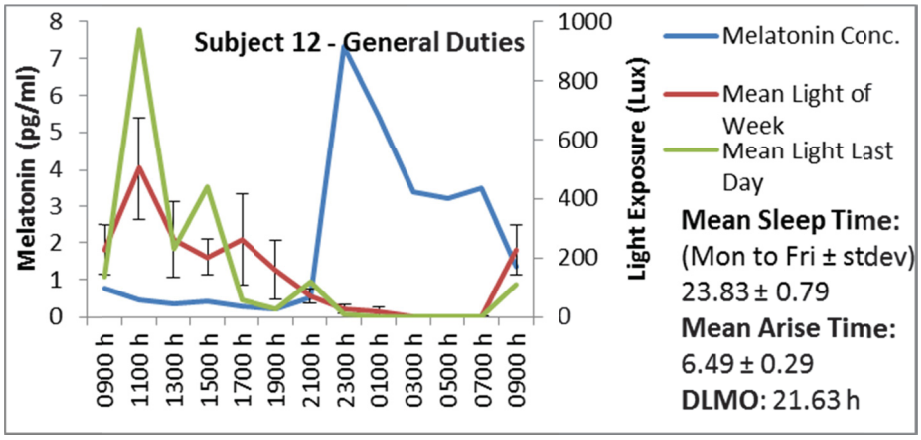

Figure 73. *Salivary melatonin (p-gm/mL) and mean ambient light exposure (lux) for subject 12 (data collection 3), plotted over 24-hours. Subject 12 has normal average bedtimes and arise times and a normal DLMO.*

3.4 Statistical comparison of daily sleep between subjects of data collections 2 (January Alert 2012) and 3 (June Alert 2013)

The data illustrating daily sleep are plotted in Figures 74-76.

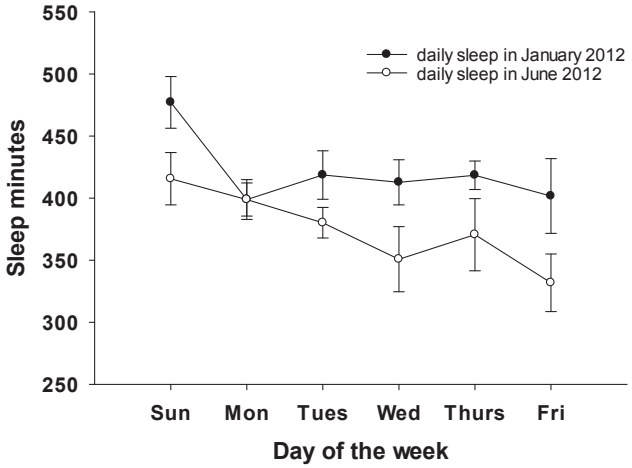

Figure 74. *Daily sleep period, mean sleep minutes are plotted over days for each of the January and June 2012 data collections at CFS Alert. Solid circles are January subjects and open circles are June subjects. All values are means ± s.e.m.*

Repeated measures ANOVA with 'month' as a between factor and 'days' as the repeated measure, indicates a significant main effect of 'month' $F(1, 23) = 4.98$, $p = .036$, a significant main effect of 'days' $F(5, 115) = 3.87$, $p = .003$ and the 'days' x 'month' interaction $F(5, 115) = .38$, $p = .86$ is not significant.

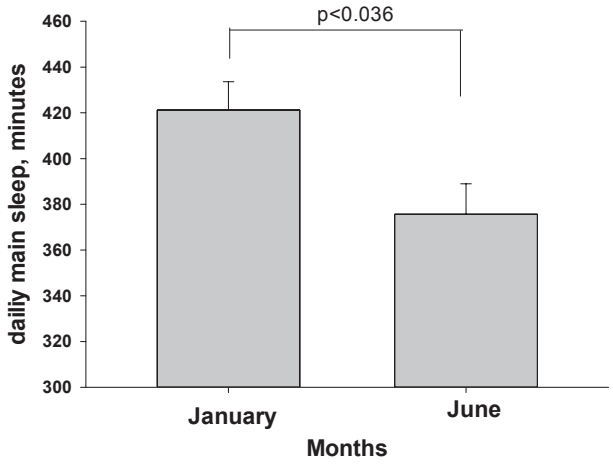

Figure 75. *Main effect of 'month' for daily sleep period is plotted for each of the January and June 2012 data collections CFS Alert. Both values are mean ± s.e.m.*

The subjects in the June data collection obtain approximately 46 minutes less sleep each day compared to their January counterparts (Figure 75).

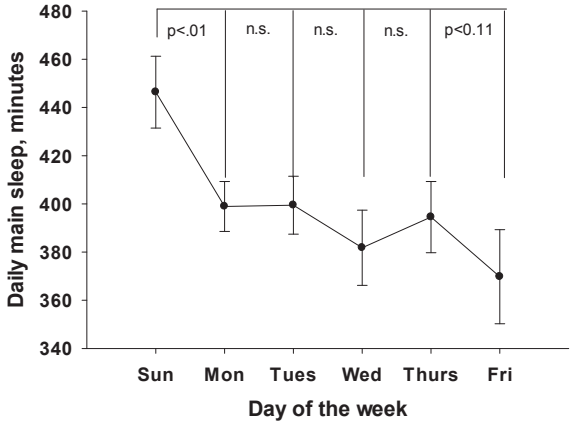

Figure 76. *Main effect of 'days' (collapsed over 'months') for daily sleep period is plotted over days. All values are mean ± s.e.m.*

Daily sleep minutes falls from Sunday to Monday and remains relatively stable during the balance of the week. However, the fall in daily sleep from Thursday to Friday is almost statistically significant (p<0.11) Figure 76.

3.5 Statistical comparison of total melatonin production between January and June in CFS Alert

To compare the mean total melatonin production between January and June in CFS Alert, the melatonin profile for each individual was integrated using the trapezoidal rule. Both the total melatonin production for the entire day and the melatonin production between DLMO and dim light melatonin offset (MelOFF) were calculated. To calculate MelOFF, a 2.7 pg/ml melatonin threshold was used, similar to the DLMO calculation, and a linear interpolation between data points was performed to find MelOFF to the closest minute. Unfortunately we were unable to calculate MelOFF for subjects 28, 29 and 32 for Data Collection 2 (January) and for subjects 3, 10 and 11 for Data Collection 3 (June), therefore these subjects were not included in the calculation of mean melatonin production between DLMO and MelOFF. For the calculation of total daily melatonin production, subjects that did not produce an appreciable amount of melatonin were excluded (subject 29 for Data Collection 2, subject 10 for Data Collection 1). One-way ANOVAs were used to determine whether the total melatonin production (total daily production and production between DLMO and MelOFF) was statistically different between the data collections (January and June). We found that despite the differences in the total melatonin production between January and June, these differences were not statistically significant regardless of the method used to calculate total melatonin production. Statistical statements are provided in the figure legends for Figure 77 (total daily melatonin production) and Figure 78 (total melatonin production between DLMO and MelOFF).

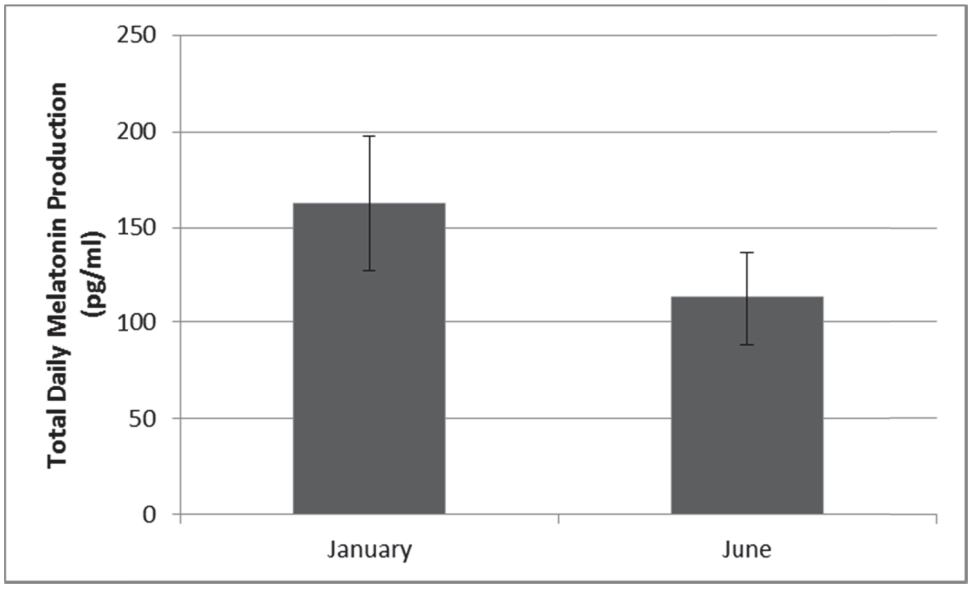

Figure 77. *Total daily melatonin production (pg/ml) for January and June data collections. Data represents mean ± SEM. The two group were not found to be statistically different [F(1,21)=1.22, p=0.28).*

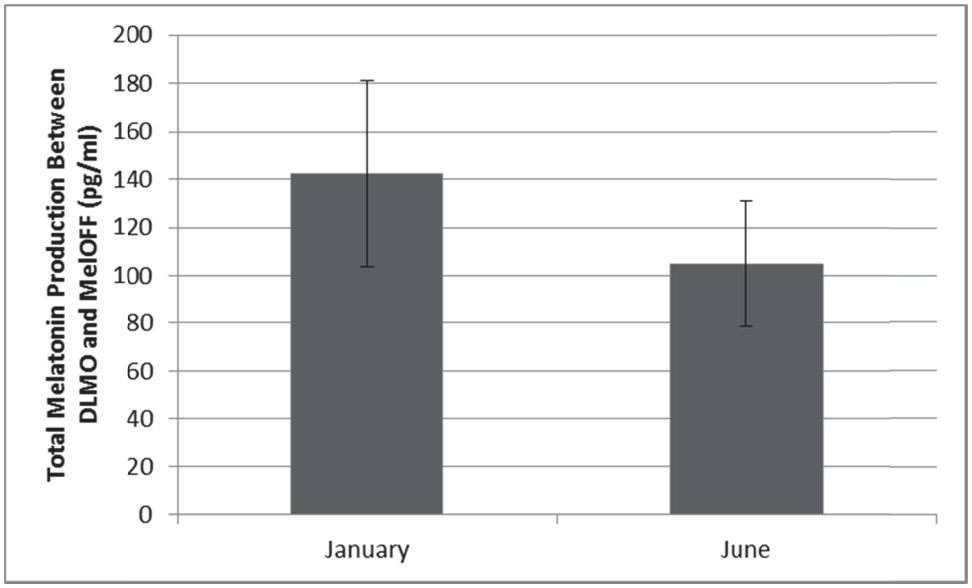

Figure 78. *Total melatonin production (pg/ml) between DLMO to MelOFF for January and June data collections. Data represents mean ± SEM. The two group were not found to be statistically different [F(1,17)=0.87, p=0.36).*

3.6 Statistical comparison of duration of melatonin production between January and June in CFS Alert

To compare the duration of melatonin production, the amount of time between DLMO and MelOFF was calculated, and differences between January and June experiments were statistically assessed (see Figure 77). As mentioned above, we were unable to calculate MelOFF for subjects 28, 29 and 32 for Data Collection 2 (January) and for subjects 3, 10 and 11 for Data Collection 3 (June), therefore these subjects were not included in the calculation. In January, the mean duration of melatonin production was found to be 11.78 h ± 3.45 h, and in June the mean duration of melatonin production was found to be 10.39 h ± 2.16 h (mean ± standard deviation). A one-way ANOVA was used to determine whether the duration of melatonin production was statistically different between the data collections (January and June). We found that despite the 1.4 h difference in the duration of melatonin production between January and June, this difference was not statistically significant [$F(1,17) = 0.837$, $p = 0.37$].

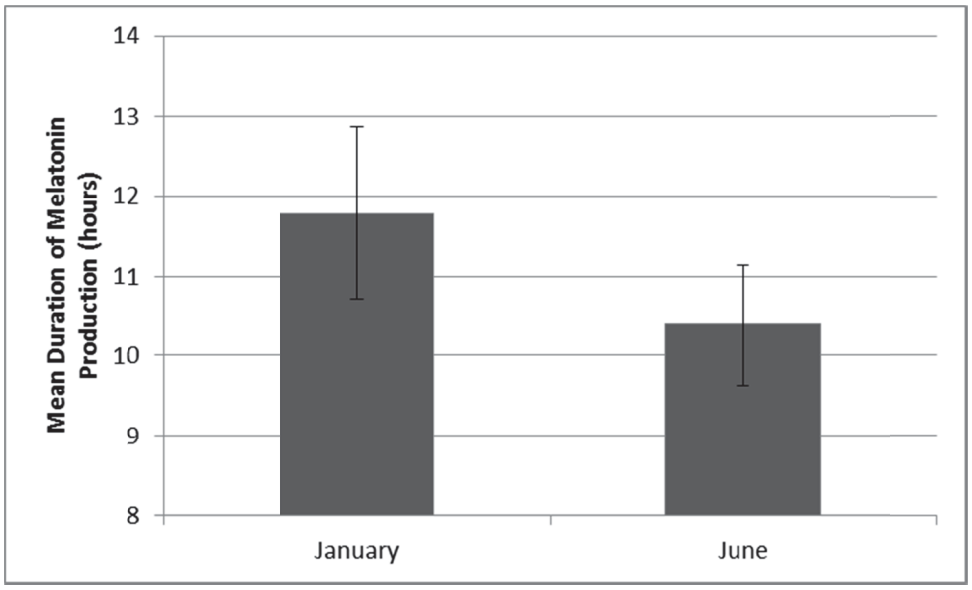

Figure 79. *Mean duration of melatonin production, calculated as the amount of time from DLMO to MelOFF. Data represents mean ± SEM.*

3.7 Statistical relationship between sleep duration and duration of melatonin production

The correlation between sleep duration and duration of melatonin production (DLMO to Dim Light Melatonin Offset) was evaluated to determine whether the reduced duration of melatonin production in the summer vs. the winter contributed to the reduction of sleep time that we observed. A scatter plot of mean sleep duration vs. duration of melatonin production (see figure 77 below) shows that only a very weak correlation exists between the factors, with a Pearson Product Correlation Coefficient (R^2) equal to 0.0856. This indicates that only a fraction of the

reduced sleep time that is observed between seasons can be attributed to the reduced duration of melatonin production by each individual. It is important to note, however, that many psychological, physiological, dietary, and environmental factors are known contribute to an individual's sleep duration.

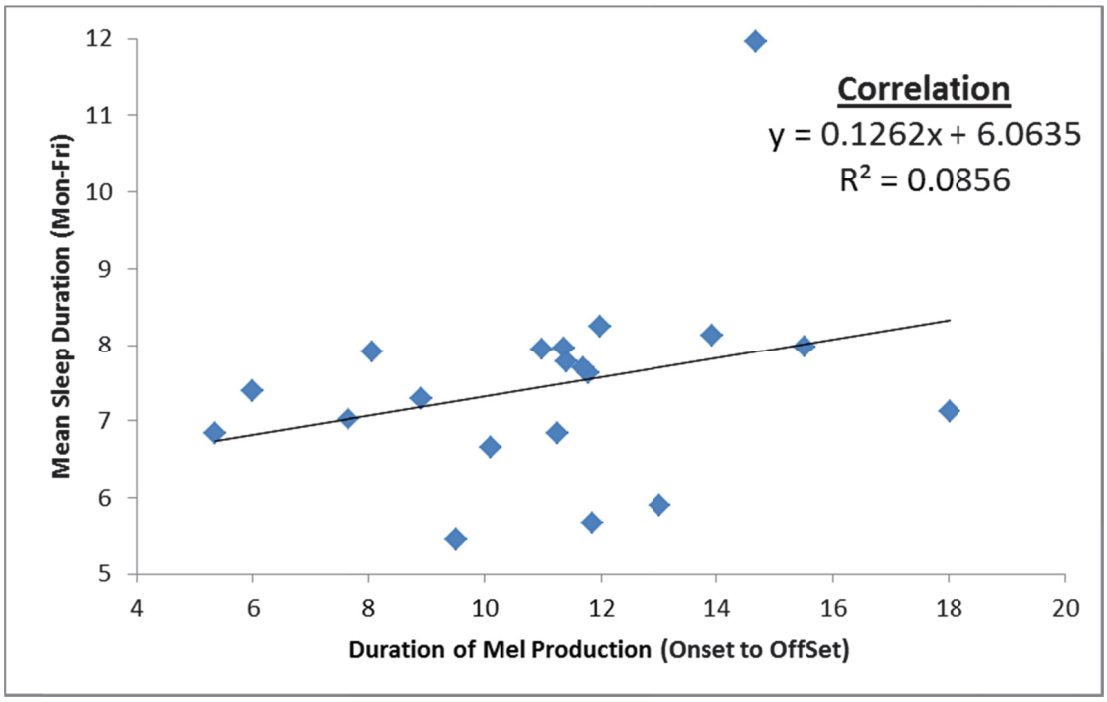

Figure 80. *Mean sleep duration from the week prior to data collection graphed against duration of melatonin production, calculated as the amount of time from DLMO to dim light melatonin offset. Data from January and June data collections are pooled into one population.*

4 Discussion

4.1 Data collection 1 – SARTechs

Arctic winter exercises are not normally conducted since it is dangerous to travel over the land (usually on Land Over Snow Vehicles or LOSVs a.k.a. snowmobiles) where rocky terrain, ice ridges and crevasses cannot be readily seen before contact. In contrast, Arctic winter survival training is executed in a static environment where there is no travel over the land. The static environment of the SARTech survival course provided us with a perfect opportunity to get this snapshot of circadian physiology during early adaptation to the Arctic winter and we are grateful to the SARTechs that participated for enabling this work. It should be noted that the data from the SARTechs cannot be used to inform us about an end-state of adapted circadian physiology associated with operating out on the land during Arctic winter since the subjects were only in the Arctic for 8 days of which only 5 days were out on the land. However, we were interested in a 'snap-shot' of circadian physiology during early adaptation to the Arctic winter environment while working and living out on the land. In this regard, the acute exposure to the perpetual darkness of Arctic winter did not appear to significantly disrupt circadian physiology. Sleep problems and resulting compromise in modelled performance effectiveness appears to be more related to operational and sleep hygiene issues. In summary, it is evident that some subjects obtain good sleep quantity and quality and thus have good modeled performance, but it is also evident that some subjects have limited sleep when they transition from a tent to a snow shelter whether the snow shelter is an igloo or a snow cave. Over the limited observed period of 5 days out on the land, sleep timings and DLMOs are generally normal although several subjects had abnormal DLMOs (7 subjects with a normal DLMO, 4 subjects with a late DLMO and 1 subject with an early DLMO).

4.2 Comparison of daily sleep and melatonin production between January and June and the utility of using light treatment and exogenous melatonin

In both summer and winter conditions, for Alert-based subjects, circadian physiology seems to be preserved with some unique attributes. For example, there were clear seasonal trends in melatonin production between summer and winter Arctic seasons. Although the seasonal trends in melatonin production did not reach statistical significance, possibly due to low subject numbers, it is notable that the lower melatonin production in the Arctic summer correlates to the reduced duration of sleep obtained. Anecdotally, our Arctic data collectors seem to be in agreement that from a sleep perspective, they had more difficulties in Arctic summer than in Arctic winter. The daily sleep data (Figures 74-76) indicates that Arctic summer subjects obtain about 46 minutes less sleep than their Arctic winter counterparts. The reduction of total melatonin production and reduced duration of melatonin production during the summer months, compounded with the presence of continuous sunlight, could lead to a reduced desire to sleep or more likely, a reduced ability to sleep. Therefore, we believe that there is utility in testing the use of exogenous melatonin in CFS Alert over the summer months to initiate and prolong the biological night where and when necessary to improve sleep hygiene and thus operational readiness. The use of Chronoptix™ eyeglasses, which filter out all wavelengths below 520 nm (blue and green light) that would

otherwise suppress endogenous melatonin, may also have utility in the high arctic over the summer months. The donning of these glasses during physiological night in the Arctic summer would prevent suppression of endogenous melatonin and permit production of melatonin during the full physiological night, thus leading to better sleep hygiene and operational readiness. Similarly, we believe that there is utility in testing the use of light treatment in CFS Alert during the winter months where and when necessary to reduce symptoms of Seasonal Affectiveness Disorder when present, and to exert additional control over an individual's circadian system.

Regarding cognitive effectiveness, there are several operational issues and interpersonal sleep hygiene issues that have a significant impact on performance effectiveness. As for operational concerns, the most notable that we observed is the obligatory schedule demands on the Meteorology Technicians that are posted to Alert. These individuals are required to broadcast serial nocturnal weather reports from the airfield control tower to incoming aircraft, which often results in poorly timed sleep. Subject 23 in the Arctic winter data collection and Subject 6 in the Arctic summer data collection were both Meteorology Technicians, and both regularly operated at worrisome levels of modeled cognitive performance, well beyond equivalence to BAC 0.08%. Subject 6 was a rather unique participant as her circadian system was well adapted to a nocturnal work schedule, indicated by her time of melatonin onset. However, she remained quite deficient in sleep. We suggest that two meteorology Technicians should be posted to Alert to share this difficult duty.

The sleep hygiene issues that we observed in our subjects leads to reduced modelled cognitive performance. It is evident that our subjects did not obtain sufficient sleep during weekdays, especially in the Arctic summer (Figure 74). Then on weekends, they obtain even less sleep, resulting is significant sleep pressure on Sunday evenings leading to additional Sunday night sleep as a step towards compensating for the acute sleep debt. We suggest that future Commanding Officers of CFS Alert take heed of this finding and make an effort to advocate for longer sleep periods among Alert staff Monday through Thursday. This may include orders to wrap up evening activities in the mess at an appropriate time (e.g., 2200-2300 h).

Several of the subjects that we tested demonstrated low melatonin production (e.g., Subject 29 in the Arctic winter data collection, and subjects 7 and 10 in the Arctic summer data collection). From our experience, reduced melatonin production is frequently observed and is not necessarily a cause for concern. However, melatonin has many benefits including the anti-cancer effects of its antioxidant properties, and its hypnotic effects for sleep promotion. Individuals that produce such low amounts of melatonin may reap these benefits by supplementing their endogenous melatonin production with a very low dose of exogenous melatonin (i.e., in a pill). A dose of 0.5 mg to 1 mg daily, taken 1 hour prior to bedtime, would be appropriate in our opinion.

In summary, some subjects obtain good sleep quantity and quality and thus have good modeled performance. Yet other subjects have limited sleep and less than ideal modeled performance. Sleep timings and DLMOs are generally normal among CFS Alert personnel although several subjects had abnormal DLMOs. Proper sleep hygiene needs to be promoted at CFS Alert, especially Monday to Thursday.

5 Conclusions

While there is measurable circadian impact during the winter in CFS Alert staff, the current data suggests that the impact during arctic summer represents a particularly challenging environment to obtain sufficient sleep. The presence of continuous sunlight, compounded with a reduction of total melatonin production and a reduced duration of melatonin production, contributes to the reduced desire to sleep in CFS Alert during the summer months. Consequently, cognitive performance of the staff of CFS Alert is affected due to the reduction of sleep duration.

References

[1] Paul, M. A., Gray, G. W., Lieberman, H. R., Love, R. J., Miller, J. C., and Arendt, J. (2010). Management of circadian desynchrony (jetlag and shiftlag) in CF air operations. TR 2010-002, DRDC Toronto.

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List of symbols/abbreviations/acronyms/initialisms

BAC	Blood Alcohol Content
CAF	Canadian Armed Forces
CFS	Canadian Forces Station
DLMO	Dim Light Melatonin Onset
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
FAST™	Fatigue Avoidance Scheduling Tool
KUDLIK	A small Inuit light and source of heat from burning of seal or whale fat
SARTech	Search and Research Technicians who are airborne paramedics
Wrist Actigraph	A watch-like device with an accelerometer to measure amplitude and frequency of movement to measure activity and sleep

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Background. Previous research conducted by DRDC Toronto shows that human circadian rhythms can be manipulated using appropriately-timed treatments of light and/or supplementary melatonin. The seasonal extremes of photoperiod in the high Arctic places pArcticular strain on the human circadian system, which may lead to Seasonal Affective Disorder (SAD) in the winter months and difficulty obtaining sufficient sleep in the summer months. The goal of the work reported here was to study the circadian rhythms of personnel deployed to the high Arctic by tracking the melatonin produced by the body and identifying the timing of daily onset of melatonin production (DLMO, or Dim Light Melatonin Onset). This will permit follow-up work and recommendations for the treatment of discordant human circadian rhythms and associated conditions with the aforementioned countermeasures. **Methods.** Three research trials were conducted, two in the built environment of CFS Alert, and one on land during the SARTech Arctic Survival Course. During all three trials, subjects wore motion logging devices (Actigraphs), which measure ambient light as well as motion. Sleep data obtained from the Actigraphs was used to model the cognitive effectiveness of each subject. Furthermore, saliva was collected at regular intervals to measure melatonin and assess DLMO. **Results.** In general, sleep duration was found to be significantly different between the January and June data collections at CFS Alert, with subjects in June sleeping an average of 46 minutes less than their January counterparts each day. Sleep duration was also found to fall significantly from Sunday to Monday for subjects in both January and June, resulting in reduced cognitive effectiveness in many of the subjects through the week. Circadian stress and poor cognitive effectiveness was most pronounced in the meteorology technicians that we studied, which we attribute to their variable work schedules. **Conclusions.** The Arctic summer represents a pArcticularly challenging environment for obtaining sufficient sleep, which affects cognitive performance of staff during work hours. A reduction of total melatonin production and a reduced duration of melatonin production in the Arctic summer are contributing factors to the reduced desire to sleep in CFS Alert during the summer months.

Contexte. Des recherches antérieures menées par RDDC Toronto indiquent que le rythme circadien humain peut être modifié à l'aide de séances de photothérapie administrées au bon moment et/ou de suppléments de mélatonine. Les variations extrêmes de la photopériode liées aux saisons dans le Haut Arctique exercent une pression particulièrement forte sur le rythme circadien humain, ce qui peut entraîner un trouble affectif saisonnier (TAS) dans les mois d'hiver et une difficulté à dormir suffisamment durant les mois d'été. L'objectif des travaux décrits était d'étudier le rythme circadien du personnel envoyé dans le Haut Arctique en mesurant régulièrement la mélatonine fabriquée par l'organisme et en déterminant le moment où elle est produite quotidiennement (début de la production de mélatonine dans des conditions de faible luminosité). Cette surveillance permettra de faire un travail de suivi et de formuler des recommandations sur le traitement des perturbations du rythme circadien humain et des affections associées au moyen des contre mesures susmentionnées. **Méthodes.** On a procédé à trois essais de recherche, soit deux dans l'environnement aménagé de la station des Forces canadiennes (SFC) Alert et un autre sur le terrain durant le cours de survie en Arctique destiné aux Tech SAR. Lors des trois essais, les sujets portaient un dispositif d'enregistrement du mouvement (ActiGraph), qui mesure la lumière ambiante et le mouvement. Les données sur le sommeil obtenues grâce aux dispositifs Actigraph ont servi à modéliser l'efficacité cognitive de chacun des sujets. En outre, de la salive a été recueillie à intervalles réguliers pour mesurer la quantité de mélatonine et déterminer le début de la production de mélatonine dans des conditions de faible luminosité. **Résultats.** En général, selon les données recueillies à la SFC Alert, la durée du sommeil était nettement différente entre janvier et juin, les sujets dormant en moyenne 46 minutes de moins par jour en juin que leurs homologues en janvier. Nous avons aussi constaté que la durée du sommeil des sujets diminuait considérablement du dimanche au lundi tant en janvier qu'en juin, ce qui entraînait une baisse de l'efficacité cognitive chez de nombreux sujets toute la semaine durant. Le stress imposé par les variations du rythme circadien et la baisse d'efficacité cognitive étaient plus prononcés chez les techniciens en météorologie évalués, phénomène que nous avons attribué à leurs horaires de travail variables. **Conclusions.** Il est particulièrement difficile de dormir suffisamment pendant l'été en Arctique, et le manque de sommeil a des répercussions sur la performance cognitive du personnel pendant les heures de travail. La baisse de la production totale de mélatonine et la plus courte période de production de la substance en été dans l'Arctique sont des facteurs qui réduisent l'envie de dormir à la SFC Alert pendant les mois d'été

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endogenous melatonin; circadian desynchrony; fatigue; sleep hygiene; modeled cognitivie effectiveness