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Sleep/wake cycles of personnel working a Mars day (24.65H)

Laura M. Colletti
San Jose State University

SLEEP/WAKE CYCLES OF PERSONNEL WORKING A MARS DAY (24.65H)

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Laura M. Colletti

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APPROVED FOR THE DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

Kevin Jordan, Ph. D.
Professor of Psychology, San Jose State University

Melissa M. Mallis, Ph. D.
Director of Scientific Affairs, Alertness Solutions

Kevin Corker, Ph. D.
Professor of Industrial and Systems Engineering,
San Jose State University

APPROVED FOR THE UNIVERSITY

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ABSTRACT

SLEEP/WAKE CYCLES OF PERSONNEL WORKING A MARS DAY (24.65H)

by Laura M. Colletti

Time in bed per 24 hours obtained from actigraphy and sleep logs of twenty-four personnel operating the Mars Exploration Rovers (MER) was examined to determine the impact of delaying work schedule start times 39 minutes daily for three months. The results suggest: 1) personnel working a rapidly rotating work schedule (39 minutes daily) decreases time in bed and the length of time in bed is more variable, 2) personnel working a 39-minute rapid rotation (MER rotation) obtained more sleep on non-work days (off-days) than during work days, and 3) there was no difference in the amount of sleep obtained by personnel whose family and permanent residence was remote from JPL compared to personnel whose permanent residence was local to JPL.

ACKNOWLEDGEMENT

While working in the Fatigue Countermeasures Group at NASA Ames Research Center under the direction of Dr. Melissa Mallis, I received this unique opportunity to observe people working a schedule that coincided with a Mars sol while operating two rovers. My gratitude is extended to Melissa for providing the opportunity as well as her advice, support and oversight in all aspects of the study. Additionally, I would like to thank Dr. Kevin Jordan for his guidance in all aspects of the study including writing the thesis and Dr. Kevin Corker for providing insightful comments from his vast experience. Many associates of the Fatigue Countermeasures Group provided support or advice requiring acknowledgement of their efforts including Lucia Arsintescu, Sandy Bowman, Summer Brandt, Patrick Chapman, Charlie DeRoshia, Sig Mejdal, Tammy Nguyen, Ray Oyung, Dinah Reduta, Heike Rentmeister-Bryant, Yuri Tada, and Hans Van Dongen. Additionally, I would like to acknowledge family and friends who provided support including my husband, Doug Pargett, and good friend, Trudy Wardrop. And most importantly, I would like to thank the Mars Exploration Rover personnel, who volunteered for the three-month study while working their difficult schedule. My gratitude is also extended to Steve Squyres and Andrew Mishkin for recruiting people and Diane Mann for her assistance in running the study at JPL.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Humans operate on a near 24-hour period showing circadian rhythms in many behavioral and physiological factors including sleep/wake cycles, body temperature, activity, alertness, and neurobehavioral performance (Colquhoun, 1971; Minors & Waterhouse, 1990). Previous research has shown that sleep loss or a misalignment of the human circadian rhythm increases subjective and physiological sleepiness, negative affect, performance errors, adverse health, and accidents (Akerstedt, 1991; Bonnet, 2000). This is important in reference to the demands of the Mars Exploration Rover (MER) Surface Operations mission, which required personnel to perform mission critical tasks on schedules coinciding with a Mars day (24.65 hour), also referred to as a Mars sol. Schedules were coordinated with Mars daylight times since the rovers were reliant on sunlight for both electrical power and navigation. To adjust to a Mars sol, personnel had to start the work day 39 minutes (0.65 hour) later each day for three months (e.g., start work at 09:00 on one day and the next day 09:39). A hypothetical work schedule that shifts 39 minutes daily is shown in Figure 1 to illustrate the Mars sol work schedule and the impact on habitual sleep, which was disrupted during evening and night shifts.

The MER mission required 24/7 operations to operate two rovers, Spirit and Opportunity, located on opposite sides of Mars and timezones 12 hours apart. Each sol, an 18-hour operational process for each rover was conducted to process the data from the rovers and specify the rovers' activities for the next sol. This process required the receipt of the rover's data, engineering assessment of the transmitted data, scientific assessment of the data and activity planning for the next sol, validation of the plans, command sequence generation, and transmission of the commands (Mishkin & Laubach, 2006).

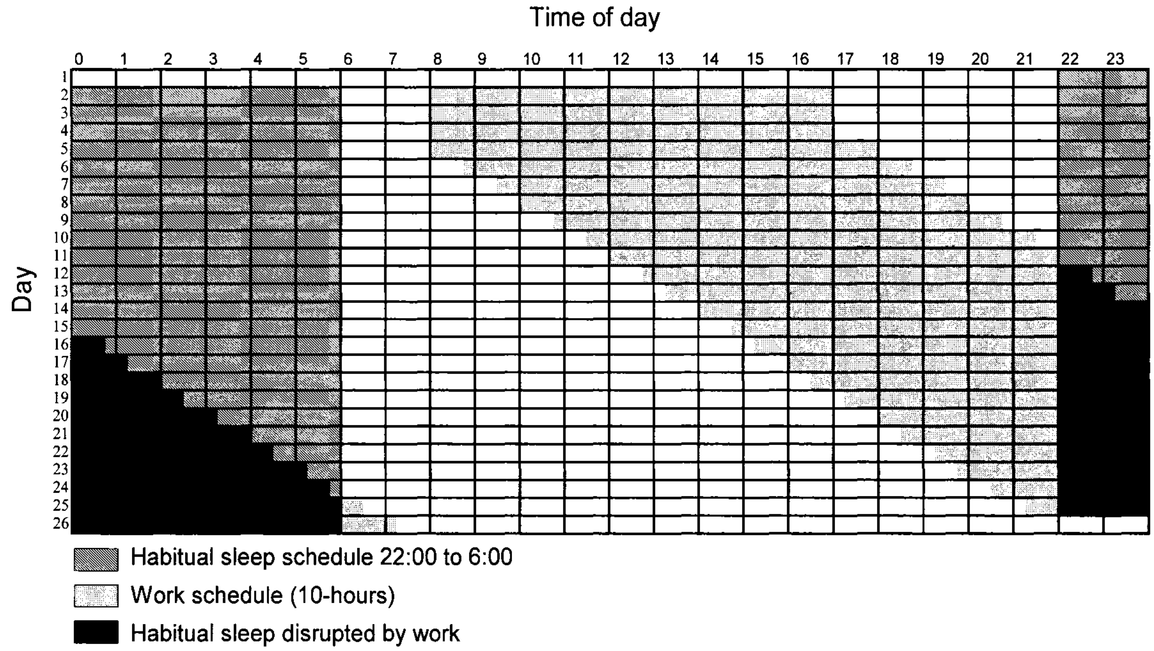

Figure 1. A hypothetical Mars sol work schedule to illustrate the disruption on habitual sleep by delaying work start times 39 minutes each day. The first five days are a normal nighttime sleep and daytime work schedule. Beginning on day six, work start times are delayed 39 minutes each day.

Although controlled laboratory studies have been performed on Mars sols, no previous studies were identified that explored the ability of personnel to shift work schedules 39 minutes daily for an extended period while being exposed to outside Earth-based exogenous cues such as sunlight and social cues. Thus, an exploratory actigraphic ambulatory study was conducted during the first three months of MER operations to investigate the sleep patterns of personnel while delaying their work schedule 39 minutes each day.

Previous isolation studies that controlled for masking effects such as lighting, meal timing, and social interactions, demonstrated that the free-running circadian rhythm of temperature in humans is on average 25 ± 0.51 hours with slight variations induced by exogenous factors such as a social cues or a gong signal for periodic test sessions (Wever, 1986). Temperature rhythms closely follow alertness cycles with higher temperatures occurring during wake and lower temperatures occurring during sleep. A subsequent isolation study using a forced-desynchrony protocol estimated the average intrinsic period of body temperature, melatonin, and cortisol rhythms to be 24.18 hours (ranging from 24:02 to 24:29) (Czeisler et al., 1999). Czeisler suggested that the longer 25-hour period determined by previous studies may have been due to individual participants' preferentially selecting light exposure near bedtime. This is known to induce phase delays in the intrinsic period. Given these results, which suggest the endogenous period is longer than 24 hours, one would hypothesize that humans may be able to adjust to the longer day. However, an isolation study conducted in dim light conditions found that the human circadian oscillator cannot entrain to a scheduled 24.6-hour day (16.4 hour wake and 8.2 hour sleep cycle); although the schedule did exert an effect by lengthening the periods of participants from their baseline levels (Wright, Hughes, Kronauer, Dijk, & Czeisler, 2001). Unlike isolation studies that evaluated human circadian rhythms in non 24-hour days, MER personnel were exposed to 24-hour Earth-based exogenous cues, which may have entrained circadian rhythm periods to 24 hours. These results suggested that sleep would be disrupted working a Mars sol.

Bright light and social cues are strong “zeitgebers,” or time-givers, for entraining the circadian pacemaker (Duffy, Kronauer, & Czeisler, 1996; Waterhouse et al., 1998; Wever, 1979). For shift workers, these environmental cues conflict with the ability to align the circadian pacemaker to a nocturnal orientation (Monk, 2000). Shifting work schedules by 39 minutes daily led to work start times delaying approximately 5 hours weekly or 20 hours monthly such that personnel were required to work both day and night shifts over the three month period. The severity of disruption to the intrinsic period would increase during work shifts occurring at night due to conflicts between the circadian rhythm and exogenous factors. Bright light and social cues, such as meal times, noise, and social interactions of a day-oriented society would have interfered with adaptation during MER work schedules occurring at night.

As mentioned previously, the circadian rhythm modulates many different functions of the body to ensure that activities such as sleep occur at appropriate times of the day. To conceptualize the regulation of sleep, a two-process model was proposed by Borbely (1982), which postulates a homeostatic sleep/wake process (S) that rises across time of wakefulness and declines during sleep and interacts with a sleep-independent circadian process (C; Achermann, 2004). The two processes, the homeostatic and circadian, interact to modulate neurobehavioral and biological rhythms in humans throughout a 24-hour period. The impact of this interaction is that the duration of sleep is time-of-day dependent such that sleep will be more disrupted when it occurs during daytime hours at the circadian peak phase for wakefulness (Akerstedt & Gillberg, 1981; Czeisler, Weitzman, Moore-Ede, Zimmerman, & Knauer, 1980). These effects have been shown by Akerstedt (2003) for night shift workers who typically experience shortened sleep terminating early due to the circadian arousal signals for wake at daytime. Further, early morning shift workers also experience reduced sleep compared to day shift workers due to early termination of sleep in the morning (Tilley, Wilkinson, Warren, Watson, & Drud, 1982).

In July 1997, personnel at the Jet Propulsion Laboratory (JPL) in Pasadena, California who were living on Mars time to operate the Mars Pathfinder and Sojourner described the experience as extremely fatiguing. Mishkin (2003) stated, "Around Sol 30, the rover and lander uplink teams revolted. Both teams had been living on Mars time for a month, and we were exhausted" (p. 292). Additionally, Mishkin indicated that engineers were more fatigued than the scientists who could work on their own schedules and did not need to stay on Mars time.

During the MER mission, however, both scientists and engineers worked on Mars time; therefore, everyone worked a schedule that rotated 39 minutes daily. Another factor that could have potentially contributed to sleep loss was identified as the distance of personnel's permanent residence to the study location. Typically, the scientists' permanent residence was out-of-state or remote from JPL, but for the three-month mission, a temporary move to a hotel or other temporary residence near JPL was required. With their home, spouse, and family remotely located from them while working at JPL, these personnel may not have had the same social zeitgebers interfering with their ability to work the MER rotation as personnel who lived locally. Personnel that lived local to JPL, on the other hand, may have been exposed to more 24-hour social zeitgebers while working the MER rotation including daily chores, house maintenance, and social obligations with family. Thus, it was hypothesized that sleep patterns would be more disrupted for personnel with permanent residences local to JPL due to 24-hour social zeitgebers interfering with their ability to stay working a 39-minute rotating work schedule compared to those that lived remotely.

The present study examined the ability of MER Surface Operations personnel to maintain sleep patterns while living in the 24.0-hour light/dark cycle of an Earth day while performing mission critical operations in accordance with a Mars sol schedule. In particular, this study examines the time in bed per 24 hours obtained by personnel during different work schedules including two weeks before the rovers landed (baseline), approximately three months of the 39-minute rotating work schedule (MER-rotation), and approximately two weeks after the MER rotation when personnel stopped working a continuous rotation and began working a more stable schedule (MER Earth-time). The life expectancy of the rovers exceeded 90 days and a schedule that occurred between 07:00 and 21:00 was observed instead of the continuous rotation. This was possible due to improvements in software tools, reusable command sequences, and increased team experience, which reduced the operations each sol to 11 hours (Mishkin & Laubach, 2006). Sleep was determined by participants wearing a wrist actigraph throughout the study. This unobtrusive device provides a valid and reliable measure for detecting sleep in normal, healthy adult populations over time (Ancoli-Israel et al., 2003). Comparisons of actigraphy to polysomnography, the gold standard for sleep assessment, have yielded 91 - 93% overall agreement in total sleep time for adults (age 20 – 30 years) with lower correlations (0.81 to 0.91) observed in nursing home populations (Ancoli-Israel et al., 2003). This research addressed the following three issues:

1. **To determine whether the sleep obtained by the MER operations personnel differs among baseline, MER-rotation, and MER Earth-time schedules.** It was hypothesized that time in bed per 24 hours during the MER-rotation schedule would decrease and be more variable than during baseline and MER Earth-time schedules.
2. **To determine whether the MER operations personnel's sleep differed between work days and non-work days while working a 24.65-hour work schedule.** It was hypothesized that the sleep would be reduced on work days compared to days off work during the MER-rotation schedule. This recovery of sleep debt on days off has been found to occur in the working population and increases for nightshift workers (Tepas & Carvalhais, 1990).
3. **To determine whether any differences observed in sleep can be attributed to whether a participant's permanent residence was local or remote to the JPL vicinity.** It was hypothesized that personnel whose permanent residence was local to JPL before the rovers landed would obtain less time in bed per 24 hours than personnel whose residence and family were remote. This is because those who lived local to JPL would experience disruptions to the MER schedule by 24-hour social environmental factors.

METHOD

Participants

Thirty MER Surface Operations personnel, seven females and 23 males, age 21 to 59 years of age ($M = 38.2$, $SD = 11.0$) volunteered for this study, which was approved by the San Jose State University Human Research Institutional Review Board (see Appendix A for the Approval Letter). All participants gave informed consent prior to participating in the study (see Appendix B for the Consent Form). The participants were almost equally divided on locality to JPL: sixteen lived local to JPL and thirteen reported their residences in Mountain, Central, or Eastern Time zones, and one international participant (GMT-3) volunteered as well.

Recruitment occurred with assistance from the MER Surface Operations managers. Participation was not limited by age, gender, or race. No monetary compensation was given to participants; however, an analysis of their personal sleep history was made available to them upon request.

Apparatus

The Actiwatch recorder (AW-64; Mini-Mitter, Inc., Bend, OR) is a small waterproof, wristworn device (17 grams) used to measure gross motor activity for estimating sleep. The Actiwatch is powered by a 3V, 150 mAmp-hr lithium manganese battery that has a lifetime of 180 days. Each Actiwatch contains an accelerometer capable of sensing motion with a minimal resultant force of 0.01g. Measurements are collected at 32 Hz and amplified, filtered, and passed into an analog to digital converter. The peak value at each second is summed over the minute to create an activity score that is logged onto the non-volatile memory. The AW-64 also has an event-marker button on the face for participants to record events such as the bed time, wake time, and periods in which the Actiwatch was removed.

Data was downloaded to a computer using a special reader and then Actiware-Sleep scoring software (version 3.3; Mini-Mitter, Inc., Bend, OR) was used to calculate the sleep measurement, defined as time in bed. The software requires a sleep analysis window to be set for each sleep episode, which is defined using the event markers pressed at bedtime and wake time. Time in bed per 24-hour period between the hours of 00:00 to 23:59 was calculated from the time in bed measure to determine whether personnel obtained an equivalent amount of sleep per 24 hours during the 24-hour and 24.65-hour work schedules. This provided a common 24-hour measurement period for the different schedules. Time in bed was selected as the dependent measure of sleep because the accuracy of the actigraph to detect wake and sleep declines with sleep disturbances (Ancoli-Israel et al., 2003) and time in bed provides a conservative measure of the time allotted for sleep.

The paper-and-pencil Daily Sleep Log (see Appendix C) is a daily log with inputs for bed times and awakenings. These sleep times were used to validate the Actiwatch event markers or mark the sleep times if event markers were unavailable. Additionally, participants reported their work schedules, naps, and subjective ratings of alertness and fatigue. Participants also marked extended periods of time in which the Actiwatch was not worn and recorded anomalies such as traveling to different time zones. These items provided additional information to help interpret the activity data. Instructions for use were included with the Daily Sleep Log. This study was conducted secondary to the primary objective of personnel operating the Mars Exploration Rover. Therefore, this log was completed by the personnel only if time permitted.

Three paper-and-pencil surveys were administered throughout the protocol: the Pre-study, Background, and Post-study. The Pre-study Questionnaire (Appendix D) consists of 17 items to collect contact information and some preliminary demographic data. The Background Questionnaire (Appendix E) is a 46-item survey with questions about participants' age, gender, family status, sleep profile, and commute profile. A 28-item paper and pencil Post-study Questionnaire (Appendix F) was administered at the end of the study to determine the subjective impact of working a Mars sol on personnel.

Two additional documents were created: a study description to aid in recruitment (Appendix G) and a procedures handout to instruct participants on using the Actiwatch and Daily Sleep Log (Appendix H).

Procedure

Upon signing the Consent Form (see Appendix B), reviewing the study description (Appendix G), and completing the Pre-study Questionnaire (see Appendix D), participants were sent an Actiwatch, Daily Sleep Log, Background Questionnaire, and Procedures Handout (see Appendix C, E, and H) two weeks before the MER landing on January 4, 2004. Materials were mailed directly to the participants with a self-addressed envelope for immediate return of the questionnaire and materials at the end of the study. Participants were trained using written materials including the overall study description

(Appendix G), the procedures handout (Appendix H), and the sleep log instructions at the beginning of the Daily Sleep Log (Appendix C).

Actiwatches are usually worn on the non-dominant wrist. However, in order to increase compliance, participants were allowed to place the Actiwatch on the dominant wrist for the duration of the study if discomfort occurred. A review of the research on actigraph wrist placement reported inconclusive results (Ancoli-Israel et al., 2003).

The Actiwatch was worn on the wrist at all times, including sleep and wake, except during bathing or high-impact activities to avoid damaging the watch. Upon attempting to sleep or upon awakening, the participant pushed an event marker on the top of the watch. They also input their sleep/wake time on the daily sleep log. At regular intervals, the researcher would travel to JPL to swap equipment with participants due to the limited memory capacity of the Actiwatch (a maximum of 44 days for the one-minute sampling cycle). It would have been preferable if participants wore the same Actiwatch throughout the protocol; however, experience during an operational readiness test found the high workload and unusual schedules of the participants interfered with getting the same Actiwatch back to each participant after processing without missing one or several sleep cycles. It was determined more important to avoid potentially losing days worth of data. Therefore, the participants would immediately receive a replacement Actiwatch, when turning in the previous one for downloading, battery change, memory clearing, and re-coding. At the end of the protocol, the Post-study Questionnaire (Appendix F) was distributed and the materials were picked up or returned via pre-paid delivery service to NASA Ames Research Center.

RESULTS

Six participants were removed from the analyses due to missing sleep log data (n = 2), inconsistent sleep log entries compared to actigraphy (n = 1), medical issues (n = 1), internationally located (n = 1), or family emergencies (n = 1). Actiwatch software cannot accurately predict active sleep from restful wake without specifying bedtimes. Those participants with no sleep log data, limited event markers to record bedtimes, or inaccurate sleep log data will be analyzed using other methods such as circadian rhythm analyses in future reports. Participants with medical conditions, family emergencies, or who lived internationally had different schedules which would be best analyzed on a case-by-case basis. Therefore, analyses were computed using the remaining twenty-four participants out of the original thirty. Of the 24 participants, fourteen participants' permanent residences were local to JPL and ten participants had permanent residences outside driving distance of JPL.

The Actiwatch was worn on average for 109.2 days (range 49 to 136 days). The average number of days per work schedule was 13.9 days (range 3 to 42 days) for baseline, 77.3 days (range 37 to 100 days) for MER-rotation, and 20.1 days (range 9 to 33 days) for the MER Earth-time schedule. The start dates for baseline, MER-rotation, and MER Earth-time schedules were determined by the post-study questions requesting the start and end dates for working a Mars sol. The two rovers were in operation in Mars time zones approximately 12 hours apart and the first rover, Spirit, landed January 4, 2004 and Opportunity landed January 24, 2004. Based on the study protocol, it was expected that participants would wear the Actiwatch for 14 days at baseline before working a Mars sol. However, given the different job assignments to the rovers and the 20-day difference in the rovers landing dates, some personnel wore the Actiwatches longer during baseline.

In order to evaluate the hypotheses under study, two separate mixed model analyses of variance were conducted. The first analysis was a 3 x 2 mixed model analysis with schedule (baseline, MER-rotation, and MER Earth-time) as the within-subjects factor and location of permanent residence (local and remote) as the between-subjects factor. The second analysis was a 2 x 2 mixed analysis of variance to investigate type of day (working or non-working days during the MER-rotation) as the within-subjects factor and location of permanent residence as the between-subjects factor. Two dependent measures were examined for each model: 1) time in bed per 24 hours and 2) standard deviation of the time in bed per 24 hours. Thus, a total of four mixed model analyses were run. Additionally, the timing of sleep was examined.

Sleep periods or days were removed if participants were sick, both the event markers and sleep log entries were missing, or sleep log entries varied greatly from the actigraphy data. Additionally, New Year's Eve (12/31/03) and Daylight Savings day (04/04/04) were removed if the sleep period varied more than two hours from the preceding and following two days. Two Actiwatch recordings for participants D and K were missing due to hardware problems and sleep log entries were used instead.

Timing of sleep during the different schedules

To determine how the timing of sleep changed during the different work schedules, sleep fractions or percentage of sleep periods in which participants were in bed at each hour of the day (Lewis & Masterton, 1957; Naitoh, Banta, Kelly, Bower, & Burr, 1991) were plotted for the different work schedules (Figure 2). Sleep from midnight to 04:00 was below 80% during the baseline period, which suggests that other factors were affecting the sleep schedules of personnel and this period did not represent a true "baseline." Sleep during the MER Earth-time schedule was above 80% from midnight to 04:00 (range 80 – 88%) suggesting personnel slept more consistently during the night for this work schedule.

While personnel worked the MER rotation shifting 39 minutes daily, time in bed during the night hours from midnight to 4:00 (range 52% to 66%) was lower than baseline. Additionally, time in bed increased during the day and early evening with a

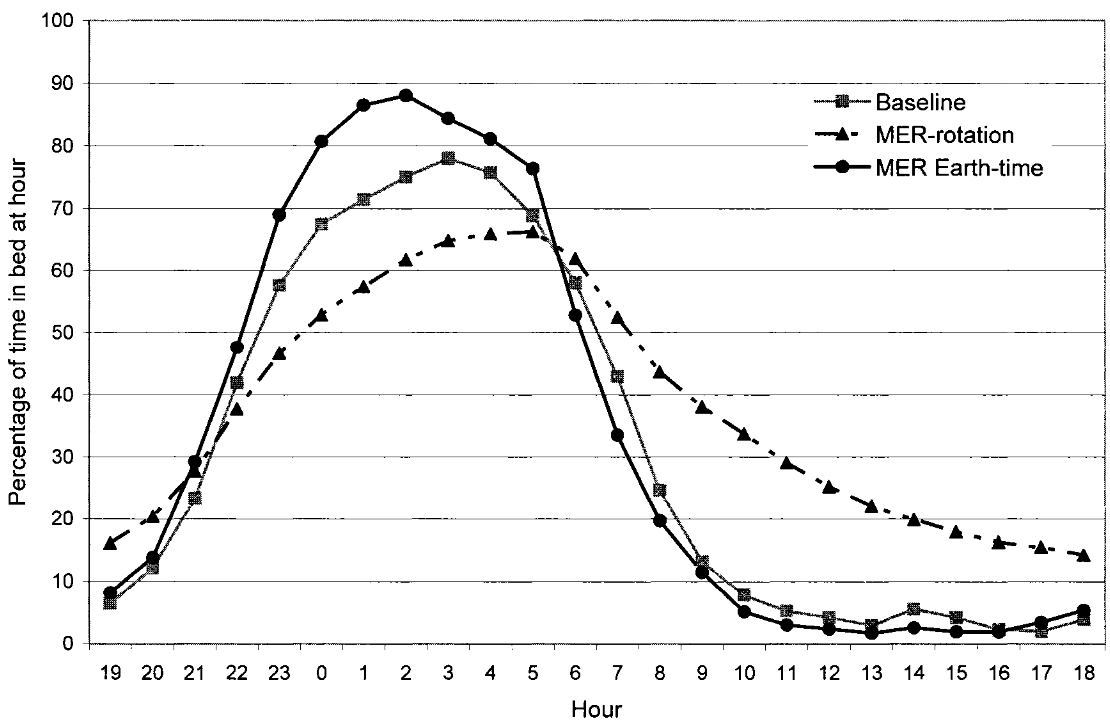

Figure 2. Percentage of sleep episodes (also referred to as sleep fractions) in which participants were in bed at each hour of the day for the different work schedules.

larger percentage of sleep episodes occurring in the late morning (43% at 08:00) and decreasing across the day until only 14% of the sleep episodes occurred at 18:00. The highest percentage of sleep was still obtained during normal sleep times from 00:00 to 07:00 and the smallest percentage of sleep episodes occurred during the early evening 16:00 to 19:00. It was estimated that the personnel would work night shifts only one-third of the time over the 90-day mission (Bass, Wales, & Shalin, 2004). If personnel had adapted to a Mars sol, there would be no sleep bias to the Earth day and sleep would be distributed across all hours. However, sleep still occurred predominantly during the biological night. This suggests that personnel did not adapt to a Mars sol, which is not surprising since sleeping during the biological night increases sleep propensity and duration. The peak time of day in which most sleep episodes occurred was 03:00 for baseline, 05:00 for the MER-rotation, and 02:00 for the MER Earth-time schedule.

Type of schedule and location of permanent residence

To determine whether the time in bed obtained by the MER operations personnel differed among baseline, MER-rotation, and MER Earth-time operations, a repeated-measures ANOVA with schedule as the within factor and permanent residence as the between factor was run. Two participants were missing baseline data due to late recruitment, and one participant stopped wearing the Actiwatch after 49 days before working a MER-rotation schedule; their data was able to be included by using mixed-model ANOVA.

Average hours of time in bed for participants differed significantly across baseline ($M = 8.18$, $SD = 0.70$), MER-rotation ($M = 7.81$, $SD = 0.67$), and MER Earth-time ($M = 7.73$, $SD = 0.61$) schedules ($F(2, 41) = 8.1, p < .01$). Further comparisons found that baseline time in bed was significantly higher than the MER-rotation ($t(41) = 3.26, p < .01$) and MER Earth-time schedules ($t(41) = 3.71, p < .001$; Figure 3). Time in bed for the MER-rotation schedule was not significantly different from the MER Earth-time schedule ($t(41) = 0.50$, n.s.). There was no main effect of living local versus remote from JPL ($F(1, 22) = 0.02$, n.s.) and there was no interaction effect ($F(2, 41) = 0.75$, n.s.). Results suggest that participants obtained more sleep before the landing of the rovers while the time in bed per 24 hours working a MER-rotation and MER Earth-time schedule was about the same. Additionally, living remote or local from JPL had no effect on time in bed.

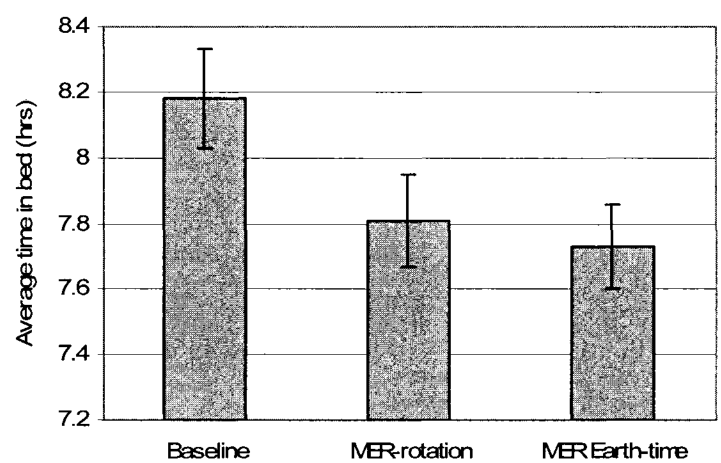

Figure 3. Average time in bed per 24 hours for participants across baseline, MER-rotation, and MER Earth-time work schedules. Error bars represent standard error of the mean.

By averaging sleep across each participant, resolution is lost in the data analysis. For example, the minimum time in bed for each participant across all sleep episodes for a MER-rotation schedule ranged from 0 to 5 hours and the maximum ranged from 10.7 to 18 hours; yet the minimum time in bed averaged across each participant was 6.4 hours and maximum was 9.0. Therefore, the variability of each participant's time in bed was also analyzed.

To examine the variability of sleep, the standard deviation of time in bed was used. A significant main effect was found for the standard deviation of average time in bed for participants across baseline, MER-rotation, and MER Earth-time work schedules ($F(2, 41) = 8.44$, $p < .001$; Figure 4). The variability of time in bed during the MER-rotation schedule was significantly higher than baseline ($t(41) = -3.68$, $p < .001$) and MER Earth-rotation ($t(41) = 3.37$, $p < .01$) schedules. The variability of time in bed was not significantly different between baseline and the MER Earth-time schedules ($t(41) =$ -0.34, n.s.). There was no main effect of living local versus remote from JPL (F(1, 22 = 0.42, n.s.) and there was no interaction effect ($F(2, 41) = 2.08$, n.s.). These results suggest that a work schedule that rotates 39 minutes daily and not location of permanent residence causes increased variability in the length of sleep episodes, which could result in circadian disruption affecting alertness and performance.

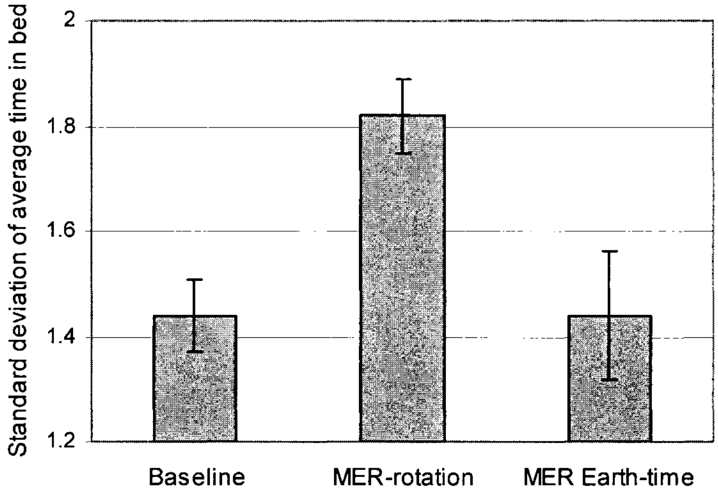

Figure 4. The variability of time in bed for the different work schedules. Error bars represent standard error of the mean.

Type of day and location of permanent residence

To determine whether the average sleep duration (time in bed per 24 hours) of personnel working a Mars sol (MER-rotation schedule) differs between non-working days and working days, a repeated-measures ANOVA was run. A day was scored as a work day if the participant worked more than two hours within the 24 hour period. Only twenty-one participants were included in this analysis due to removal of three participants with missing work schedules from the sleep log.

The 2x2 ANOVA comparing work-days and non-working days and permanent residence during the MER-rotation found a significant effect between days working and not working ($F(1, 19) = 64.55, p < .001$); however, no significant effect of permanent residence being local or remote from JPL was found ($F(1, 19) = 1.23$, n.s.) and no interaction was found ($F(1, 19) = 0.67$, n.s.). Time in bed while working ($M = 7.59$, $SD =$

0.62) was significantly different from time in bed while not working ($M = 8.63$, $SD = 0.71$; Figure 5).

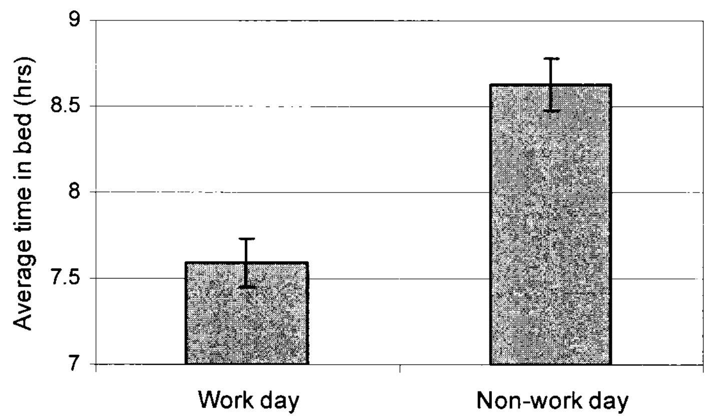

Figure 5. Average time in bed per 24 hours while working versus not working. Error bars represent standard error of the mean.

These results suggest that personnel slept more on days off, therefore potentially compensating for sleep lost while working. Sleeping longer on non-work days is common for all permanent workers; additionally, night shift workers tend to sleep less during workdays and sleep more on non-work days compared to day workers (Tepas & Carvalhais, 1990). Findings from a sleep dose-response study by Belenky et al. (2003) suggest that this additional sleep may not have fully restored neurobehavioural performance. Belenky et al. found psychomotor vigilance task performance did not return to baseline levels after three days of 8-hours of recovery sleep. Additionally, these results suggest permanent residences being local or remote from JPL did not contribute to variations in time in bed per 24 hours for personnel working a Mars sol. The three participants who did not complete work schedules in their sleep log lived remotely (two Eastern and one Central Time). However, it cannot be determined whether their non-compliance in filling in the sleep log was due to traveling between time zones, work tasks, or other factors.

The same 2x2 ANOVA on the standard deviation of time in bed across participants found no significant effect between days working and not working ($F(1, 19) = 0.42$, n.s.), no significant effect of permanent residence being local or remote from JPL ($F(1, 19) = 0.10$, n.s.), and no interaction effect ($F(1, 19) = 0.017$, n.s.). These results suggest that permanent residences being local or remote from JPL and working compared to not working did not contribute to the variability in sleep lengths while working a Mars sol schedule.

DISCUSSION

There were three major findings from this study: 1) personnel working a rapidly rotating work schedule (39 minutes daily) decreased time in bed and the length of time in bed was more variable, 2) personnel working a 39-minute rapid rotation (MER rotation) obtained more sleep on non-work days (off-days) than during work days, and 3) there was no difference in the amount of sleep obtained by personnel whose family and permanent residence was remote from JPL compared to personnel whose permanent residence was local to JPL.

Average time in bed decreased during a MER-rotation schedule (7.81 hours) compared to the baseline work schedule before the MER rotation (8.18 hours); however, time in bed did not vary between the MER rotation and Earth-time. Additionally, an increase in variability in time in bed per 24 hours (sleep periods ranged from 0 to 18 hours) occurred while working a MER rotation compared to baseline and MER Earth-time. Although the average sleep time during the MER rotation and Earth-time were similar; the increased variability during the MER rotation suggests the sleep/wake patterns of personnel working a Mars sol schedule were disrupted. Additionally, time in bed represents the time available to sleep. Actual sleep (time in bed minus time awake) would be lower due to normal sleep rhythms and sleep disruptions.

During the MER rotation, personnel obtained about one hour more time in bed during non-work days compared to work days, suggesting that personnel may have been compensating for sleep loss occurring while working a Mars sol. Although the average time in bed (7.6 hours) during the work days does not seem like an unreasonable amount of sleep, the dependent measure (time in bed per 24 hours) only represents time in bed and not actual sleep. Further analyses will need to be performed to investigate actual sleep times and quality of sleep based on sleep onset time.

Most humans need seven to nine hours of sleep, although the actual sleep needed to feel rested varies among individuals (National Sleep Foundation, 2006). Sleep debt occurs when sleep is chronically reduced below the number of hours needed to feel rested. Recent laboratory studies on sleep restriction found that performance is impaired during consecutive days of sleep restriction (Belenky et al., 2003; Van Dongen, Maislin, Mullington, & Dinges, 2003). However, Belenky et al. found performance stabilized after several days of five and seven hours of sleep restriction to a new level lower than baseline. In contrast, Van Dongen et al. found that performance continued to decline with four and six hours of sleep restriction. A nightly deterioration in performance has also been observed in sleep-deprived night shift workers (Tilley et al., 1982). Based on this research, this sleep loss experienced by MER personnel was likely to be associated with performance decrements.

The plot of sleep fractions (Figure 2) suggests that personnel were sleeping more during daylight hours during the MER rotation. Sleep architecture changes and sleep is more disturbed when occurring during the day due to the circadian propensity for wake (Akerstedt & Gillberg, 1981). This effect has been observed in night shift workers that typically sleep during the day and obtain less sleep than day workers (Tepas & Carvalhais, 1990). Although an increase in daytime sleep occurred during the MER rotation relative to baseline, the majority of sleep still occurred at night, suggesting that personnel maintained a nocturnal-orientation. If personnel adjusted to the 24.65-hour schedule, it would be expected that sleep would be evenly distributed across all hours of the day during the MER rotation. However, the majority of sleep still occurred at night and the early morning suggesting that a nocturnal preference for sleep was prominent for the majority of personnel due to the strong control of the circadian clock.

Decreased percentages of night time sleep were observed in the plots of sleep fractions during baseline. Potential reasons for the decreased sleep during the night at baseline include: 1) personnel worked unusual hours to support MER operations but personnel had not begun working a Mars sol, 2) traveling to JPL from a different timezone may have disrupted sleep patterns or, 3) their reported start and end dates for working a Mars sol from the Post-study Questionnaire were inaccurate. Although, the percentage of night-time sleep decreased during baseline, the time in bed per 24 hours was greater at baseline than the MER-rotation work schedule.

The location of permanent residence before the rovers landed, whether remote or local, had no significant effect on time in bed during the MER rotation. It was hypothesized that personnel who lived local to JPL would be exposed to more social zeitgebers than those who lived remotely. One possible reason for the lack of significance is that other factors contributed to sleep patterns of these two groups such as number and age of children, and actual work schedule. Additionally, remote personnel may have traveled to their home timezones during the mission increasing fatigue due to jetlag.

Shifting work schedules 39 minutes daily led to work start times occurring during both day and night shifts over the three month period. Again, many factors contributed to the sleep patterns of personnel, including different work schedules, job requirements, management scheduling, social responsibilities, and personal preference in scheduling. Personnel may have attempted to delay sleep bed times 39 minutes daily and/or transitioned sleep times frequently between Earth and Mars time. Other factors may also have contributed to disruptions in sleep/wake cycles. Personnel may have rapidly switched between work schedules 12 hours apart due to the rovers being located in different time zones on opposite sides of Mars. Or personnel may have traveled to their permanent residence, which could have been up to 3 or more hours away. All of these schedule changes would have led to sleep loss and fatigue due to conflicts between the endogenous circadian rhythm and external zeitgebers such as activity, social interactions, and light.

Moreover, there were many individual endogenous factors that could have affected the response of personnel to the disruption in sleep/wake cycles observed while working a Mars sol including age, gender, and morningness/eveningness (Monk & Folkard, 1985). Morningness/eveningness, which defines a person as a morning active "lark" or an evening active "owl," may be associated with the period of the endogenous circadian rhythm (Kerkhof & Van Dongen, 1996). Shiftworkers classified as more evening types may be able to adjust to shiftwork easier due to the ability to sleep during late morning hours.

Older people (> 40 years old) are less tolerant of shiftwork (Akerstedt & Torsvall, 1981). This is thought to be due to an advance in the endogenous period towards morning hours (Lieberman, Wurtman, & Teicher, 1989) and a reduction in sleep efficiency (Dijk, Duffy, & Czeisler, 2001). Parents with children, especially females, may obtain less sleep working late shifts due to the demands of caring for family or sleep may be disrupted by young children. Additionally, the endogenous period of younger females (< 55 years old) is shorter, amplitude smaller, and mean value higher than males, which could also affect the ability to work a MER schedule (Wever, 1986). These factors indicate that a large variability in sleep/wake patterns of the MER personnel would be obtained. However, the sample size of this study is too small to use inferential statistics to determine the extent these factors played in the participant's sleep/wake cycle while working a Mars sol.

This research was a subset of a study sponsored by NASA Ames Research Center to improve our understanding of the ability of individuals to adapt their sleep/wake cycles to a Mars sol while being exposed to 24.0-hour Earth-based time cues. Results of other research analyzing the MER schedule support the preliminary findings of this study, which suggests that sleep was disrupted while working a schedule that rotated 39 minutes daily. Circadian rhythm analysis of the activity of one participant showed a decrease in circadian rhythm stability while working the MER rotation compared to the baseline schedule (DeRoshia, Colletti, Oyung, & Mallis, 2005). Analyses of the Post-study Questionnaire presented at the NASA Ames Human Factors Symposium 2004 reported that 48% (n=13) of participants found it difficult working a Mars sol, 26% (n = 7) were neutral, and 26% (n = 7) found it easy (Colletti, DeRoshia, & Mallis, 2004). Additionally, an open-ended question about what participants found most challenging about working a Mars sol identified the following issues: major changes in schedules (due to switching between rovers or between Earth and Mars time), social/daily living, working during the night hours, sleeping during the day, and difficulties sleeping due to disruptions from children. These issues are similar to those experienced by other shiftworkers (Monk, 2000).

The current study only begins to investigate the effects of working a schedule that rotates 39 minutes daily to coincide with a Mars sol. However, preliminary results suggest that personnel working a 39-minute rotating work schedule obtained less time in bed per 24 hours than needed. This is suggested by the decrease in sleep obtained between baseline and the MER-rotation schedules and the increase in sleep obtained on non-work days. Personnel tended to maintain a nocturnal orientation for sleep as seen in Figure 2, the plot of sleep fractions, and the variability in sleep times decreased during the MER Earth-time schedule. Reduced sleep leads to decrements in neurobehavioral performance and increments in negative moods potentially leading to errors and accidents at work or off-duty including driving home (Belenky et al., 2003; Van Dongen et al., 2003). Future studies will investigate factors contributing to the reduced sleep including sleep quality based on time of day, timezone changes, and major shifts in work start times.

The implications of these findings for future missions is that managers and schedulers must expect that personnel will continue to live on Earth time even when work schedules are delayed 39 minutes daily to coincide with the Mars sol. Thus, efforts should be made to minimize the impact on personnel to increase their performance and the safety of the mission. For example, decrease work hours during shifts that occur during the late night and early morning and ensure sufficient days off for recovery sleep. Additionally, missions should continue to educate personnel and their families on fatigue issues and provide napping facilities as was established during the MER mission.

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Appendices

Appendix A

SJSU Approval Letter

San José State
UNIVERSITY

Office of the Academic Vice President
Academic Vice President Graduate Studies and Research
One Washington Square
San José, CA 95192-0025
Voice: 408-283-7500
Fax: 408-924-2477
E-mail: gradstudies@sjsu.edu
http://www.sjsu.edu

To: Laura Colletti
1766 Drew Ave.
Mountain View, CA 94043

From: Pam Stacks, *Pam Stacks*
Interim AVP, Graduate Studies & Research

Date: December 23, 2003

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

> "Sleep/Wake Cycles of Personnel Working a Mars Day (24.65 Hours)."

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Pam Stacks, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subjects portion of your project is in effect for one year and data collection beyond December 23, 2004 requires an extension request.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services that the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

cc: Dr. Kevin Jordan

Appendix B

Consent Form

CATEGORY II – HUMAN RESEARCH MINIMAL RISK CONSENT

To the Research Participant: Please read this consent form and the attached protocol and/or subject instructions carefully. Make sure all your questions have been answered to satisfaction before signing.

A. **I agree to participate** in the Sleep Wake Cycle of MER Personnel Working a Mars Sol research experiment as described in the attached protocol or subject instruction. I understand that I am employed by not applicable who can be contacted at not applicable.

B. **I understand that my participation could cause me minimal risk*, inconvenience, or discomfort.** The purpose and procedures have been explained to me and I understand the risks and discomforts as described in the attached research protocol.

C. **To my knowledge,** I have no medical conditions, including pregnancy, that will prevent my participation in this study. I understand that if my medical status should change while I am participating in the research experiment there may be unforeseeable risks to me (or the embryo or fetus if applicable). I agree to notify the Principal Investigator (PI) or medical monitor of any known changes in my condition for safety purposes.

D. **My consent to participate has been freely given.** I may withdraw my consent, and thereby withdraw from the study at any time without penalty or loss of benefits to which I am entitled. I understand that the PI may request my withdrawal or the study may be terminated for any reason. I agree to follow procedures for orderly and safe termination.

E. **I am not releasing NASA from liability for any injury** arising as a result of my participation in this study.

F. **I hereby agree that all records collected by NASA in the course of this study are available** to the research investigators, support staff, and any duly authorized research review committee. I grant NASA permission to reproduce and publish all records, notes, or data collected form my participation, provided there will be no association of my name with the collected data and that confidentiality is maintained, unless specifically waived by me.

G. **I have had an opportunity to ask questions and have received satisfactory answers** to all my questions. I understand that the PI for this study is the person responsible for this activity and that any questions regarding the research will be addressed to him/her during the course of the study. I have read the above agreement, the attached protocol and/or subject instruction prior to signing this form and I understand the contents.

H. **For San Jose State University (SJSU) questions** or concerns about research participant's rights, contact Pam Stacks, Interim AVP for Graduate Studies and Research at SJSU. Phone Number: (408) 924-2480

* **Minimal Risk** means that the probability and magnitude of harm or discomfort anticipated in the research are not greater, in and of themselves, than those ordinarily encountered in daily life or during the performance of routine physical or psychological examination or tests.

Signature of Research Participant Date	Signature of Principal Investigator Date
Printed/Typed Name of Research Participant	Printed/Typed Name of Principal Investigator
Address	Telephone Number of Principal Investigator
City, State, Zip Code	
Telephone Number of Test Subject	

Appendix C

Daily Sleep Log

NASA Ames Research Center
Fatigue Countermeasures Group

Daily Sleep Log

I.D. No. ____________________

Start date ____________________

End Date ____________________

Please do not hesitate to contact the following individuals with any questions, concerns or clarifications:

Laura M. Colletti	Dr. Melissa M. Mallis
Sr. Research Associate	Principal Investigator
lcolletti@mail.arc.nasa.gov	Melissa.M.Mallis@nasa.gov
(650) 604-0292	(650) 604-3654

Wakeup (local time)	Date: 10/23/03 Time: 0615 Timezone (if changed) ________ How rested do you feel upon awakening? Not at all 0 (1) 2 3 4 5 6 7 8 9 Extremely
Naps, Work & Alertness	Naps: 2130 to 2330 / ______ to ______ / ______ to ______ ǐ Day off Work schedule: 12:30am - 7am √Worked MER Operations Actiwatch off (times/why): 615-630 shower, 2-3 pm exercise Mark all periods of peak alertness (o----o) and peak fatigue (l----l) Mid-night 1 2 3 4 5 6 7 8 9 10 11 Noon 13 14 15 16 17 18 19 20 21 22 23
Bedtime (local time)	Date: 10/24/03 Time: 800 Timezone (if changed) PDT How sleepy do you feel upon attempting to sleep? Not at all 0 1 2 3 4 5 6 7 (8) 9 Extremely
Notes (flights, sick, TZ)	Flew from ORD - BUR from 815 - 1257

Use the Daily Sleep Log to record your daily wake up times, bed times, work schedule, naps, actiwatch removal times and time of day of peak performance and fatigue. You can leave this log by your bedside and complete it upon awakening and before attempting to sleep. There are four sections to be completed 'Wakeup', 'Naps, Work & Alertness', 'Bedtime' and 'Notes'. An example is provided to help understand how to complete the log. Local times can be reported in either 24-hr or am/pm formats.

EXAMPLE (Filled-in form on back of previous page)

Upon awakening, Tom began a new page in the diary and input his ***Wakeup*** information. In the ***Wakeup*** section, he awoke on October 23, 2003 (**Date**) at 0615 (**Time**). Upon awakening, he was not rested (**How rested do you feel upon awakening?**).

In the ***Naps, Work & Alertness*** section, Tom recorded his activities during the day. He took a nap from 2130 to 2330. He did not have the day off so ĭ **Day off** is not checked. He worked from 12:30am to 7am (**Work schedule**) and he worked on MER Operations so ĭ **Worked MER Operations** is checked. His actiwatch was off (**Actiwatch off**) to shower from 615 - 630 and to exercise from 2-3pm. On the timeline (), he was most alert from 1430 to1930 (marked using '**o---o**') and most fatigued (marked using '**l----l**') from 2130 to midnight and also from 330 to 530. The symbols (o and l) were drawn in the start and end times. Notice that you can have multiple periods marked for peak alertness and peak fatigue – if experienced more than once per day.

Just before going to sleep, Tom recorded his bedtime (**Bedtime**) and sleepiness level in the ***Bedtime*** section. He went to bed and attempted to sleep on October 24, 2003 (**Date**) at 0800 (**Time**). Tom also input his timezone since it changed during his flight (**Timezone (if changed)**). Tom is extremely sleepy (**How sleepy do you feel upon attempting to sleep?**).

(Example continued on next page)

The *Notes* section should be used to report any information useful in interpreting the actiwatch data such as flights, difficulties sleeping, sleeping in a car and illness. In this case, Tom took a flight from ORD to BUR from 815-1257. The actiwatch is set to Pacific timezone and he is returning to the actiwatch default timezone.

ADDITIONAL INFORMATION

The main purpose of the Sleep Log is to help interpret the data from the actiwatch. The actiwatch only shows movement so additional information helps interpret whether the movement is sleep or a period of little movement. Information such as wakeup time, bedtime, naps, and work schedule and notes are extremely useful in interpreting the actiwatch data. Please try to complete this information as best as possible.

Questions about peak alertness and the quality of your sleep and sleepiness are additional information that allow for more complete interpretation of the data. If providing this additional information becomes too time-consuming then skip it and provide the essentials such as your sleep episodes and work schedule.

If you have two major sleep episodes per day or your sleep/work schedule is extremely unique, you may find it easier to fill-in more than one page per day/24-hour period. Please don't hesitate to use more than one page if you find it fits your schedule better.

If you have any questions, please don't hesitate to contact us at the numbers or email addresses listed on the second page.

Wakeup (local time)	Date: ___________ Time:_______________ Timezone (if changed) ________ How rested do you feel upon awakening? Not at all 0 1 2 3 4 5 6 7 8 9 Extremely
Naps, Work & Alertness	Naps: _______ to _______ / _______ to _______ / _______ to _______ ☐ Day off Work schedule: ________________________________ ☐ Worked MER Operations Actiwatch off (times/why): ____ Mark all periods of peak alertness (o----o) and peak fatigue (l----l) Mid-night | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Noon | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23
Bedtime (local time)	Date: ___________ Time:_______________ Timezone (if changed) ________ How sleepy do you feel upon attempting to sleep? Not at all 0 1 2 3 4 5 6 7 8 9 Extremely
Notes (flights, sick, TZ)	

Forty copies of this page were included in the Daily Sleep Log to coincide with the maximum number of days the Actiwatch was worn.

Appendix D

Pre-study Questionnaire

Pre-Study Questionnaire

1. In what time zone is your permanent residence (i.e, where you normally live when NOT working MER operations)? ________________

2. Will you be living local to JPL during the MER operations? (check one)
   ____ yes ____ no

3. What is your position (e.g., SOWG, IST, SRET,...)? ____________________

4. How much sleep do you need to feel well rested? _________ (hr)

5. Age (check one): _____ 18 – 29 _____ 30 – 39 _____ 40 – 49 _____ 50+

6. Gender (check one): _____ F _____ M

7. Name: ____

8. Address: ____

9. City, State, Zip Code: _____________________________

10. Country: ____

11. Work number: ______________________________________

12. Cell number: _______________________________________

13. Home number: ______________________________________

14. Fax number: _______________________________________

15. Email address: _____________________________________

16. Are you expecting your contact information to change during MER operations? (check one)
    ____ yes ____ no

17. If yes, please explain and provide alternative contact information.

    ____

    ____

    ____

Appendix E

Background Questionnaire

ID #

Date:

Background Questionnaire

Fatigue Countermeasures Program

Human Factors Research and Technology Division

NASA Ames Research Center

Moffett Field, CA

2002

ID #

Date:

BACKGROUND QUESTIONNAIRE

This background questionnaire is being provided to all those who have agreed to participate in the MER activity study.

DO NOT WRITE YOUR NAME ON THIS SURVEY. This will ensure anonymity for you and your company. This survey will be administered to as many as 40 subjects and will be held in the strictest confidence.

For research purposes only

We very much appreciate your participation.

ID # Date:

GENERAL SURVEY DIRECTIONS:

I. Please answer all questions, and please be as accurate as possible. All information is confidential and anonymous.

II. Please mark boxes and lines as follows:

Small boxes should get a checkmark or an "x": ☐ ➪ √ or X

Large boxes should get a number: ☐ ➪ 204

Lines should get text: ______ ➪ kids

III. Watch for special instructions relating to a question or set of questions.

A. GENERAL

1. Gender? ☐ male ☐ female

2. If male, skip to question #4. Do you use oral contraceptives? ☐ yes ☐ no

3. If yes to question #2, How long have you used them? ☐ yrs ☐ mos

4. Age? ☐ yr.

5. Date of birth? ☐ mm/dd/yy

6. Weight? ☐ lb.

7. Height? ☐ ft ☐ in

8. Do you have children? ☐ yes ☐ no

If you answered yes, how many children do you have in each age category:

_____ < 1 yrs old _____ age 1 to 5 _____ age 6 to 13 _____ age 14 to 18 _____ > 18 yrs old

How many children will reside in your place of residence during MER operations? ________

ID # Date:

9. Do you have a bed partner or room-mate?	☐ yes	☐ no		
10. According to him or her, or to your knowledge, how often in the past 3 months have you had:	never	less than once/week	1–2 times/ week	3–4 times/ week
a. loud snoring	☐	☐	☐	☐
b. long pauses between breaths while sleeping	☐	☐	☐	☐
c. legs twitching or jerking	☐	☐	☐	☐
d. episodes of disorientation or confusion during sleep	☐	☐	☐	☐

e. other sleep problems, please describe ______________________________

____

____

11. What is your usual amount/frequency of caffeine consumption? (Enter number of cups of coffee/caffeinated soft drinks)	☐	daily	☐	weekly
12. What is your usual smoking frequency? (Enter number of packs of cigarettes)	☐	daily	☐	weekly
13. What is your usual amount/frequency of alcohol consumption? (Enter number of drinks: where 1 drink = one 1.5 oz of liquor, one glass of wine, or one 12 oz beer)	☐	daily	☐	weekly

14. Do you exercise on a regular basis? If no, skip to **Section B**.	☐ yes	☐ no

ID # Date:

15. How often do you exercise?

less than once/week	1–2 times/ week	3–4 times/ week	over 4 times/ week
☐	☐	☐	☐

a. List type(s) of exercise you do: ______________________

____

B. SLEEPING AT HOME

Based on **an average night of sleep at home** , please give one best answer to each of the following questions. **Use your local 24-hour clock.**

17. What time do you usually go to bed? ☐ time, 24-hr clock

18. How long after going to bed do you usually fall asleep? ☐ hr and ☐ min

19. How many times on average do you wake up? ☐ times

20. If you wake during the night, what most often awakens you? (Check **ONLY** one answer.)
    - ☐ bathroom
    - ☐ children/spouse
    - ☐ other ______________
    - ☐ can't sleep
    - ☐ noise

21. If you wake during the night, on average, how long does it take you to go back to sleep? ☐ hr and ☐ min

22. What is the amount of total sleep you get on average? ☐ hr and ☐ min

23. On your days off work, what time do you usually get out of bed? ☐ Time, 24-hr clock

ID # Date:

24. On average, how much sleep per 24 hr day have you obtained during the past 30 days? ☐ hr and ☐ min

25. How much sleep per 24 hr day do you usually need to feel fully alert for the day? ☐ hr and ☐ min

26. Do you consider yourself a morning person or evening person? ☐ morning person ☐ evening person

27. At what time of day do you feel most alert? (please shade/circle your alert times below)

0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200

28. How often do you take a nap at home? (If "never," skip to #29.)

never	rarely 1-10 /yr.	sometimes 1-3 /mo.	often 1-4 /wk	very often 5-7 /wk
☐	☐	☐	☐	☐

29. On average, how long are your naps? ☐ hr and ☐ min

30. How often do you have problems problems getting to sleep?

never	rarely 1-10 /yr.	sometimes 1-3 /mo.	often 1-4 /wk	very often 5-7 /wk
☐	☐	☐	☐	☐

31. How often do you take medication to help you sleep? (If "never," skip to #33.)

never	rarely 1-10 /yr.	sometimes 1-3 /mo.	often 1-4 /wk	very often 5-7 /wk
☐	☐	☐	☐	☐

32. If you take medication to help you sleep, please specify the medication and dose. name: ____________ dose: ____________

33. Rate the effectiveness of the medication.

not at all effective		moderately effective		very effective
☐	☐	☐	☐	☐

ID # Date:

34. How often do you use alcohol to help you sleep?

never	rarely 1-10 /yr.	sometimes 1-3 /mo.	often 1-4 /wk	very often 5-7 /wk
☐	☐	☐	☐	☐

35. Overall, what kind of sleeper are you?

very poor	poor	good	very good
☐	☐	☐	☐

D. DUTY & HOUSING

36. Is your home local to JPL? ☐ yes ☐ no

37. If "no", what timezone do you typically live? ________

38. Where will you stay during MER operations? ☐ house ☐ apartment ☐ hotel ☐ other

If you selected "other", please specify: ___________

39. Typically, how long will it take to commute to JPL during MER operations? [ ] hrs [ ] mins

40. If you had your own choice to schedule your duty day, what time would you pick to work your shift? (24 hr clock) [ ] begin time [ ] end time

41. What shift rotation will you be working? _______________

42. Will you be rotating your work schedule to match a Mars day? ☐ yes ☐ no

ID # Date:

E. FATIGUE

43. Did you attend training about fatigue countermeasures? ☐ yes ☐ no

44. In what ways does fatigue affect your performance? ____________________

45. List in rank order three strategies that you plan to use to cope with fatigue during the MER operations.
    1. __________
    2. __________
    3. __________

46 Did you work a schedule linked directly to Martian time during the Mars Pathfinder mission? ☐ yes ☐ no

46. What three changes would you make to reduce fatigue during MER operations? List the most important first.
    1. __________
    2. __________
    3. __________

Appendix F

Post-study Questionnaire

ID #

Date:

Post-Study Questionnaire

Fatigue Countermeasures Program
Human Factors Research and Technology Division
NASA Ames Research Center
Moffett Field, CA

ID #

Date:

POST-STUDY QUESTIONNAIRE

This questionnaire is being provided to all those who have agreed to participate in the MER Sleep/Wake Cycles of MER Personnel in Working a Mars Sol Schedule study, protocol HRII-03-44.

DO NOT WRITE YOUR NAME ON THIS SURVEY. This will ensure anonymity for you and your company. This survey will be administered to as many as 40 subjects and will be held in the strictest confidence.

For research purposes only

We very much appreciate your participation.

ID # Date:

GENERAL SURVEY DIRECTIONS:

I. Please answer all questions, and please be as accurate as possible. All information is confidential and anonymous.

II. Please mark boxes and lines as follows:

Small boxes should get a checkmark or an "x": ☐ ➪ √ or X

Large boxes should get a number: [ ] ➪ [204]

Lines should get text: ______ ➪ kids

III. Answer these questions based on the time period during MER operations. Watch for special instructions relating to a question or set of questions.

A. GENERAL

1. Describe typically times and reasons for removing the actiwatch. (e.g., to shower at night) ______________________ ______________________

2. On which wrist did you wear the Actiwatch? non-dominant hand ☐ dominant hand ☐

3. Age [ ]

4. What was your usual amount/frequency of caffeine consumption during the MER operation? (Enter number of cups of coffee/caffeinated soft drinks) [ ] daily [ ] weekly

5. Did you exercise on a regular basis during MER operations? If no, skip to **Section B**. yes ☐ no ☐

ID # Date:

6. How often did you exercise?

less than once/week	1–2 times/ week	3–4 times/ week	over 4 times/ week
☐	☐	☐	☐

a. List type(s) of exercise you did: ______________________

____

B. SLEEPING DURING MER OPERATIONS

Based on **an average night of sleep during MER operations**, please give one best answer to each of the following questions. **Use your local 24-hour clock.**

7. How long after going to bed did you usually fall asleep? ☐ hr and ☐ min

8. How many times on average did you wake up? ☐ times

9. If you woke during the night, what most often awakened you? (Check **ONLY** one answer.)
   - ☐ bathroom
   - ☐ children/spouse
   - ☐ other ______________
   - ☐ couldn't sleep
   - ☐ noise

10. If you woke during the night, on average, how long did it take you to go back to sleep? ☐ hr and ☐ min

11. What is the amount of total sleep you got on average per 24-hrs on your days off duty? ☐ hr and ☐ min

ID # Date:

12. What is the amount of total sleep you got on average per 24-hrs on your days working a Mars sol? ☐ hr and ☐ min

13. How often did you have problems getting to sleep?

never	rarely 1 or 2 /times	sometimes 1-3 /mo.	often 1-4 /wk	very often 5-7 /wk
☐	☐	☐	☐	☐

14. How often did you take a nap? (If "never," skip to #15.)

never	rarely 1 or 2 /times	sometimes 1-3 /mo.	often 1-4 /wk	very often 5-7 /wk
☐	☐	☐	☐	☐

15. On average, how long were your naps? ☐ hr and ☐ min

16. How often did you take medication to help you sleep? (If "never," skip to #19.)

never	rarely 1 or 2 /times	sometimes 1-3 /mo.	often 1-4 /wk	very often 5-7 /wk
☐	☐	☐	☐	☐

17. If you took medication to help you sleep, please specify the medication. name: ____________________

18. Rate the effectiveness of the medication.

not at all effective		moderately effective		very effective
☐	☐	☐	☐	☐

19. How often did you use alcohol to help you sleep?

never	rarely 1 or 2 /times	sometimes 1-3 /mo.	often 1-4 /wk	very often 5-7 /wk
☐	☐	☐	☐	☐

20. On average, how much sleep per 24-hr period did you obtained during MER operations? ☐ hr and ☐ min

ID # Date:

21. Overall, what kind of sleeper were you during MER operations?

very poor	poor	good	very good
☐	☐	☐	☐

C. FATIGUE DURING MER OPERATIONS

22. How difficult was it working a Mars Sol?

very difficult	somewhat difficult	neutral	somewhat easy	very easy
☐	☐	☐	☐	☐

Please explain:

____

____

____

23. What day did you <u>start</u> working a Mars Sol? ☐ mm/dd/yy

24. What day did you <u>stop</u> working a Mars Sol? ☐ mm/dd/yy

25. Specify how your mood changed during the MER operations:

Mood	Strongly Increased	Moderately Increased	Neither Increased Nor Decreased	Moderately Decreased	Strongly Decreased
Fatigue	☐	☐	☐	☐	☐
Irritableness	☐	☐	☐	☐	☐
Concentration	☐	☐	☐	☐	☐
Energy	☐	☐	☐	☐	☐
Sleepiness	☐	☐	☐	☐	☐

ID #

Date:

26. List in rank order three strategies that you used to cope with fatigue during the MER operations.

1. ______________________________

2. ______________________________

3. ______________________________

27. What did you find most challenging about your schedule?

____

____

____

____

____

28. Please add any additional comments or recommendations about MER scheduling

____

____

____

____

____

Appendix G

Study Description

Documentation of Sleep/Wake Cycles of MER Surface Operations Personnel working Mars Sol (24hr 39min day) Schedule

SUMMARY/IMPACT

The investigation will be an actigraphic ambulatory exploratory study to determine the ability of MER Surface Operations Personnel to maintain Mars consistent sleep/wake cycles while being exposed to the 24hr light/dark cycle of Earth as well as the effects it will have on overall sleep patterns. Little scientific research has been done to investigate the impact that living on a Mars schedule will have on sleep/wake cycles. The data collected will be used to improve our understanding of the ability of individuals to adapt their sleep/wake cycles to a Mars day (sol) while being exposed to Earth based time cues. The data and results will be used in scheduling development to help minimize fatigue and maximize neurobehavioral performance and alertness for future Mars related operations to reduce the chance of a fatigue related accident or incident.

BACKGROUND

Rotating shifts, night shifts and exceptionally long days are all irregular schedules that can potentially result in sleep disruptions, sleep loss and performance decrements. MER Surface Operations Personnel are required to perform mission critical NASA tasks in accordance with a Mars day (sol) schedule, requiring individuals to shift 39minutes/day; resulting in a phase delay and rotating shift work schedule. Additionally, individuals might be required to work exceptionally long shifts during high operational demands while being under a great deal of stress. These are just some examples which can result in the misalignment of circadian rhythms (light/dark cycle) and the sleep/wake cycle, which has been documented to increase subjective and physiological sleepiness, adverse health effects, performance errors and accidents.

PARTICIPANTS

We are seeking MER Surface Operations Personnel, both male and female volunteers, working either rotating Mars schedules or individuals working standard Earth day schedules. A non-intrusive actiwatch device, the size of a wristwatch and a subjective sleep/wake diary will be used in collecting data on sleep/wake cycles. The study will begin two weeks before the MER landing and will continue for two weeks after completion of the MER operations. Volunteers will receive a wrist actiwatch (a miniature ambulatory microprocessor unit that detects and records movement) and a sleep diary, to track habitual sleep/wake cycles for the duration of MER surface operations. Volunteers will be asked to perform their normal daily activities while wearing the actiwatch on the non-dominant wrist.

DAILY SLEEP DIARY AND ACTIWATCH DEVICE

Objective activity monitoring will be carried out using a wrist actigraph device to document and study sleep/wake patterns. Wrist actigraphic monitoring has been shown to be a reliable way in which to objectively monitor sleep-wake cycles in ambulatory high compliance. Volunteers will also be asked to complete a sleep/wake diary twice a day (a.m. and p.m.). The morning part of the diary includes questions about time of sleep awakening and quality of sleep. On the evening part of the diary, there are questions about work schedule, daytime alertness, daytime sleepiness, and the number of naps that day. The sleep diaries have been adapted to be suitable for those involved in MER-specific field operations. Analog scales for rating of sleepiness, physical and mental energy, are also listed in the diary pages to determine the effect of the sleep/wake cycle on physical and psychological well-being. Completion of the sleep/wake diary takes approximately 2-3 minutes. Questionnaires about background information, morningness preference and performance will also be administered before and after study participation. All aspects of this study are voluntary and MER operations shall remain your top priority.

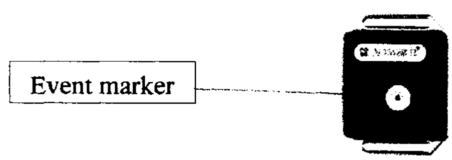
Appendix H

Procedures Handout

Procedures to Document
Sleep/Wake Cycles of MER Surface Operations
Personnel Working Mars Sol (24hr 37min day) Schedule

The actiwatch and *Sleep History Log* will assist us in determining your sleep/wake cycle during MER operations. In order to accurately interpret your schedule, please follow these recommendations:

- Wear the actiwatch on your non-dominant wrist at all times, especially while sleeping. Note that the actiwatch is always on.
- Remove the actiwatch only during showers, water sports or heavy activity (construction work or fixing car) where damage could occur to the watch. The actiwatch is water resistant; however, the band absorbs water and dries slowly. Activities such as running or aerobics are acceptable to wear the watch. Wear the watch again as soon as it is practical.
- Push the event marker (on the face of the watch, see figure below) when attempting to sleep or nap. If you watch TV or read in bed before going to sleep, do not push the event marker until you attempt to sleep.



Actiwatch should be worn on the <u>non-dominant,</u> wrist

- Push the event marker upon waking. This is the time you stop trying to sleep. If you stay in bed to read, push the event marker upon waking and then continue to read in bed.
- Enter the date and estimated times you attempt to sleep and wake-up in the *Sleep History Log* to help us interpret the actiwatch data. Use either military times (e.g., 2100) or indicate am or pm (e.g., 10pm).
- If you fall asleep unexpectedly or forget to push the event marker, enter the date and estimate the time on the *Sleep History Log* and put a checkmark in the "forgot event marker" column.
- If you forget to wear the actiwatch while sleeping, report the date and the sleep time on the *Sleep History Log,* checkmark the "forgot event marker" column and report "Actiwatch off" in the "Notes" column.
- If the actiwatch is not worn for an extended period or you forget to wear it, record this in the "Notes" column of the *Sleep History Log* with the date and time of inactivity. For example, "Forgot to wear actiwatch on 9/1 from 8am-6pm."
- Report important information that may help us interpret your sleep in the "Notes" column of the *Sleep History Log* such as naps, disturbed sleep, operational demands or traveling/sleeping in different time zones other than Pacific Time.

Contact the following researchers with questions or problems:

Laura Colletti, Sr. Research Associate
lcolletti@mail.arc.nasa.gov
(650) 604-0292

Melissa Mallis, Principal Investigator
Melissa.M.Mallis@nasa.gov
(650) 604-3654