# NAVAL POSTGRADUATE SCHOOL

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# THESIS

**EFFECTS OF NOISE, TEMPERATURE, HUMIDITY, MOTION AND LIGHT ON THE SLEEP PATTERNS OF THE CREW OF THE HSV-2 SWIFT**

by

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September 2005

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**13. ABSTRACT**

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# ENVIRONMENTAL EFFECTS OF NOISE, TEMPERATURE, HUMIDITY, MOTION AND LIGHT ON THE SLEEP PATTERNS OF THE CREW OF THE HSV-2 SWIFT

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# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ASW | Anti-Submarine Warfare |
| ATFP | Anti-Terrorism Force Protection |
| CNO | Chief of Naval Operations |
| EEG | Electroencephalogram |
| EMG | Electromyogram |
| EOD | Explosive Ordnance Disposal |
| EOG | Electrooculography |
| FAST | Fatigue Avoidance Scheduling Tool |
| FDC | Fire Direction Center |
| GOMEX | Gulf of Mexico Exercise |
| HGH | Human Growth Hormone |
| HSI | Human Systems Integration |
| HSV | High Speed Vessel |
| IRD | Interim Requirements Document |
| ISR | Intelligence, Surveillance, Reconnaissance |
| LCS | Littoral Combat Ship |
| MIO | Maritime Interdiction Operations |
| MIW | Mine Interdiction Warfare |
| NPS | Naval Postgraduate School |
| NSWC | Naval Surface Warfare Center |
| NTC | National Training Center |
| OEF | Operation Enduring Freedom |
| PSG | Polysomnography |
| REM | Rapid Eye Movement |
| SAFTE | Sleep, Activity, Fatigue and Task Effectiveness |
| SCN | Suprachiasmatic Nucleus |
| SOF | Special Operations Forces |
| SUW | Surface Warfare |

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# EXECUTIVE SUMMARY

With the added emphasis being placed on reducing crew sizes onboard ships and the increased workload demanded by the asymmetric nature of the Global War on Terror (GWOT), it is necessary to investigate the factors that may influence crew performance. Sleep is an important element in an individual's performance. Sleep, in turn, is influenced by many factors, both environmental and personal. This study quantified the effects of noise, temperature, humidity, motion and light on the sleep patterns of the crew of HSV-2 SWIFT during Gulf of Mexico Exercise (GOMEX) 05-1.

SWIFT was chosen for this study because she is a catamaran that incorporates technologies that allow her to deploy to sea with a crew of 41. SWIFT is also being used to model the Littoral Combat Ship (LCS) and test Sea Power 21 concepts, such as Sea Basing, and the use of LCS mission module packages (HSV SWIFT Demonstrates, 2004).

Noise dosimeters, temperature and humidity monitors, actiwatches and questionnaires were used to collect data on independent variables (noise, temperature, humidity, motion and light). Actiwatches were also worn by the crew of SWIFT to measure the dependent variable, sleep.

The weather during GOMEX 05-1 was mild, limiting the range of three of the independent variables, temperature, humidity and motion. Additionally, since SWIFT was used as the command and control ship for the exercise, she was not required to operate at high speeds or with large maneuvers.

Results of this study show that with the exception of light, the independent variables did not have significant affect upon participant sleep. This is likely due to the limited range of the majority of the independent variables and the small number of participants in this study.

The participants in this study averaged between 6 and 7 hours of sleep per day for the majority of the exercise. Averaging less than 8 hours of sleep a day will cause an increase in sleep debt. Sleep debt is the difference between an actual night's sleep and a full

night's sleep (8 hours) and its effects are cumulative. This debt must always be repaid to fully recover from the period of sleep deprivation (Dement & Vaughan, 1999). Sleep deprivation in turn can lead to reduced performance, concentration, reaction times and memory consolidation. Deficient sleep can produce increased memory lapses, accidents, injuries, behavior problems and mood problems (National Heart, Lung, and Blood Institute, 2004). Human performance is not always affected by short sleep periods, but there is a cumulative effect (Matthews, Davies, Westerman & Stammers, 2000). It is possible that in a MIW operation or exercise greater in length than GOMEX 05-1, you would witness a decrease in the performance of the crew of the SWIFT. While physical tasks are relatively unchanged by periods of sleep deprivation, cognitive tasks are greatly affected (Belenky, Krueger, Balkin, Headley & Solick, 1987; How et al., 1994). With an increase in sleep deprivation among the crew of the SWIFT while coordinating the movements of other US Navy warships in a Mine Interdiction Warfare (MIW) exercise or operation, mistakes could be made that adversely impact the exercise or operation.

Analysis of the demographic variables investigated whether demographic factors and the averaged values of the environmental variables affected participant sleep. Sea time was found to be highly correlated with the average amount of sleep a participant received during GOMEX 05-1. From the model of sea time and average participant sleep we concluded that for every year of sea time a participant had, his sleep dropped by approximately 11 minutes per day. Light was also found in this analysis to have a significant impact on participant sleep efficiency. From the model of light and participant sleep efficiency, we concluded that for every increase in light value, as measured in lux, participant sleep efficiency dropped by 4%.

The type of research conducted here needs to be pursued further, especially with the small crew sizes demanded by the US Navy in future vessel designs. The identification of variables that contribute more to sleep will also give engineers information they can use to better build ships in the future.

# I. INTRODUCTION

## A. OVERVIEW

According to Chief of Naval Operations (CNO) ADM Vernon E. Clark: "The LCS is key to enhancing our ability to establish sea superiority not just for our carrier strike groups and expeditionary strike groups but for future joint logistics, command and control, and prepositioned ships moving to support forces ashore" (Truver, 2003).

The Littoral Combat Ship (LCS) is the future of the United States Navy. Moving away from the traditional blue water focus of the US Navy, LCS will enable dominance in the littorals and revolutionize sea based power projection. High Speed Vessel SWIFT (HSV-2) was leased from Incat Australia as a test platform for LCS. She is an aluminum hulled catamaran with a semiplaning wave piercing hull that can reach speeds up to 42 knots (O'Neil, 2003).

HSV-2 SWIFT numbers 40 sailors per crew (Ryan & Grimland, 2003). A decrement in the performance of any individual will affect the performance of the crew to a greater degree than would be found on a traditionally manned US Navy warship.

Sleep deprivation can severely impact personnel (Allnutt, Haslam, Rejman & Green, 1990; How, et al., 1994; Belenky, et al., 1987). Noting the crew size of SWIFT, it is vital that the US Navy understand the causes of sleep deprivation among her crew. A preliminary study conducted onboard SWIFT in May, 2004 found most of the factors causing disturbed sleep are environmental factors, such as noise, temperature, light and motion (McCauley, Miller & Matsangas, 2004).

Several studies have quantified environmental effects such as noise, temperature, humidity, light and motion on sleep (Griefahn, 1990; Johnson & Kobrick, 2001; Lewy, Wehr & Thomas, 1980; O'Hanlon, Miller & Royal, 1977), but none studied their combined effects onboard US Navy warships. This thesis will describe the importance of sleep and the impact of sleep deprivation on crew performance. This thesis attempted to address the question of whether the shipboard environmental effects of noise, temperature, humidity, motion and light impact the sleep patterns of the crew of HSV-2

SWIFT. Unfortunately, due to the limited range in the environmental conditions and the small number of participants, this question could not be answered. However, this study does discuss a methodology from which a more robust study can be formulated to analyze these environmental effects on sleep.

To conduct a more vigorous study, measurements of the environmental effects of noise, temperature, humidity, motion and light should be measured in disparate locations, under varying conditions, with a greater number of participants and, if possible, across multiple platforms. This would increase the amount and range of the data to allow for a more powerful statistical approach than the descriptive statistics used in this thesis.

A combination of environmental and personal factors will affect the sleep of sailors and marines living onboard US Navy warships. Sleep deprivation will more likely occur in more extreme operational conditions than seen in this study. For this reason, further studies should be conducted in extreme operational environments, such as those found in the Arabian Gulf during summer. Additionally, studies such as the one discussed in this thesis should be completed on different platforms to determine the differences in environmental factors that affect sleep between hull types so that the results can be applied to future vessel design.

## B. BACKGROUND

SWIFT took part in GOMEX 05-1, conducted in the vicinity of Naval Surface Warfare Center (NSWC) Panama City, FL, December 2004. GOMEX 05-1 was a mine warfare exercise that graduated mine countermeasures squadron staff and ships to deployment ready status. GOMEX 05-1 included air, surface and Explosive Ordnance Disposal (EOD) assets. SWIFT was used as the mine countermeasures command flagship and coordinated the movements of the other participants in the exercise (Naval Support Activity-Panama City, 2005).

This thesis will examine the effects of noise, temperature, humidity, motion and light on the sleep patterns of the crew of HSV-2 SWIFT during GOMEX 05-1. HSV-2 SWIFT was chosen for this study to examine crew sleep on an unconventional hull type manned with a small crew. Noise dosimeters, temperature and humidity monitors, actiwatches and questionnaires will be used to quantify the data.

## C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

This study observed the sleep patterns of 21 sailors onboard one of the US military's high speed vessels in order to capture data from a crew operating onboard a non-conventional hull form. Participants in this study were officers and enlisted sailors of HSV-2 SWIFT. The participants are unique among US sailors in that they serve onboard one of three high speed vessels being used by the US military. These 21 sailors, therefore, represent a relatively large subset from a small population.

The amount of equipment available for this study was limited. Five noise dosimeters, five temperature and humidity monitors and 23 actiwatches were used to collect data. The weather during GOMEX 05-1 was mild, limiting the range of three of the variables measured: temperature, humidity, and motion. Additionally, since SWIFT was used as the command and control ship for the exercise, she was not required to operate at high speeds or with large maneuvers

This was an observational study and had neither a control group nor baseline conditions. Participants were volunteers, therefore selection was not randomized. Due to these limitations, caution should be taken in extending the results of this study to the entire population of the US Navy.

## D. HUMAN SYSTEMS INTEGRATION

Traditionally, Human Systems Integration (HSI) incorporates the seven domains listed below (MANPRINT Domains, 2005). The US Navy has added an eighth domain, habitability. Habitability includes workspace and berthing design and hazardous environmental impacts on humans (Dolan, 2005). This thesis examines the environmental factors that influence sleep and evaluates human effectiveness based on a validated performance model. As such, it specifically addresses issues relating to manpower, personnel, human factors engineering, system safety, health hazards, survivability and habitability.

> **MANPOWER** is the number of military and civilian personnel required and potentially available to operate, maintain, sustain, and provide training for systems

> **PERSONNEL** defines the cognitive and physical capabilities required to be able to train for, operate, maintain, and sustain materiel and information systems.
>
> **TRAINING** is the instruction or education, and-on-the-job or unit training required to provide personnel their essential job skills, knowledge, and attitudes.
>
> **HUMAN FACTORS ENGINEERING** defines the integration of human characteristics into system definition, design, development, and evaluation to optimize human-machine performance under operational conditions.
>
> **SYSTEM SAFETY** involves the design features and operating characteristics of a system that serve to minimize the potential for human or machine errors or failure that cause injurious accidents.
>
> **HEALTH HAZARDS** The design features and operating characteristics of a system that create significant risks of bodily injury or death; prominent sources of health hazards include: acoustics energy, chemical substances, biological substances, temperature extremes, radiation energy, oxygen deficiency, shock (not electrical), trauma, and vibration.
>
> **SOLDIER SURVIVABILITY** defines the characteristics of a system that can reduce fratricide, detectability and probability of being attacked, as well as minimize system damage, soldier injury, and cognitive and physical fatigue. (MANPRINT Domains, 2005)

Sleep can have a detrimental affect upon cognitive and physical performance (Allnutt et al., 1990; How et al., 1994; Belenky et al., 1987). By measuring sleep, this thesis falls under the manpower, personnel and human factors engineering domains. This thesis quantifies the environmental factors affecting sleep and identifies the variables that weigh most heavily on sleep. This type of information will give engineers information they can use to better plan future ships. As such, this thesis falls under the system safety, health hazards, survivability and habitability domains of HSI.

## E. THESIS ORGANIZATION

Chapter II contains a review of the literature for the dependent variable sleep and studies that examined the relationships between the independent variables and sleep. Chapter III explains the methods used in this study. Chapter IV contains the statistical analysis used in this study. Chapter V concludes with a discussion of the results and recommendations for future research.

# II. LITERATURE REVIEW

## A. OVERVIEW

The United States military has identified sleep as an important component in determining human performance. Section B begins with a review of sleep and its impact on performance. Section C examines the effects of motion on sleep. Section D investigates the impact of temperature and humidity on sleep. Section E describes how noise disturbs sleep. Section F examines the consequences of light exposure on sleep. Section G concludes with an examination of emerging US Navy hull forms.

## B. SLEEP

### 1. Introduction

Sleep is an intricate cycle of stages that is largely responsible for controlling bodily functions such as gastrointestinal, cardiovascular, health, immune function and cognitive processing. It used to be thought that the brain was quiescent during sleep, but it is known now that in some stages of sleep, the brain activity is more active than while waking. Overall, brain activity during sleep only decreases by 10 percent overall as compared to waking activity (Maas, 2001).

### 2. Sleep Stages

Sleep stages can be labeled as either Rapid Eye Movement (REM) or normal, non-REM, sleep. There are 4 levels of non-REM sleep, with Stage 1 being the lightest and Stage 4 the deepest (Matthews et al., 2000). In Stage 1 sleep, heart rate stabilizes, breathing becomes shallow and a subject may retain awareness of his/her surroundings; this stage can persist from 10 seconds to 10 minutes. Stage 2 sleep may last from 10 to 20 minutes following Stage 1 sleep and is the beginning of actual sleep. In this stage, subjects will become detached from their surroundings. Stage 3 sleep proceeds into Stage 4 and is characterized by slow wave brain activity. In Stage 4 sleep, body muscles are completely relaxed, blood pressure drops and blood supply to the brain is at a minimum. In addition, pulse and respiration are slowed. During slow wave sleep, much of the human growth hormone (HGH) is released, providing for cell restoration and growth and increasing the effectiveness of the immune system. After 30 to 40 minutes of stage 4 sleep, the body begins to move back through sleep stages 3 and 2 toward REM sleep. This first REM cycle lasts several minutes and is where the subject is likely to first dream. Dreaming occurs frequently in REM, although it is seen in other stages of sleep also. The subject's eyes will also begin to flit back and forth, hence the term Rapid Eye Movement. During REM sleep, blood pressure, heart rate, respiratory rate and blood flow to the brain increases. Throughout REM sleep, the brain inhibits neural commands to the motor functions to keep the body from moving about as the brain is highly active. REM sleep is associated with memory storage and retention, memory organization and reorganization, new learning and retention. This cycle continues every 90 to 110 minutes until the subject awakens (Maas, 2001).

Deeper stages of sleep dominate the early sleep period with lighter stages predominant later in the sleep period. REM sleep duration increases as the period of sleep increases (Matthews et al., 2000). Figure 1 is a graphic display of a typical sleep period.

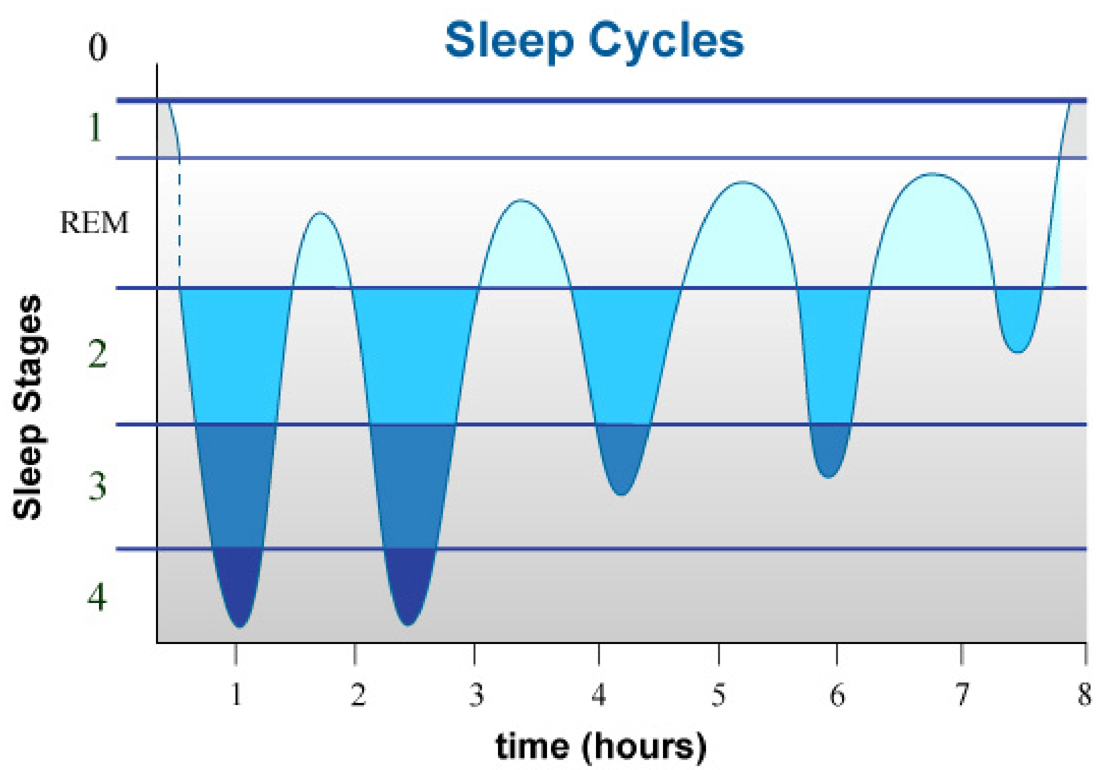


Figure 1. Sleep Stages (From: Miller, 2005)

If a person's sleep is shortened, he/she may not enjoy the recuperative effects of slow wave sleep and the benefits to cognitive performance resulting from both REM sleep and non-REM sleep (Miller, 2005). It is believed that for most adults, 8 hours of sleep is necessary to receive full beneficial effects of sleep (Maas, 2001).

### 3. Sleep Debt

Sleep debt can be defined as "the increased pressure for sleep that results from an inadequate amount of physiologically normal sleep" (Van Dongen, Rogers & Dinges, 2003, p. 6). It is the difference between an actual night's sleep and a full night's sleep (8 hours) and its effects are cumulative. For example, if a person averages 4 hours of sleep per day (out of the required 8) for an entire week, the subject will have accumulated 28 hours of sleep debt over that week. This debt must always be repaid to fully recover from the period of sleep deprivation (Dement & Vaughan, 1999).

### 4. Circadian Rhythms

Circadian rhythms are "an intricate and orderly series of psychological and physiological changes that occur approximately every twenty-four hours" (Maas, 2001, p. 46). Circadian rhythms are found in all animals and, without external cues, will approximate the revolution of Earth. Human circadian clocks average 24.18 hours across age groups (Czeisler, et al., 1999).

Circadian rhythms are regulated by the suprachiasmatic nucleus (SCN), the body's biological clock. The SCN controls body temperature, hormone secretion, urine production and changes in blood pressure, bodily operations timed with the sleep/wake cycle (National Institute of Neurological Disorders and Stroke, 2005). Disruption of circadian rhythms can result in fatigue, negative bodily symptoms and subjective displeasure (Waye, Clow, Edwards, Hucklebridge & Rylander, 2003).

Circadian rhythms vary throughout the day with predictable dips occurring in arousal between 2-7am and 2-5pm. These dips are correlated with human performance (Mitler, et al., 1987). Disturbances in circadian rhythms often result in disturbances in sleep (Arendt, 2000). An external time signal, such as an alarm clock, can affect circadian rhythms. These are known as zeitgebers ("time givers" in German) (National Institute of Neurological Disorders and Stroke, 2005).

Czeisler, Weitzman, Moore-Ede, Zimmerman and Knauer (1980) determined that length of sleep was correlated with body temperature fluctuations associated with the human circadian cycle and not with hours of wakefullness. In addition, REM sleep latency, REM sleep buildup, sleep time choice and subjective alertness measurements were also correlated to temperature fluctuations.

**5. Measurements**

In a clinical setting, sleep is measured using polysomnography (PSG), which includes recording electrical brain activity measured with an electroencephalogram (EEG), which utilizes electrodes positioned on the scalp. PSG is also uses eye movements through electrooculography (EOG) using electrodes placed near the eyes. An electromyogram(EMG) measures the electrical fluctuations caused by muscle movements. Electrodes are placed over muscles in the chin which, for humans, displays a large amount of oscillation during sleep. Figure 2 displays the placement of PSG graphically (National Institutes of Health, 2005).

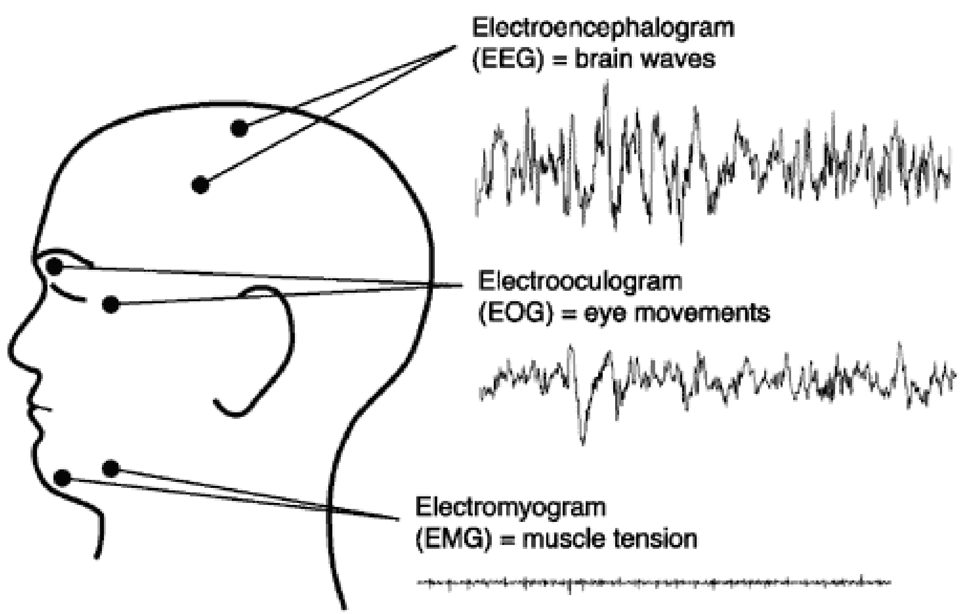


Figure 2. Placement of electrodes to determine EEG, EOG, and EMG (From: National Institutes of Health, 2005).

However, for assessing sleep in most field settings, PSG is not feasible. Actigraphs have been found to be cost effective in measuring "longitudinal, natural assessments of sleep-wake patterns" (Sadeh, Hauri, Kripke & Lavie, 1995, p. 300). Horne, Pankhurst, Reyner, Hume and Diamond (1994) found that actigraphs offer an easier, less expensive and practical substitute for EEGs, achieving an 88% equivalency with EEGs in detecting wakefulness in their study. Friedman et al. (2000) found that the results of sleep measurements using actigraphs and PSG were highly correlated.

### 6. Sleep Deprivation at Sea

Sleep periods for sailors can be irregular and disrupted. For example, U.S. submarines operate on an 18 hour rotating work schedule, with sleep disrupted by drills, causalities, maintenance, routine operations, wartime operations, etc. SWIFT numbers 40 personnel per crew; out of necessity with this size crew, most will stand watch. During a study of merchant marine personnel, it was found that watchstanders averaged overall less total sleep, 6.6 hours, than personnel who did not stand watch. In addition, watchstander sleep was found to be more broken and taking place during physiologically unsuitable times (Sanquist, Raby & Maloney, 1996). In another study conducted onboard five Coast Guard cutters, 10-45% of the crews experienced one or more episodes of mild fatigue in a low operational tempo environment, with watchstanders obtaining less sleep and more broken periods of sleep (Miller, Smith & McCauley, 1998).

### 7. Sleep and Performance

Harrison and Horne (2000) state:

> If there is a particular need to draw on innovation, flexibility of thinking, avoidance of distraction, risk assessment, awareness for what is feasible, appreciation for one's own strength and weaknesses at that current time (metamemory), and ability to communicate effectively, then these are the very behaviors that we feel are most likely affected by SD [sleep deprivation], not only when people are working alone but also in a team. (p. 246)

Insufficient sleep can result in reduced performance, concentration, reaction times and memory consolidation. Deficient sleep can produce increased memory lapses, accidents, injuries, behavior problems and mood problems (National Heart, Lung, and Blood Institute, 2004).

Both individual and team performance decrease with diminished sleep (Allnutt et al., 1990; How et al., 1994; Belenky et al., 1987). Human performance is not always affected by short sleep periods, but there is a cumulative effect (Matthews et al., 2000). Belenky et al. (2003) conducted a 10 day experiment in which participants were broken into groups allowed to obtain 3, 5, 7 and 9 hours of sleep for the first 7 days, followed by three days of recovery. Over the 7 day period, performance levels in a psychomotor vigilance test dropped for every group, with the exception of the 9 hour group. During the recovery period, the performance levels for the 5 and 7 hour groups stayed at the reduced level observed during the last days of sleep restriction, displaying no recovery. The 3 hour group had a high rate of recovery the first day, as measured by the performance test, but then leveled out for the last two days, still never recovering baseline levels. The 9 hour group stayed at the baseline level throughout the recovery period. Figure 3 displays this graphically.

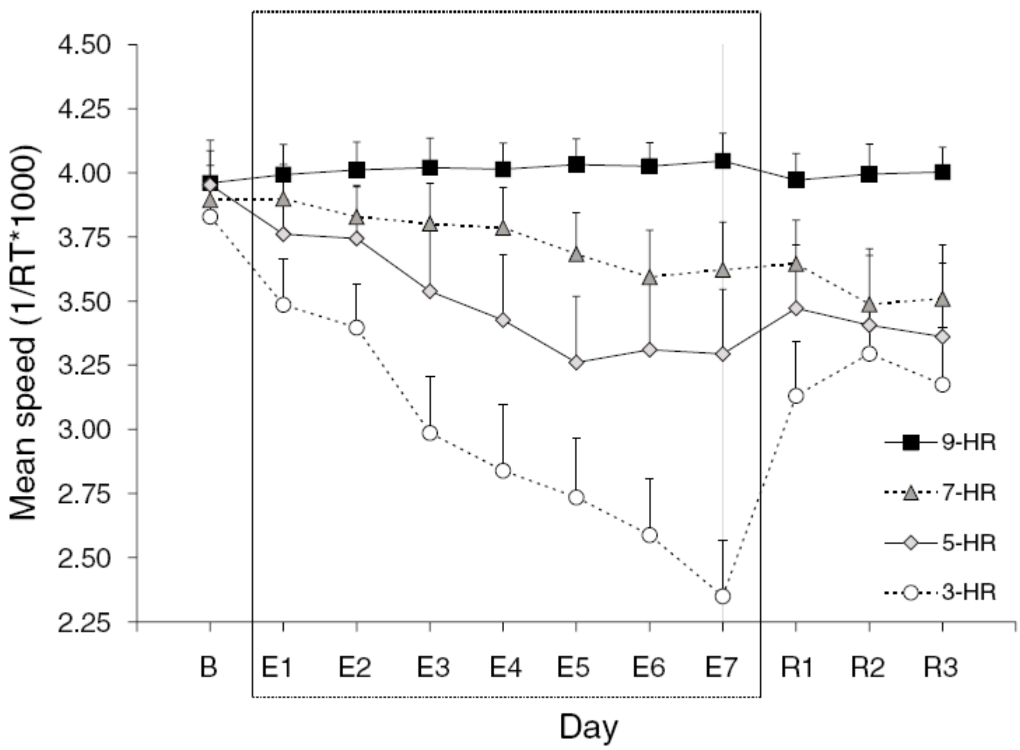


Figure 3. Mean psychomotor vigilance task speed (and standard error) across days as a function of time in bed group (From: Belenky et al., 2003, p. 6).

The researchers concluded from these results that the human body appears adaptable to sleep deprivation, maintaining a reduced performance for a period of time.

In addition, this adaptation continues even during periods of recovery, impeding full recovery from sleep deprivation. When queried about their level of impairment, participants failed to report impairment. This result speaks to the insidious nature of sleep deprivation. Sleep deprived individuals do not know they are impaired.

While physical tasks are relatively unchanged by periods of sleep deprivation, cognitive tasks are greatly affected (Belenky et al., 1987; How et al., 1994). Areas of the brain in which cognitive functions are performed show progressively less activity as the time of sleep deprivation increases. There is a 25% loss in performance of cognitive tasks with each day of sleep deprivation (Belenky, n.d.).

Higher cognitive tasks such as those involving calculation, creativity and thinking ahead are more susceptible to sleep deprivation than other cognitive tasks that are not as demanding (Belenky et al., 1987; Evans, Mackie & Wylie, 1991). Task duration, difficulty, feedback, practice, complexity and short term memory use are all factors that play into how well a task is performed if an individual is sleep deprived. Tasks that are interesting, contain feedback, are well practiced and are motivating can decrease the affects of sleep deprivation. In addition, increasing the time allowed to complete a task can also decrease the affects of sleep deprivation (Belenky et al., 1987).

Banderet, Stokes, Francesconi, Kowal and Naitoh (1980) reported the results of a study in which soldiers in a U.S. Army Artillery Fire Direction Center (FDC) team were given missions over a 36 hour period without sleep. The investigators found that routine, repetitive functions were adequately performed, but that higher level cognitive functions, such as checking to see if missions erroneously targeted civilian or friendly force locations, broke down.

Uninteresting and routine tasks, such as monitoring a radar display, are also highly susceptible to sleep deprivation (Wilkinson, 1964). Reductions in team performance due to sleep deprivation have been found to be less than reductions in individual performance. This may be due to team members compensating for those most affected by sleep deprivation (Allnutt et al., 1990).

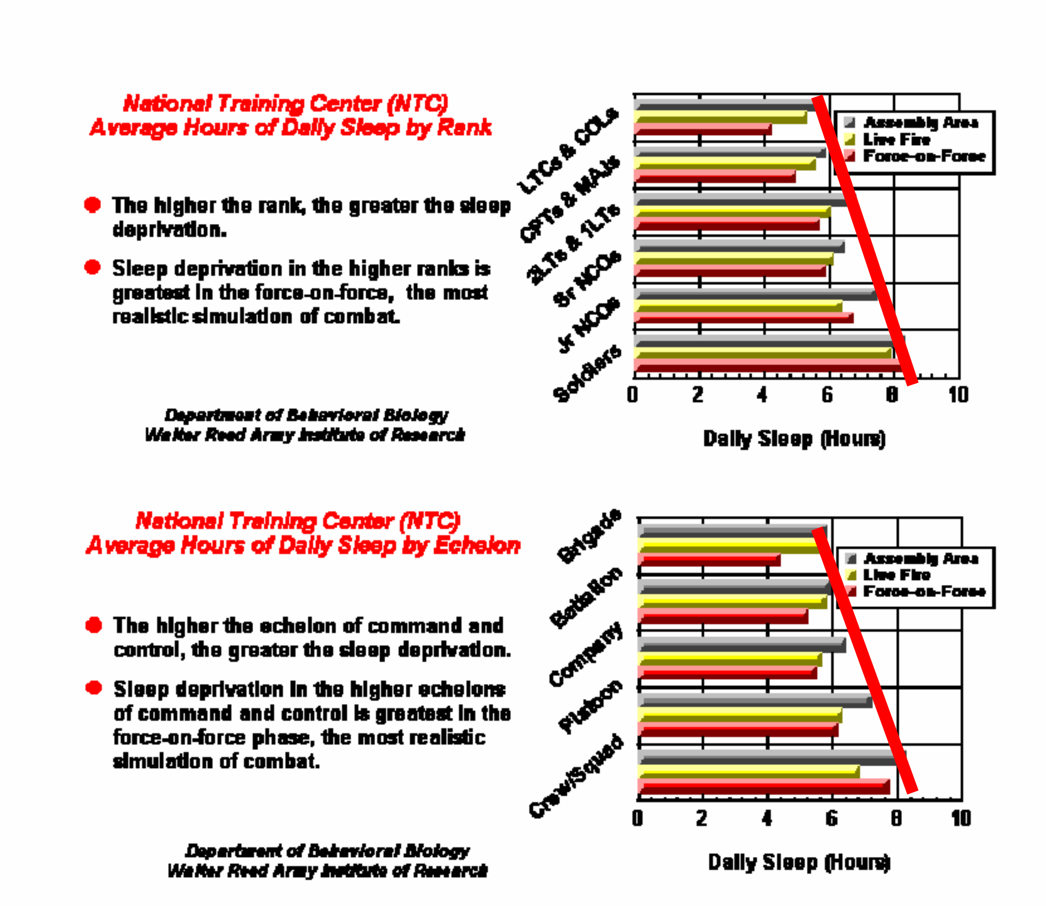


Figure 4. Sleep patterns at the National Training Center (After: Belenky, n.d., p. 4)

It has been found that military leaders obtain less sleep than subordinates. Figure 4 displays the outcome of a study at the National Training Center (NTC) where it was discovered that the lower ranks and lower echelons of command received more sleep than higher ranks and higher echelons of command (Belenky, n.d.). In the military services, there is almost a myth of self-deprivation (including sleep) that one should aspire to in military organizations, possibly leading to injury and death (Shay, 1998).

#### 8. Managing Sleep Loss

Wickens, Lee, Liu, and Becker (2004) outline several methods for managing or reducing sleep loss, specifically: naps, sleep credits (defined as sleeping for long periods before times of known sleep deprivation), sleep management plans, stimulant drugs (such as caffeine) and prohibiting work during periods of low circadian activity. External motivation has also been found to be effective in combating sleep deprivation (Matthews et al., 2000).

Some companies are allowing sleep deprived personnel to nap, such as Burlington Northern Santa Fe, the second largest railroad company in America; company officials report their employees who nap are more effective (On-the-Job Naps, 1998).

Other strategies include protecting night shift workers from sunlight before they sleep and appropriate timing of sleep according to circadian rhythms of sailors to determine the most effective sleep schedules. In a study conducted by the Naval Postgraduate School (NPS) at Recruit Training Center, Great Lakes, Illinois, it was determined that a shift in an 8 hour sleep period gave recruits an average of 22 minutes more sleep each night (Baldus, 2002). In another study, NPS researchers studied the effects of shift work and high operational tempo during Operation Enduring Freedom (OEF) in February 2002 onboard the JOHN C. STENNIS (CVN-74). The entire crew was put on the night shift to support nighttime flight operations. The study concluded that there were great differences in the quality and quantity of sleep determined by where personnel worked, particularly topside personnel. The study proposed a possible link between sunlight exposure prior to rest and lack of sleep due to an inhibition in the release of melatonin, which results in sleep deprivation. Other factors in sleep deprivation may have included work environments, light levels, health issues, combat stress and the type of work performed (Nguyen, 2002).

#### 9. Conclusion

Sleep can be labeled as either Rapid Eye Movement (REM) or normal, non-REM, sleep. There are 4 levels of non-REM sleep, with Stage 1 being the lightest and Stage 4 the deepest (Matthews, et al., 2000). If a person’s sleep is shortened, he/she may not enjoy the recuperative effects of slow wave sleep and the benefits to cognitive performance resulting from both REM sleep and non-REM sleep (Miller, 2005).

Sleep is an essential component of human performance. Insufficient sleep can result in reduced performance, concentration, reaction times and memory consolidation. Deficient sleep can produce increased memory lapses, accidents, injuries, behavior problems and mood problems (National Heart, Lung, and Blood Institute, 2004).

Insufficient sleep can result in sleep debt. Sleep debt is the difference between an actual night's sleep and a full night's sleep (8 hours) and its effects are cumulative. This debt must always be repaid to fully recover from the period of sleep deprivation (Dement & Vaughan, 1999).

Circadian rhythms are "an intricate and orderly series of psychological and physiological changes that occur approximately every twenty-four hours" (Maas, 2001, p. 46). Circadian rhythms vary throughout the day with predictable dips occurring in arousal between 2-7am and 2-5pm. These dips are correlated with human performance (Mitler, et al., 1987).

Wickens et al. (2004) outline several methods for managing or reducing sleep loss, specifically: naps, sleep credits (defined as sleeping for long periods before times of known sleep deprivation), sleep management plans, stimulant drugs (such as caffeine) and prohibiting work during periods of low circadian activity. External motivation has also been found to be effective in combating sleep deprivation (Matthews et al., 2000).

Sleep periods for sailors can be irregular and disrupted, with watchstanders obtaining less sleep and more broken periods of sleep (Miller et al., 1998). For assessing sleep in most field settings, such as US Navy warships, PSG is not feasible. Actigraphs have been found to be cost effective in measuring "longitudinal, natural assessments of sleep-wake patterns" (Sadeh, et al., 1995, p. 300).

## C. MOTION

There is a dearth of information on the effects of motion on sleep. Results seem to indicate that sleep is not significantly affected by motion. In a preliminary study of ship motion and fatigue onboard the SWIFT, however, motion was reported by the subjects as the fourth largest factor causing sleep deprivation (McCauley et al., 2004). This finding underlines the importance of quantifying the effects of motion upon sleep, especially with the unconventional hull designs being fielded by the US Navy.

As can be seen in Figure 5, SWIFT is a catamaran. Catamarans are sometimes uncomfortable in high sea states, having quick, stiff rolls. When traveling at low speeds, catamarans have a "corkscrew" effect (O'Neil, 2003). This is different from a conventionally hulled ship where motion is in more of a rolling pattern that can be better anticipated and corrected for (e.g., grabbing onto a handrail).


Figure 5. HSV2 SWIFT (From: High Speed Vessel SWIFT Joins Navy, 2003)

O'Hanlon et al. (1977) conducted a study measuring the effects of motion on sleep, among other variables, utilizing a trainer that replicated the motions of a Surface Effects Ship (SES). An SES rides on a cushion of fan created air held inside skirts or seals (O'Neil, 2003). When subjects were exposed to motion conditions, researchers discovered significant decreases in absolute time spent in sleep Stage 1 and the number of sleep stage changes. Additionally, sleep cycle length was significantly greater in the motion condition. At least two subjects were wakened by motion sickness. The investigators also looked at the effect of motion on circadian cycles as measured by body temperature. They found no significant differences in body temperatures between static and motion conditions that indicated a change in circadian cycles. The researchers concluded that generally, motion does not affect sleep, with the exception of personnel wakened by motion sickness.

While an SES may have motion characteristics unlike those of the SWIFT, both ship types utilize unconventional hull designs being used in modern navies and have much smaller crew sizes than those found on traditional warships. It is, therefore, important to quantify the effects of motion on sleep in order to understand their impact on these reduced sized crews and add to the sparse body of literature which currently exists.

## D. TEMPERATURE AND HUMIDITY

### 1. Introduction

Unlike motion, sleep is affected by temperature and humidity (Libert et al., 1988; Haskell, Palca, Walker, Berger & Heller, 1981; Okamoto-Mizuno, Tsuzuki, Mizuno & Iwaki, 2005; Dewasmes, Telliez & Muzet, 2000**.** Additionally, adaptation to heat does not lead to increased sleep quality (Johnson & Kubrick, 2001; Libert et al., 1988).

Results from a preliminary study of fatigue and motion onboard SWIFT indicate that heat, cold and humidity caused over 50% of participants disrupted episodes of sleep. Specifically:

> Heat: Twelve participants (63%) reported that heat interferes with their sleep.
>
> Cold: Eleven participants (58%) reported that cold interferes strongly or promotes strongly their sleep. This finding combined with the corresponding finding from heat, leads to the conclusion that there may be a problem with temperature in the berthing compartments.
>
> High humidity: Ten participants (52%) reported that high humidity interferes with their sleep, five (26%) of whom, reported strong interference. (McCauley et al., 2004)

These results highlight the importance of quantifying the effects of temperature on sleep for the crew of the SWIFT. Due to SWIFT's small crew size, any impact on the sleep of one individual will have a greater impact on crew effectiveness than would be found on a traditionally manned US Navy warship.

### 2. Temperature and Sleep

A human's natural comfort zone sits between 22.8˚C (73.04˚F) and 26.1˚C (78.98˚F) in the summer and between 20˚C (68˚F) and 23.9˚C (75˚F) in the winter. Less humidity is acceptable at higher temperatures than at lower temperatures (e.g., 60%RH at 26.1˚C and 85%RH at 20˚C) (Wickens et al., 2004). Heat also causes reduced sleep quality and affects sleep patterns. In addition, allowing time for adaptation to heat does not decrease its effect upon sleep quality (Johnson & Kobrick, 2001).

Libert et al. (1988) conducted a study during which six men had their sleep patterns monitored while being exposed to two temperatures, 20˚C and 35˚C.

Researchers observed that the participants exhibited less total sleep, more broken sleep patterns, increased wakefulness and shorter REM sleep periods at 35˚C. Researchers found the subject's thermoregulation adapted to the change in heat conditions from 20˚C to 35˚C, but sleep patterns did not adapt.

In a study conducted by Haskell et al. (1981), it was determined that cold was more disruptive to sleep than heat. Figure 6 is a graphic representation of their findings.

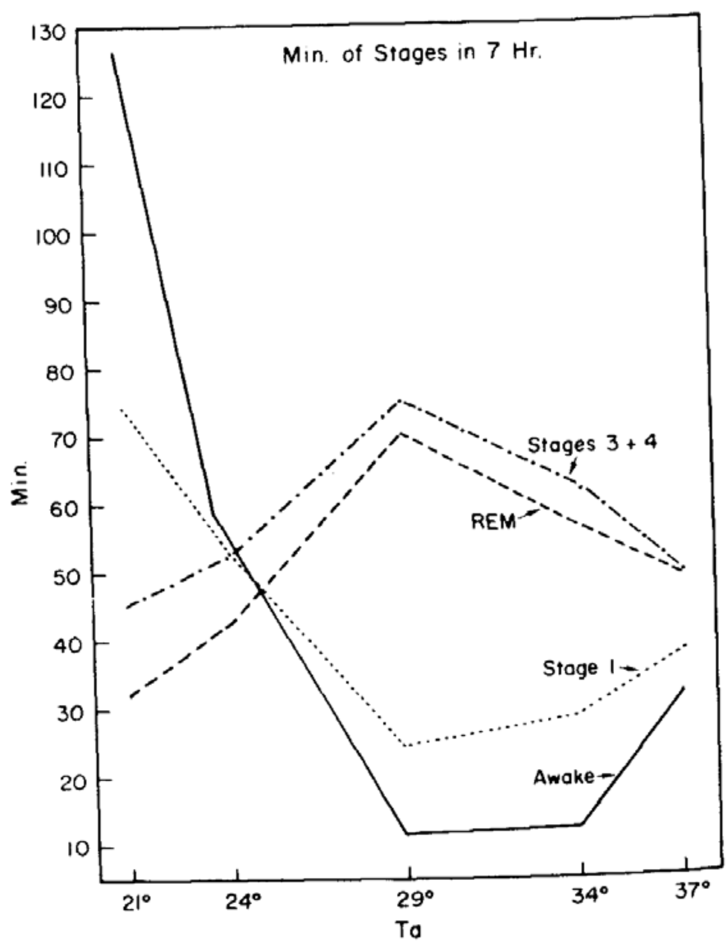


Figure 6. Minutes of wakefulness, stage 1, stages 3+4 and REM sleep across ambient temperature (Ta) conditions for all subjects (From: Haskell, Palca, Walker, Berger & Heller, 1981, p. 496)

It appears that ambient temperature of approximately 29˚C is optimal for maximizing REM, Stage 3 and Stage 4 sleep and minimizing Stage 1 sleep and wakefulness.

The apparent discrepancy between Libert et al. (1988) and Haskell et al. (1981) may be due to procedural differences. In Libert et al. (1988), participants were exposed to higher heat conditions in the morning, well before the defined sleep period, and were in a controlled laboratory setting during the entire experiment. Haskell et al. (1981), on the other hand, exposed participants to experimental conditions an hour and a half prior to their normal bedtime and allowed participants to go home between experiments.

Dewasmes et al. (2000) measured the effects of temperature upon sleep after an eight hour exposure to either a baseline temperature of 24˚C or a higher temperature of 28.5˚C, followed by 6 hours of sleep at baseline conditions, discovering that increasing air temperature between baseline and experimental conditions increased REM sleep percentage and duration.

Okamoto-Mizuno et al. (2005) conducted two experiments in which they exposed participants to 26˚C RH 50% and 32˚C RH 80% in 3 hr 45min blocks (with a half hour transition between treatments). In the first experiment participants were exposed to 26˚C RH 50%, then 32˚C RH 80%. The investigators reported a decrease in sleep efficiency and an increase in wakefulness in the second treatment condition. The second experiment reversed the order of treatments. The researchers discovered an increase in wakefulness during both treatments and a decrease in slow wave sleep during the first treatment condition; stage one sleep increased during the treatment of higher heat / humidity and stage four sleep decreased. They concluded that introduction to humid heat in the beginning of a sleep cycle can be more disruptive to sleep stage distribution than its introduction toward the end of a sleep cycle.

### 3. Temperature Habitability Standards

Individual thermal wellbeing is determined by multiple external and personal aspects, such as air temperature, mean radiant temperature, air velocity, relative humidity, personal activity and clothing (Guide for Crew Habitability on Ships, 2002). The American Bureau of Shipping states a thermal environment should be acceptable to 80% of a space’s inhabitants. Figure 8 is a summary of the American Bureau of Shipping standards for indoor climates. The American Bureau of Shipping assumes the occupants will be dressed in characteristic indoor clothing, engaged in light and sedentary work and will remain in the space for longer than 20 minutes. The HAB+ requirement in Figure 7 is used to identify a space where crew comfort is considered, as in berthing spaces, bridge, engine control room, hospital and indoor workspaces (Guide for Crew Habitability on Ships, 2002).

**Summary of Indoor Climate Requirements**

| *Item* | *Requirement or Criterion* | |
|---|---|---|
| | **HAB** | **HAB+** |
| Air Temperature | Non-adjustable air temperature of 22° ± 1°C (71.5° ± 2°F) | Adjustable range of air temperatures between ≥18°C (64°F) and ≤ 26.5°C (80°F) |
| Relative Humidity | A range from 30% minimum to 70% maximum | |
| Vertical Gradient | The acceptable range is 0 - 3°C (0 - 6°F) | |
| Air Velocity | Not exceed 30 meters-per-minute or 100 feet-per-minute (0.5m/s or 1.7 ft/s) at the center of the space | |
| Horizontal Gradient (Berthing areas) | The horizontal temperature gradient in berthing areas shall be <10°C (18°F) | |

Figure 7. American Bureau of Shipping Indoor Climate Requirements (From: Guide for Crew Habitability on Ships, 2002, p. 40)

The Naval Sea Systems Command Shipboard Habitability Design Criteria Manual for air conditioning and heating states:

> **Air Conditioning**. All berthing, messing, medical, electronics, and necessary control spaces on surface ships shall be air conditioned to maintain as a maximum, 80 degrees Fahrenheit dry bulb [As from a standard thermometer] and 62.5 degrees Fahrenheit dew point under external ambient conditions up to 90 degrees Fahrenheit dry bulb and 81 degrees Fahrenheit wet bulb [Wet bulb is an environmental index that is an approximation of air temperature, radiant heat and humidity (TLVs and BEIs, 2004)] and sea water temperature of 85 degrees Fahrenheit, with the personnel on board and normal machinery operating.
>
> **Heating**. The criterion for all surface ships and submarines shall be the capability to sustain space temperature of at least 65 degrees Fahrenheit dry bulb in all living, sanitary, messing, medical, control spaces, and normal working stations, in ambient external conditions as low as 10

degrees Fahrenheit dry bulb, and sea water temperature of 28 degrees Fahrenheit, with the personnel on board and normal machinery operating. (Naval Sea Systems Command [NAVSEA], 1995, pp. 3-4).

### 4. Conclusion

Temperature affects sleep (Libert et al., 1988; Haskell et al., 1981; Okamoto-Mizuno et al., 2005; Dewasmes et al., 2000). Results indicate that high temperatures (e.g., 35˚C) adversely impact sleep, while more moderate temperatures (e.g., 20˚C) enhance sleep (Libert et al., 1988). Cold, however, has also been found to have more of a negative impact on sleep than heat (Haskell et al., 1981). The apparent discrepancy between Libert et al. (1988) and Haskell et al. (1981) may be due to procedural differences. High humidity in conjunction with high temperature has been found to adversely affect sleep (Okamoto-Mizuno et al., 2005). Heat exposure prior to a sleep period may also negatively impact sleep (Dewasmes et al., 2000). Finally, adaptation to heat does not affect the ability of the body to obtain adequate sleep in high temperature conditions (Johnson & Kubrick, 2001; Libert et al., 1988).

Both the US Navy and private industry have established standards for temperature in berthing spaces (NAVSEA, 1995; Guide for Crew Habitability on Ships, 2002). These standards require that temperature is adjustable within specific ranges under certain environmental conditions.

Results from a preliminary study completed onboard SWIFT in May, 2004 indicated that temperature and humidity cause disrupted sleep in the ship's crew. Due to SWIFT's small crew size, any impact on the sleep of one individual will have a greater impact on crew effectiveness than would be found on a traditionally manned US Navy warship. Additionally, the operating environments in which US Navy ships conduct missions (e.g., Arabian Gulf, Gulf of Oman, Horn of Africa, etc.) are often hot and humid places. It is imperative that examination of the consequences of temperature on sleep be investigated.

## E. NOISE

### 1. Introduction

Everyday, sailors in the US Navy are exposed to high levels of noise, from flight decks to engineering spaces. The US Navy considers the consequences of individual noise exposure in work settings, but the effects of noise on the sleep of sailors has not been well studied. Like temperature, noise affects sleep (Thiessen, 1978; Suter, 1991; Berglund & Lindvall, 1995; Ohrstrom, 1995; Bonnet & Arand, 2000; Ohrstrom & Skanberg, 2004). Heat, however, causes more disruption in sleep than noise (Libert et al, 1991).

Results from a preliminary study of sleep and motion onboard SWIFT indicate background and random noise caused 42% and 68% of participants disrupted episodes of sleep, respectfully (McCauley et al., 2004). These findings highlight the importance of quantifying the effects of noise on US Navy warships, especially with the reduced manning levels of future vessel designs.

### 2. Sound Basics

Sound is generated by a vibrating object and moves out through a medium, such as air (Matthews et al., 2000). A human receiver then may hear this sound. Humans can hear from 20hz to 20,000hz, with the greatest sensitivity around 4,000hz (Wickens et al., 2004). The decibel (dB) is the unit of measurement for sound intensity and is measured on a logarithmic scale; an increase of 10dB almost doubles how loud a sound is perceived (Matthews et al., 2000).

Sound is reported using several different scales. The US Navy uses dB(A) and a time weighted average (TWA) of 8 hours as a baseline for frequencies from 20hz to 16,000hz (Office of the Chief of Naval Operations, 2002). The A-Weighted Scale is defined as “Weighting network that proximates the average human ear to sound” (Bolton & Johnson, 1999, p. 58). The A-Weighted Scale is also defined as a filtered value of the sound level as the ear and brain perceives it (Amble et al., 1975). The time weighted average evens out noise exposure over a period of time, exchanging intensity against duration (Wickens et al., 2004). The TWA values are set with the assumption that the worker will be able to recover from the noise exposure away from the workplace. If the worksite is also the place where the worker sleeps and relaxes for durations greater than 24 hours, the background noise in the spaces the worker is sleeping or relaxing in should not exceed 70dB (TLVs and BEIs, 2004). The US Navy sets exposure limits at 84 dB(A) and 140 dB peak sound pressure level or greater as hazardous (Office of the Chief of Naval Operations, 2002).

### 3. Noise and Sleep

Noise sometimes causes people to completely awaken during their rest cycle and can also result in a sleeper going from heavy to light sleep, decreasing deep stages and amount of REM sleep, increasing their body movements while sleeping and changing their heart rate (Suter, 1991). The aspects of noise that can affect sleep are level, fluctuations, exposure number, type, time and informational content. In addition, individual characteristics such as illness, age, noise sensitivity and variable sleep times can affect noise related sleep disturbances (Berglund & Lindvall, 1995). Noise can also act as an arouser and cause prolonged sleep latency, but in times of severe sleep deprivation, noise may be overcome to allow sleep (Bonnet & Arand, 2000). Psychophysiological responses to noise exposure greater than 40dB(A) have been discovered in laboratory and real-life settings. Heart rate, pulse and respiration rates have all been shown to increase, without habituation over time (Berglund & Lindvall, 1995).

In a study measuring the effects of a white noise level of 93dB (+/- 2) on changes in sleep stages, researchers found that REM sleep decreased and stage 1 and stage 2 sleep increased (stage 1 sleep only increased modestly); stage 3 and stage 4 sleep were unaffected. There was also a significant rise in the number of switches to wakefulness (Scott, 1972).

An analysis of the level of noise events and participant sleep conducted by Ohrstrom (1995) concluded that increased levels of noise events resulted in more disrupted sleep, extended the time required to fall asleep and had higher incidence of body movements. In addition, sleep quality decreased. The results of three experimental groups are displayed in Figures 8 and 9.

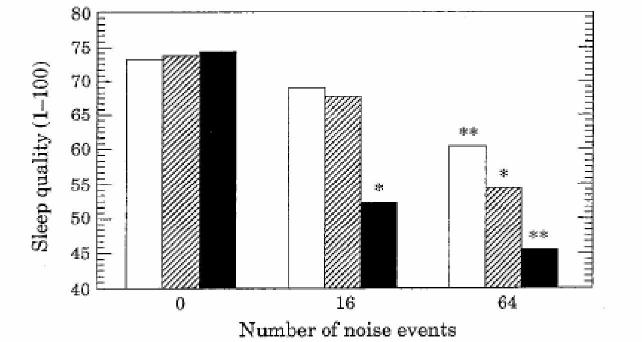


Figure 8. Sleep quality vs. number of noise events (From: Ohrstrom, 1995, p. 610)

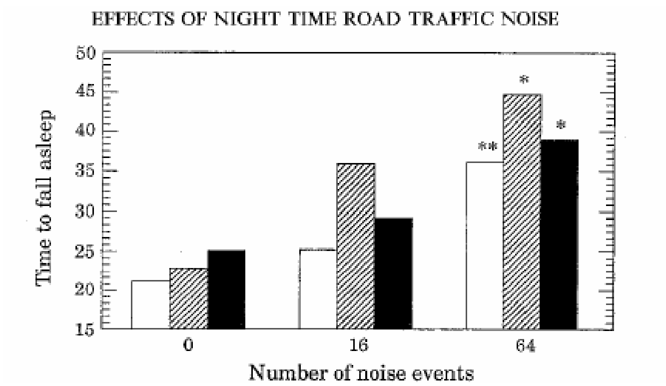


Figure 9. Time to fall asleep vs. number of noise events (From: Ohrstrom, 1995, p. 611)

A study conducted by Ohrstrom and Skanberg (2004) studied the effects of traffic and ventilation noise on the sleep of subjects in laboratory and home settings. They used actigraphs and questionnaires to assess sleep. The researchers found that traffic noise caused a greater reduction in sleep quality than ventilation noise. They did not find statistically significant differences between the results of sleep in the laboratory and home settings. The researchers further concluded that the results from the actigraphs and questionnaires were contradictory; for example, the actigraphs reported better sleep quality when subjects were exposed to the ventilation noise than when they were exposed to a no-noise condition, while the questionnaires reported the opposite. The investigators were inclined to accept the findings from the questionnaires because they all reported reduced sleep quality with exposure to noise.

Griefahn (1990) developed a model for determining limits for noise disruptions during the night (Figure 10). As can be observed, the greater the number of interruptions, the lower the decibel level must be to obtain ‘no reactions’ from subjects.  This model may not be entirely accurate.  For example, Ohrstrom (1995) found 25% of subjects wakened when exposed to 32 noise events at 45dB(A) (the model shows an approximate 54dB(A) level needed to awaken subjects after 32 noise events), indicating this model may be inaccurate for the entire population.

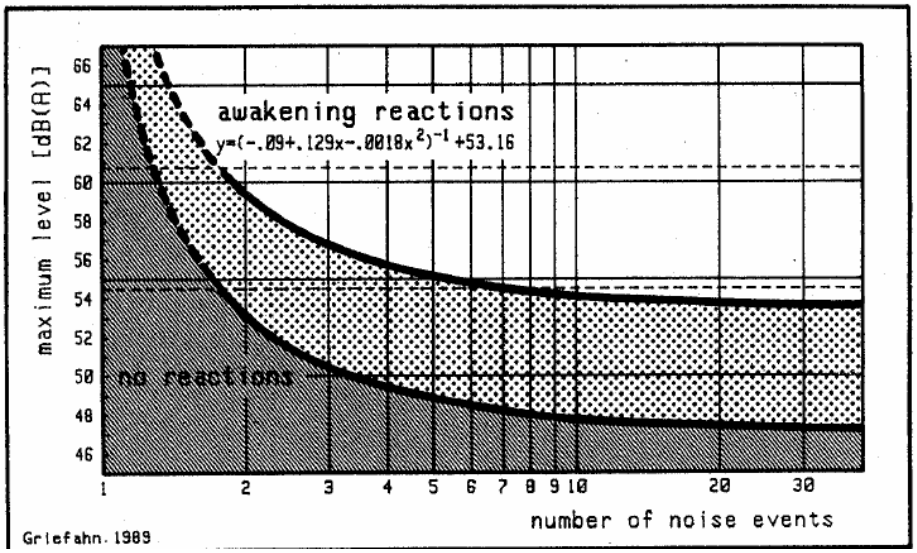


Figure 10.    Limits for noise emission during the night.  Number of noises vs. maximum level (From: Griefahn, 1990, p. 1165).

Ohrstrom (2000) detailed laboratory experiments conducted over several years. During one experiment, participants were exposed to 37 irregular noise levels with a maximum of 80dB(A) and a steady noise level of 51.4dB(LAeq).  In another experiment, participants received treatments of intermittent noise of 60dB(A) LAmax and 70dB(A) LAmax.  The results of these two experiments demonstrate, that intermittent noise causes more disruptions in sleep than steady levels of noise and that sleep quality decreased with exposure to higher LAmax noise levels.  In addition, the number of body movements increased with increased noise levels.  Participants during an additional experiment were exposed to 37 noise events with a LAmax of 60dB and placed into noise sensitive and non-noise sensitive groups.  Ohrstrom found that noise sensitive individuals were able to acclimatize themselves to the noise and obtained better sleep toward the end of the experiment. Non-noise sensitive participants, however, had poorer sleep at the end of the study when compared to the beginning.

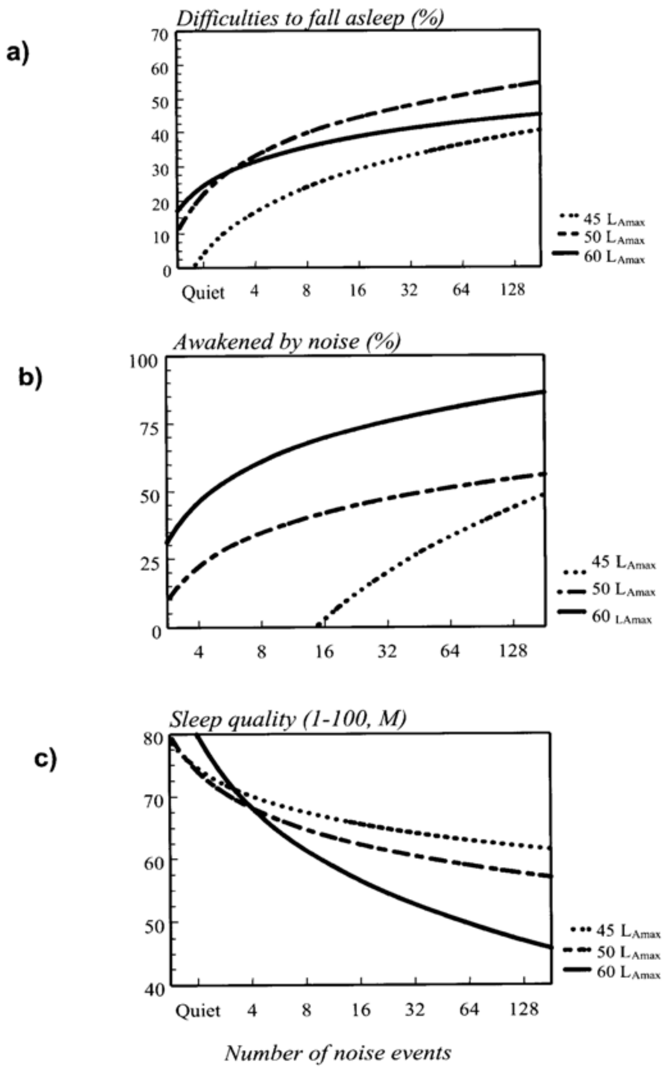


Figure 11. a-c: Relation between number of noise events and (a) difficulties to fall asleep, (b) awakenings by noise and (c) perceived sleep quality (From: Ohrstrom, 2000, p. 74)

In three additional experiments, Ohrstrom was able to establish an association between the number of noise events and reported sleep quality, awakenings caused by noise and difficulties in falling asleep (Figure 11). Figure 11 displays an important finding: the number of noise events is more influential than the decibel level in disrupting subject's sleep.

Thiessen (1978) examined the affects of randomized traffic noise levels on the sleep of young (16-25 yrs. of age), middle aged (46-51 yrs. of age) and old (55-75 yrs. of age) participants. He found that the sleep of young and old participants have nearly identical responses to noise. Middle aged participants had a higher probability of both changes in sleep stage level and wakening than both young and old participants, being more sensitive by approximately 15dB(A). These results are graphically displayed in Figures 12 and 13.

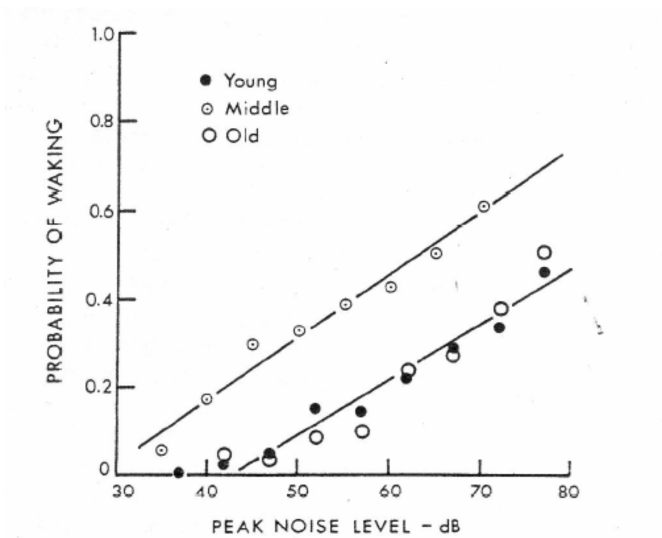


Figure 12. Probability of waking vs. peak noise level (From: Thiessen, 1978, p. 220)

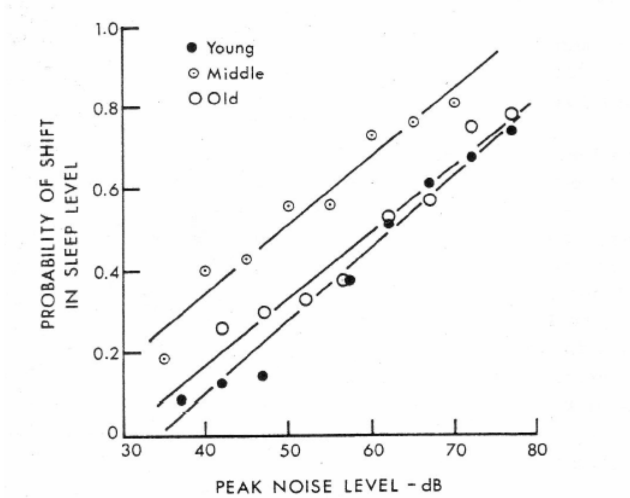


Figure 13. Probability of shift in sleep level vs. peak noise level (From: Thiessen, 1978, p. 220)

Thiessen also discovered that over a period of 24 days of traffic noise exposure, participants' wakening responses steadily declined, suggesting adaptation or habituation. Figure 14 presents this graphically. The upper line represents the number of sleep stage changes and the lower line represents the number of participant awakenings.

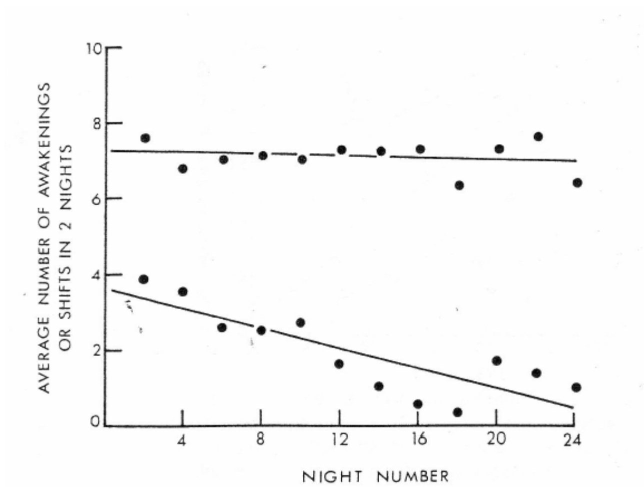


Figure 14. Days vs. numbers of awakenings (lower line) and number of sleep stage changes (upper line) (From: Thiessen, 1978, p. 219)

From Thiessen's results it appears that increased noise levels caused greater probabilities in both waking and sleep stage changes across all age groups, with middle aged participants having greater sensitivity. Additionally, acclimatization is seen in the number of awakenings, but not with the number of sleep stage changes over a long period of time. This may indicate that noise still disrupts sleep in people who are considered acclimatized to its effects.

In an analysis of heat and noise exposure, Libert et al. (1991) determined that these variables adversely affected sleep patterns. Subjects were exposed to two heating conditions (20˚C and 35˚C), a constant background noise level of 45dB(A) and intermittent traffic sounds ranging in duration and intensity (79dB(A) to 86dB(A)). At night, background noise levels were kept at 30dB(A) and peak events were reduced by 15dB(A). At night, total sleep time decreased and wakefulness, sleep state changes, stage one events, awakenings, and moves toward awakenings all increased. When exposed to noise during the night, subjects experienced increased frequencies of sleep stage alterations, moves toward awakenings and stage one events. When the researchers compared results from heat and noise exposure, they found that heat had a significant greater effect than noise upon sleep. Researchers also found within nights exposed to disruptive heat and noise, there was no indication of adaptation to either; in fact, the latter part of the night displayed more disruption in sleep than the earlier parts.

Berglund, Kihlman, Kropp and Ohrstrom (2004) found a direct relationship between ambient noise levels and disrupted sleep in homes. They also found that traffic noise causes psychosocial stress. In houses with sound levels of 63-68 db (LAeq, 24hr) people felt more tired, stressed, irritated and unsociable than those people whose homes had lower sound levels of 45db (LAeq, 24hr).

Horne, Pankhurst, Reyner, Hume and Diamond (1994) measured the sleep of 400 people living near four airports in Great Britain. They found that only a few aircraft noises affected participant sleep and that other social and personal factors had a much larger influence on awakenings. The investigators also discovered that males responded more often to aircraft noises than females. Additionally, during the first and last hours of sleep, participants displayed less response to aircraft noises.

Fidell, Pearsons, Tabachnick and Howe (2000) conducted two studies at three airports that were receiving either a decrease or increase in air traffic. They found that participant sleep was affected little by these changes. The investigators also concluded that comparatively few noise events disrupted participant sleep and that they had adapted well to living near airports.

Vallet, Gagneux, Blanchet, Favre and Labiale (1983) measured long term effects of exposure to traffic noise on participants living in areas of high traffic noise for a minimum of four years. They compared the differences between sleeping in noisy and quiet areas of participants' homes. The investigators found that REM sleep was significantly higher in the quiet area than in the noisy area of the homes. In addition, REM sleep latency was significantly lower in the quiet area. Intervals of waking were lower in the quiet area, as well ($p<.05$, one tailed). After analyzing noise levels, the investigators found that a mean of 50.3 dB(A) peak noise level caused awakenings, 48.5dB(A) produced sleep stage changes, 47.6dB(A) resulted in transient reactions and 37dB(A) caused changes in cardiac response. Younger participants (<45 years of age) were found to be more sensitive than older participants to solitary noises resulting in transient events and sleep stage changes.

The researchers also concluded there was no acclimatization to noise among the participants. The differences in this finding with the results of Thiessen (1978) and Fidell et al. (2000) may be due to the setting of the experiment combined with the type of noise exposure. Thiessen (1978) used a laboratory setting and recordings of traffic noise, while Fidel et al. (2000) examined aircraft noise exposure.

### 4. Soundscape

In residential settings there are noise soundscapes. A soundscape is physically defined by noise source location (e.g., streets), barriers such as buildings and quiet areas. A perceived soundscape is the assessment of the individual toward the physical soundscape and is measured through subjective means (Berglund, et al., 2004). Some homes have quiet areas located away from a noise source while some are fully exposed to noise. Skanberg and Ohrstrom (2002) found greater reported annoyance to noise exposure among people who lives in homes without a quiet area.

Figure 15 displays the results of several studies that measured reported annoyance in areas with access to a quiet area (noise/quiet) and without access (noise). There is clearly more subjective annoyance in those areas without access to a quiet side (Kihlman, 2002).

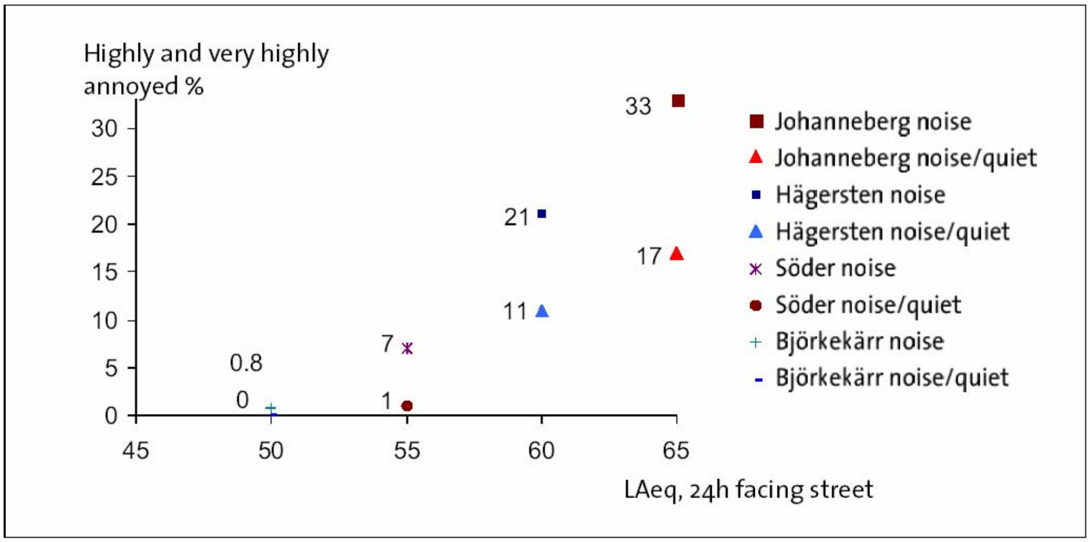


Figure 15. Subject annoyance with noise exposure in locations with access to a quiet side and those without (From: Kihlman, 2002, p. 3)

### 5. Noise Standards

In a report prepared for the World Health Organization in 1995, researchers recommended a continuous sound pressure level of no more than 30-35dB indoors, a maximum of 45dB(LAmax) for intermittent noise exposure and decreasing the number of noise events. In addition, even if noise intrusions are below 45dB(LAmax), consideration needs to be given to settings with low background levels, sites where mixtures of vibration and noise are present and locales containing low frequency noises. The researchers also suggested reducing noise intrusions in the beginning of a sleep period, and concentrating on reducing the number and intensity of random noise events before decreasing the level of constant sound (Berglund & Lindvall, 1995).

According to the American Bureau of Shipping, the maximum acceptable noise level of cabins, staterooms, and berthing spaces is 50 dB(A) (LAeq). The American Bureau of Shipping established this level to improve comfort, communication and performance of the crew. Comfort is defined as "the ability of the crew to use a space for its intended purpose with minimal interference or annoyance from noise". It assumes the occupants will remain in the space for longer than 20 minutes (Guide for Crew Habitability on Ships, 2002).

The Naval Sea Systems Command Shipboard Habitability Design Criteria Manual states that acceptable "A" weighted airborne noise levels for berthing and living spaces are 70 dB(A) (NAVSEA, 1995).

### 6. Conclusion

As has been shown, noise affects sleep (Thiessen, 1978; Suter, 1991; Berglund & Lindvall, 1995; Ohrstrom, 1995; Bonnet & Arand, 2000; Ohrstrom & Skanberg, 2004). Psychosocial stress and psychophysiological responses have also been found with noise exposure (Berglund et al., 2004; Berglund & Lindvall, 1995).

Intermittent noise causes more disruptions in sleep than background noise (Ohrstrom, 2000; Ohrstrom & Skanberg, 2004). The greater the number of noise intrusions, the more sleep is disrupted, the lower the sleep quality and the lower the decibel level must be to not interrupt sleep (Ohrstrom, 1995; Griefahn, 1990). In times of severe sleep deprivation, noise may be overcome to allow sleep (Bonnet & Arand, 2000).

People can adapt to noise (Thiessen, 1978; Fidell et al., 2000). Vallet et al. (1983), however, did not discover acclimatization among their participants. The differences between the results of Vallet et al. (1983) and the results of Thiessen (1978) and Fidell et al. (2000) may be due to differences in both the types of noise used in the experiments and their experimental settings.

There are recommended and required standards for noise (Berglund & Lindvall, 1995; NAVSEA, 1995; Guide for Crew Habitability on Ships, 2002). As is the case with temperature, it is important to quantify the operational noise range in berthing spaces to verify the implementation of these standards.

The sleep of SWIFT's crew is affected by noise (McCauley et al., 2004). This demonstrates the importance of understanding the factors that disrupt sleep on US Navy warships, especially with the reduced manning levels of future vessel designs.

## F. LIGHT

### 1. Introduction

Like temperature and noise, exposure to light affects sleep (Lewy, Wehr & Thomas, 1980; Czeisler et al., 1989; Boivin, Duffy, Kronauer & Czeisler, 1994; Cauter & Buxton, 2000; Duffy, Kronauer & Czeisler, 1996; Czeisler et al., 1989; Mitchell, Hoese, Liu, Fogg & Eastman, 1997). Circadian rhythms can shift with exposure to light (Czeisler et al., 1989; Boivin, Duffy, Kronauer & Czeisler, 1994). Social factors have minimal impact on circadian cycles, while the light and dark cycle is the primary driver of circadian variation (Duffy et al., 1996). Time of exposure to bright light also determines the amount of phase shift in the circadian cycle (Cauter & Buxton, 2000; Duffy, et al., 1996; Czeisler et al., 1989; Mitchell, et al., 1997).

A US Navy warship's daily schedule determines when lighting in berthing spaces is either on or off. Additionally, the brightest lights onboard may be in the bunk spaces (Hunt & Kelley, 1995). These social and environmental determinants of light exposure in the berthing spaces may very well affect the sleep of the SWIFT's crew and underline the importance of quantifying their effect.

### 2. Light and Melatonin

Circadian rhythms are primarily regulated by light through stimulation of the suprachiasmatic nucleus (SCN) (Card & Moore, 1991). Brainard et al. (2001) speculate that there appears to be a photopigment in the eye that regulates circadian reception to light. Upon exposure to light, the retina signals the SCN, causing inhibition of release of melatonin by the pineal gland (National Institute of Neurological Disorders and Stroke, 2005). Melatonin is a naturally occurring hormone that induces sleep (Maas, 2001). Melatonin secretion is at its lowest point during the day, begins to increase at sunset and peaks around 0200 in young people and 0300 in elderly people (Dean, Morgenthaler & Fowkes, 1993). Figure 16 displays this graphically.

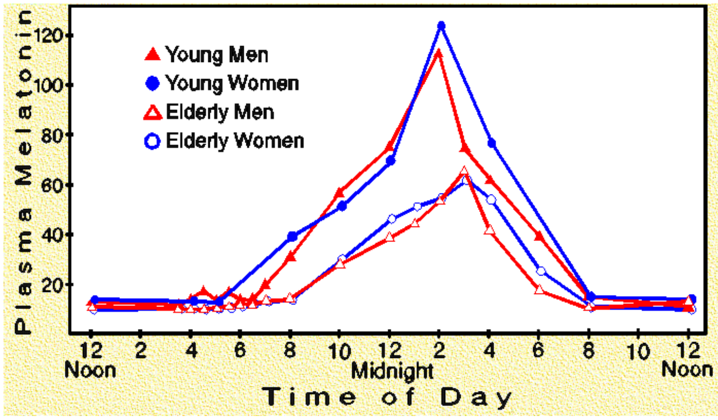


Figure 16. Melatonin release (From: Dean, Morgenthaler, Fowkes, 1993, p. 51)

### 3. Light and Sleep

A study by Lewy et al. (1980) found that bright light (1500 and 2500 lux) inhibits melatonin secretion in humans, but that low level light (500 lux) does not. Czeisler et al. (1986) exposed a participant to a 27 hour day in a laboratory with four-hour treatments of light every evening. During the treatment, the light level was kept between 7,000 and 12,000 lux, the equivalent of normal light exposure at sunrise. The investigators found a six hour phase shift in the participant's circadian rhythms. These results suggested that exposure to bright light can reset circadian cycles.

In another related study, Czeisler et al. (1989) exposed participants to bright light (7,000 to 12,000 lux), background light (100 to 200 lux) and darkness (<0.02 lux) for a three day period. The timing of the exposure to bright light varied: bright light exposure, followed by background lighting; background light with bright light exposure in the middle of normal background light period; background light exposure followed by bright light exposure. This schedule created average circadian shifts of +3.6 hours, +8.6 hours and -5.9 hours, respectively. These results led the researchers to conclude that the circadian clock is more sensitive to light than was previously thought. The researchers also examined the same schedule without exposure to either background lighting or darkness during the times of bright light exposure in the other trials. This created relatively small shifts in the circadian clocks, leading the investigators to conclude that bright light exposure was the driving factor in the circadian clock shifts.

Boivin et al. (1994) exposed two groups to five hours of either bright light (approximately 1,260 lux) or darkness (approximately 0.03 lux) scheduled 1.5 hours after an initial measure of body temperature minimum and 12 hours from the middle of the sleep period. The 1,260 lux level was used to investigate the effects of relatively low light on circadian cycles. Background lighting during the experiment was approximately 10-15 lux. The investigators found that the group exposed to bright light had a phase advance (+2.77 hours) in their circadian cycles and the group exposed to dim light had a phase delay (-1 hour). Results showed either minor or no differences in the circadian phases between the background lighting and dim light conditions. The one hour phase delay in the control group was attributed to the slightly longer than 24 hour duration of the normal circadian cycle. The schedule for both groups was the same, leading investigators to conclude that light had a direct effect on circadian cycles.

Mitchell et al. (1997) investigated the phase shifts of circadian rhythms after exposure to bright light before and after the body's temperature cycle minimum point. At the same time they shifted the normal sleep/darkness patterns of the subjects to nine hours before and after their normal sleep times (median 23:45 to 07:45), replacing it with an eight hour work schedule. The investigators designed a 2x2 factorial experiment with bright light (facilitating/conflicting) and direction of sleep/darkness shift (delayed/advanced). Bright light was considered facilitating if it occurred in the same sequence as the sleep/darkness shift (e.g., delayed shift with bright light exposure before body temperature minimum) and conflicting if it followed an opposite sequence (e.g., delayed shift with bright light exposure after body temperature minimum). Participants received 3 hours of bright light (5,000 lux) exposure each 8 hour shift timed to occur either 3 hours before or 3 hours after the minimum body temperature. This was determined by previous studies to be 3 hours prior to the normal sleep period. Investigators concluded that facilitating bright light showed higher circadian phase shifts than conflicting bright light (7.7 hours vs. 2.6 hours) and that higher numbers of participants achieved greater phase shifts with facilitating bright light than with conflicting bright light (88% vs. 38%).

Duffy et al. (1996) discovered that social factors have minimal impact on circadian cycles, while the light and dark cycle is the primary driver of circadian variation. Participants experienced two reversed programs of rest, sedentary activity and social contact while exposing them either to bright light (7,000 to 13,000 lux) or darkness (<0.03 lux). Bright light exposure was timed for two groups (3 and 4) to produce phase advances and for two groups (1 and 2) to produce phase delays in circadian cycles. In addition, groups 1 and 3 were exposed to darkness and considered control groups, while groups 2 and 4 were exposed to bright light. Investigators found that circadian phase shift direction was found to be dependent upon the time of bright light exposure and was not correlated with social factors. In addition, the circadian phase shift with the control groups was found to be explained by the somewhat greater than 24 hour circadian rhythms, while normalized differences in phase shifts for the groups exposed to bright light were statistically the same (5.75 hrs for advanced phase and 6.11 hrs for delayed phase), though in opposite directions.

Cauter and Buxton (2000) examined the effects of exposure to dark/sleep pulses during different times of day on circadian rhythms. Initially, all participants were placed in a reclining position and placed under a low light of approximately 35 lux. On Day 2, the sleeping period was limited to 0200-0800. On Day 3, participants were assigned to either a control group or three experimental groups. The experimental groups were exposed to different periods of darkness (0900-1500 / 1400-2000 / 1900-0100) and encouraged to sleep. The experimental group that experienced darkness from 0900-1500 showed a nearly one hour difference (-77 +/- 10 minutes) in phase shift from the control group. On day four the participants were again placed in a reclining position and placed under low light level (approximately 35 lux). There were no significant differences in phase shift from day 3 to day 4.

In a study conducted by Daurat et al. (1993), subjects were exposed to both bright light (approximately 2000-2500 lux) and dim light (approximately 150 lux). The investigators found that bright light did not affect the circadian clock. However, bright light did cause a delay (2-3 hours) in the requested bedtimes of four (of eight) subjects. In addition, bright light delayed the lowest amount of motor activity (as measured with actiwatches) by two hours. Alertness and performance were enhanced at night by exposure to bright light. This led the researchers to conclude that bright light can overcome, alertness, to some degree.

Clodore et al. (1990) studied the effects of exposure to bright light (2000 lux) and dim light (50 lux) between 0500 and 0700 on circadian rhythms and performance tests. They concluded that participants exposed to bright light displayed greater motor activity and performance speed (in 3 out of 5 tasks) than participants exposed to the dim light during the morning. In addition, those exposed to bright light also showed heightened alertness earlier than individuals exposed to dim light. Circadian shift was found to be advanced from baseline measures.

Daurat, Aguirre, Foret and Benoit (1997) researched sleep recovery effects after either continuous exposure to bright light (between 1,000 and 2,000 lux) or a light and dark cycle, with light exposure <50 lux between 1800 and 0800 and 1500 to 2000 lux during the remaining hours. The exposure was conducted during 36 hours of sleep deprivation. They found that during two days of recovery, participants exposed to dim light showed slow wave sleep recovery during the first night, while participants exposed to bright light displayed equivalent levels of slow wave sleep during both recovery nights.

Hunt and Kelley (1995) recorded the light levels onboard a submarine and found that light levels were too low to cause melatonin inhibition and that the brightest lights were the ones located in the bunk spaces. Kelly, Gill, Hunt and Neri (1996) studied the affects of an eighteen-hour rotating schedule on submarine sailors. Submariners are separated from those time cues caused by natural light and social factors that cause normalization of the circadian cycle, suggesting that circadian rhythms of submariners may be unique. In their study, they found that even without these cues, submariners who followed the eighteen-hour cycle were able to obtain an overall average of seven hours of sleep measured with actigraphs and sleep logs. However, the sleep took place predominantly in more than one period and sailors on the eighteen hour schedule slept more during the daytime than sailors on a normal twenty-four hour schedule, possibly indicating a shift in the normal circadian cycle.

#### 4. Conclusion

Light exposure affects sleep through the inhibition of melatonin secretion in humans (National Institute of Neurological Disorders and Stroke, 2005). Bright light (e.g., 1500 and 2500 lux) inhibits melatonin secretion in humans, but low level light (e.g., 500 lux) does not (Lewy et al., 1980). Circadian rhythms can shift with exposure to light (Czeisler et al., 1989, 1994). Social factors have minimal impact on circadian cycles, while the light and dark cycle is the primary driver of circadian variation (Duffy et al., 1996). Time of exposure to bright light also determines the amount of phase shift in the circadian cycle (Cauter & Buxton, 2000; Duffy et al., 1996; Czeisler et al., 1989; Mitchell et al., 1997). Exposure to bright light enhances performance (Daurat et al., 1993; Clodore et al., 1990).

Due to the strong effect of light on sleep and the social structure that determines when sailors are exposed to light in berthing spaces, it is imperative that the effects of light exposure upon sleep in berthing spaces be investigated and quantified.

### G. EMERGING HULL FORMS

#### 1. Littoral Combat Ship (LCS)

The Littoral Combat Ship (LCS) is one of the future frontline units being developed for the US Navy. It will incorporate a hull design that is meant to go in fast (upwards of 40 kts) and bring the fight to the enemy close to shore (Ulrich & Edwards, 2003).

Figure 17. Lockheed Martin concept photo for LCS (From: Program Executive Officer Ships, 2005a)

LCS will be a multi-mission ship capable of mobility, special operations force (SOF) deployment, intelligence, surveillance, reconnaissance (ISR), maritime interdiction operations (MIO), homeland defense, anti-terrorism force protection (ATFP), mine interdiction warfare (MIW), antisubmarine warfare (ASW) and surface warfare (SUW) (Hamilton & Landay, 2004). LCS is being conceived as a modular ship with mission module packages consisting of hardware and personnel to supplement the core crew. For example, if there is a need to sweep an area clear of mines, an MIW mission module would be loaded onto LCS; when that mission is over, that same ship could be loaded with another mission module, such as ASW, and used to hunt submarines (Ulrich & Edwards, 2003). This mission module system gives the US Navy greater flexibility in securing the littoral and decreases the need for mission specific ships. LCS will also incorporate the latest in information technology to operate in the future highly networked Navy, conceptualized in FORCEnet. It will also use a high number of unmanned vehicles for everything from mine warfare to strikes on terrorist camps (Ulrich & Edwards, 2003).

Figure 18. General Dynamics concept photo for LCS (From: Program Executive Officer Ships, 2005b).

LCS will incorporate a non-traditional hull type that will allow her increased operational speeds and a shallower draft. Currently, two teams led by General Dynamics and Lockheed Martin have competing designs for the LCS. Each team envisions a different type of hull design. Lockheed Martin is building a semi-planing mono hull (Figure 17). She will have a length of 115 meters, beam of 13 meters and reach 45kts.

General Dynamics is designing a trimaran (Figure 18) with a length of 127 meters and beam of 30.4 meters that will reach speeds up to 46kts (Hamilton & Landay, 2004).

According to its Interim Requirements Document (IRD), LCS has an objective and threshold of 15 and 75 personnel in the core crew, respectively (Littoral Combat Ship, 2003). Threshold is defined as**:** **"**A minimum acceptable operational value below which the utility of the system becomes questionable" (Chairman of the Joint Chiefs of Staff, 2005, p. GL-15).

Objective is defined as**:**

> The desired operational goal associated with a performance attribute, beyond which any gain in utility does not warrant additional expenditure. The objective value is an operationally significant increment above the threshold. An objective value may be the same as the threshold when an operationally significant increment above the threshold is not significant or useful (Chairman of the Joint Chiefs of Staff, 2005, 2005, p. GL-14).

In May of 2004, Lockheed Martin and General Dynamics were awarded contract options for building two LCS ships. Lockheed Martin was awarded a contract to build the first LCS, to be named USS FREEDOM, in December 2004 (Navy's First Littoral Combat Ship, 2005). A keel laying ceremony was held for USS FREEDOM on June 3, 2005 (Keel Laid, 2005).

### 2. SWIFT

To test and gain experience with innovative hull designs, the U.S. Navy contracted for and took possession of the High Speed Vessel SWIFT (HSV-2) August 15, 2003 (Figure 19) (Ryan & Grimland, 2003). The vessel is a catamaran with semiplaning wave piercing aluminum hulls built by Incat Australia.


Figure 19. HSV2 SWIFT (From: High Speed Vessel SWIFT Joins Navy, 2003)

She is 310 ft long, has a beam of 87.3ft (overall), weighs 1800 long tons (fully loaded) and can reach 42kts (O'Neil, 2003). She has a crew of 40 and room for two MH-60S helicopters, 250 Marines and can transport one M1A1 main battle tank (Ryan & Grimland, 2003). She has two crews in four-month rotations, utilizing the blue/gold concept pioneered by the submarine community (High Speed Vessel SWIFT Joins Navy, 2003).

SWIFT is being used to test Sea Power 21 concepts, such as Sea Basing, and the use of LCS mission module packages (HSV SWIFT Demonstrates, 2004). She has an extensive Command and Control, Communications, Computers and Intelligence (C4I) suite for her use in MIW and for potential use of Unmanned Vehicles, including Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs) and Unmanned Underwater Vehicles (UUVs).

The SWIFT is also being tested for use in a myriad of mission roles including MIW Command and Control (C2), Medical Evacuation and Support, Amphibious Warfare and Riverine Operations. For example, she was used in September 2003 in a logistical role in the 5$^{th}$ Fleet Area of Responsibility (AOR) (McKain, 2003). She also trained during the West African Training Cruise-04 in riverine operations and small boat raids (High Speed Vessel SWIFT Joins Navy, 2003). In December 2004, SWIFT took part in GOMEX 05-1. GOMEX 05-1 was a mine warfare exercise that graduated mine countermeasures squadron staff and ships to deployment ready status. SWIFT was used as the mine countermeasures command flagship and coordinated the movements of the other participants in the exercise (Naval Support Activity-Panama City, 2005).

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# III. METHODS

## A. OVERVIEW

The objectives of this thesis were to examine the effects of noise, temperature, humidity, motion and light on the sleep patterns of the crew of the HSV-2 SWIFT and to measure crew effectiveness. Data were gathered continuously from the time SWIFT was underway on December 3, 2004 until she pulled in on December 11, 2004.

This section discusses the methodology used in gathering the data for answering the objectives of this study. Section B describes the participants who volunteered for this observational study. Section C shows the equipment used to gather the data. Finally, Section D explains the procedure.

## B. PARTICIPANTS

This study observed sailors onboard one of the US military's high speed vessels in order to capture data from a crew operating onboard a non-conventional hull form. Participants in this study were officers and enlisted sailors of HSV-2 SWIFT. Three of the participants were officers. Of the enlisted sailors, two ranked E7 and above and fifteen were E6 and below, for a total of 21 out of a crew of 41. Two participants were female, one officer and one enlisted sailor. The female sailors slept in the same berthing area, regardless of rank. Enlisted sailors slept primarily on the PORT side of the ship, while Officers slept on the STBD side. Figure 20 displays the locations of the Berthing spaces. Participants 4, 5, 14, 16, 19 and 20 slept in Berthing 5. Participants 1, 6, 8-10 and 13 slept in Berthing 6. Participants 11, 18 and 21 slept in Berthing 7. Participants 7 and 15 slept in Berthing CPO2. Participant 12 slept in Berthing 9. Participants 2 and 3 slept in Female Berthing. Participant 17 slept in XO's Berthing. Table 1 summarizes this information along with age, height, weight and number of years at sea experience for each participant.

Table 1. Participant Demographics.

| Participant | Rank | Gender | Age | Height | Weight (lbs.) | Sea time (years) | Berthing |
|---|---|---|---|---|---|---|---|
| 1 | E-6 | M | 28 | 6' 2" | 240 | 4 | 6 |
| 2 | E-5 | F | 27 | 5' 5" | 162 | 3 | Female |
| 3 | E-6 | F | 25 | 6' 5" | 150 | 1.6 | Female |
| 4 | E-6 | M | 38 | 7' 2" | 210 | 7 | 5 |
| 5 | E-6 | M | 36 | 5' 8" | 192 | 4 | 5 |
| 6 | E-6 | M | 30 | 5' 10" | 194 | 5 | 6 |
| 7 | E-7 | M | 38 | 5' 10" | 220 | 10 | CPO 2 |
| 8 | E-6 | M | 35 | 5' 10" | 215 | 8 | 6 |
| 9 | E-6 | M | 35 | 5' 10" | 190 | 12 | 6 |
| 10 | E-5 | M | 27 | 5' 10" | 180 | 2 | 6 |
| 11 | E-5 | M | 22 | 5' 10" | 170 | 2 | 7 |
| 12 | 0-2 | M | 24 | 6' 1" | 185 | 2 | 9 |
| 13 | E-6 | M | 44 | 6' 0" | 240 | 8 | 6 |
| 14 | E-6 | M | 34 | 5' 9" | 215 | 8 | 5 |
| 15 | E-8 | M | 37 | 5' 11" | 200 | 13 | CPO 2 |
| 16 | E-5 | M | 27 | 5' 4" | 135 | 4 | 5 |
| 17 | 04 | M | 38 | 6' 0" | 235 | 10 | XO |
| 18 | E-6 | M | 35 | 5' 6" | 173 | 3.5 | 7 |
| 19 | E-6 | M | 35 | 5' 11" | 206 | 11 | 5 |
| 20 | E-4 | M | 21 | 5' 5" | 165 | 1.2 | 5 |
| 21 | E-6 | M | 36 | 5' 11" | 210 | 10 | 7 |

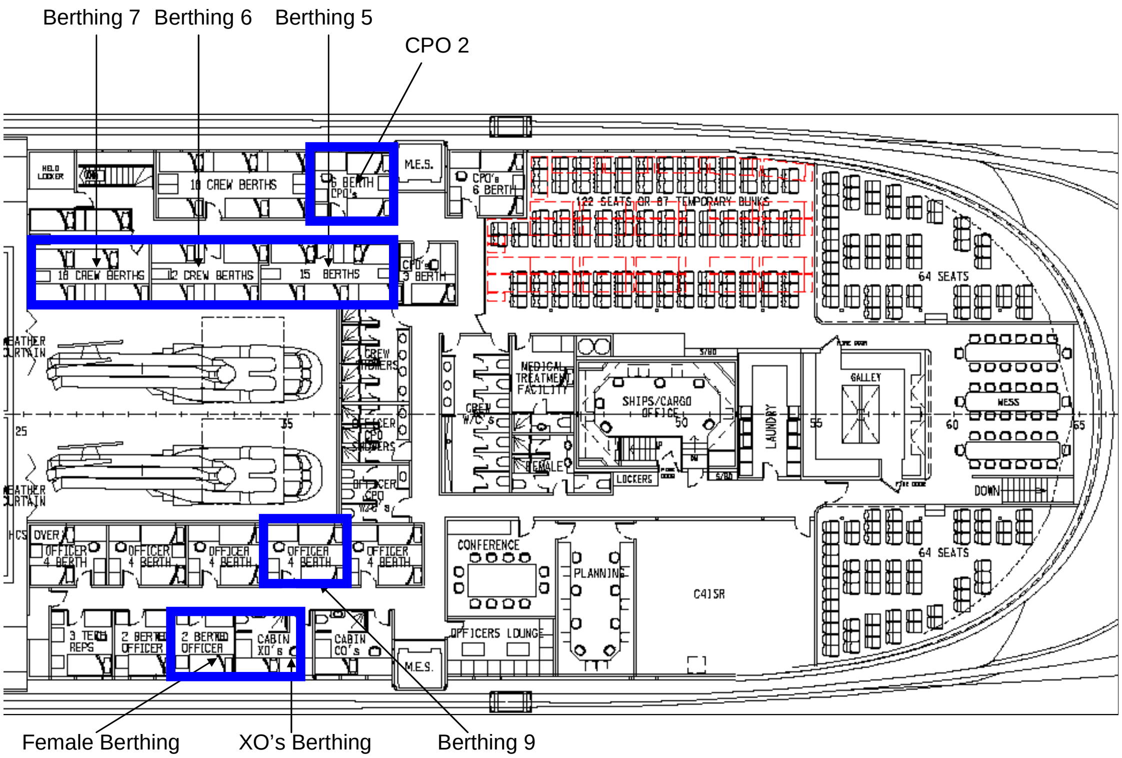


Figure 20. Berthing spaces where personnel slept (After: Morrison, 2004)

## C. INSTRUMENTS

### 1. Noise

Five Quest Model Q300 Noise Dosimeters were used in this study. They were obtained from Mr. Mike Tianen and Ms. Elvie Danque of Naval Hospital Camp Pendleton, Port Hueneme, CA. Figure 21 displays a Quest Q300 and highlights important information about the Q300. Table 2 contains information about the specific noise dosimeters used and where onboard SWIFT they were placed.


**<u>Characteristics</u>**:
1. **Measuring Ranges**:
   a. 40-110db
   b. 70-140db
2. **Battery**:
   a. 9 volt
   b. 48 hours of operation.
3. **Temperature**
   a. Operating: -10C to +50C
   b. Storage: -20C to +60C
4. **Humidity**
   a. 0 to 95% non-condensing
5. **Size**
   a. 5.5 x 2.8 x 1.4 inches
6. **Weight**
   a. 15.5 ounces
7. **Components**
   a. Microphone with cable.
   b. Meter
   c. Download cable
   d. Calibrator

Figure 21. Quest 300 Noise Dosimeter (After: Instructions for Q300, 1997, p. 41)

Table 2. Noise dosimeter equipment details.

| Equipment | Port Hueneme Serial Numbers | Quest Technologies Serial Numbers | Location |
|---|---|---|---|
| Dosimeter | 66099M1782 | QC0050028 | Berthing 5 |
| Dosimeter | 66099M1817 | QC0050022 | Berthing 6 |
| Dosimeter | 66099M1818 | QC0050003 | Berthing 7 |
| Dosimeter | 66099M2004 | QCA030109 | Berthing CPO 2 |
| Dosimeter | 66099M2005 | QCA030111 | Berthing 9 |
| Calibrator | 66099M1843 | QI9010056 | N/A |

The Q300 is programmed to allow three separate noise dosimeters within one (Instructions for Q300, 1997). Table 3 displays the settings programmed into the Q300s for this study. An overall range of 40dB -110dB was selected to focus on the constant and intermittent noises that could cause interruptions in the participant’s sleep. Dosimeter 1 (within each Q300) was set to current US Navy, Department of Defense (DOD), standards. It was intended to measure events that occur above 80dB. Dosimeter

2 was set to International Electrotechnical Commission (IEC), proposed DOD standards; it was also set to measure events occurring above 80dB. Dosimeter 3 was set to the IEC, proposed DOD standards, with the exception of the threshold of 0dB to capture events that occur below 80dB (Quest Noise Dosimeter Setup, 2004).

Table 3. Settings for Q300

| | | |
|---|---|---|
| Instrument Range: | 40 - 110 | dB |
| **Measuring Parameters:** | | |
| DOSIMETER1 | | |
| Criterion: | 84 | dB |
| ExchangeRate: | 4 | dB |
| Threshold: | 80 | dB |
| UpperLimit: | 130 | dB |
| Weighting: | A | |
| TimeConstant: | Slow | |
| DOSIMETER2 | | |
| Criterion: | 85 | dB |
| ExchangeRate: | 3 | dB |
| Threshold: | 80 | dB |
| UpperLimit: | 131 | dB |
| Weighting: | A | |
| TimeConstant: | Slow | |
| DOSIMETER3 | | |
| Criterion: | 85 | dB |
| ExchangeRate: | 3 | dB |
| Threshold: | 0 | dB |
| UpperLimit: | 131 | dB |
| Weighting: | A | |
| TimeConstant: | Slow | |

The Q300 noise dosimeters are enclosed within a diecast aluminum case that safeguards them both physically and from electrical interference, such as that received from radios (Instructions for Q300, 1997). Figures 22 and 23 display pictures of one of the Q300s used in the study and the cable used to download information to a computer.

To download data to a computer, the microphone is removed from the top of the Q300 and the noise dosimeter connection side of the cable is placed onto the connection on top of the Q300. The serial portion of the download cable is then placed into the computer where it can be retrieved using QuestSuite Professional Software.


Figure 22. Q300 Noise Dosimeter

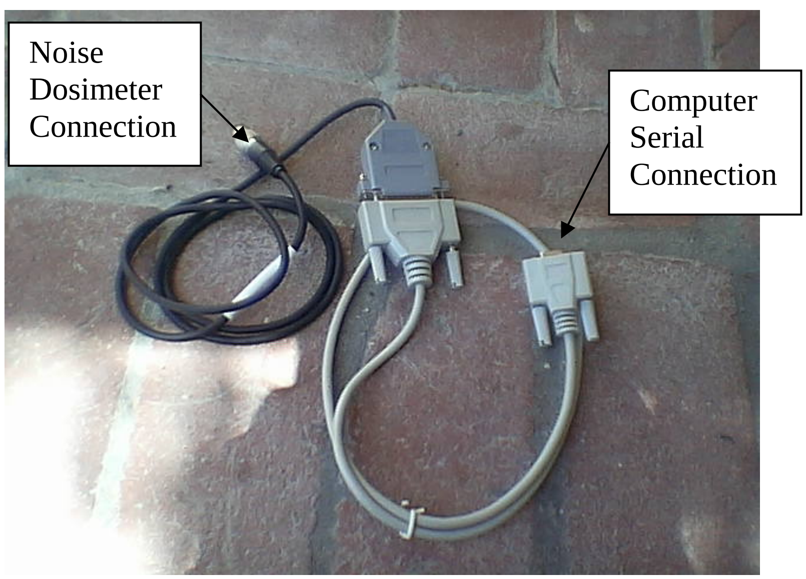


Figure 23. Q300 Noise Dosimeter Download Cable

Figure 24 is a graphical display of noise measurements obtained in Berthing 5 on 10DEC04. LAVG is the average db level of sound measured within a specified period of time, one minute for this study. LEQ (equivalent sound level) is LAVG utilizing a 3dB exchange rate.  An exchange rate (this study used 3dB and 4dB exchange rates) refers to the change in the amount of noise (dB) that will either double or halve the dose accumulation rate.  For example, an employee who is allowed to work in an area averaging 84dB every 8 hours would only be able to work for four hours if the noise level was 87dB.  Slow Max and Fast Max refer to the maximum dB level measured with Slow or Fast response rates, 1 second and 0.125 second, respectively.  The response rate determines how quickly the unit responds to fluctuating noise.  LPEAK refers to the maximum dB level measured within a period of time.  LPEAK measurements are independent of response rate and weighting noise dosimeter settings.  Noise dosimeters for this study were set to the A weighting scale.  The A weighting scale approximates human hearing (QuestSuite Professional Software, 2002).

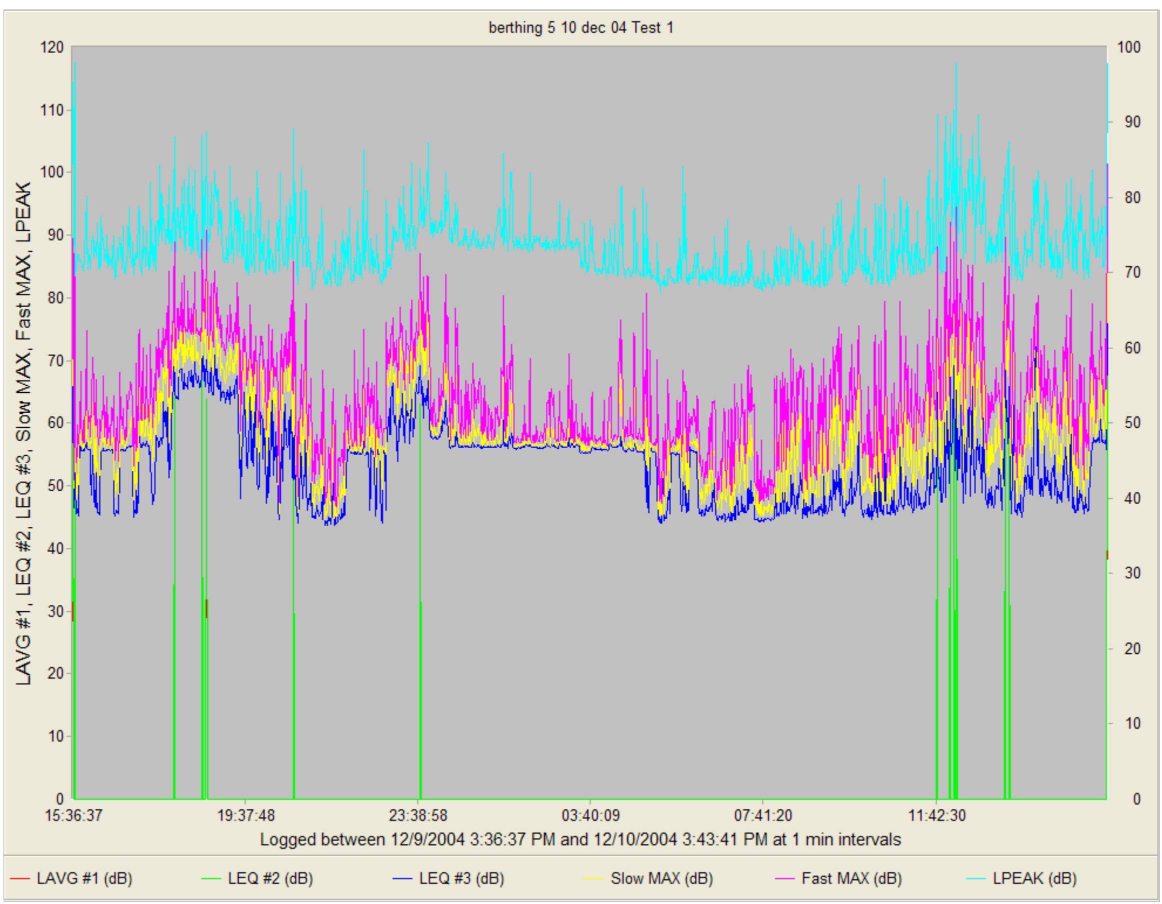


Figure 24.    Q300 Output

### 2. Temperature and Humidity


| Technical data | |
|---|---|
| **Parameter** | Humidity/Temperature |
| **Sensor** | Humidity sensor/ NTC (internal) |
| **No. of channels** | 2 channels (internal %RH; °C) |
| **Measuring range** | 0 to 100 %RH<br>-10 °C to +50 °C |
| **Resolution** | 0.1 %RH / 0.1 °C |
| **Accuracy/System ±1 digit** | ± 3 %RH<br>± 0.5 °C |
| **Memory** | **3,700 readings** |
| **Application temp.** | -10 °C to +50 °C |
| **Storage temp.** | -40 °C to +70 °C |
| **Battery type** | Lithium (1/2 AA) |
| **Weight** | 80 g |

Figure 25. Testo 175H1 (From: Compact data logger, n.d.)

The Testo 175H1's were used to measure temperature and humidity in five berthing spaces (Table 4). Testo 175H1 specifications are highlighted in Figure 25. The Testo 175H1 measures both temperature, from +14F (-10C) to +122F (+50C), and humidity, from 0% to 100% RH. Table 4 contains information about the specific Testo 175H1s used and where onboard SWIFT they were placed.

Table 4. Testo 175 H1 equipment details

| Equipment | Serial Number | Location |
|---|---|---|
| Data logger | 20018789/309 | 5 |
| Data logger | 20014391/306 | 6 |
| Data logger | 20035236/406 | 7 |
| Data logger | 20035220/406 | 9 |
| Data logger | 20035239/406 | CPO 2 |

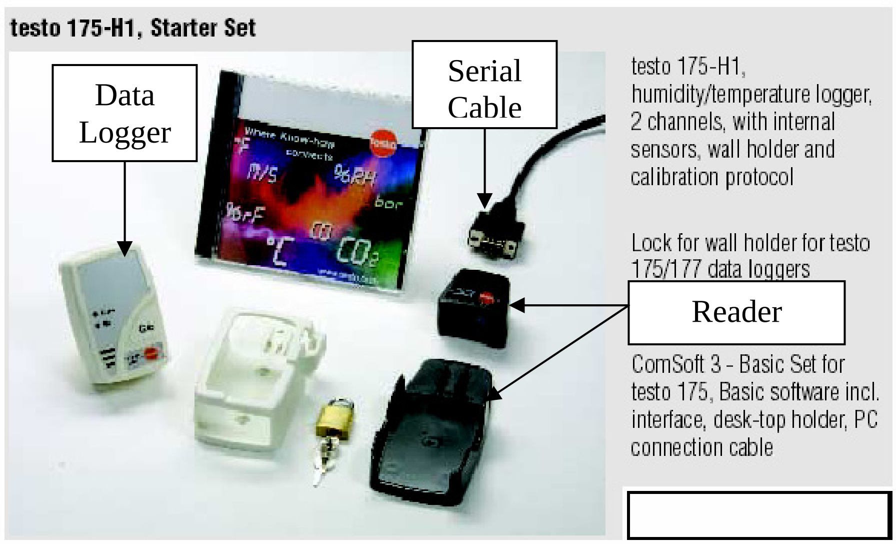


Figure 26. Testo 175H1 components (From: Compact data logger, n.d.)

Figure 26 displays the components of the 175H1. The data logger is placed inside the reader which downloads the temperature and humidity data through the serial cable to a computer. Figure 27 presents the graphical output of temperature (in green) and humidity readings (in red) measured in Berthing 5 on December 10, 2004. Percentage of Relative Humidity (%RH) is read on the left and degrees in Fahrenheit on the right.

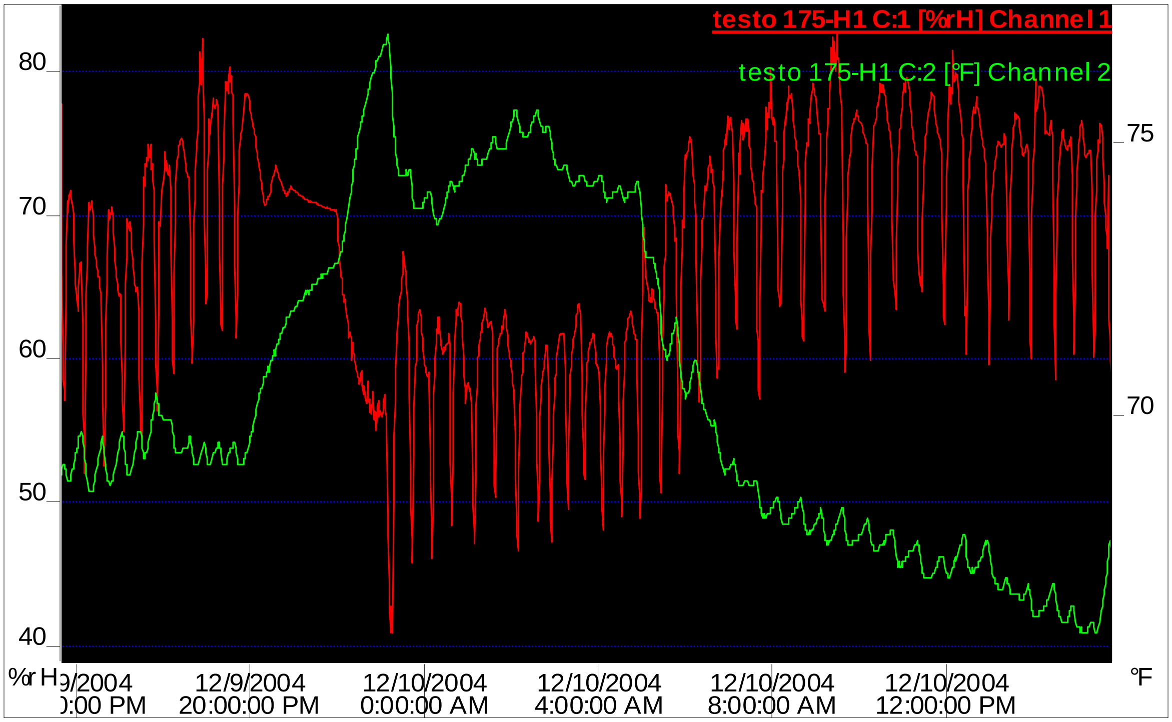


Figure 27. Testo 175H1 Output

### 3. Light


- Weight: 16 grams
- Size: 28 x 27 x 10 mm*
- Non-Volatile Memory: 64 kbytes
- Recording Time at one minute sample interval:15 days
- Lux Range: 0.1 to 150,000
- Battery Life: 180 days

Figure 28. Mini Mitter Actiwatch-L (From: AW-L Actigraph, 2005)

Light was measured in Berthing 5 and Berthing 6, using two Mini Mitter Actiwatch-L's. The Actiwatch-L utilizes a photodiode whose spectral sensitivity approximates that of a human (Actiwatch Instruction Manual, 2002). Figure 28 displays an Actiwatch-L and its basic information. Table 5 refers to the light measuring performance of the Actiwatch-L.

Table 5. Light measuring performance of the Actiwatch-L (From: Actiwatch Instruction Manual, 2002, p. 4-1)

| Parameter | Value | Condition or Unit |
|---|---|---|
| Peak spectral sensitivity | 580 | nm (nanometers) |
| Wavelength window | 330 to 720 | nm |
| Minimum illumination sensitivity | 0.1 | lux |
| Maximum illumination sensitivity | 150,000 | lux |
| Linearity | <2% | From 0.1 to 150,000 lux |
| Uncertainty | <10% | Typical from 400 to 800 nm |
| Resolution | 2% of lux value | Typical |
| Temperature variation of spectral sensitivity | <0.1% | From 400 to 800 nm |
| Angular response | ±50 degrees | to 1/2 power point |
| Active area | 5.16 | $mm^2$ |

Figure 29 is a picture of the data output of the Mini Mitter Actiware software Version 3.4 used to analyze the light data. Light data is pictured in Figure 29 as yellow bars. Light is measured and displayed as units of lux; as the level of lux increases, the bar raises higher. A lux is defined as "a unit of illumination from a source of one-foot-candle intensity at a distance of one meter" (Actiwatch Instruction Manual, 2002, p. 4-3).

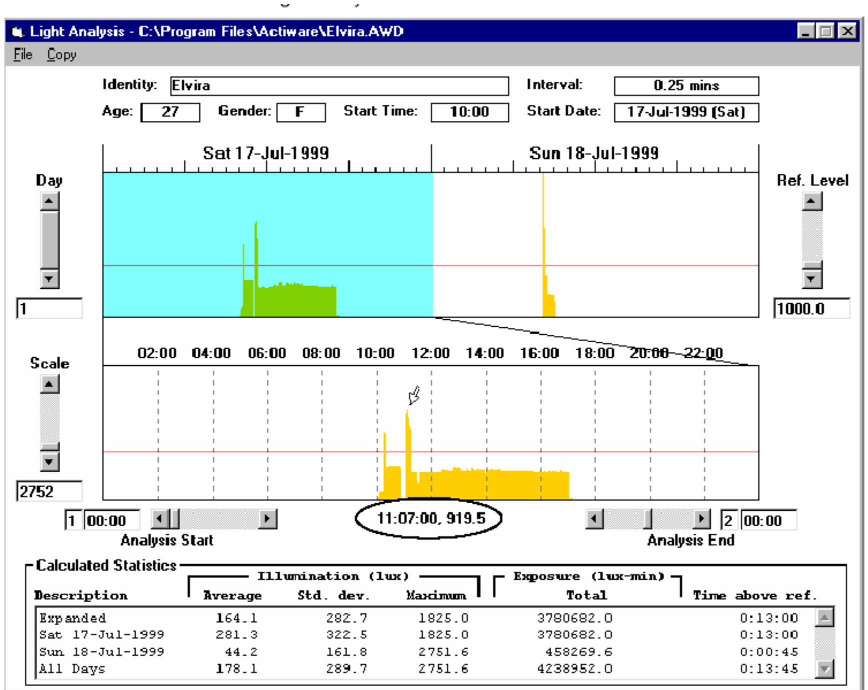


Figure 29. Actiware Light Analysis (From: Actiwatch Instruction Manual, 2002, p. 4-3)

### 4. Motion and Weather

| THURSDAY | | FRIDAY | | SATURDAY | |
|---|---|---|---|---|---|
| 09 DEC 2004 | | 10 DEC 2004 | | 11 DEC 2004 | |
| Morning | Afternoon | Morning | Afternoon | Morning | Afternoon |
|  |  |  |  |  |  |
| FRONTAL PASSAGE TONIGHT | | | | | |
| Wind (kts) | | Wind (kts) | | Wind (kts) | |
| SE 13-17 | S TO SW 13 – 17 W/ GUSTS TO 24 KTS | NW 20 - 25 KTS | NW 20 – 25 GUSTS TO 28-33 KTS | NW TO N 20-25 W/ GUSTS TO 35 KTS | NW TO N 20-25 W/ GUSTS TO 35 KTS |
| Visibility (nm) | | Visibility (nm) | | Visibility (nm) | |
| UNR | 6 HZ & 1-3 MI IN PRECIP | UNR | UNR | UNR | UNR |
| Sea State / Sigwave | | Sea State / Sigwave | | Sea State / Sigwave | |
| 3 / 4 – 5FT | 4 / 5 - 6FT | 4/ 5 - 7FT | 4 / 5 - 7FT | 4 / 5 - 7FT | 4 / 5 - 7FT |
| Temperature (F) | | Temperature (F) | | Temperature (F) | |
| Max | Min | Max | Min | Max | Min |
| 74 | 64 | 75 | 64 | 60 | 45 |

Figure 30. Forecast for December 9, 2004 (From: Warner, 2004)

Ship motion accelerometers were not activated for this phase of the study, but wave height and weather data were obtained for each day to approximate ship motion. An aerographer's mate first class petty officer from Atlantic Meteorology and Oceanography Facility Jacksonville, Florida (NLMOF) rode the SWIFT during GOMEX 05-1 and provided weather briefs each night. An example is displayed in Figure 30 above. It shows a deterioration in weather that occurred from the afternoon of Thursday, December 9, 2004, until SWIFT pulled in on the Saturday, December 11, 2004. Sea state was the variable used from the weather reports to investigate ship motion effects upon sleep. Table 6 displays the factors that define a particular level of sea state.

Table 6. Sea State (From: Sea State Table, 2005)

| Wind Speed (Kts) | Sea State | Significant Wave (Ft) | Significant Range of Periods (Sec) | Average Period (Sec) | Average Length of Waves (FT) |
|---|---|---|---|---|---|
| 3 | 0 | <.5 | <.5 - 1 | 0.5 | 1.5 |
| 4 | 0 | <.5 | .5 - 1 | 1 | 2 |
| 5 | 1 | 0.5 | 1 - 2.5 | 1.5 | 9.5 |
| 7 | 1 | 1 | 1 - 3.5 | 2 | 13 |
| 8 | 1 | 1 | 1 - 4 | 2 | 16 |
| 9 | 2 | 1.5 | 1.5 - 4 | 2.5 | 20 |
| 10 | 2 | 2 | 1.5 - 5 | 3 | 26 |
| 11 | 2.5 | 2.5 | 1.5 - 5.5 | 3 | 33 |
| 13 | 2.5 | 3 | 2 - 6 | 3.5 | 39.5 |
| 14 | 3 | 3.5 | 2 - 6.5 | 3.5 | 46 |
| 15 | 3 | 4 | 2 - 7 | 4 | 52.5 |
| 16 | 3.5 | 4.5 | 2.5 - 7 | 4 | 59 |
| 17 | 3.5 | 5 | 2.5 - 7.5 | 4.5 | 65.5 |
| 18 | 4 | 6 | 2.5 - 8.5 | 5 | 79 |
| 19 | 4 | 7 | 3 - 9 | 5 | 92 |
| 20 | 4 | 7.5 | 3 - 9.5 | 5.5 | 99 |

Motion data was also collected from Sunday, December 5, 2004 until Saturday, December 11, 2004 using an Actiwatch-L placed on the PORT side of the messdecks. Mini Mitter Actiwatches contain an accelerometer that measures the rate and amount of motion omni-directionally with a sensitivity of 0.01g. The accelerometer creates an electrical current in proportion to the magnitude of the motion and saves the information as activity counts within the defined time period, set at 1 minute for this study. The actiwatch is most sensitive to movement perpendicular to itself, making it ideal to sense motion created by a moving arm. The actiwatch samples motion 32 times per second. The highest movement value for that second is then added to other values determined within a defined epoch. The raw number is then applied against a calibration constant and displayed to the user (Actiwatch Instruction Manual, 2002).

Specifically, the Actiwatch Data Acquisition algorithm senses and categorizes motion by:

1. The piezo-electric sensor generates a voltage when it undergoes a change in acceleration.
2. Thirty-two (32) times per second, the filtered, amplified voltage from the piezo-electric sensor is converted to a digital value, is used to adjust a running baseline value, and is compared to the baseline value.
3. Every second, the maximum deviation from the baseline for that second is determined, and added to an accumulated activity value.
4. At the end of each epoch, the accumulated activity value is compressed into an 8-bit value and stored in Actiwatch memory.
5. When the data are downloaded by the Windows software, the 8-bit values are decompressed to 15-bit raw activity counts.
6. The Actiwatch-specific calibration constant is applied to the raw activity counts, resulting in calibrated activity data that are displayed to the user in the Windows software and recorded in .awd files for later use (Actiwatch Activity Data, n.d.).

Activity counts are then displayed in the Actigraph Software. Mini Mitter Actiware software Version 3.4 was used for this study. Information from the actiwatches was downloaded into Actiware software using a Mini Mitter ActiReader, displayed in Figure 31. The Actiwatch is placed face down on the reader and the information is downloaded through an RS-232 cable to the computer running the Actiware Software. The computer used for this study was a Dell Inspiron 8200.


Figure 31. Mini Mitter Actireader (From: Actiwatch Software, ActiReader, 2005)

### 5. Sleep

21 of SWIFT's crew wore Actiwatch-L's and Actiwatch-64's to measure the amount of sleep they received during GOMEX. Actiwatch-L's are described in the preceding two sections. Actiwatch-64's are similar to Actiwatch-L's with the exception that they are not capable of reading light and can record for a longer period of time (45

days vice 15 for the Actiwatch-L). Also, they contain an event marker that can be pressed by the participant to denote an event such as the beginning of a nap (AW-16 & AW-64, 2005). Figure 32 displays an Actiwatch-64.


- Weight: 16 grams
- Size: 28 x 27 x 10 mm*
- Non-Volatile Memory:
  - AW-64 = 64 kbytes
- Recording Time at one minute sample interval:
  - AW-64 = 45 days
- Battery Life: 180 days
- Waterproof to IEC Standard 60529 IPX7 (water tight to a depth of one meter for 30 minutes)

Figure 32. Mini Mitter Actiwatch 64 (From: AW-16 & AW-64, 2005)

Mini Mitter actiwatches were selected due to their size and relative high rate of survivability. The Mini Mitter actiwatch uses a digital integration technique that has been found by investigators to be more sensitive to human movements than other types of actigraphs. This is due to the fact that unlike other actigraphs, Mini Mitter actiwatches take into account the strength of a movement. In digital integration, activity is sampled several times a second and then averaged within a defined epoch (Gomy & Allen, 1999).

The software used to analyze the data obtained from the Mini Mitter Actiwatch-L's and Actiwatch 64's was Mini Mitter Actiware Sleep version 3.4. As described in the preceding section, the Actiwatch data is downloaded through the Mini Mitter Actireader to the computer and displayed using the Actiware software.

The Actiware software allows the user to view either a summary of the entire time the Actiwatch was measuring data (within the Actogram portion of the software) or two days (within the Sleep Analysis portion of the software). The software also allows a user to analyze a section of the measured data (such as the blue highlighted area in Figure 33).

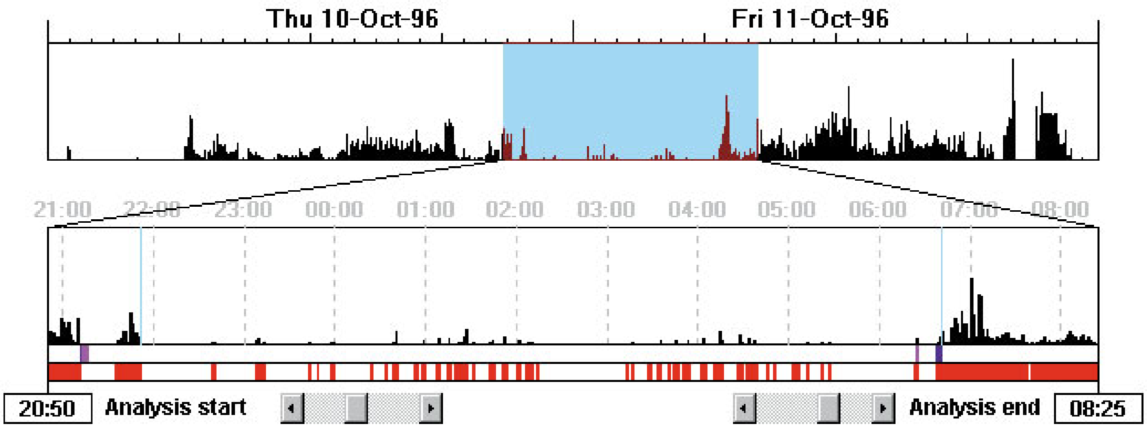


Figure 33. Mini Mitter Actiware Software 3.4 Sleep Analysis (From: Actiwatch Software, Actiware-Sleep 2005).

Each subject's sleep period was analyzed using the Actiware Software Sleep Analysis section. The scale setting in the Sleep Analysis section was set to 200. Actiware-Sleep 3.4 also allows the user to analyze the subject's data for naps using the Nap Analysis section. Nap analysis for this study used the following settings: Minimum Nap 15, Maximum Nap 180 and Sensitivity 35.

## D. PROCEDURE

Noise data were gathered in five berthing spaces using Quest Q300 noise dosimeters. Temperature and humidity information was gathered using five Testo 175H1 temperature and humidity monitors. Light information was obtained in two berthing spaces using Mini Mitter Actiwatch-L's. Ship motion accelerometers were not activated for this phase of the study, although wave height and weather data were obtained for each day to approximate ship motion. Additionally, an Actiwatch-L was placed on the PORT side of the messdecks to provide another indicator of ship motion. Sleep information was gathered from 21 sailors of the HSV-2 SWIFT blue crew using Mini Mitter Actiwatch-L's and Actiwatch-64's, worn on their non-dominant hand. All instruments were programmed for one minute epochs and set for Greenwich Mean Time. The Quest Q300's, Testo 175H1's and Actiwatch-L's (measuring light in berthing spaces) were placed on top of lockers (Figure 34) in the berthing areas; this allowed for a location that was out of the way of the crew's daily activities, but that still permitted access to the desired information. Figure 35 displays the berthing areas in which the measuring equipment was placed.

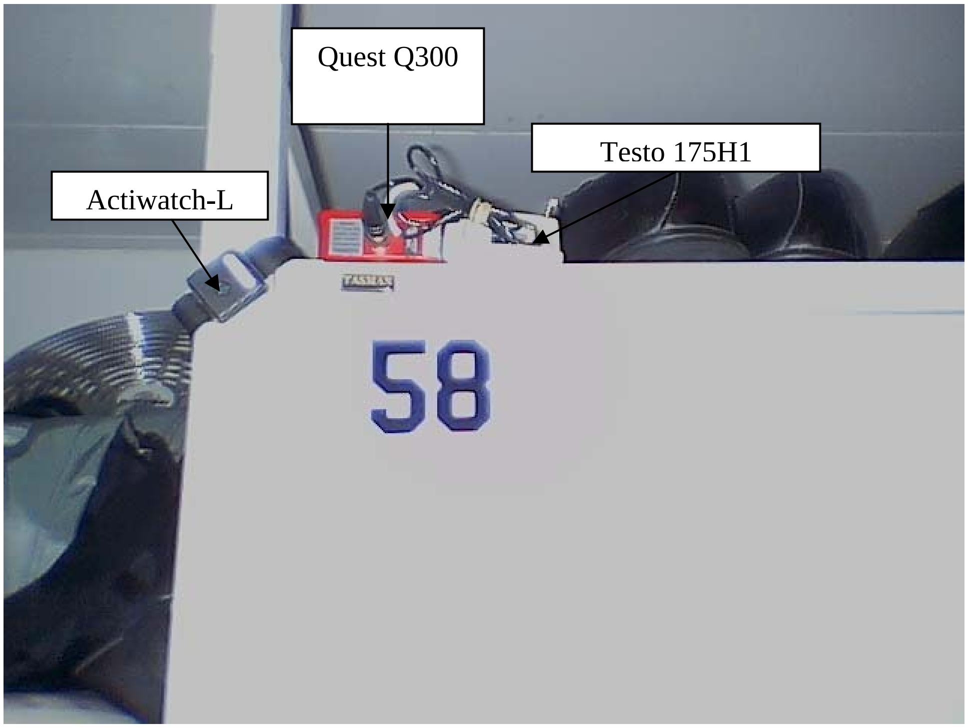


Figure 34. Equipment location

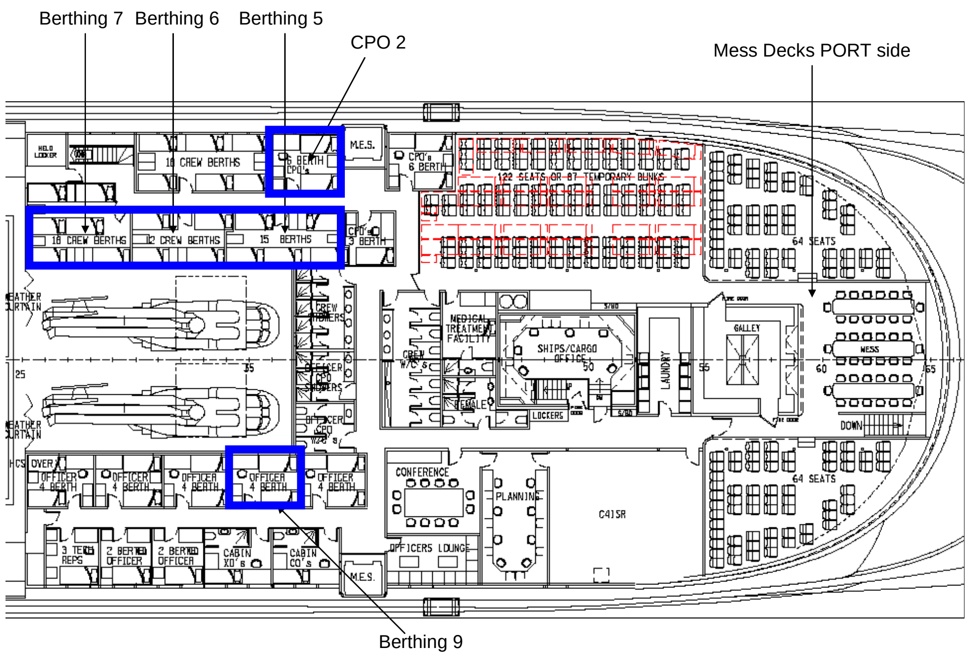


Figure 35. Spaces where measuring equipment were located (After: Morrison, 2004)

Data were gathered during Gulf of Mexico Exercise (GOMEX) 05-1, conducted in the vicinity of Naval Surface Warfare Center (NSWC) Panama City, FL, December 2004. GOMEX 05-1 was a mine warfare exercise that graduated mine countermeasures squadron staff and ships to deployment ready status. GOMEX 05-1 included air, surface and explosive ordnance disposal (EOD) assets. SWIFT was used as the mine countermeasures command flagship and coordinated the movements of the other participants in the exercise (Naval Support Activity, 2005).

On December 3, 2004, the day SWIFT was underway for GOMEX, two Human Systems Integration (HSI) students from the Naval Postgraduate School (NPS) gathered the participants on the Mess Decks to explain the reason and procedures for the study, distributed Internal Review Board (IRB) consensus forms and issued Mini Mitter Actiwatches. In addition, participants were asked to fill out a Pre-Emarkation Survey that asked for demographic and historic information regarding fatigue and motion onboard SWIFT.

Participants were asked to wear the Actiwatches continuously for the duration of the study and were given two sets of questionnaires to fill out. One questionnaire, the Environmental Questionnaire, asked participants to list the environmental factors that affected their sleep for each sleep period. The Questionnaire Survey and Sleep Log asked participants daily questions of motion and fatigue and to log their sleep and wake times.

One participant dropped out of the study after two days. One participant did not return his actiwatch. One participant's actiwatch failed. Two participants removed their actiwatches when they slept. Three participants stopped wearing their actiwatches before the end of the study. Eleven participants returned Environmental Questionnaires. Fifteen participants returned Questionnaire Survey and Sleep Logs.

Each day, after Executive Officer's inspection of messing and berthing (approximately 1000 local time), data was downloaded from each noise dosimeter using QuestSuite Professional software to a Dell Inspiron 8200 laptop. Batteries were also changed in the noise dosimeters. Additionally, data from the Testo 175H1 temperature and humidity monitors were downloaded using Testo Comsoft Basic software to the laptop. The other equipment did not require daily downloads. In the berthing spaces, temperature controls were set and locked and dehumidifiers were installed and running.

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# IV. RESULTS

## A. INTRODUCTION

Sleep efficiency and average participant sleep were evaluated and are presented graphically. Sleep efficiency is defined as "an index of the amount of time in bed that is actually spent sleeping" (Actiwatch Instruction Manual, 2002, p. A-6). The value of sleep efficiency was determined by Mini Mitter Actiware Software Version 3.4 for a participant's sleep period. The values for average sleep are derived from the values of actual sleep calculated by Mini Mitter Actiware Software Version 3.4 for a participant's sleep period. Actual sleep is the amount of time scored by the Mini Mitter Actiware Software as sleep during a participant's sleep period (Actiwatch Instruction Manual, 2002, p. A-5). After the first day at sea, the participants in this study appeared to acclimatize to their at-sea schedule, averaging between 6 and 7 hours of sleep per day for the remainder of the exercise. Sleep efficiency was nearly constant throughout the exercise, averaging 78.86%, varying among participants between a low of 76.77% and a high of 81.68%.

Analysis was also conducted with demographic data. Average values of the environmental variables measured while the participants slept were also included in the analysis to examine possible relationships between the demographic and dependent variables. The five dependent variables examined during this analysis were the total sleep a participant received during the study, each participant's average sleep efficiency, the average amount of time each day a participant slept, the average amount of sleep periods per day and the average length of a participant's sleep period. Because the sample sizes were very small, the relationship between variables was studied by looking only at pairwise linear dependence via Pearson's test for correlation. Sea time was found to be highly correlated with the average amount of sleep a participant received during GOMEX 05-1 (p-value = .001 with sample correlation of -.778). For this particular data, the estimated average change in sleep is a drop of 11 minutes per year of sea time. Light was also found in this analysis to have a significant impact on participant sleep efficiency (p-value = .304 with sample correlation of -.703). From the regression model of light and participant sleep efficiency, we concluded that for every increase in light value, as measured in lux, the estimated average participant sleep efficiency dropped by 4%.

## B. SLEEP

### 1. Sleep Efficiency and Average Sleep

Figure 36 displays the average values of participant sleep and sleep efficiency. With the exception of participants 4, 5 and 15, there appears to be a relationship between participant average sleep and sleep efficiency. Participants 5, 12, 13, 18, 19 and 20 were able to maintain average sleep levels between 7 and 8 hours of sleep per day. Participants 4, 7, 8, 14 and 16 averaged between 6 and 7 hours of sleep per day. Participants 9 and 15 averaged between 5 and 6 hours of sleep per day. None of the differences in average sleep appear to be linked to berthing. Participants 4, 12, 14, 15, 16, 18 and 19 averaged between 80% and 89% sleep efficiency. Participants 5, 7, 13, 20 and 21 maintained between 70% and 79% sleep efficiency per day. Participant 18 averaged over 90% sleep efficiency during this study.

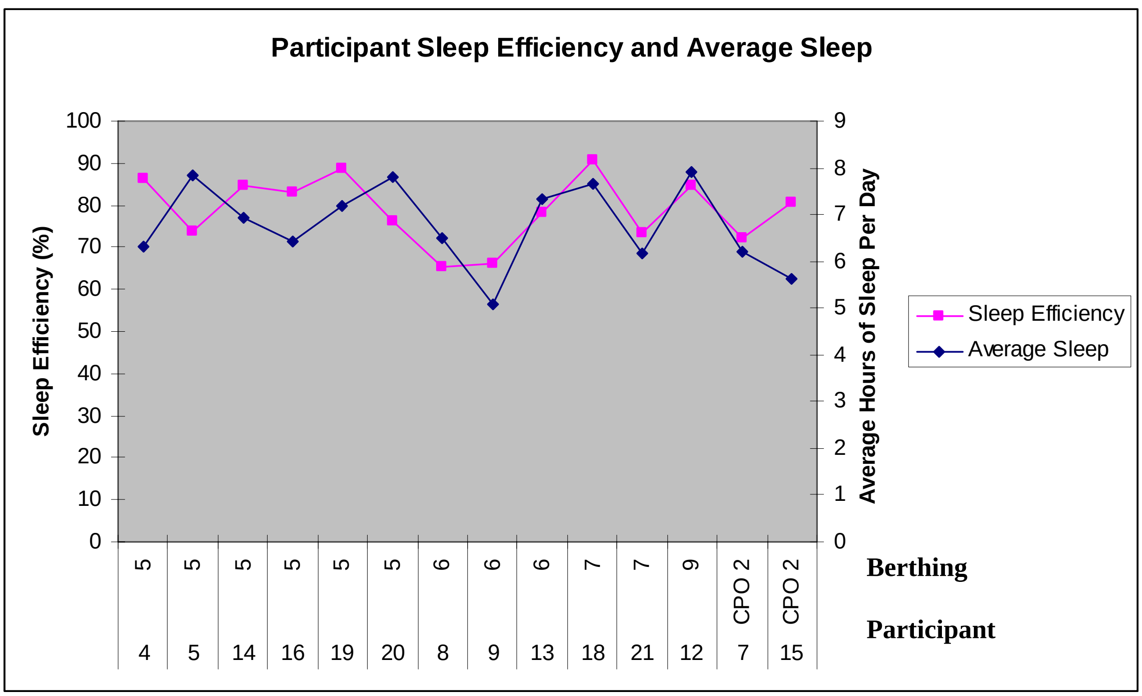



Figure 36. Participant Sleep Efficiency and Average Sleep

### 2. Average Sleep and Sleep Efficiency by Day

Figure 37 displays average participant sleep by calendar day underway (December, 2004). On December 4$^{th}$, average participant sleep was over 7 hours. However, over the next day, average sleep dropped down to 6.58 hours. After December 4$^{th}$, average participant sleep appeared to reach a steady state of between 6 and 7 hours per day, suggesting acclimatization by the participants to their at-sea schedule. On December 10$^{th}$ average sleep dropped down to 5.74 hours, but this value is low because participant 9 only obtained 2 hours of sleep that day. The value for December 11$^{th}$ only covers 12 hours due to completion that day of GOMEX 05-1. The average sleep obtained by the participants during the exercise was less than the 8 hours of sleep necessary to receive the full beneficial effects of sleep (Maas, 2001). The whiskers extended from each data point represent one standard deviation. The standard deviation of the data is approximately 1.5 hours across all days with the exception of December 7$^{th}$ and December 9$^{th}$ which had standard deviations of 0.8 and 0.7 hours, respectively.

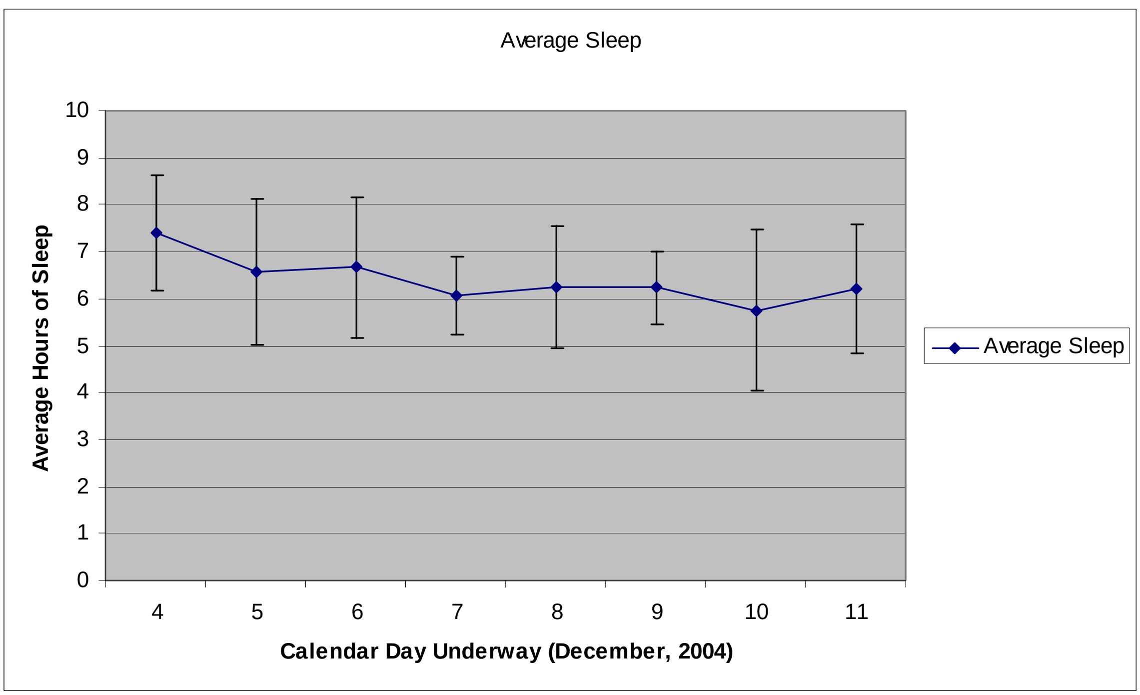



Figure 37. Average Sleep and Average Sleep +/- one Standard Deviation by Calendar Day

Figure 38 displays average participant sleep efficiency by calendar day underway (December, 2004). Sleep efficiency was nearly constant throughout the exercise, averaging 78.86%, varying among participants between a low of 76.77% and a high of 81.68%. The whiskers extended from each data point represent one standard deviation. The standard deviations varied between 7% and 12%.

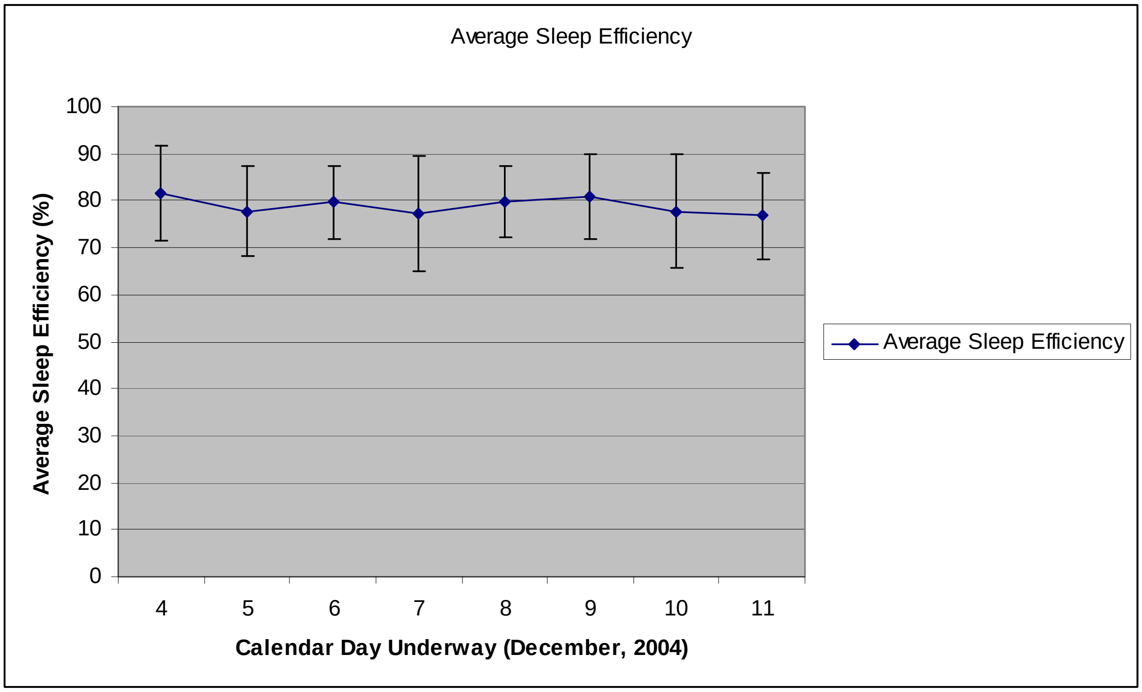



Figure 38. Average Sleep Efficiency and Average Sleep Efficiency +/- one Standard Deviation by Calendar Day

## C. DEMOGRAPHIC ANALYSIS

### 1. Introduction

This section discusses analysis conducted with demographic data. Average values of the environmental variables measured while the participants slept were also included in the analysis to examine possible correlations with the demographic and dependent variables. The five dependent variables examined during this analysis were the total sleep a participant received during the study, each participant's average sleep efficiency, the average amount of time each day a participant slept, the average amount of sleep periods per day and the average length of a participant's sleep period. We were not able to use total sleep time on three participants, 7, 12 and 16. Participants 7 and 16 removed themselves from the study after 5 and 3 days, respectively. Participant 12 removed his actiwatch during the study. Microsoft Excel and SPSS were used to evaluate the data. Pearson and Spearman correlation matrices were used to analyze the data. Table 7 summarizes the findings from the correlation matrices. Light was the only one of the environmental variables found to correlate with any of the dependent variables. Light correlated with Sleep Efficiency (correlation coefficient -0.703, p-value .034, two tailed). Light was also found to be correlated with berthing space (correlation coefficient 0.976, p-value .000, two tailed). The variable light was only measured in two berthing spaces, 5 and 6, due to equipment availability. The average light value for berthing 5 (0.472 lux) was much lower than that for berthing 6 (3.38 lux). Berthing 5 also contained 6 participants while berthing 6 contained 3. It is due to these differences that care must be exercised in using this finding to draw any general conclusions.

The demographic variables of participant age, height, weight, sea time and rank were examined in this analysis. Sea time was found to be highly correlated with the total amount of sleep a participant received during GOMEX 05-1 (correlation coefficient -0.807, p-value .003, two tailed) and also the average sleep a participant received during the exercise (correlation coefficient -0.778, p-value .001, two tailed). The dependent variables of average sleep time and total sleep time were found to be directly correlated (correlation coefficient 1, p-value .000, two tailed). We note that total sleep time had only 11 participants, due to participants 7, 12 and 16, mentioned above, while average sleep time was able to be measured for 14 participants. For this reason, average sleep time will be used to describe the interaction of participant sea time and sleep. The rest of the section describes the analysis in greater detail. Appendix B contains the correlation matrices used to analyze the data.

Table 7. Correlation Table Summary

| | Measures | Sleep Efficiency | Average Sleep | Total Sleep | Average Number of Daily Sleep Episodes | Average Length of Sleep Period |
|---|---|---|---|---|---|---|
| **Environmental** | Background Noise | - | - | - | - | - |
| | LPEAK Noise | - | - | - | - | - |
| | Relative Humidity | - | - | - | - | - |
| | Temperature | - | - | - | - | - |
| **Demographic** | Berthing | - | - | - | - | - |
| | Age | - | - | - | - | - |
| | Height | - | - | - | - | - |
| | Weight | - | - | - | | - |
| | PORT Motion | - | - | - | - | - |
| | Sea State | - | - | - | - | - |
| | Light | + | - | - | - | - |
| | Sea Time | - | + | + | - | - |
| | Rank | - | - | - | - | - |

### 2. Statistical Analysis

#### *a. Sea Time*

This finding that sea time is correlated with average participant sleep is similar to the findings of Belenky (n.d.) where it was discovered that the lower ranks and lower echelons of command received more sleep than higher ranks and higher echelons of command. We explore this relationship in a bit more detail.

Figure 39 is a scatterplot of participant sea time vs. their daily average sleep. The scatterplot also shows a linear relationship between the two variables and an $R^2$ value of .606. The two curved lines on either side of the linear model indicate the 95% confidence limits for the expected average sleep.

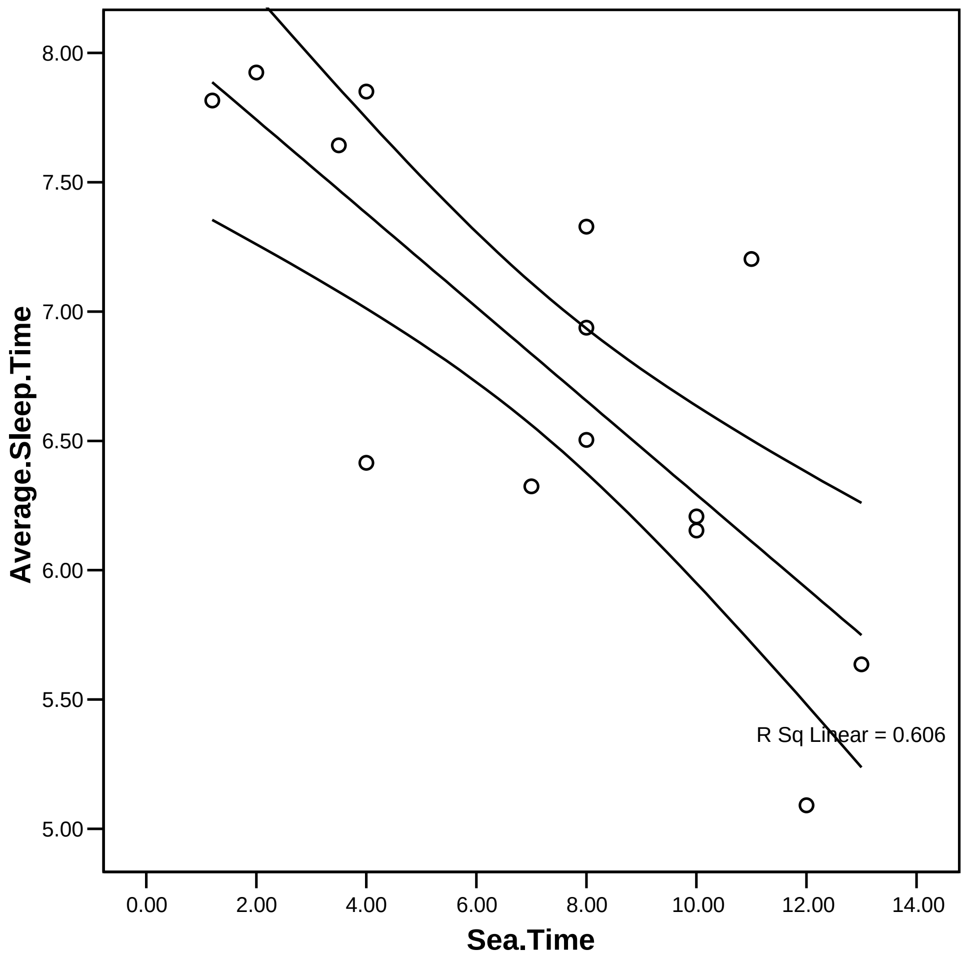



Figure 39. Scatter Plot of Sea Time vs. Average Sleep

Linear regression was then run in SPSS. The estimated slope is -.181 with a standard error of .042. It has an $R^2$ value of .606 which indicates that sea time accounts for 60.6% of the variability of average sleep for this data.

***b. Light***

Figure 40 is a scatterplot of participant light exposure vs. their daily average sleep efficiency. The scatterplot shows a linear relationship between the two variables and an $R^2$ value of .495. The two curved lines on either side of the linear model indicate the 95% confidence limits around the expected average sleep efficiency of the data. The red circle contains the values of the participants in berthing 5. The blue circle contains the values of the participants in berthing 6. The values for participants 8 and 9 are indicated in green. You can clearly see the differences between the berthing spaces. It appears that the values for participants 8 and 9 are driving the model. This plot underscores the fact that care must be taken when interpreting these results. It is not clear whether the decrease in sleep efficiency is due to light or something else causing differences between berthing spaces 5 and 6.

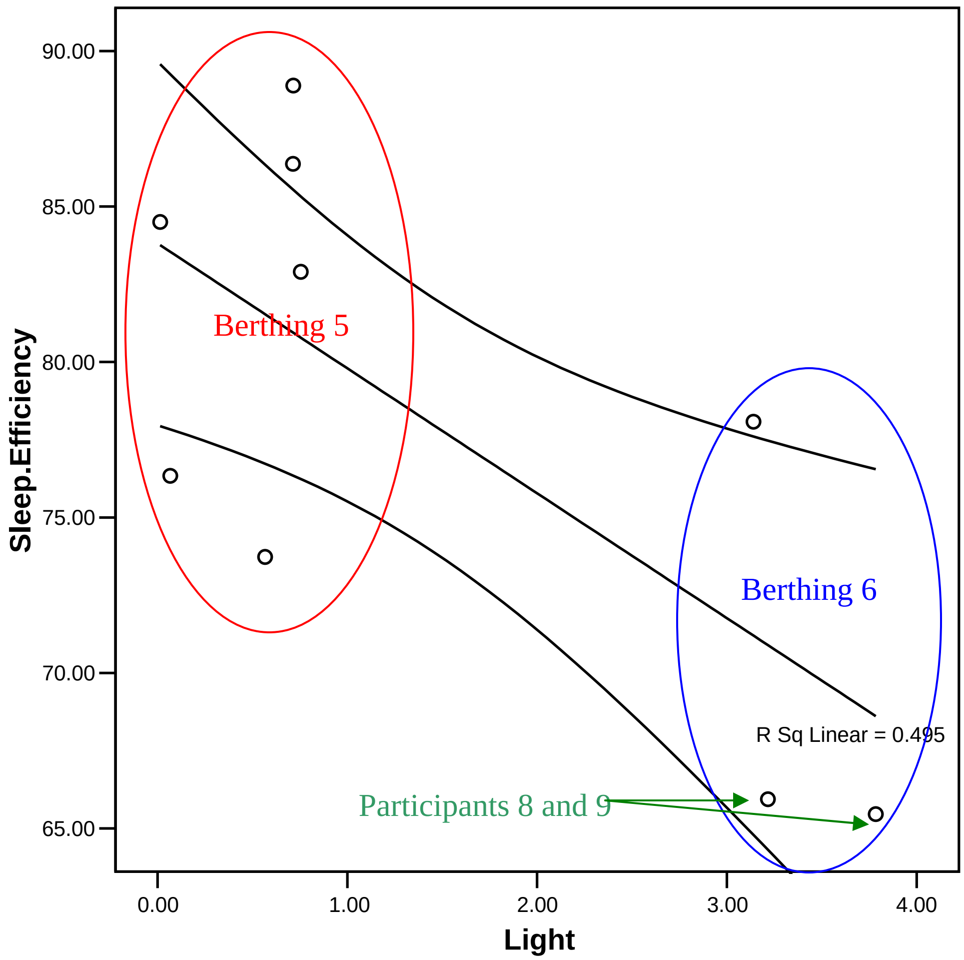



Figure 40. Scatter Plot of Light vs. Sleep Efficiency

Linear regression was then run in SPSS. The estimated slope is -4.02 with a standard error of 1.534. It has an $R^2$ value of .495 which indicates that light accounts for 49.5% of the variability of sleep efficiency for this data.

### *c. Participants 8 and 9*

After observing that participants 8 and 9 appeared to be driving the interaction between light and sleep efficiency, we wanted to take a closer look at these two participants. Table 8 is a summary of the independent, demographic and dependent variables examined for this section for all participants compared to participants 8 and 9. Participant 8 had higher than average values for background noise, LPEAK noise, relative humidity, light, age, sea time, weight and average number of daily sleep episodes. Participant 8 had average or lower than average values for the variables temperature, PORT motion, sea state, rank, height, sleep efficiency, total sleep time, average sleep time and average length of sleep period. Participant 9 had higher than average values for background noise, LPEAK noise, relative humidity, PORT motion, sea state, light, age, and sea time. Participant 9 had average or lower than average values for the variables temperature, rank, height, sleep efficiency, total sleep time, average sleep time, average number of daily sleep episodes and average length of sleep period. For participant 8, the variable light is clearly the greatest in percentage difference between the values of all participants and participant 8. For participant 9, both the variables light and PORT motion show the greatest in percentage difference between the values of all participants and participant 9. These observations are highlighted in yellow and bolded in Table 8.

Table 8. Average Values of Variables for Participants 8 and 9

| Independent Variables | Average Values for all Participants | Values for Participant 8 | Values for Participant 9 |
|---|---|---|---|
| Background Noise | 55.464 | 57.367 | 57.275 |
| LPEAK Noise | 89.057 | 90.601 | 90.512 |
| rH | 64.748 | 69.88 | 71.144 |
| Temperature | 66.782 | 63.337 | 62.921 |
| **PORT Motion** | **0.679** | 0.399 | **1.914** |
| Sea State | 3.051 | 3.051 | 3.126 |
| Age | 33.93 | 35 | 35 |
| **Light** | **1.441** | **3.785** | **3.216** |
| Rank | E6 | E6 | E6 |
| Sea time | 7.264 | 8 | 12 |
| Height | 70.43 | 70 | 70 |
| Weight | 196.86 | 215 | 190 |
| Sleep Efficiency | 78.863 | 65.46 | 65.94 |
| Total Sleep Time | 50.785 | 48.78 | 38.18 |
| Average Sleep Time | 6.788 | 6.504 | 5.091 |
| Average Number of Daily Sleep Episodes | 1.297 | 1.73 | 1.07 |
| Average Length of Sleep Period | 5.399 | 3.76 | 4.76 |

## G. CONCLUSION

With moderate weather, the ranges of the majority of the independent variables were limited and statistical analysis was restricted to descriptive statistics. The first day at-sea the participants averaged over 7 hours of sleep. After the first day at sea, the participants averaged between 6 and 7 hours of sleep per day for the majority of the exercise. This inadequate amount of sleep was also displayed in the participants average sleep efficiency scores. Sleep efficiency was nearly constant throughout the exercise, averaging 78.86%, varying among participants between a low of 76.77% and a high of 81.68%.

Analysis of the demographic variables investigated whether demographic factors and the averaged values of the environmental variables affected participant sleep. Sea time was found to be highly correlated with the average amount of sleep a participant received during GOMEX 05-1.

# V. DISCUSSION AND RECOMMENDATIONS

## A. DISCUSSION

### 1. Methodology

This thesis addressed the question of whether the shipboard environmental effects of noise, temperature, humidity, motion and light impact the sleep patterns of the crew of HSV-2 SWIFT. Unfortunately, due to the limited range in the environmental conditions and the small number of participants, this question could not be answered. However, this study does discuss a methodology from which a more robust study can be formulated to analyze these environmental effects on sleep.

To conduct a more vigorous study, measurements of the environmental effects of noise, temperature, humidity, motion and light should be measured in disparate locations, under varying conditions, with a greater number of participants and, if possible, across multiple platforms. This would increase the amount and range of the data to allow for a more powerful statistical approach than descriptive statistics.

With the emphasis the US Navy is putting in fielding emerging hull forms with reduced size crews, like those of LCS and SWIFT, it is important that additional research be conducted to evaluate the effects of these environmental factors on sleep onboard these ships. Comparing the results obtained from analyzing an emerging ship design against a conventional hull form, like those of a destroyer or frigate, would yield comparative data and allow for a better understanding of their differences.

### 2. Analysis

The first day at-sea the participants averaged over 7 hours of sleep. After the first day at sea, the participants averaged between 6 and 7 hours of sleep per day for the remainder of the exercise. This average sleep was less than the 8 hours of sleep necessary to receive the full beneficial effects of sleep (Maas, 2001). This inadequate amount of sleep was also displayed in the participants average sleep efficiency scores. Sleep efficiency was nearly constant throughout the exercise, averaging 78.86%, varying among participants between a low of 76.77% and a high of 81.68%. Averaging less than 8 hours of sleep a day will cause an increase in sleep debt. Sleep debt is the difference between an actual night's sleep and a full night's sleep (8 hours) and its effects are cumulative. This debt must always be repaid to fully recover from the period of sleep deprivation (Dement & Vaughan, 1999). Insufficient sleep can result in reduced performance, concentration, reaction times and memory consolidation. Deficient sleep can produce increased memory lapses, accidents, injuries, behavior problems and mood problems (National Heart, Lung, and Blood Institute, 2004). Human performance is not always affected by short sleep periods, but there is a cumulative effect (Matthews et al., 2000). It is possible that in a MIW operation or exercise greater in length than GOMEX 05-1, you would witness a decrease in the performance of the crew of the SWIFT. While physical tasks are relatively unchanged by periods of sleep deprivation, cognitive tasks are greatly affected (Belenky et al., 1987; How et al., 1994). With an increase in sleep deprivation among the crew of the SWIFT while coordinating the movements of other US Navy warships in a MIW exercise or operation, mistakes could be made that adversely impact the exercise or operation.

Analysis of the demographic variables investigated whether demographic factors and the averaged values of the environmental variables affected participant sleep. Pearson product moment of correlation was the only test that provided for the accuracy and variability needed for this analysis. From the model of sea time and average participant sleep we concluded that for every year of sea time a participant had, his sleep dropped by approximately 11 minutes per day. This finding is similar to the findings of Belenky (n.d.) where it was discovered that the lower ranks and lower echelons of command received more sleep than higher ranks and higher echelons of command. This was a troubling, but not unexpected finding. Shay (1998) discusses the myth of self-deprivation (including sleep) in military organizations. The ethos of self deprivation in the military can lead to death and serious injury and is therefore dangerous for the men and women serving beneath the individuals in the military who follow it. As has been discussed above, cognitive ability is greatly affected by sleep deprivation (Belenky et al., 1987; How et al., 1994). The very people the military depends upon to make clear and effective decisions are impaired by sleep deprivation. With the added emphasis being placed on reducing crew sizes onboard ships and the increased workload demanded by the asymmetric nature of the Global War on Terror (GWOT), it is important that considerations for sleep be made for military leaders.

Light was also found in this analysis to have a significant impact on participant sleep efficiency. From the model of light and participant sleep efficiency, we concluded that for every increase in light value, as measured in lux, participant sleep efficiency dropped by 4%. Exposure to light affects sleep (Lewy, et al., 1980; Czeisler et al., 1989; Boivin, et al., 1994; Cauter & Buxton, 2000; Duffy, et al., 1996; Czeisler et al., 1989; Mitchell et al., 1997). Light exposure affects sleep through the inhibition of melatonin secretion in humans (National Institute of Neurological Disorders and Stroke, 2005). Melatonin is a naturally occurring hormone that induces sleep (Maas, 2001). Additionally, circadian rhythms can shift with exposure to light (Czeisler et al., 1989, 1994). Circadian rhythms are "an intricate and orderly series of psychological and physiological changes that occur approximately every twenty-four hours" (Maas, 2001, p. 46). Disturbances in circadian rhythms often result in disturbances in sleep (Arendt, 2000). A US Navy warship's daily schedule determines when lighting in berthing spaces is either on or off. Additionally, the brightest lights onboard may be in the bunk spaces (Hunt & Kelley, 1995). Environmental determinants of light exposure in the berthing spaces have been found to affect the sleep of the SWIFT's crew and underline the importance of further research into this area.

## B. RECOMMENDATIONS

### 1. Lessons Learned

#### *a. Extreme Environments*

Due to ship availability, this study was conducted in the Gulf of Mexico during the winter. Future studies should be conducted in more extreme locales, such as the North Atlantic, where the effect of an independent variable upon sleep may be more easily identifiable.

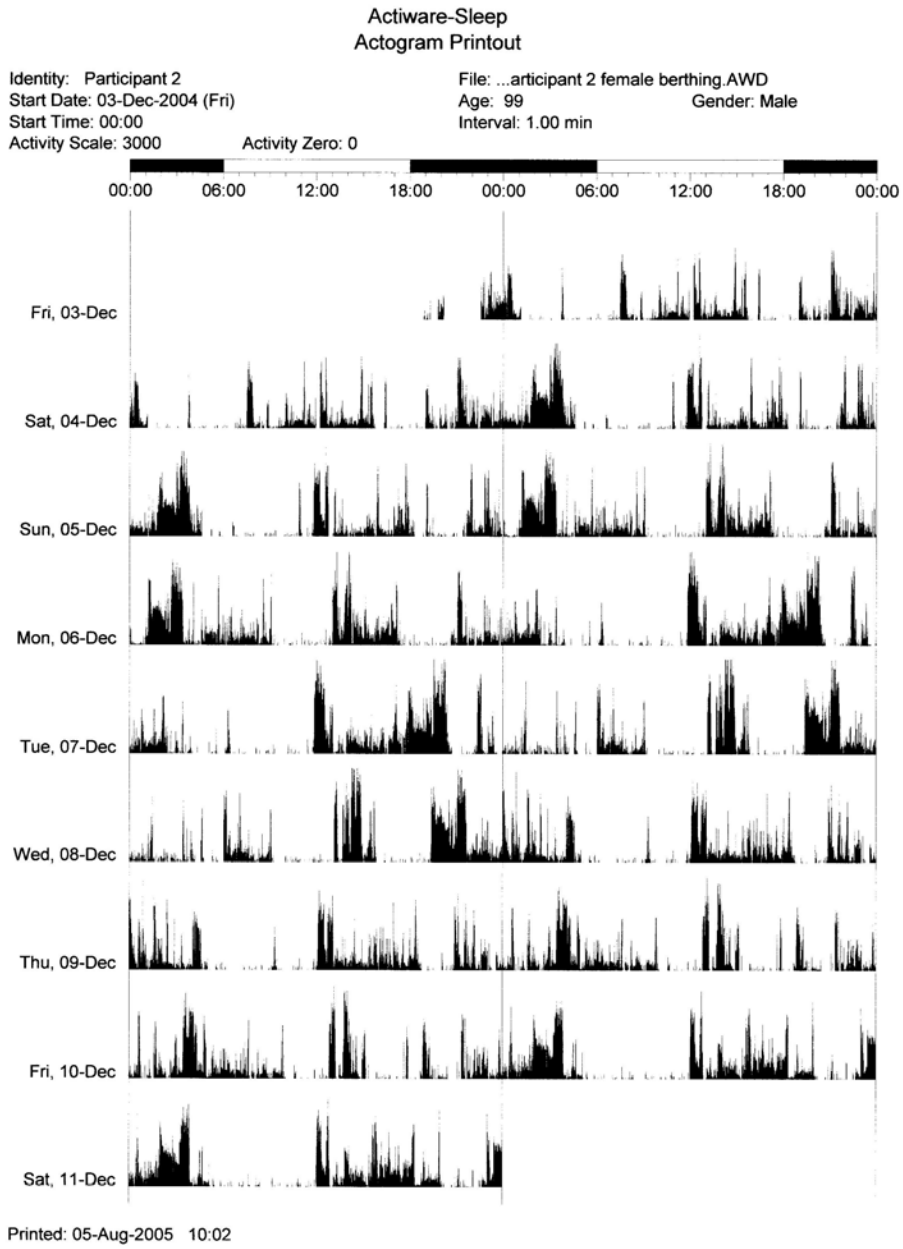
#### *b. Equipment*

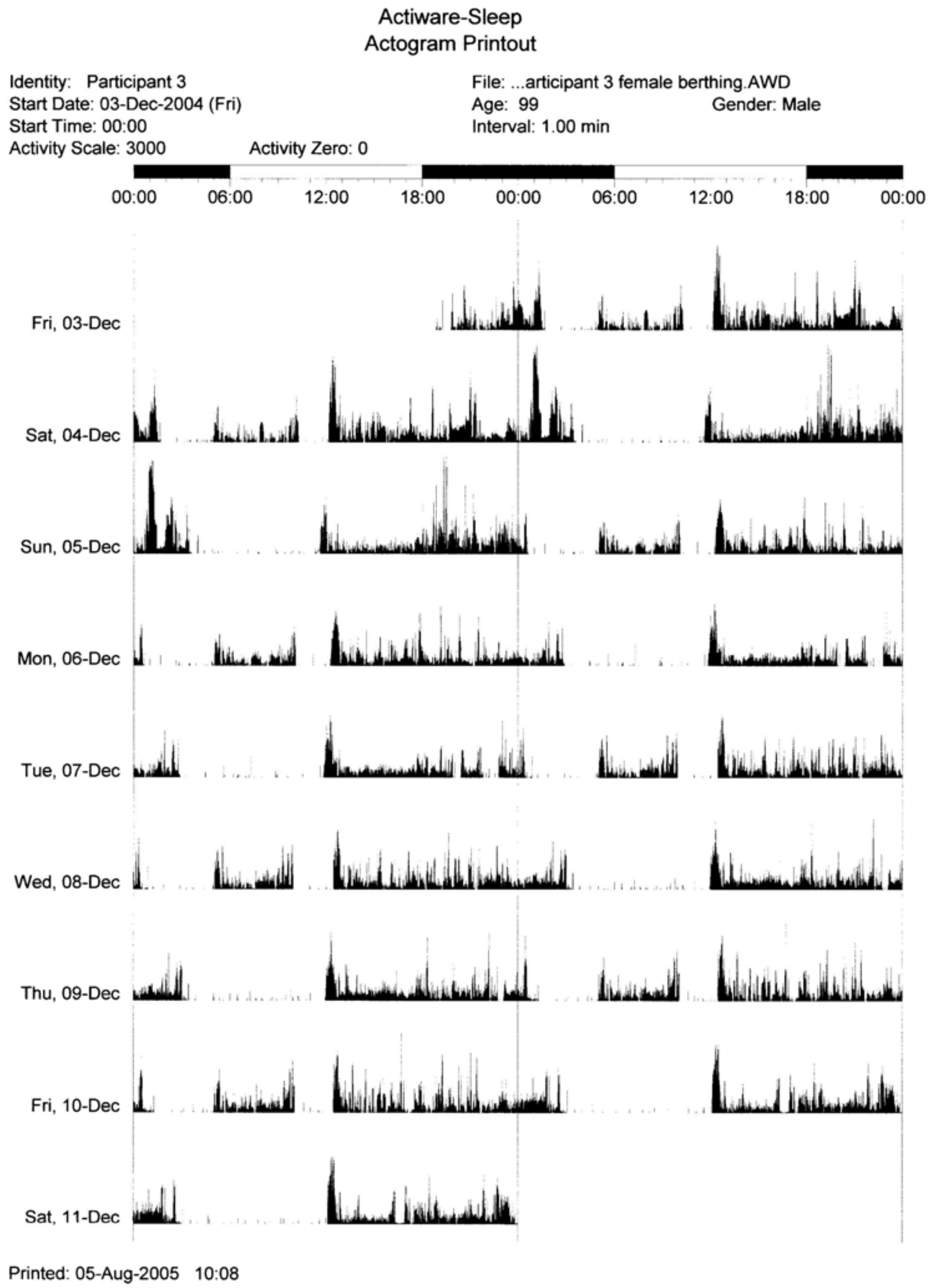
Equipment availability also constrained the range of this study. Placing additional noise dosimeters, temperature and humidity monitors and actiwatches in more berthing spaces would have allowed for a more complete study. It is further recommended that a noise survey of the ship be conducted prior to the experiment to identify possible noise sources.  Noise dosimeters can then be placed in areas with suspected noise offenders, such as engineering spaces, to identify noise sources responsible for sleep disruption and to correlate this information with noise dosimeters in the berthing spaces.  Motion accelerometers should also be used to collect ship motion data.  This information can then be used together with weather observations to better identify the effects of ship motion on sleep.

### 2. Future Research

A combination of environmental and personal factors will affect the sleep of sailors and marines living onboard US Navy warships.  Sleep deprivation will more likely occur in more extreme operational conditions than seen in this study.  For this reason, further studies should be conducted in extreme operational environments, such as those found in the Arabian Gulf during summer.  Additionally, studies such as the one discussed in this thesis should be completed on different platforms to determine the differences in environmental factors that affect sleep between hull types so that the results can be applied to future vessel design.

# APPENDIX A. ACTOGRAMS

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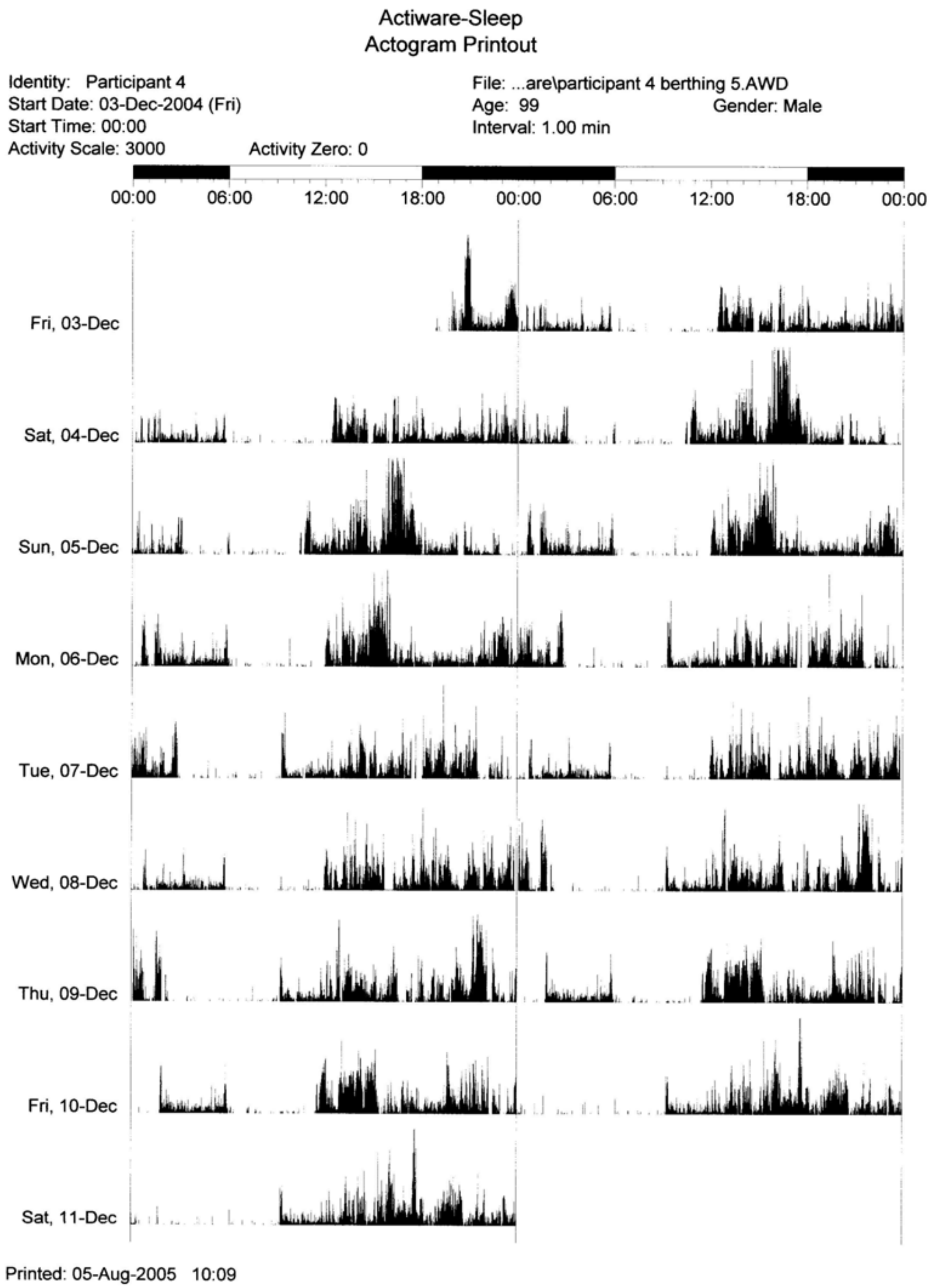
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Gender: Male
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06:00
12:00
18:00
00:00
06:00
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18:00
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Sat, 04-Dec
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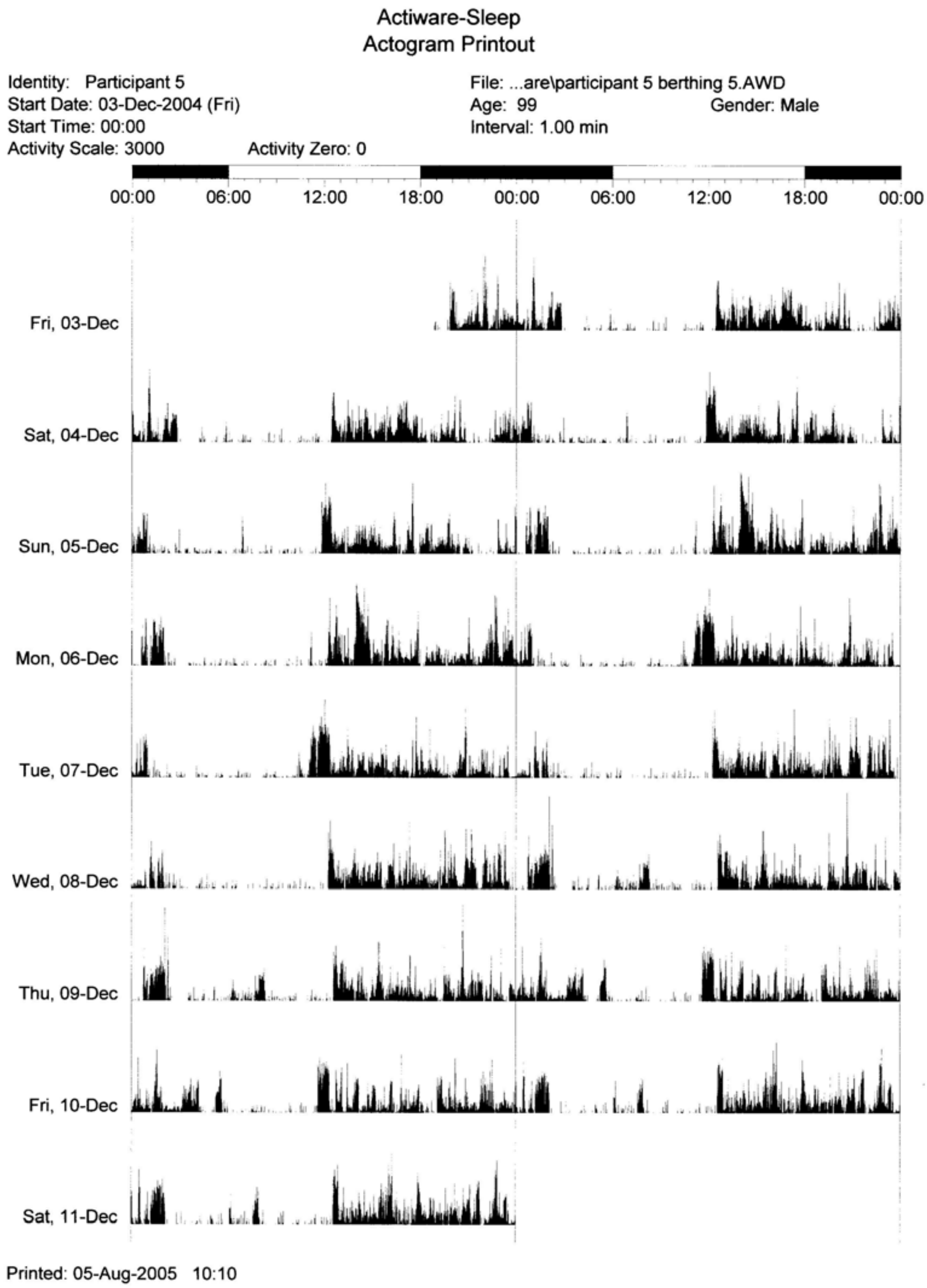
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Gender: Male
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06:00
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06:00
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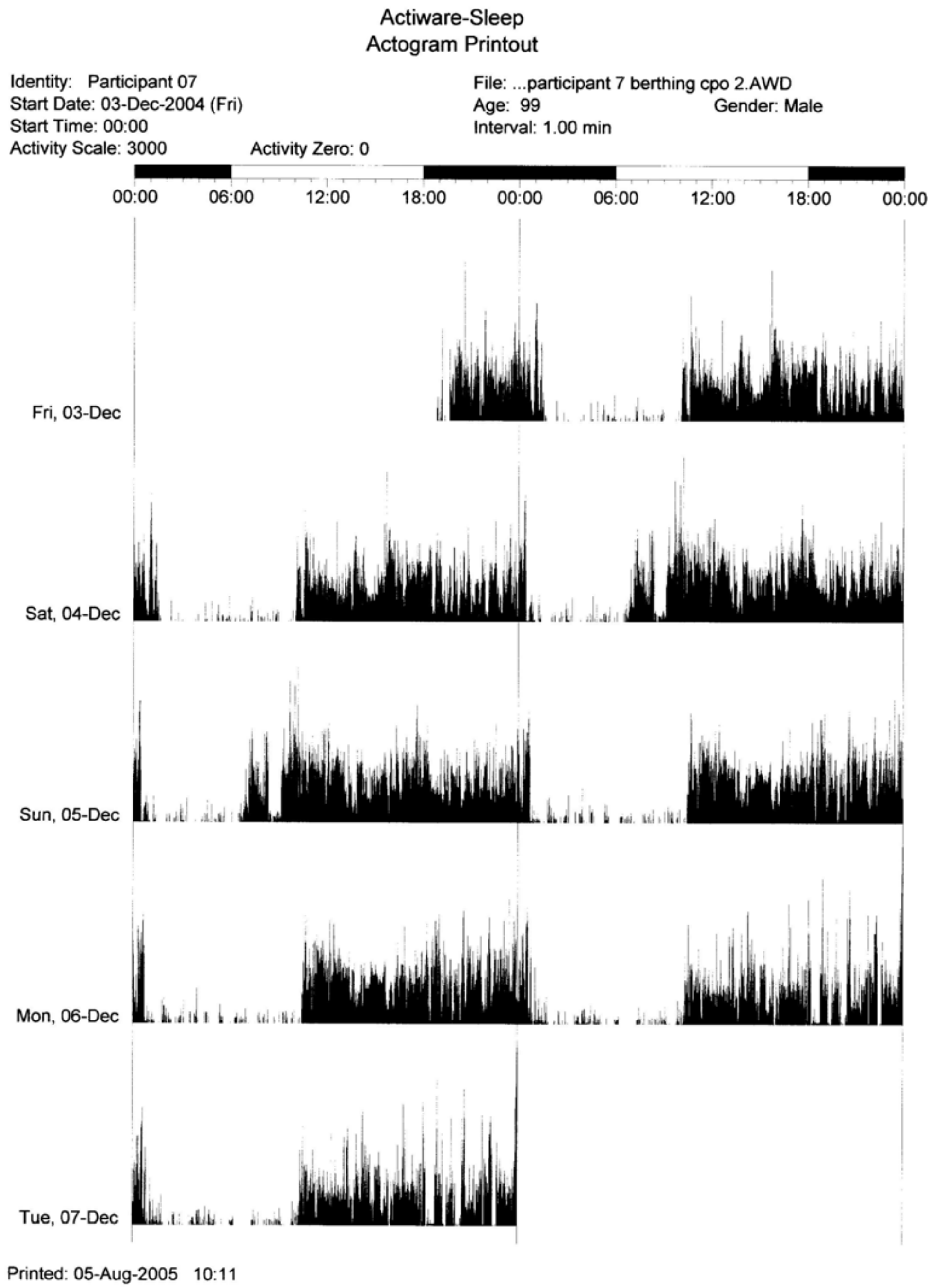

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Age: 99
Gender: Male
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06:00
12:00
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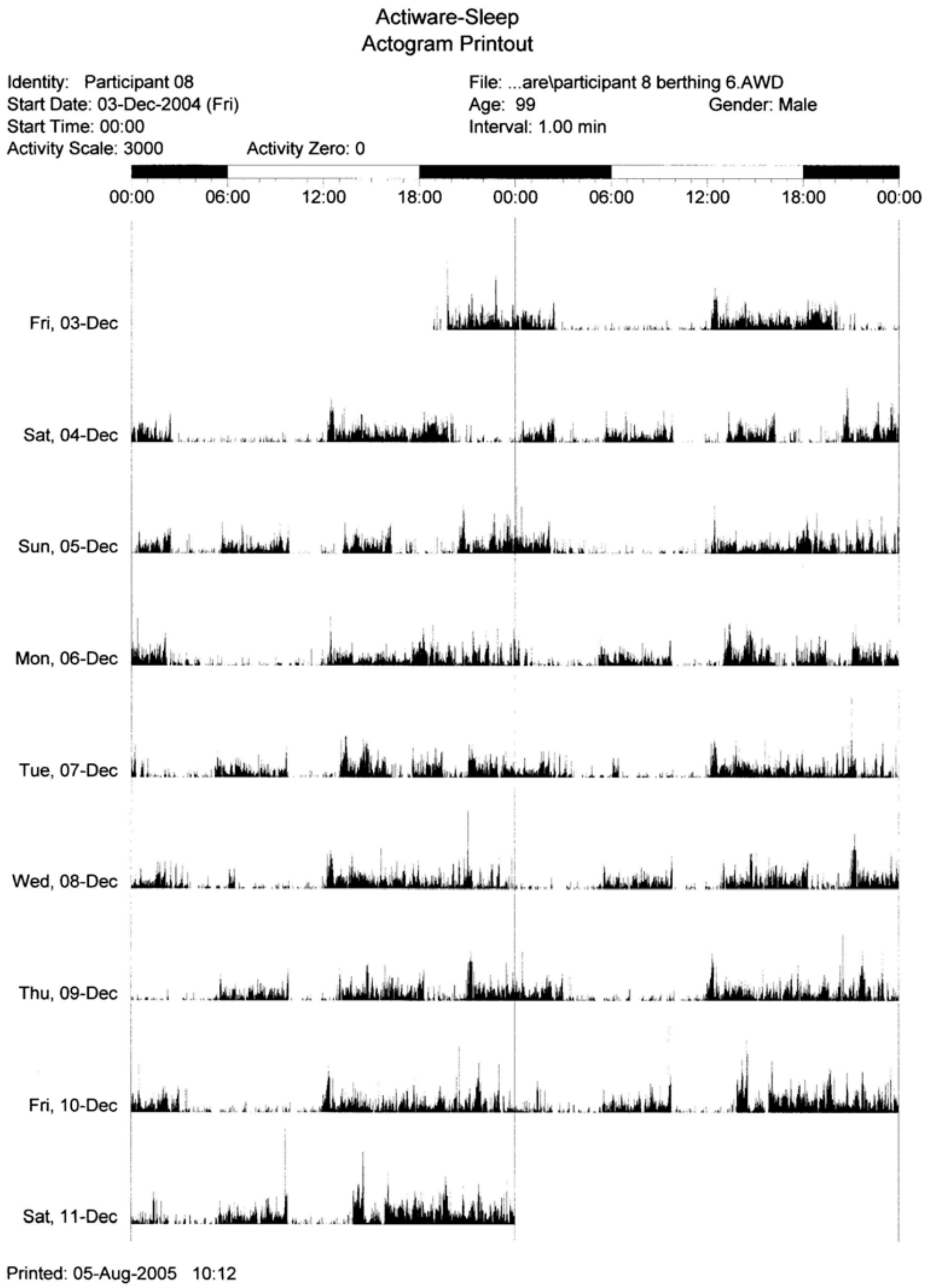
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Interval: 1.00 min
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06:00
12:00
18:00
00:00
06:00
12:00
18:00
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Thu, 09-Dec
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Sat, 11-Dec
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Actiware-Sleep
Actogram Printout

Identity: Participant 09
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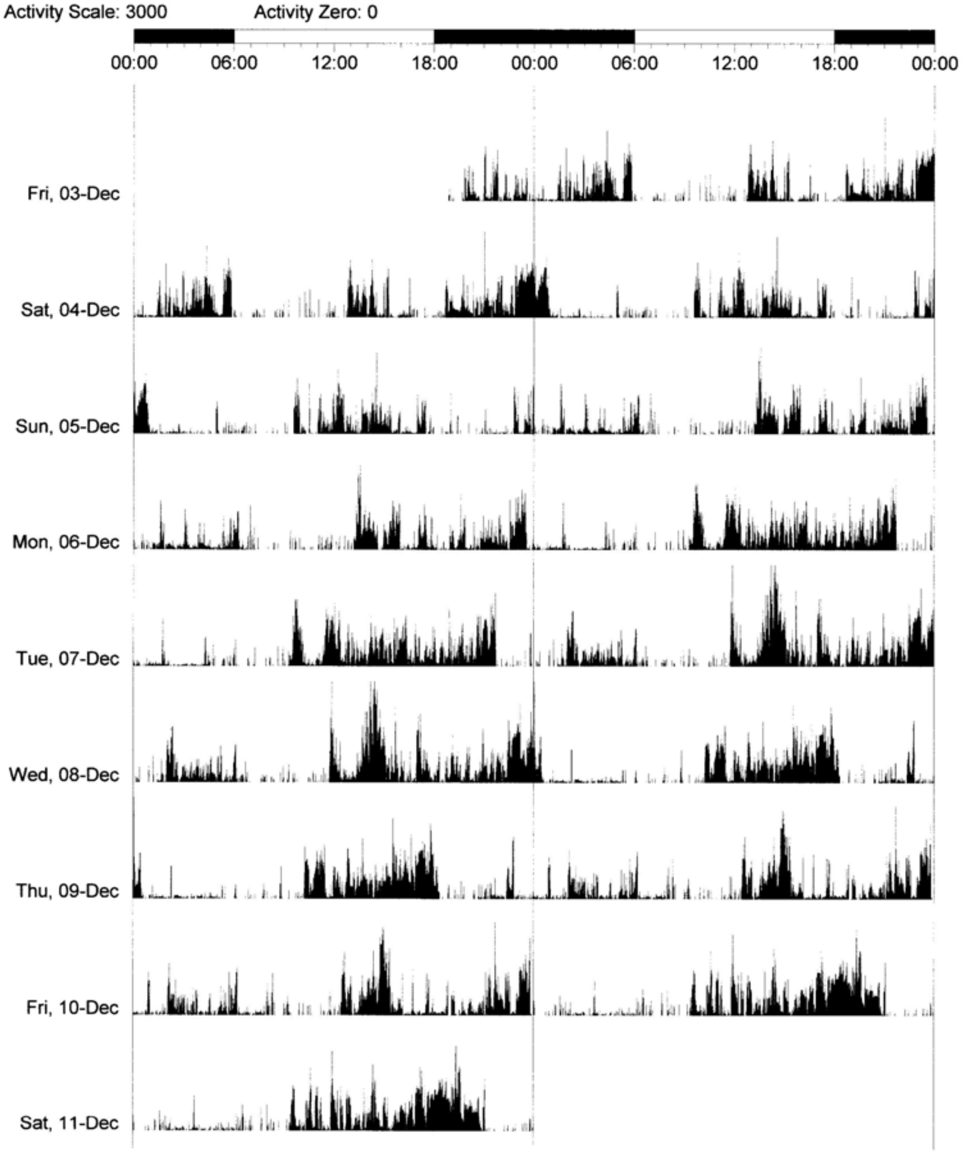
Interval: 1.00 min

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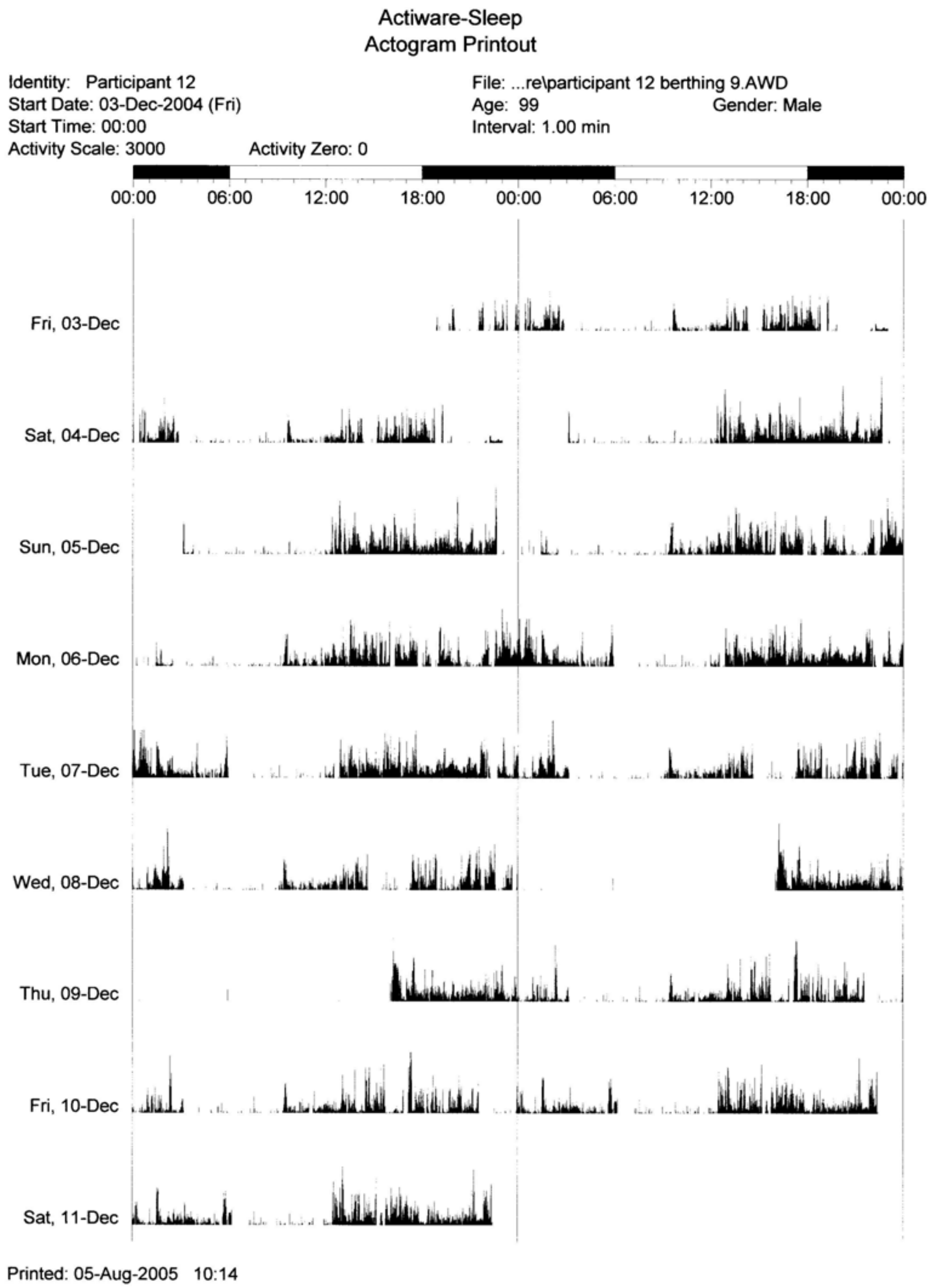

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Gender: Male
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06:00
12:00
18:00
00:00
06:00
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18:00
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Fri, 03-Dec
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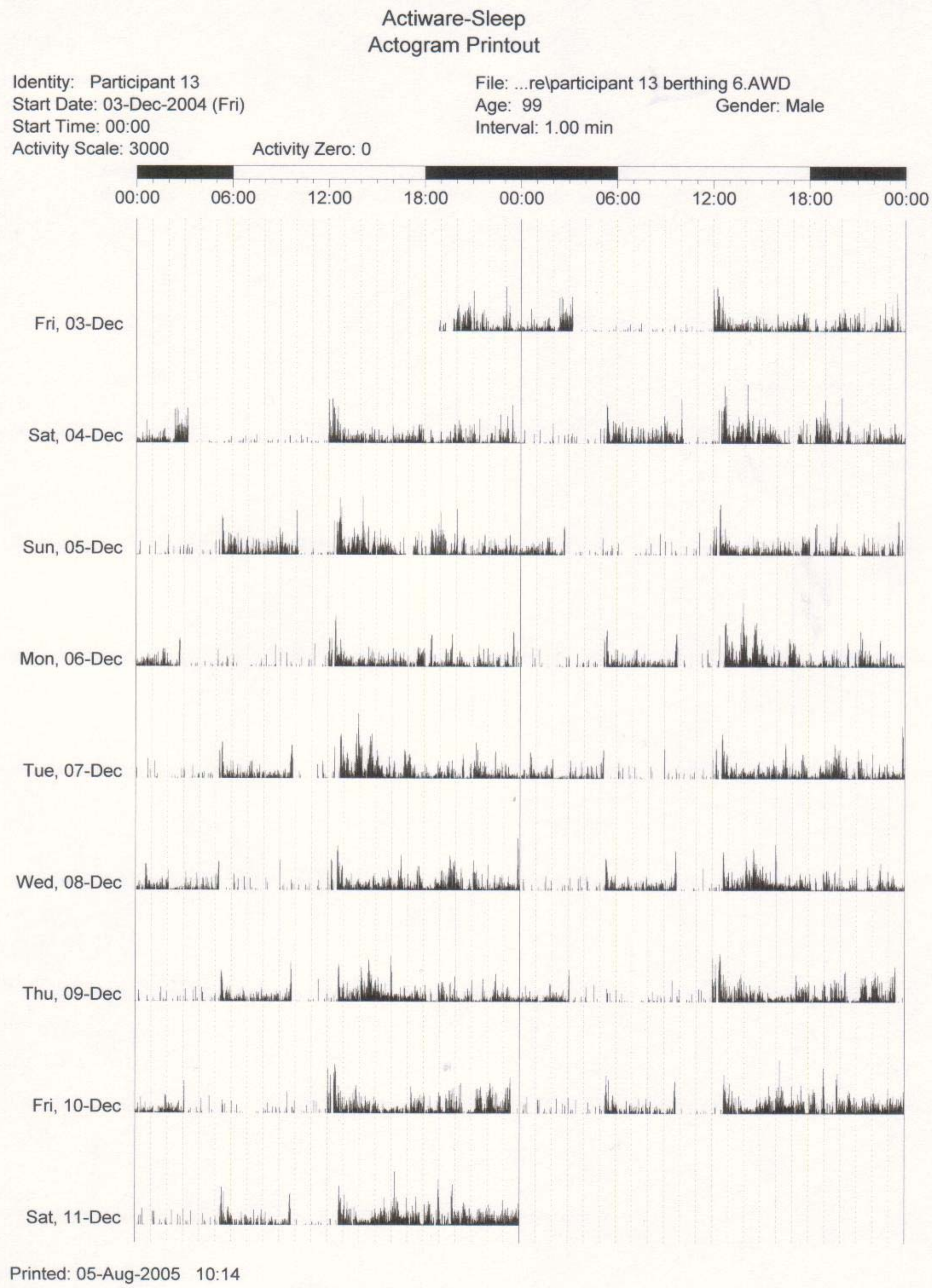
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Gender: Male
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06:00
12:00
18:00
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06:00
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Fri, 03-Dec
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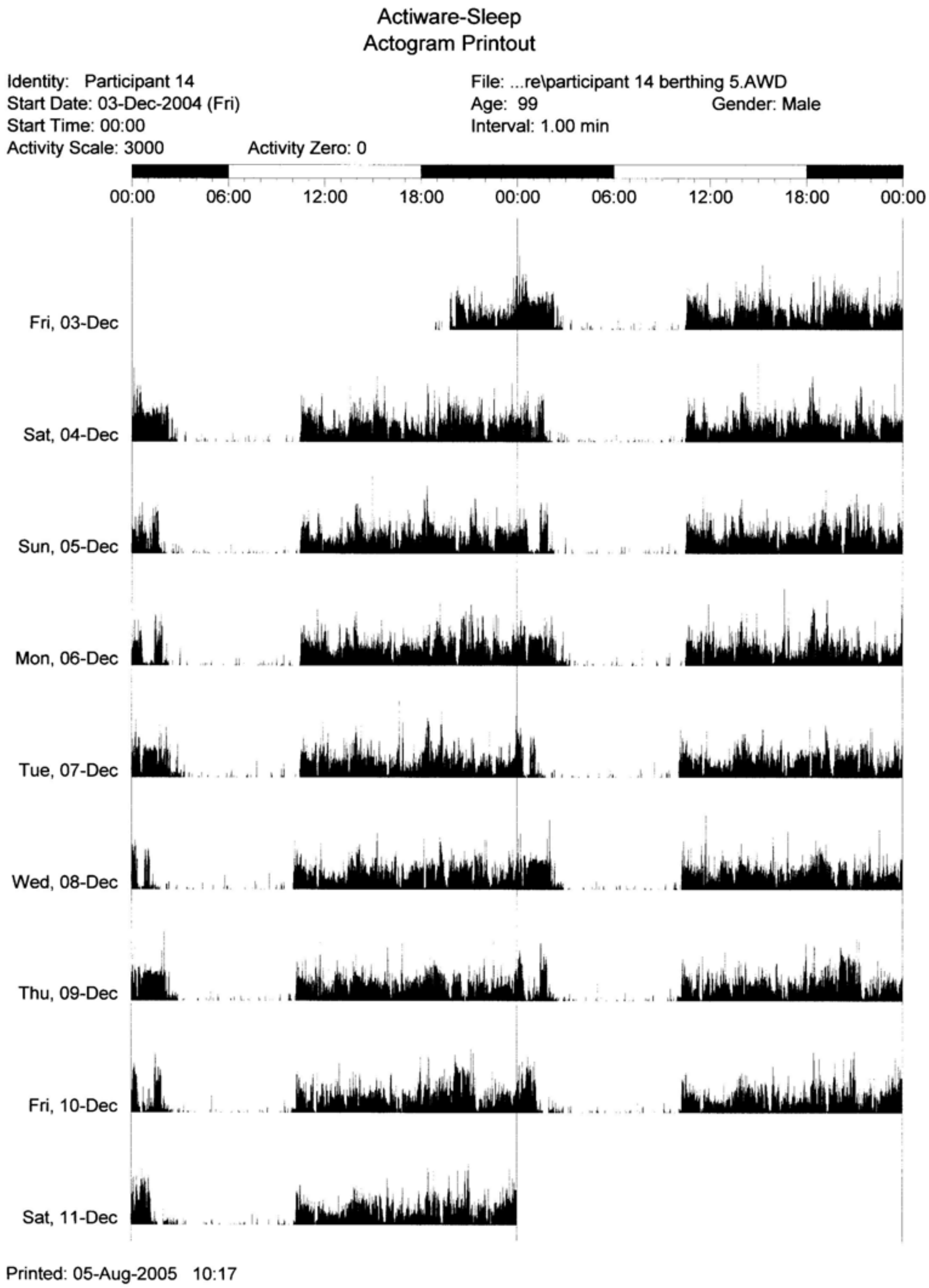
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Age: 99
Gender: Male
Interval: 1.00 min
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06:00
12:00
18:00
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06:00
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Tue, 07-Dec
Wed, 08-Dec
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Actiware-Sleep
Actogram Printout

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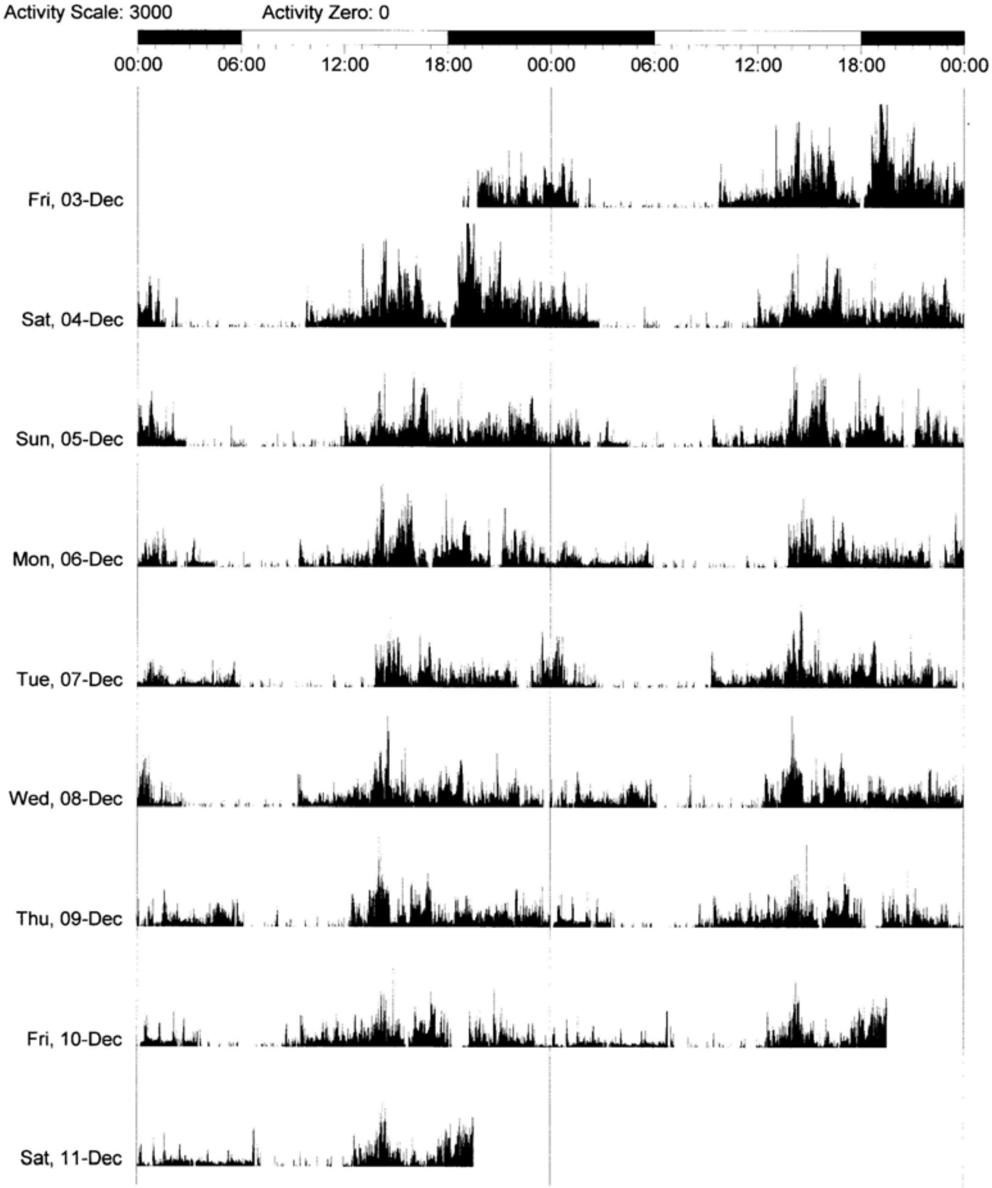
Interval: 1.00 min

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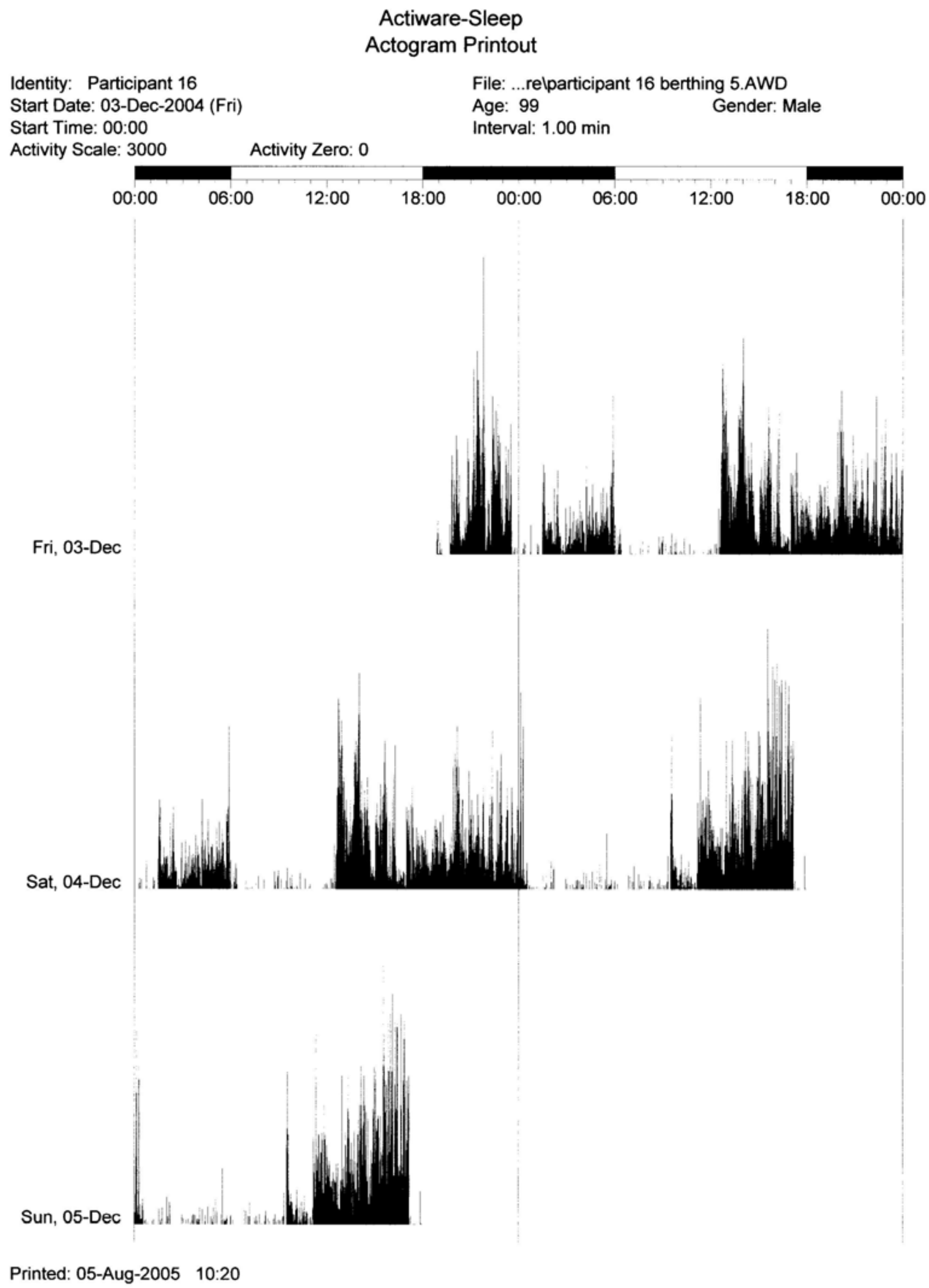
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Gender: Male
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Interval: 1.00 min
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Activity Zero: 0
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06:00
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00:00
Fri, 03-Dec
Sat, 04-Dec
Sun, 05-Dec
Printed: 05-Aug-2005 10:20

Actiware-Sleep
Actogram Printout

Identity: Participant 18
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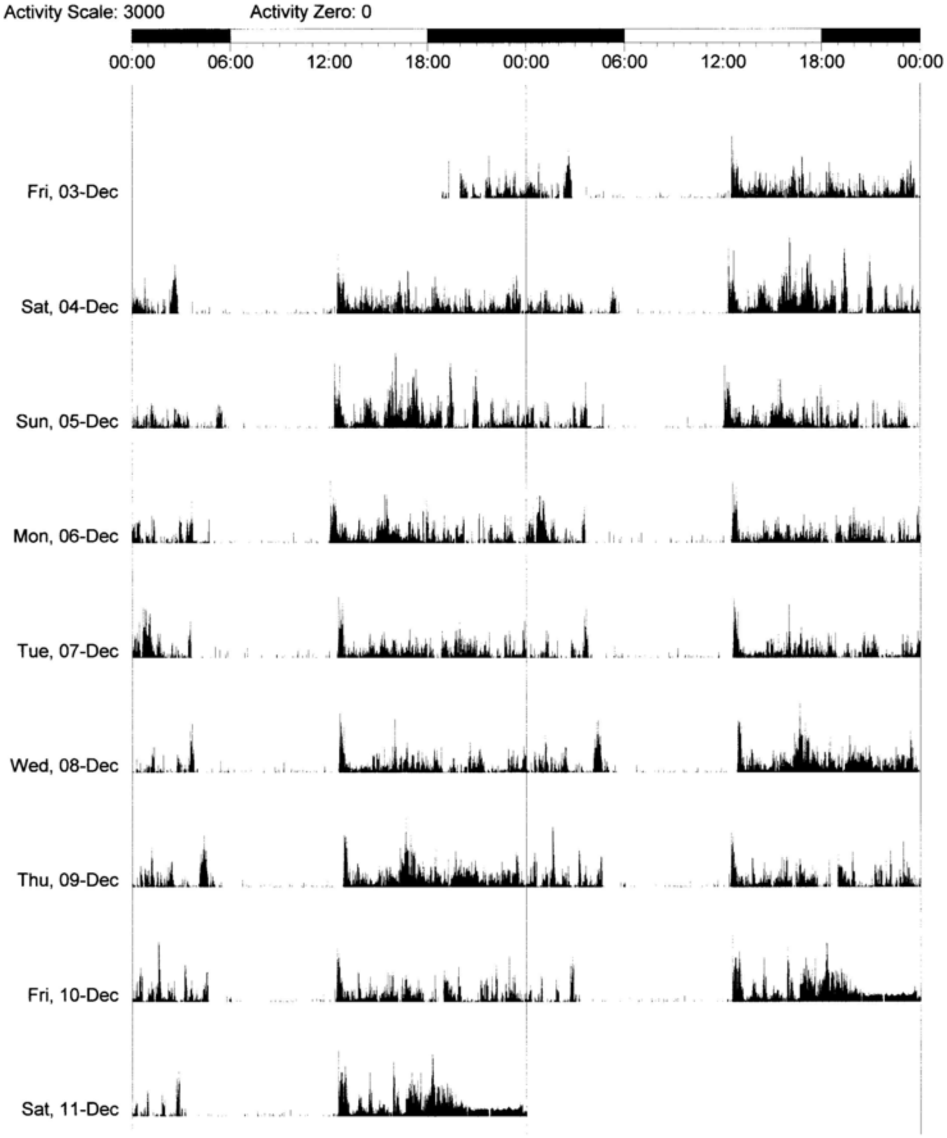
Interval: 1.00 min

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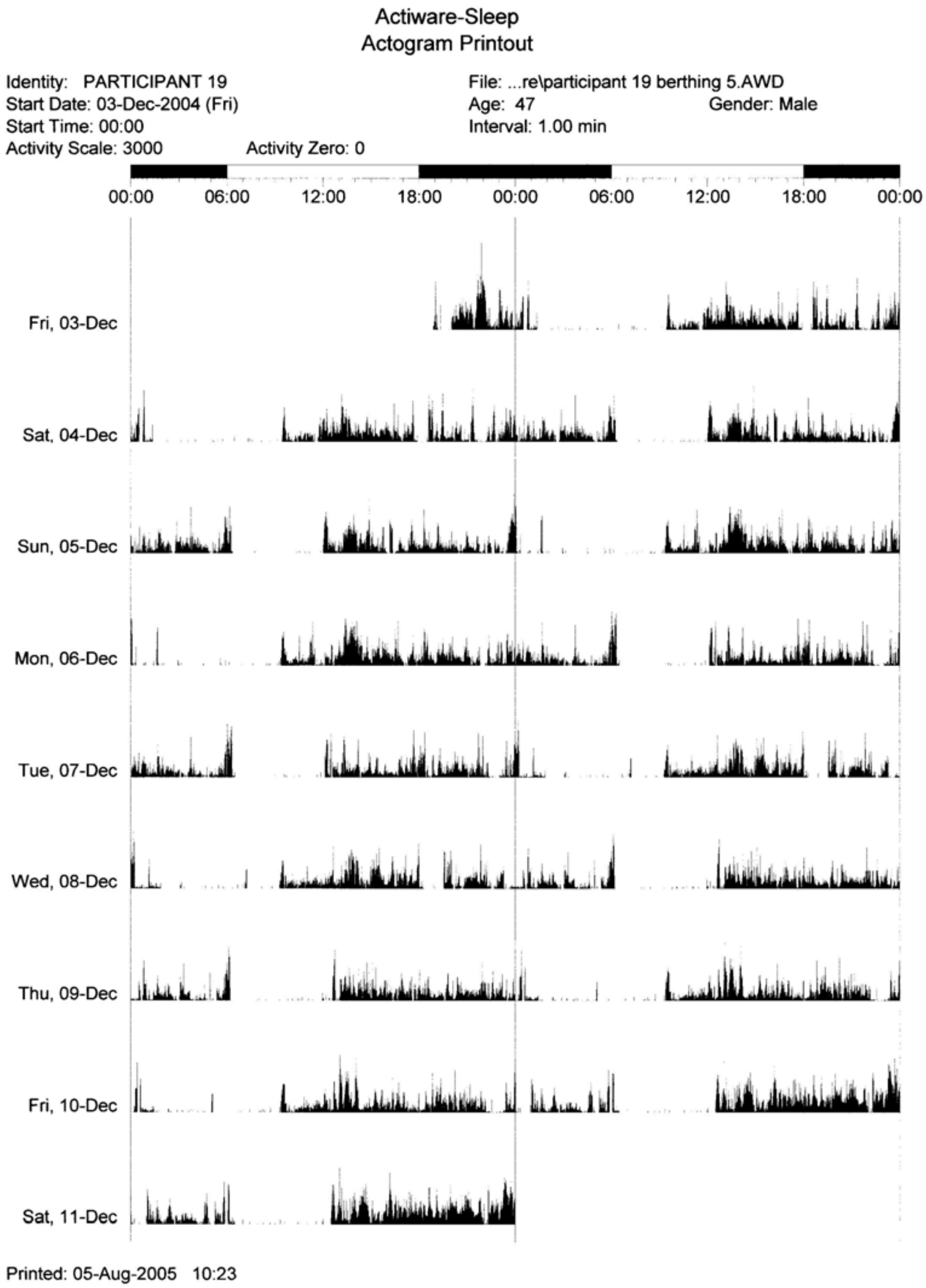
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Gender: Male
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Actiware-Sleep
Actogram Printout

Identity: PARTICIPANT 20
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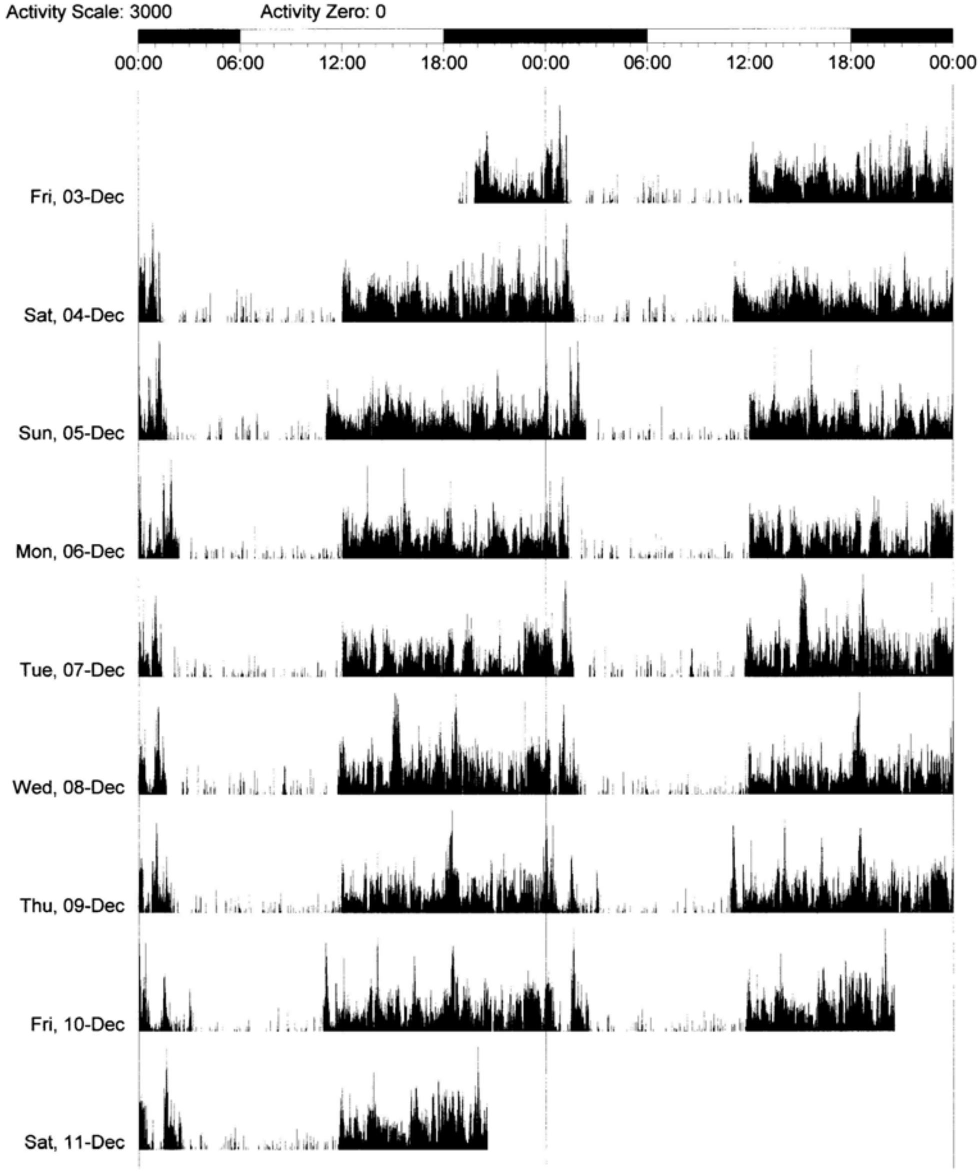
Interval: 1.00 min

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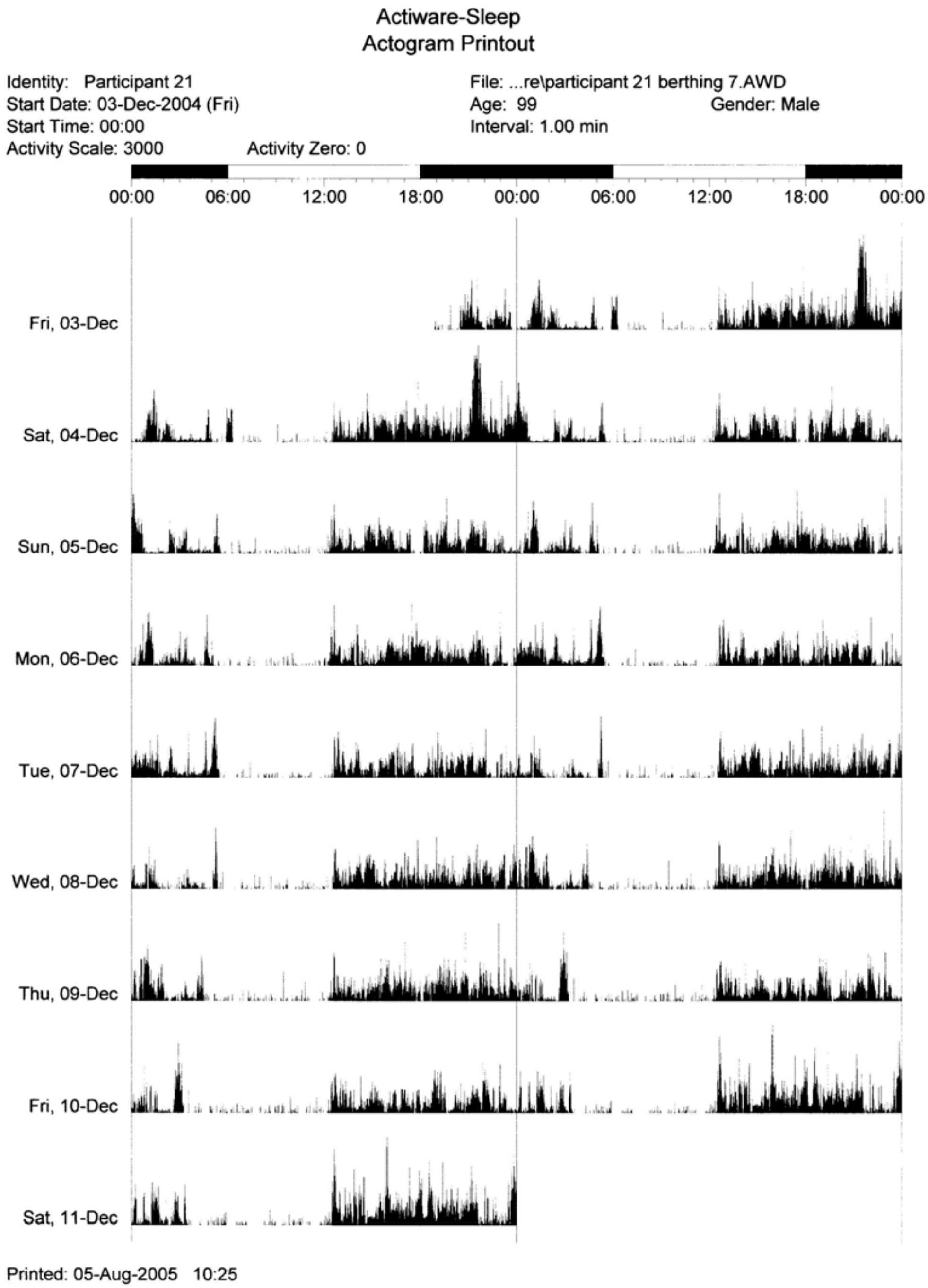

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# APPENDIX B.  CORRELATION MATRICES

**Correlations**

| | | Berthing | Background. Noise | LPEAK.Noise | Relative. Humidity | Temperature | PORT.Motion | Sea.State | Light | Age | Height | Weight | Sea.Time | Rank.Ranked | Sleep. Efficiency | Total.Sleep. Time | Average. Sleep.Time | Average. Number.Daily. Sleep. Episodes | Average. Length.Sleep. Period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Berthing | Pearson Correlation | 1 | .283 | .285 | -.183 | .071 | .210 | .355 | .976** | -.299 | .023 | -.149 | -.472 | .243 | .126 | .203 | .419 | .136 | .131 |
| | Sig. (2-tailed) | . | .327 | .324 | .531 | .809 | .492 | .213 | .000 | .299 | .937 | .612 | .088 | .402 | .667 | .549 | .136 | .643 | .656 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Background.Noise | Pearson Correlation | .283 | 1 | .918** | .584* | -.828** | .062 | .028 | .924** | .291 | -.232 | .044 | .237 | .087 | -.232 | -.312 | -.304 | -.007 | -.183 |
| | Sig. (2-tailed) | .327 | . | .000 | .028 | .000 | .842 | .925 | .000 | .313 | .424 | .880 | .414 | .768 | .424 | .351 | .291 | .982 | .531 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| LPEAK.Noise | Pearson Correlation | .285 | .918** | 1 | .704** | -.851** | .018 | .280 | .977** | .376 | -.129 | .184 | .234 | -.026 | -.170 | -.183 | -.193 | -.127 | -.037 |
| | Sig. (2-tailed) | .324 | .000 | . | .005 | .000 | .953 | .332 | .000 | .185 | .660 | .530 | .420 | .930 | .561 | .591 | .509 | .665 | .901 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Relative.Humidity | Pearson Correlation | -.183 | .584* | .704** | 1 | -.849** | .090 | .464 | .755* | .655* | .116 | .607* | .590* | -.062 | -.450 | -.545 | -.406 | -.457 | .122 |
| | Sig. (2-tailed) | .531 | .028 | .005 | . | .000 | .770 | .095 | .019 | .011 | .692 | .021 | .026 | .834 | .107 | .083 | .149 | .100 | .678 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Temperature | Pearson Correlation | .071 | -.828** | -.851** | -.849** | 1 | -.101 | -.144 | -.975** | -.575* | .141 | -.298 | -.476 | .289 | .443 | .394 | .475 | .129 | .190 |
| | Sig. (2-tailed) | .809 | .000 | .000 | .000 | . | .743 | .623 | .000 | .032 | .631 | .301 | .085 | .317 | .112 | .231 | .086 | .661 | .515 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| PORT.Motion | Pearson Correlation | .210 | .062 | .018 | .090 | -.101 | 1 | .271 | .217 | -.106 | .037 | -.304 | .255 | -.042 | -.244 | -.584 | -.474 | -.224 | -.210 |
| | Sig. (2-tailed) | .492 | .842 | .953 | .770 | .743 | . | .371 | .606 | .729 | .904 | .313 | .401 | .891 | .423 | .059 | .102 | .462 | .492 |
| | N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 8 | 13 | 13 | 13 | 13 | 13 | 13 | 11 | 13 | 13 | 13 |
| Sea.State | Pearson Correlation | .355 | .028 | .280 | .464 | -.144 | .271 | 1 | .111 | .259 | .385 | .476 | .149 | .084 | .072 | -.101 | .167 | -.439 | .437 |
| | Sig. (2-tailed) | .213 | .925 | .332 | .095 | .623 | .371 | . | .776 | .371 | .174 | .085 | .611 | .776 | .808 | .768 | .567 | .117 | .118 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Light | Pearson Correlation | .976** | .924** | .977** | .755* | -.975** | .217 | .111 | 1 | .494 | .069 | .412 | .516 | .408 | -.703* | -.536 | -.488 | -.010 | -.231 |
| | Sig. (2-tailed) | .000 | .000 | .000 | .019 | .000 | .606 | .776 | . | .177 | .861 | .271 | .155 | .276 | .034 | .171 | .183 | .981 | .549 |
| | N | 9 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 |
| Age | Pearson Correlation | -.299 | .291 | .376 | .655* | -.575* | -.106 | .259 | .494 | 1 | .392 | .755** | .653* | -.053 | -.127 | -.262 | -.351 | -.367 | .142 |
| | Sig. (2-tailed) | .299 | .313 | .185 | .011 | .032 | .729 | .371 | .177 | . | .166 | .002 | .011 | .857 | .664 | .436 | .218 | .197 | .628 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Height | Pearson Correlation | .023 | -.232 | -.129 | .116 | .141 | .037 | .385 | .069 | .392 | 1 | .505 | .252 | .286 | .164 | -.368 | -.217 | -.363 | .182 |
| | Sig. (2-tailed) | .937 | .424 | .660 | .692 | .631 | .904 | .174 | .861 | .166 | . | .066 | .385 | .322 | .574 | .266 | .457 | .202 | .535 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Weight | Pearson Correlation | -.149 | .044 | .184 | .607* | -.298 | -.304 | .476 | .412 | .755** | .505 | 1 | .566* | .174 | -.221 | -.206 | -.145 | -.572* | .476 |
| | Sig. (2-tailed) | .612 | .880 | .530 | .021 | .301 | .313 | .085 | .271 | .002 | .066 | . | .035 | .552 | .447 | .544 | .621 | .033 | .086 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Sea.Time | Pearson Correlation | -.472 | .237 | .234 | .590* | -.476 | .255 | .149 | .516 | .653* | .252 | .566* | 1 | .042 | -.282 | -.807** | -.778** | -.382 | -.117 |
| | Sig. (2-tailed) | .088 | .414 | .420 | .026 | .085 | .401 | .611 | .155 | .011 | .385 | .035 | . | .887 | .329 | .003 | .001 | .178 | .690 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Rank.Ranked | Pearson Correlation | .243 | .087 | -.026 | -.062 | .289 | -.042 | .084 | .408 | -.053 | .286 | .174 | .042 | 1 | .168 | -.535 | .061 | -.327 | .347 |
| | Sig. (2-tailed) | .402 | .768 | .930 | .834 | .317 | .891 | .776 | .276 | .857 | .322 | .552 | .887 | . | .565 | .090 | .836 | .254 | .224 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Sleep.Efficiency | Pearson Correlation | .126 | -.232 | -.170 | -.450 | .443 | -.244 | .072 | -.703* | -.127 | .164 | -.221 | -.282 | .168 | 1 | .384 | .428 | .137 | .141 |
| | Sig. (2-tailed) | .667 | .424 | .561 | .107 | .112 | .423 | .808 | .034 | .664 | .574 | .447 | .329 | .565 | . | .244 | .127 | .642 | .631 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Total.Sleep.Time | Pearson Correlation | .203 | -.312 | -.183 | -.545 | .394 | -.584 | -.101 | -.536 | -.262 | -.368 | -.206 | -.807** | -.535 | .384 | 1 | 1.000** | .421 | .318 |
| | Sig. (2-tailed) | .549 | .351 | .591 | .083 | .231 | .059 | .768 | .171 | .436 | .266 | .544 | .003 | .090 | .244 | . | . | .197 | .341 |
| | N | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 8 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Average.Sleep.Time | Pearson Correlation | .419 | -.304 | -.193 | -.406 | .475 | -.474 | .167 | -.488 | -.351 | -.217 | -.145 | -.778** | .061 | .428 | 1.000** | 1 | .241 | .381 |
| | Sig. (2-tailed) | .136 | .291 | .509 | .149 | .086 | .102 | .567 | .183 | .218 | .457 | .621 | .001 | .836 | .127 | . | . | .406 | .178 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Average.Number. Daily.Sleep.Episodes | Pearson Correlation | .136 | -.007 | -.127 | -.457 | .129 | -.224 | -.439 | -.010 | -.367 | -.363 | -.572* | -.382 | -.327 | .137 | .421 | .241 | 1 | -.786** |
| | Sig. (2-tailed) | .643 | .982 | .665 | .100 | .661 | .462 | .117 | .981 | .197 | .202 | .033 | .178 | .254 | .642 | .197 | .406 | . | .001 |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |
| Average.Length.Sleep. Period | Pearson Correlation | .131 | -.183 | -.037 | .122 | .190 | -.210 | .437 | -.231 | .142 | .182 | .476 | -.117 | .347 | .141 | .318 | .381 | -.786** | 1 |
| | Sig. (2-tailed) | .656 | .531 | .901 | .678 | .515 | .492 | .118 | .549 | .628 | .535 | .086 | .690 | .224 | .631 | .341 | .178 | .001 | . |
| | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 14 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**Correlations**

| | | | Berthing | Background. Noise | LPEAK.Noise | Relative. Humidity | Temperature | PORT.Motion | Sea.State | Light | Age | Height | Weight | Sea.Time | Rank.Ranked | Sleep. Efficiency | Total.Sleep. Time | Average. Sleep.Time | Average. Number.Daily. Sleep. Episodes | Average. Length.Slee Period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spearman's rho | Berthing | Correlation Coefficient | 1.000 | .528 | .548* | .127 | -.313 | .331 | .258 | .822** | -.250 | .188 | -.144 | -.306 | .008 | .048 | -.039 | .295 | .100 | .05 |
| | | Sig. (2-tailed) | . | .052 | .042 | .666 | .275 | .270 | .373 | .007 | .389 | .519 | .623 | .287 | .978 | .870 | .910 | .306 | .733 | .85 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Background.Noise | Correlation Coefficient | .528 | 1.000 | .855** | .618* | -.855** | -.253 | -.095 | .900** | .147 | -.060 | -.002 | .268 | .105 | -.305 | -.191 | -.297 | .068 | -.35 |
| | | Sig. (2-tailed) | .052 | . | .000 | .019 | .000 | .405 | .748 | .001 | .616 | .839 | .994 | .355 | .721 | .288 | .574 | .303 | .819 | .21 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | LPEAK.Noise | Correlation Coefficient | .548* | .855** | 1.000 | .741** | -.785** | -.220 | .134 | .733* | .363 | .233 | .256 | .321 | .341 | -.305 | -.264 | -.231 | -.126 | -.11 |
| | | Sig. (2-tailed) | .042 | .000 | . | .002 | .001 | .471 | .648 | .025 | .202 | .423 | .378 | .263 | .233 | .288 | .433 | .427 | .668 | .69 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Relative.Humidity | Correlation Coefficient | .127 | .618* | .741** | 1.000 | -.802** | -.236 | .244 | .533 | .579* | .242 | .348 | .584* | .228 | -.512 | -.655* | -.591* | -.455 | -.05 |
| | | Sig. (2-tailed) | .666 | .019 | .002 | . | .001 | .437 | .401 | .139 | .030 | .405 | .223 | .028 | .433 | .061 | .029 | .026 | .102 | .85 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Temperature | Correlation Coefficient | -.313 | -.855** | -.785** | -.802** | 1.000 | .225 | -.108 | -.817** | -.401 | .095 | -.123 | -.305 | .054 | .385 | .336 | .503 | .090 | .31 |
| | | Sig. (2-tailed) | .275 | .000 | .001 | .001 | . | .459 | .714 | .007 | .155 | .746 | .674 | .288 | .855 | .175 | .312 | .067 | .760 | .28 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | PORT.Motion | Correlation Coefficient | .331 | -.253 | -.220 | -.236 | .225 | 1.000 | .456 | -.095 | -.416 | .244 | -.435 | -.036 | -.101 | .374 | -.373 | -.055 | -.014 | -.15 |
| | | Sig. (2-tailed) | .270 | .405 | .471 | .437 | .459 | . | .117 | .823 | .157 | .421 | .137 | .907 | .744 | .209 | .259 | .859 | .963 | .61 |
| | | N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 8 | 13 | 13 | 13 | 13 | 13 | 13 | 11 | 13 | 13 | 1 |
| | Sea.State | Correlation Coefficient | .258 | -.095 | .134 | .244 | -.108 | .456 | 1.000 | -.333 | .305 | .388 | .328 | .166 | -.131 | .292 | -.127 | -.059 | -.419 | .34 |
| | | Sig. (2-tailed) | .373 | .748 | .648 | .401 | .714 | .117 | . | .381 | .289 | .170 | .252 | .571 | .656 | .311 | .709 | .840 | .136 | .23 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Light | Correlation Coefficient | .822** | .900** | .733* | .533 | -.817** | -.095 | -.333 | 1.000 | .305 | .310 | .134 | .502 | .251 | -.467 | -.476 | -.467 | .293 | -.60 |
| | | Sig. (2-tailed) | .007 | .001 | .025 | .139 | .007 | .823 | .381 | . | .425 | .417 | .731 | .168 | .515 | .205 | .233 | .205 | .444 | .08 |
| | | N | 9 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | |
| | Age | Correlation Coefficient | -.250 | .147 | .363 | .579* | -.401 | -.416 | .305 | .305 | 1.000 | .506 | .677** | .501 | .358 | -.172 | -.224 | -.396 | -.407 | .20 |
| | | Sig. (2-tailed) | .389 | .616 | .202 | .030 | .155 | .157 | .289 | .425 | . | .065 | .008 | .068 | .209 | .558 | .508 | .160 | .149 | .49 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Height | Correlation Coefficient | .188 | -.060 | .233 | .242 | .095 | .244 | .388 | .310 | .506 | 1.000 | .500 | .346 | .602* | .144 | -.533 | -.162 | -.372 | .26 |
| | | Sig. (2-tailed) | .519 | .839 | .423 | .405 | .746 | .421 | .170 | .417 | .065 | . | .069 | .226 | .023 | .623 | .091 | .580 | .190 | .35 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Weight | Correlation Coefficient | -.144 | -.002 | .256 | .348 | -.123 | -.435 | .328 | .134 | .677** | .500 | 1.000 | .493 | .336 | -.286 | -.219 | -.260 | -.515 | .40 |
| | | Sig. (2-tailed) | .623 | .994 | .378 | .223 | .674 | .137 | .252 | .731 | .008 | .069 | . | .073 | .240 | .321 | .517 | .370 | .059 | .14 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Sea.Time | Correlation Coefficient | -.306 | .268 | .321 | .584* | -.305 | -.036 | .166 | .502 | .501 | .346 | .493 | 1.000 | .358 | -.314 | -.789** | -.781** | -.458 | -.18 |
| | | Sig. (2-tailed) | .287 | .355 | .263 | .028 | .288 | .907 | .571 | .168 | .068 | .226 | .073 | . | .208 | .274 | .004 | .001 | .100 | .53 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Rank.Ranked | Correlation Coefficient | .008 | .105 | .341 | .228 | .054 | -.101 | -.131 | .251 | .358 | .602* | .336 | .358 | 1.000 | .033 | -.539 | -.126 | -.451 | .33 |
| | | Sig. (2-tailed) | .978 | .721 | .233 | .433 | .855 | .744 | .656 | .515 | .209 | .023 | .240 | .208 | . | .910 | .087 | .669 | .105 | .24 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Sleep.Efficiency | Correlation Coefficient | .048 | -.305 | -.305 | -.512 | .385 | .374 | .292 | -.467 | -.172 | .144 | -.286 | -.314 | .033 | 1.000 | .264 | .385 | .203 | .02 |
| | | Sig. (2-tailed) | .870 | .288 | .288 | .061 | .175 | .209 | .311 | .205 | .558 | .623 | .321 | .274 | .910 | . | .433 | .175 | .487 | .94 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Total.Sleep.Time | Correlation Coefficient | -.039 | -.191 | -.264 | -.655* | .336 | -.373 | -.127 | -.476 | -.224 | -.533 | -.219 | -.789** | -.539 | .264 | 1.000 | 1.000** | .428 | .31 |
| | | Sig. (2-tailed) | .910 | .574 | .433 | .029 | .312 | .259 | .709 | .233 | .508 | .091 | .517 | .004 | .087 | .433 | . | . | .189 | .34 |
| | | N | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 8 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 1 |
| | Average.Sleep.Time | Correlation Coefficient | .295 | -.297 | -.231 | -.591* | .503 | -.055 | -.059 | -.467 | -.396 | -.162 | -.260 | -.781** | -.126 | .385 | 1.000** | 1.000 | .378 | .35 |
| | | Sig. (2-tailed) | .306 | .303 | .427 | .026 | .067 | .859 | .840 | .205 | .160 | .580 | .370 | .001 | .669 | .175 | . | . | .183 | .20 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Average.Number. Daily.Sleep.Episodes | Correlation Coefficient | .100 | .068 | -.126 | -.455 | .090 | -.014 | -.419 | .293 | -.407 | -.372 | -.515 | -.458 | -.451 | .203 | .428 | .378 | 1.000 | -.68** |
| | | Sig. (2-tailed) | .733 | .819 | .668 | .102 | .760 | .963 | .136 | .444 | .149 | .190 | .059 | .100 | .105 | .487 | .189 | .183 | . | .00 |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |
| | Average.Length.Sleep. Period | Correlation Coefficient | .053 | -.354 | -.116 | -.055 | .310 | -.154 | .341 | -.600 | .200 | .268 | .407 | -.181 | .330 | .020 | .318 | .358 | -.689** | 1.00 |
| | | Sig. (2-tailed) | .857 | .215 | .692 | .852 | .281 | .616 | .233 | .088 | .492 | .354 | .148 | .535 | .249 | .946 | .340 | .208 | .006 | |
| | | N | 14 | 14 | 14 | 14 | 14 | 13 | 14 | 9 | 14 | 14 | 14 | 14 | 14 | 14 | 11 | 14 | 14 | 1 |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

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