Report No. CG-D-06-97

Fatigue And Alertness In Merchant Marine Personnel: A Field Study Of Work And Sleep Patterns

Thomas F. Sanquist
Mireille Raby
Alice L. Maloney

Battelle Seattle Research Center
P.O. Box 5395
4000 N.E. 41st Street
Seattle, WA 98105-5428

Antonio B. Carvalhais

U.S. Coast Guard
Research and Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

FINAL REPORT
JUNE 1996

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Marine Safety and Environmental Protection, (G-M)
Washington, DC 20593-0001

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The contents of this report reflect the views of the Coast Guard Research & Development Center. This report does not constitute a standard, specification, or regulation.

G.T. Gunther
Commanding Officer
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

Technical Report Documentation Page

1. Report No. CG-D-06-97	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Fatigue and Alertness in Merchant Marine Personnel: A Field Study of Work and Sleep Patterns		5. Report Date June 1996
		6. Performing Organization Code
7. Author(s) Thomas F. Sanquist, Mireille Raby, Alice L. Maloney, Antonio B. Carvalhais		8. Performing Organization Report No. R&DC 20/96
9. Performing Organization Name and Address Battelle Seattle Research Center P.O. Box 5395 4000 N.E. 41st Street Seattle, WA 98105-5428	U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, Connecticut 06340-6096	10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
		13. Type of Report and Period Covered Final Report
12. Sponsoring Agency Name and Address Department of Transportation U.S. Coast Guard Marine Safety and Environmental Protection, (G-M) Washington, D.C. 20593-0001		14. Sponsoring Agency Code Commandant (G-MSO-1) U.S. Coast Guard Headquarters Washington, DC 20593-001
15. Supplementary Notes The R&DC technical point of contact is Dr. Anita Rothblum, (860) 441-2847.		

16. Abstract

As part of its mission to improve the safety of maritime operations, the U.S. Coast Guard (USCG) has undertaken a multi-year research program to establish a technical basis for maritime operational practice and regulatory guidance in work-rest scheduling and work hour limitations. Numerous studies across various modes of transportation show fatigue to be an underlying factor in a significant percentage of accidents; further, many of the accidents appear to be a result of sleep disruption based on work schedule requirements. The current phase of the program is concerned with the following: (1) identify the nature and extent of sleep disruption-induced fatigue in the commercial maritime industry, and (2) identify the impact of watch duration on personnel fatigue.

One hundred forty-one mariners from eight commercial ships (6 tankers and 2 freighters) provided data regarding their work and sleep patterns, as well as a variety of other data pertinent to fatigue. The results show that there is a fatigue problem in the U.S. maritime industry, and by implication, internationally.
The incidence of critical fatigue indicators such as severely restricted sleep durations per 24-hour period, very rapid sleep onset times, and critically low alertness levels suggest that fatigue regularly occurs. The results point to sleep disruption, reduced time between watches, fragmented sleep, and long workdays as principal contributors to the problem. Several courses of action for fatigue reduction are discussed: (1) work and rest period guidelines and policy, (2) government-industry educational programs, and (3) design and evaluation of alternative work-rest schedules.

17. Key Words Merchant Marine, fatigue, sleep, alertness, watchkeeping, schedule, marine accident, human performance, Oil Pollution Act of 1990 (OPA '90), work hour regulations, tanker, freighter	18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161		
19. Security Classif. (of this report) UNCLASSIFIED	20. SECURITY CLASSIF. (of this page) UNCLASSIFIED	21. No. of Pages	22. Price

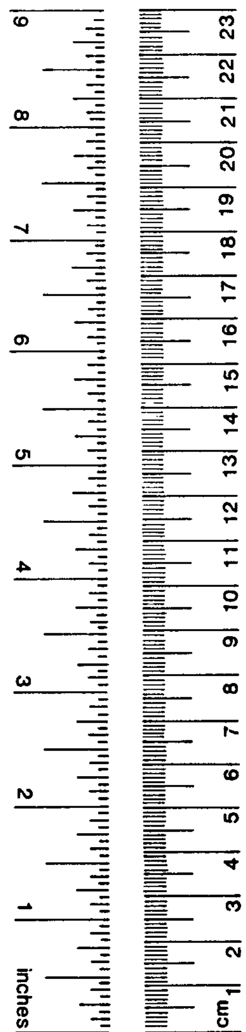
Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

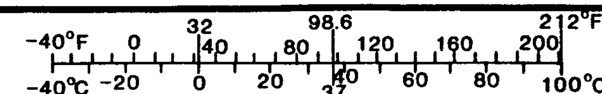


TABLE OF CONTENTS

LIST OF ABBREVIATIONS

NTSB	National Transportation Safety Board
USDOT	U.S. Department of Transportation
OPA	Oil Pollution Act
IMO	International Maritime Organization
STCW	Standards for Training, Certification and Watchkeeping
CFR	Code of Federal Regulations
BII	Background Information Inventory
RAI	Retrospective Alertness Inventory
ANOVA	Analysis of Variance
CSEM	Crew Size Evaluation Model
NASA	National Aeronautic and Space Administration
SERVS	Ship Escort Response Vessel System
OOW	Officer of the Watch
RT	Reaction Time
EEG	Electroencephalogram
KSS	Karolinska Sleepiness Scale
VAS	Visual Analogue Scale
ATS	Accumulated Time with Sleepiness
TBRI	To-be-remembered-information

EXECUTIVE SUMMARY

This project is part of a multi-year program designed to establish a technical basis for maritime operational practice and regulatory guidance in work-rest scheduling and work hour limitations. This phase of the program is concerned with the following objectives: (1) to identify the nature and extent of sleep disruption-induced fatigue in the commercial maritime industry, and (2) identify the impact of watch duration on personnel fatigue. Meeting these objectives will further our understanding of the factors contributing to fatigue in shipping, and help identify opportunities for policy and operational approaches to fatigue reduction. The fatigue issue is increasingly important in view of reduced crew complements and trials with one-man bridge operations. This report documents a field research project conducted aboard commercial tankers and cargo ships.

One hundred forty one mariners from eight commercial ships (6 tankers and 2 freighters) provided data regarding their work and sleep patterns, as well as a variety of other data pertinent to fatigue. The results show that there is a fatigue problem in the U.S. maritime industry. The incidence of critical fatigue indicators such as severely restricted sleep durations per 24-hour period, very rapid sleep onset at bedtime, and critically low alertness levels suggests that fatigue regularly occurs. The data support the following conclusions about the nature and extent of the fatigue problem:

- Critical levels of fatigue occur between 8 and 21 percent of the time, driven primarily by personnel on the 4-on, 8-off schedule. Recovery sleep periods do not occur.
- Mariners sleep an average of 6.6 hours per 24-hour period while on shipboard duty — this is 1.3 hours less than average sleep duration at home. Sleep debt is known to be cumulative and to reduce performance.
- Watchstanders generally obtain less total sleep (6.6 hours) than other personnel, and the sleep is of lower quality due to fragmentation and physiologically inappropriate sleep times.
- The steward department on tankers and the 0400 to 0800 watch on freighters have the shortest sleep durations, obtaining 6.0 hours and 5.2 hours per night, respectively.
- Port activities significantly alter the timing of sleep. Frequent changes in sleep timing are known to reduce alertness and performance.
- Tanker personnel generally work longer days than freighter personnel.

The nature and distribution of these findings indicate that the work schedule of the watchstanders is the primary contributor to the fatigue problem.

Evaluation of alertness fluctuations over the time course of individual 4-hour watches addressed the relationship between watch duration and fatigue. This type of knowledge will be useful in designing alternative watch structures and work-rest scheduling, and in evaluating their impacts. The important findings from this part of the study include:

- inconsistent levels of alertness over the watchstanding period
- a substantial drop in alertness on the 2000 to 2400 watch
- a significant decline in 0400 to 0800 watch personnel alertness
- overestimating of alertness by midnight to 0400 watch personnel
- no data indicating watch durations should be fixed at four hours.

The results of this study indicate that a fatigue problem exists in the U.S. maritime industry, and by implication, internationally. The research points to sleep disruption, reduced time between watches, fragmented sleep, and long workdays as principal contributors to the problem. Analysis of alertness profiles during watchstanding periods indicates the desirability of a higher and more consistent level of alertness throughout the 24-hour period than is currently the case. These basic results suggest several courses of action for fatigue reduction, falling into the general categories of (1) work and rest period regulation and policy, (2) government-industry educational programs, and (3) design and evaluation of alternative work-rest schedules.

Recommended Courses of Action

The federal government should initiate a guidance and policy-making process involving public dialogue both nationally and internationally. Current maritime work-rest period regulation and policy are at odds with our knowledge of human rest requirements. The existing U.S. minimum rest period of 9 hours does not translate into 9 hours of sleep; in the case of watchstanders, the average sleep duration per 24-hour period is 6.6 hours. Two of the three watches obtain this sleep in two episodes, which erodes the restorative value of the sleep. The policy-making process should be aimed at identifying work-rest schedule alternatives for maritime operations that provide the opportunity for *continuous* sleep, which will offer more restorative value.

A second course of action from the present study would be to develop a "maritime fatigue training module" that focuses on the unique aspects of shipboard work schedules. The purpose of such training is to establish a common understanding of fatigue in the maritime industry as basis for change in operational practice. This training module could be offered either as a supplement to maritime personnel attending the NASA Fatigue Countermeasures program, or could form a core basis for a specific marine industry fatigue training program. In either case, using the extensive data collected in this study would be very useful both for establishing credibility with industry personnel and for illustrating specific points about fatigue and maritime work schedules.

The third course of action recommended is to conduct a research effort to develop alternative watchstanding systems that reduce the fatigue risk factors inherent in the 4-on, 8-off system. Elements of this work would include:

- identifying alternative watchstanding systems currently in place (e.g., 12-on, 12-off)
- defining opportunities for alternative schedules in selected trade routes

- engaging shipboard personnel in the design process
- use of shipboard manning models for computer-aided schedule design and evaluation
- trial implementation and evaluation of an alternative watchstanding system.

These three recommended courses of action are the core elements of a process; each is an important aspect of addressing the maritime fatigue problem in a comprehensive way. The process is composed of complementary elements, designed to be carried out in parallel. For example, international policy development needs a technical basis for fatigue reduction (i.e., alternate work schedules). Similarly, raising the general level of awareness through a maritime-specific educational program will lead to more informed decisionmaking and operational practice. The courses of action described above will provide information that can guide international policy and practice for watchstanding in the current and future generation of commercial ships.

1.0 INTRODUCTION AND PURPOSE

Accidents related to work schedule and fatigue are a major detriment to transportation safety. A number of studies across various modes of transportation show that fatigue underlies a significant percentage of accidents (Lauber and Kayten, 1988); further, many of the accidents appear to be a result of sleep disruption based on a requirement to work throughout a 24-hour period. The National Transportation Safety Board (NTSB) has designated fatigue research in transportation as a top priority, and the modal agencies of the United States Department of Transportation (USDOT) are pursuing a variety of programs. This report represents one aspect of the U.S. Coast Guard research program aimed at reducing the impact of fatigue in the maritime industries.

The role of fatigue in shipping accidents is well-illustrated by the grounding of the *Exxon Valdez* in 1989. Prior to the grounding, which occurred shortly after midnight, the watch mate had slept as little as 5 or 6 hours, split between afternoon and early morning periods. The resulting fatigue contributed to poor navigation performance and the consequent grounding. The response of the U.S. Congress to this catastrophe was to enact the Oil Pollution Act of 1990 (OPA '90), which contained a work hour limitation for tank vessel personnel of 15 hours per 24, and 36 hours per 72. Operationally this has been implemented as a 12-hour routine workday in the tanker industry.

Although it is recognized that fatigue occurs in the maritime industries, there is very little documentation regarding the nature and extent of the problem. In order to set policy and provide the industry with operational guidance, the Coast Guard requires more information on the factors contributing to mariner fatigue. Specific divisions such as G-MSO will be able to use this information to develop more effective manning policies and regulation, work hour rules, and policies that are commensurate with the Standards for Training, Certification and Watchkeeping (STCW) of the International Maritime Organization (IMO).

This report documents a field research project conducted aboard commercial tankers and cargo ships. Mariners provided data regarding their work and sleep patterns, as well as a variety of other data pertinent to fatigue. The report discusses relevant background information for understanding the technical approach, details of the research methods, analysis of data in terms of the principal objectives of the work, the implications of the results for shipping operations, and U.S. and international maritime work schedule policies.

2.0 OBJECTIVES

There are a variety of sections in the Code of Federal Regulations (CFR) and United States Code concerned with minimum rest periods for mariners. The most visible of these is the work hour limitation for tank vessel personnel of OPA '90. As described in Section 1.0, OPA '90 was passed in quick response to the *Exxon Valdez* grounding. Limitations set forth in that act specify the maximum number of hours to be worked in a 24-hour and 72-hour period. For the 24-hour period, OPA '90 provides a minimum rest period of 9 hours (i.e., maximum of 15 hours of work per 24). The operational implementation of this rule by shipping companies is in the form of a routine 12-hour day. This permits daily fluctuations up to 15 hours as required by operations. Recent revisions to the STCW also set limits on work hours (see section 3.4).

OPA '90 was developed as a political response to a highly publicized catastrophe, to address the problem of prolonged work hours among mariners. The minimum rest period of 9 hours is based primarily on face validity (i.e., what looks right). The main impact of the work hour restriction, according to reports from tanker personnel, was to eliminate overtime differentials across personnel categories, and for some companies to employ a cargo mate (either sailing or on shore) to relieve the chief mate during port operations. Work-rest scheduling has not changed, nor has the structure or duration of the watch system. The STCW revisions are similar in their lack of impact on the watch schedule. Research indicates that work-rest scheduling may be the predominant contributor to fatigue, duration of work during the 24-hour period notwithstanding. It is therefore important to develop a human factors technical basis for work-rest scheduling in the maritime industry, and for U.S. Coast Guard policy concerning the timing and duration of minimum rest periods.

This project is part of a multi-year program designed to establish a technical basis for maritime operational practice and regulatory guidance in work-rest scheduling and work hour limitations. This phase of the program is concerned with the following objectives: (1) to identify the nature and extent of sleep disruption-induced fatigue in the commercial maritime industry, and (2) identify the impact of watch duration on personnel fatigue. Meeting these objectives will further our understanding of the factors contributing to fatigue in shipping, and help identify opportunities for policy and operational approaches to fatigue reduction. Subsequent phases of this program will be concerned with designing fatigue reduction strategies and tactics, such as alternate watchstanding schedules or manning structures, and with implementing and testing these approaches in prototype form.

3.0 BACKGROUND

Research directed at fatigue needs to be framed within the context of knowledge regarding accident patterns across a 24-hour period, the physiological determinants and behavioral consequences of fatigue, and potential regulatory interventions. Compilation of this knowledge clearly demonstrates that the operational characteristics of the shipping environment are particularly conducive to fatigue on the job, and that work hour regulation and work-rest scheduling in the industry does little to reduce fatigue.

3.1 Marine Accidents and Fatigue

Marine accidents tend to occur most frequently during the late night and early morning hours. This pattern is remarkably similar across transportation modes, and across a variety of different data sets. Figures 1 and 2 compare the number of motor vehicle accidents across the 24 hour period (Figure 1), with shipping collisions at different times of day (Figure 2). These data show remarkably similar patterns, with the largest number of accidents occurring during the late night and early morning hours, with a slight rise in frequency in the early afternoon period. Conversely, reports by workers on a conventional day work schedule indicate extremely low levels of alertness or sleep during these same periods, and much higher levels of alertness during the times of day when relatively few accidents based on human error occur.

The standard work schedule of watchstanders on merchant marine vessels involves the 4 hours on, 8 hours off, 4 hours on watch schedule. This is usually a fixed schedule of work in U.S. ships, with the first officer standing the 0400 to 0800 and 1600 to 2000 watch, the second officer standing the midnight to 0400 and 1200 to 1600 watch, and the third officer standing the 0800 to 1200 and 2000 to 24 watch. Additional and overtime duties are performed during the off-watch hours. For some operating companies, this work scheduling system changes when the ship is in port to a 6-on, 6-off schedule. This was the type of schedule that the watch mate of the *Exxon Valdez* was working prior to the accident. During the 24 hours preceding the accident, the watch mate obtained what is estimated to be less than 5 or 6 hours of sleep in two separate periods.

The accident data and work schedule characteristics of the maritime industry show several parallels with research knowledge concerning human performance and fatigue. These findings, discussed in the next section, indicate that the work-rest scheduling practices of the maritime industry are particularly conducive to degraded human performance during the late night and early morning hours.

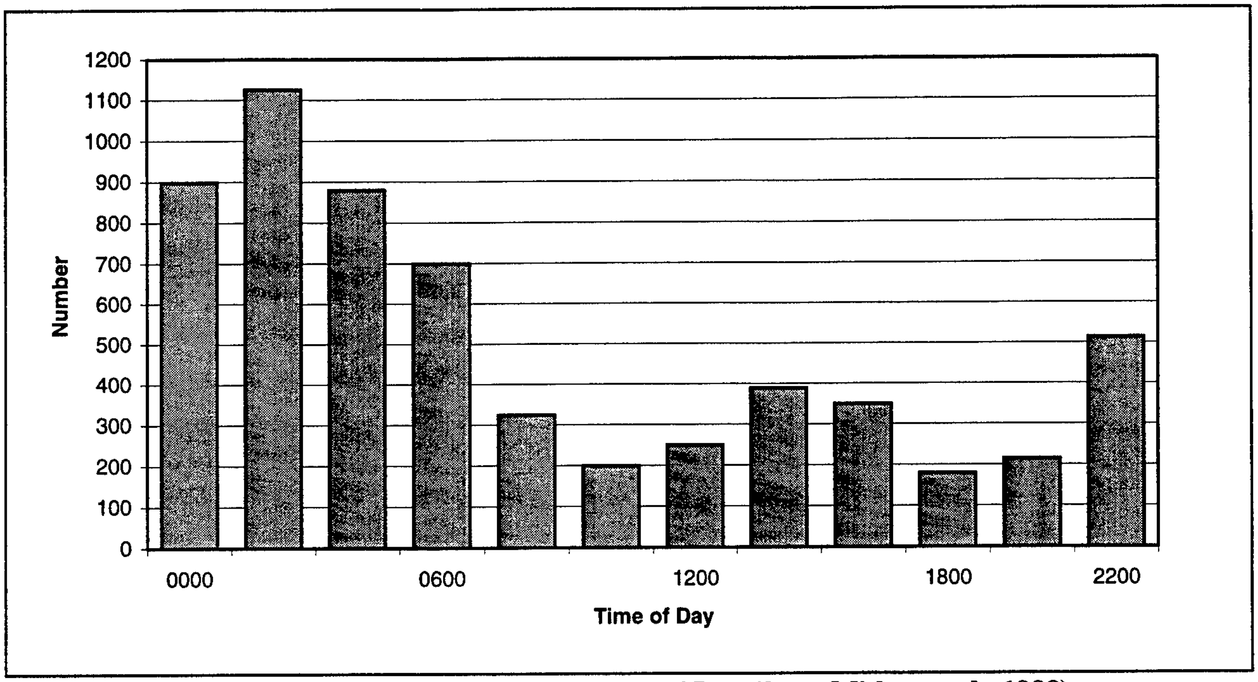


Figure 1. Number of Traffic Fatalities Across Time of Day (from Mitler, et al., 1988).

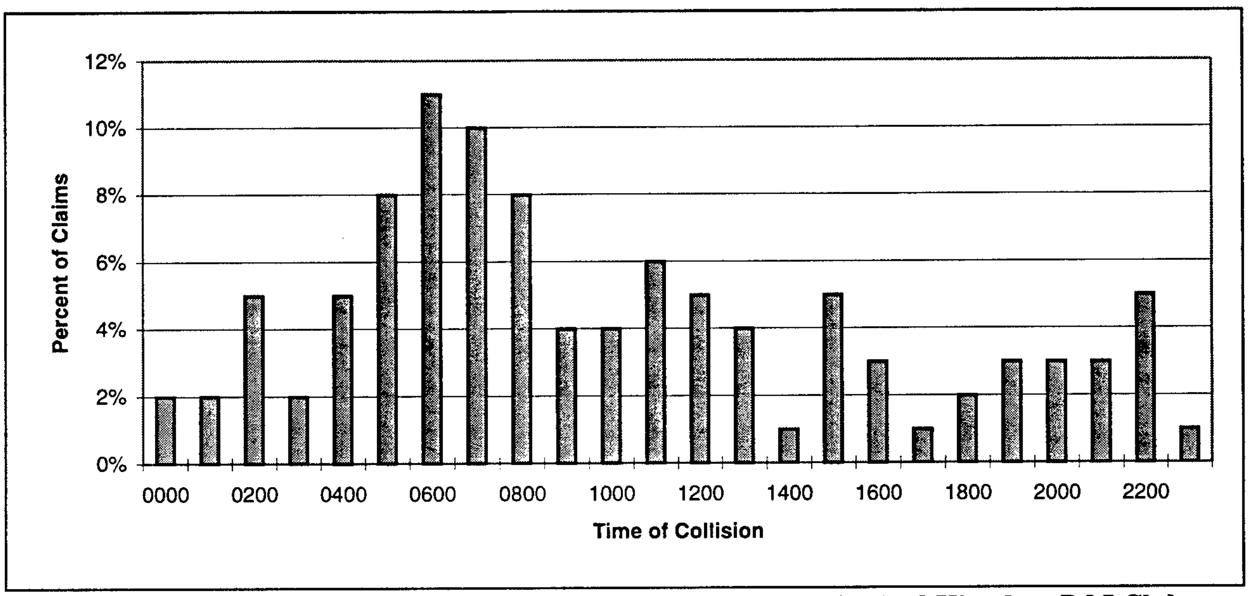


Figure 2. Percent of Shipping Collisions at Each Hour of the Day (United Kingdom P&I Club, 1992).

3.2 Human Performance Factors

The quality of human performance at work is influenced by a number of factors, including the nature of the specific job, the job role and life stress experienced by the mariner, and various physical and environmental stressors, such as weather and ship vibration. These factors can have relatively large impacts on an unpredictable basis; for example, bad weather can affect the entire crew in terms of sleep and balance compensation.

Two additional factors that have large and predictable impacts on human performance are time of day and the nature of the sleep cycle. These factors are important to consider for two reasons. First, humans exhibit regularly occurring circadian rhythms (about a day) which fluctuate over the 24-hour period. These rhythms are well-linked to the day-night cycle, although they can be partially or fully adapted to time shifts depending on circumstances. The second reason for considering these two factors is that they offer the best prospect for changes in operational practice in the maritime industry to reduce fatigue-based accidents.

3.2.1 Time of Day

There are well-documented variations in the quality of human performance over the 24-hour period. This is illustrated in Figure 3, which shows human error data obtained from studies of industrial tasks, including communications, meter reading, automobile and train driving, and hospital work. Data from these studies were combined in a meta-analysis by Folkard (1995) to reflect the aggregate error tendency across time of day.

Figure 3 shows that the human error rate is highest between the hours of midnight and 0600, with a slight increase between 1300 and 1400 (the "post-lunch dip"). These data reflect well-known fluctuations in biological rhythms, including performance efficiency and body temperature, and are thought to represent behavioral manifestations of circadian rhythms. It is probable that the sleep fragmentation and reduction associated with maritime work schedules exacerbate these natural tendencies for poor performance on the night shift.

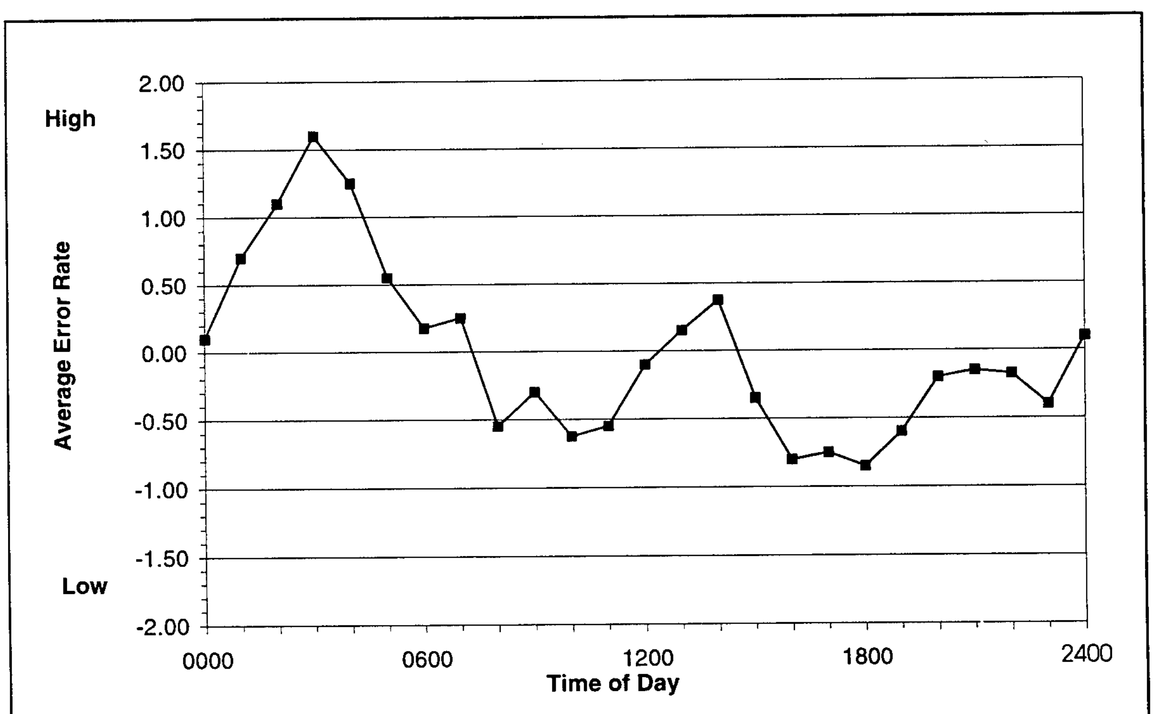


Figure 3. Aggregate Error Rates (standard scores) Over a 24-Hour Period from Studies of Industrial Tasks (after Folkard, 1995).

Figure 4 illustrates the relative risk of accidents over the course of various shift durations, based on a meta-analysis by Folkard (1995). This figure shows that relative risk increases as the number of hours on shift increases. This is especially evident in the case of a 13-hour shift. However, it is clear that relative risk after 2 or 3 hours on shift is actually as great as a 10-hour shift. From a statistical standpoint, the fact that maritime watchstanding involves routine 4-hour shifts suggests that such a work duration may actually be riskier than a longer watch. This phenomenon might be based on a time-dependent increase in mental lapses that is not compensated early in the shift by fatigue-reducing strategies such as caffeine consumption, physical movement, or varying the work routine. One implication of these data is that longer watches may actually be less risky because workers approach them with alternate strategies for alertness management.

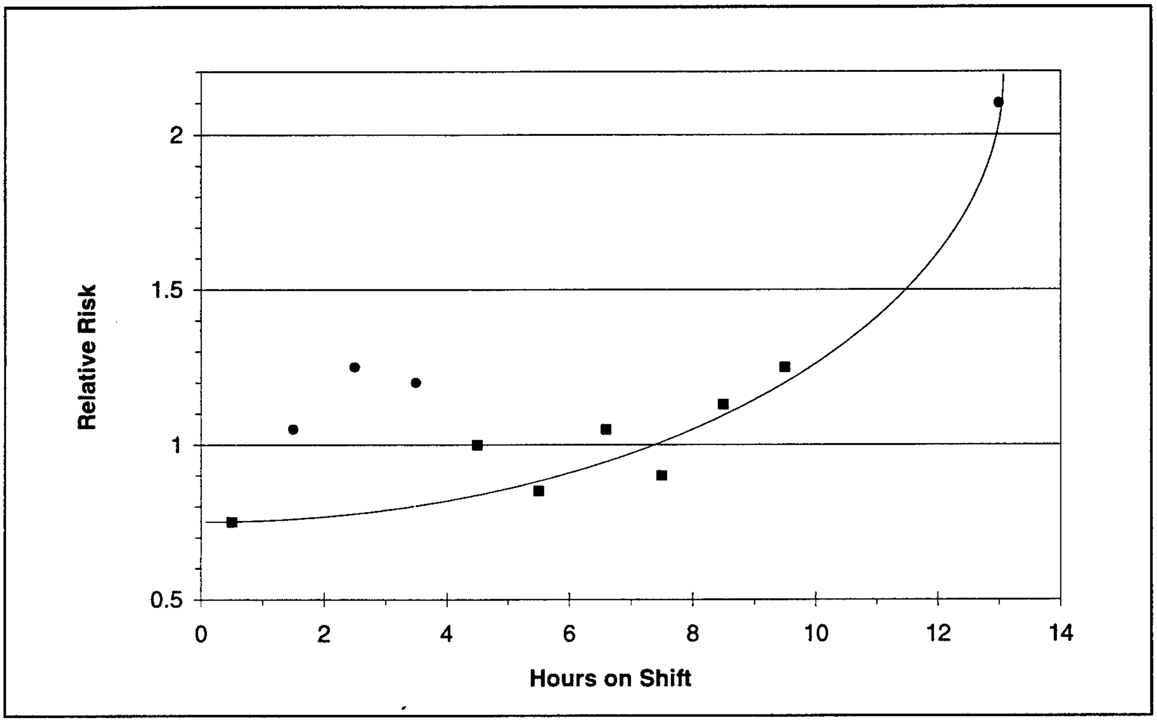


Figure 4. Relative Risk of Accident for Various Work Shift Durations (after Folkard, 1995).

3.2.2 Sleep Timing and Duration

The timing of sleep directly affects the duration of the sleep episode (Akerstedt, 1995). It has been found that sleep onset before midnight results in the longest sleeps, followed by sleep onset after midnight. As the time following midnight increases for sleep onset, the length of the resulting sleep episode decreases up to mid-day, after which there is an increase in duration of the sleep episode. Figure 5 illustrates this function.

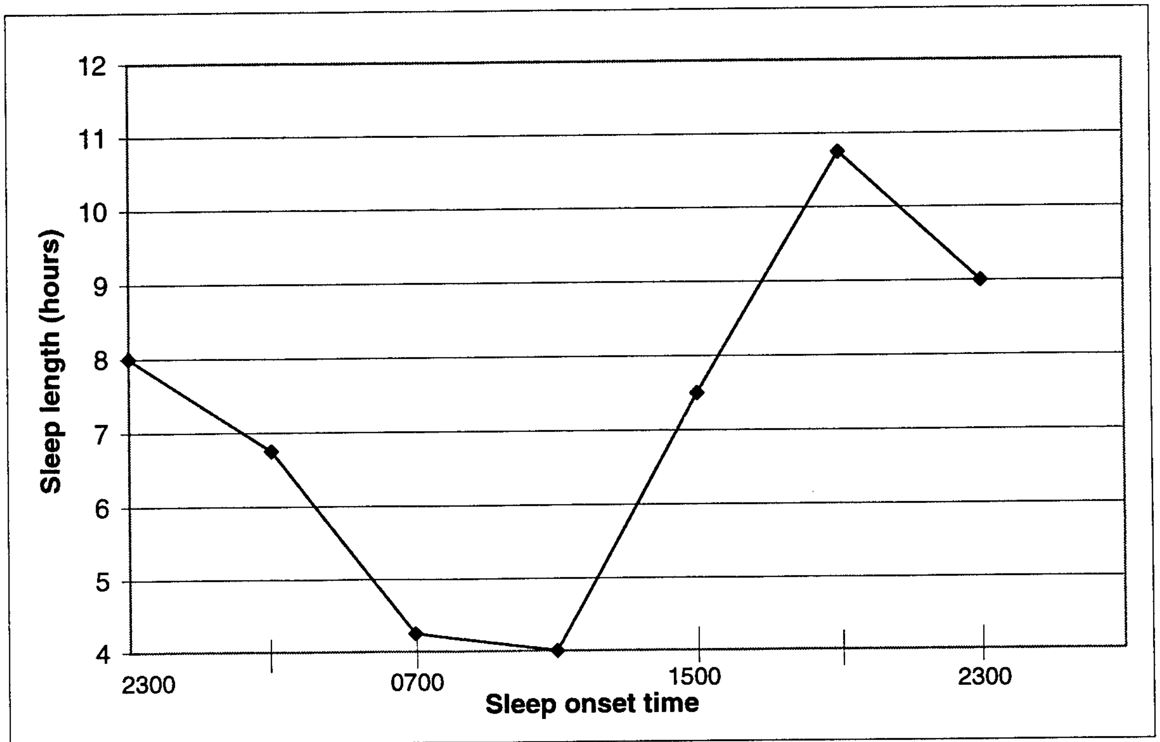


Figure 5. Total Sleep Time as Function of Sleep Onset at Different Times of Day (after Akerstedt, 1995).

The nature of the maritime watchstander's schedule interacts with his ability to obtain sleep episodes of various durations. For example, the watchstander on the midnight to 0400 watch generally goes to sleep at the end of that watch or slightly thereafter. Figure 5 shows that the person on that watch will be at a disadvantage in terms of sleep episode length, when compared, say, to a person on the 0800 to 1200 watch. Workers in this latter category tend to retire shortly after midnight. Dayworkers have the best prospect for a long sleep episode, since they generally retire prior to midnight.

While maritime schedules lead to varying sleep episode durations because of the timing of sleep, it is uncertain as to *how much sleep* a person actually needs. It could be argued that people naturally find their ways into professions that correspond with their need for sleep. Various surveys indicate that the average adult in the U.S. reports sleeping approximately 7.5 hours per night during weeknights, with longer sleep periods on weekends (Carskadon and Roth, 1991). However, a recently reported study of persons allowed to sleep without restriction over a number of days indicates that subjects slept for 8.6 hours, on average (National Commission on Sleep Disorders, 1993).

Regardless of the total need for sleep, research with shiftwork populations has found that night and early morning work leads to reduced sleep duration (Akerstedt, 1995). Further findings in relation to human performance indicate that as little as one night of sleep reduction of 1-1/2 to 2 hours is associated with a variety of human performance decrements (Gillberg, 1995). These studies also indicate that sleep that is *fragmented* (i.e., disrupted or consisting of more than a single episode) results in reduced alertness and performance. There are definite parallels between these controlled laboratory studies of sleep patterns and how mariners obtain their sleep. Notably, mariners who work the midnight to 0400, and 0400 to 0800 watches obtain reduced sleep episodes, and generally sleep at two separate times of day during the 24-hour period. Finally, research concerning the amount of time separating successive shifts suggests that at least 16 hours between shifts is necessary for a sleep duration of 7 or 8 hours (Kecklund and Akerstedt, 1995). The typical maritime watchstander schedule provides only 8 hours between successive watches.

Reduced amounts of sleep are associated with declines in human performance, as mentioned above. The nature of these performance declines is relatively pervasive, and is summarized in Table 1. Some practical maritime safety consequences of these behavioral declines include:

- incorrect bearing/range calculation
- memory loss for reported traffic
- false reporting of a radar target
- failure to recognize a potential collision

Table 1. Human Performance Consequences of Sleep Disruption (after Dinges, 1992)

Type of Effect	Nature of Effect	Behavioral Consequence
Cognitive Response Shift	Slowing on self-paced tasks, increased errors on work-paced tasks	Difficulty in mental arithmetic or code recognition
Memory problem	Increased variability in retrieval	Decreased ability to retain and recollect new information
Time-on-task decrement	Increased rate of slowing in response time or increase in errors	Slow response to unexpected events
Optimum response shift	Reduction in speed of fastest response times	Reduced fine motor performance
Lapse (block, gap, pause)	Periods of very delayed responding or of nonresponding	Periods of very delayed responding or no responding
False response	Increase in number of false responses during high signal load tasks	Increased reporting and response to targets not requiring response

3.3 Synopsis of Previous At-Sea Fatigue Research

Sleep duration and quality in at-sea operations have been evaluated in several European studies, including Rutenfranz, et al. (1988) and Fletcher, et al. (1988). Rutenfranz, et al. used a variety of self-report measures, such as diaries and alertness ratings. They found that watchkeepers had a lower average sleep duration than dayworkers, and that third officers (0800 - 1200 watch) reported the lowest quality and amount of sleep. The quality of sleep data indicated that sleep onset before midnight is best, followed by sleep after midnight, followed by daytime sleep – this confirms the studies cited previously. Compensation for sleep loss is not possible because of a lack of days off. In synthesizing the results of this research program, Colquhoun (1995) concludes that the typical maritime watchstanding schedule leads to incomplete adaptation of physiological circadian rhythms, and that *"the key to such rhythm adaptation lies in the taking of a single, uninterrupted sleep at the same time of day, each day."*

Previous work concerning fatigue and sleep patterns in the U.S. was conducted by Pollard, et al. (1990). This work was limited by methodological problems and did not receive particularly good cooperation on the part of mariners; thus, the detailed measurement studies such as those performed by the Europeans have not been carried out in the U.S. There is reason to believe that it is necessary to carry out work of this sort on U.S. ships for several reasons. First, the European results showed average work days for the mariners of approximately 10 hours. This is substantially less than the work days of typical U.S. tanker personnel. Second, the sleep durations reported in the European study are over 7.5 hours in many instances. Third, the sample of ships was quite heterogeneous, including two research vessels, two oil tankers, and one container ship. This relatively small sample yielded fairly small numbers in each of the categories of interest (first, second, and third watchkeepers, and dayworkers). Given the individual variability possible in measures pertaining to sleep, fatigue, and alertness, it seems prudent to carry out similar work on U.S. ships on a somewhat larger scale with a more homogeneous sample of ships.

3.4 Work Hour Regulations and Policies in the Maritime Industry: Is There a Need for Change?

The principal work hour regulations for the United States are specified in Title 46 of the United States Code, part 8104. As mentioned previously, OPA '90 introduced the limitation on total work hours of tanker personnel: 15 hours per 24, and 36 hours per 72 (part 8104(n)). U.S. Code part 8104(a) requires the officer in charge of a watch upon leaving port to have been off duty for the previous 6 hours. These work hour regulations provide for a minimum rest period of 9 hours in the case of OPA '90. No language is devoted to the timing of the rest period, or whether it should be obtained in single or multiple episodes.

Recently, the IMO addressed work-rest scheduling through a chapter added to the STCW. In particular, this guideline proposes a minimum 10-hour rest period during any 24-hour period. The STCW further specifies that the hours of rest may be divided into two periods, one of which should be at least 6 hours in length.

These rules and policies contrast quite sharply when compared to U.S. regulation concerning minimum rest periods for aircrew. For example, aircrew are required to obtain at least *9 consecutive hours of rest* following a flight of less than 8 hours before they may be scheduled for another flight (14 CFR §121.471). The difference here is notable — in aviation, the requirement is for hours of *consecutive rest*, whereas in the maritime industry the total rest period is less, and substantial leeway is given operators for assigning work that results in nonconsecutive rest periods during the 24-hour day. Based on the findings regarding the impact of sleep fragmentation and time between shifts on sleep duration and human performance, it appears that the work-rest regulations and policies of the maritime industry are at odds with our knowledge of beneficial work-rest scheduling. Although the operational demands of shipping occur throughout the 24-hour day, it is possible that there are opportunities for strategic napping to improve alertness (Rosekind, et al., 1995), training to improve awareness of circumstances that influence fatigue, and for more fundamental changes in work practices that would result in longer, more continuous rest periods for mariners.

3.5 Working Hypothesis

The data reviewed above are consistent with the general view expressed by Lauber and Kayten (1988) that transportation safety is compromised by fatigue resulting from sleep disruption and circadian rhythm desynchronization. They suggest that applied research be directed toward establishing work practices and regulation that incorporate knowledge of the human need for sleep and biological rhythms.

In order to frame the research approach to address the objectives identified in Section 2.0, it is useful to have a working hypothesis. Based on the data reviewed above, our working hypothesis is as follows:

> *Maritime work schedules lead to fragmented and reduced sleep. This will reduce sleep quality and alertness during work periods, and will depend on watch schedules and voyage phase.*

This working hypothesis can be broken down into a series of less complex questions and statistical analyses that will help identify particular problem areas, and potential means to reduce fatigue and improve alertness.

4.0 METHODS

The methods selected for use in this research are based on several considerations: (1) demonstrated sensitivity in measuring alertness and fatigue and the factors contributing to them, (2) relative cost of the measures, and (3) the relative intrusiveness of the measures. Because of the applied nature of this project, we were not trying to develop new measures; instead our philosophy was to employ the best (and most practical) approaches that have demonstrated sensitivity in field settings in the past. Cost of the measures is clearly important because of budget and time limitations — our guiding principle was the need to gather a fairly large sample within the budget. Finally, because we were working in a field setting with commercial mariners, it was very important to use unobtrusive measures. Experience has shown that cooperation with the study decreases in proportion to the invasiveness of the research procedures.

A variety of research strategies and tactics were considered in the initial stages of this research. The costs and benefits in terms of the considerations listed above were evaluated for a variety of field research settings. This resulted in the recommendation of the strategy we selected, which is described in this section. The detailed evaluation of alternative field settings and measurement approaches is described in Appendix 1. The methods selected have been employed extensively in other settings — flight operations, in particular (Rosekind, et. al., 1995). Similar research protocols are now being employed for fatigue studies aboard the space shuttle.

4.1 *Original Methods*

The original methodological approach to this research was to combine survey, self-report, and human performance measures to gather converging data. This procedure was pilot-tested on one ship using round-the-clock data collection because of the requirement to account for circadian rhythms. Data were collected from crew members for a single voyage segment of 4 days duration between ports. The resulting data suggested that the various measures would be sensitive to time-of-day effects. However, our experience indicated that the requirements on both the crew and the research staff were too demanding and expensive to expand this procedure to larger-scale data acquisition. One of the principal difficulties was that the procedure imposed an additional 72-minute load (across all testing sessions) on mariners, who are limited to a 12-hour workday. The procedure itself was disrupting sleep and work.

4.2 *Revised Methods*

Based on the pilot test of the original methods, and considerable feedback from operational mariners, a revised approach to the project was adopted. The key features of the revised approach involved (1) development of a logbook for obtaining self-report data on sleep episodes and alertness during the workday, (2) use of an extensive Background Information Inventory (BII) survey, and (3) self-report of alertness fluctuations on an hourly basis throughout the day by means of a Retrospective Alertness

Inventory (RAI). Performance testing was excluded from the work based on the knowledge that high correlations exist between performance data and self-reports of alertness and/or sleep deprivation (Gillberg, Kecklund, and Akerstedt, 1994), and the considerable cost that would be incurred to collect such data. Recent work suggests that the demands of field research with uncontrolled schedules are best handled through self-report data (Folkard, et al., 1995).

The feedback provided by mariners in the pilot test was quite valuable in gaining perspective on the fatigue problem and how to measure it in a meaningful way in an at-sea setting. The mariners stressed that measurements obtained over a 4-day period were not going to give us particularly accurate representations of either their sleep patterns or their alertness and fatigue levels. It was determined that a more accurate sample would be obtained if we collected data for a complete voyage cycle, and more than one complete cycle, if possible. A voyage cycle, in the case of the trade routes we studied, involves a round trip starting at a port in one of the Pacific Coast states and sailing either to Alaska or Hawaii, with an intermediate port sometimes included. One of the freight ships studied was coastwise between British Columbia and Los Angeles. The data collection instruments and procedures are described in Appendix 2.

The primary tool used to gather data for extended periods (10 to 30 days) was a *mariner logbook.* This logbook was developed to collect the following data: sleep timing and duration for up to three sleep episodes per day, alertness before and after three work periods, sea state, whether the ship was at sea or in port, and additional information useful for interpreting these primary data. The booklet was pocket-sized and provided a sufficient number of pages for entering 10 days of data. For ships engaged in longer data collection periods, multiple booklets were used. Mariners were instructed to fill out the booklets as close to the time of the sleep or work period as possible. The total time required to fill out the logbook on any one day was approximately two minutes.

The BII consisted of a standard survey form that mariners filled out during their free time. The survey contained questions related to sleep behavior on the ship and at home; questions related to chronic fatigue; various personality scales; and questions related to general health, work habits, and means used to reduce fatigue. There were 72 total questions in the BII; the survey took approximately 60 minutes to complete.

The third principal instrument was the RAI. This tool was developed by Folkard and colleagues as a means of rapidly gathering alertness ratings over a 24-hour period (Folkard, et al., 1995). The RAI consists of a single page and rates each hour of the 24-hour period on a scale of 1 (very alert) to 9 (very sleepy), with a score of 0 if the respondent is usually sleeping at that hour. Respondents provide a single estimate of their alertness, in contrast to the daily ratings obtained with the logbook. Data analysis re-scaled these values to correspond with the mariner logbook alertness rating scale of 1 (very sleepy) to 9 (very alert). Previous research has shown the ratings on this instrument to correlate very highly with ratings obtained on a daily basis and with human performance data. In the present research, mariners provided retrospective alertness ratings for the following scenarios: (1) at home, (2) at sea, (3) beginning of sea tour, and (4) end of sea tour.

4.3 Procedure for Ship Selection and On-Board Research Protocol

Because of the desire for a relatively homogeneous sample of ships on a defined trade route, our focus was on tankers and freight ships on West Coast runs. The research team identified a number of companies as potential participants, and letters requesting participation were sent from the Chief, Office of Marine Safety and Environmental Protection (G-M), to the presidents of each of these companies. Briefings by the principal investigator and Coast Guard technical representative were provided for those companies that agreed to participate. In order to ensure participants that their data remain confidential, ships are referred to simply in terms of type and trade route.

Previous work has shown that advance planning and notification of mariners involved in these studies is critical to voluntary participation. Therefore, research staff coordinated extensively with ship schedulers at each company involved, providing descriptive material concerning the study, the on-board time requirements, and any other information requested. With the assistance of the company schedulers, researchers met the ship at a designated port to introduce the research protocol. On any particular ship there was either one or two researchers, who rode the ship between two ports, usually for a total voyage duration of approximately five days.

Once aboard the ship, the researcher convened a group meeting at the convenience of the crew to introduce the general nature of the study and to request voluntary participation, and to designate times and locations for individual meetings. Mariners would then meet individually or in small groups with the researcher for more detailed explanations of the study requirements, and to address any questions. Mariners were compensated $50 for their participation.

Introducing the protocol to 20+ crew members generally took about 3 days following port departure. The following two days were used to address any further questions that crew members had, and to periodically reinforce the need to fill out logbooks in a timely manner. Data were retrieved from the ship by meeting the vessel in the next port following completion of the data collection period (at least 10 days and 2 ports).

4.4 Description of Ship and Subject Samples

The research protocol, including the first pilot-test ship, involved data collection from a total of 141 individual mariners on 8 different ships. The average age of the participants was 42.9 ± 11.48. Table 2 lists the individual ship type and number of mariners studied. During the time periods under study, the ships encountered no significant heavy weather that would adversely affect alertness.

Table 2. Summary of Ships and Number of Participants

Ship Number	Type	Trade Route	Time Period	Number of Days	Number of Crew Participating
1 (pilot study)	Tanker	West Coast-Alaska	February 1995	4	14
2	Tanker	West Coast-Alaska	June 1995	30	23
3	Tanker	West Coast-Alaska	October 1995	17	19
4	Tanker	West Coast-Alaska	January 1996	30	11
5	Tanker	West Coast-Alaska	February 1996	25	19
6	Freighter	West Coast U.S.	February 1996	20	24
7	Tanker	West Coast-Alaska	March 1996	30	17
8	Freighter	West Coast-Hawaii	March 1996	25	14
Total					**141**

Because mariners work round-the-clock schedules, we focused our effort on sampling from all categories of worker – watchstanders, command personnel (master and chief engineer), dayworkers (e.g., able-bodied seamen and unlicensed engineers), and the steward department. Each of these classes of worker has different work-rest schedule constraints by the nature of their job. Table 3 provides a summary of the sample in terms of work category and number of subjects.

Table 3. Number of Subjects in Each Mariner Category and Ship Type

	Ship Type		Totals
Watch Type	Tanker	Freighter	
1 – Midnight to 0400	18	5	23
2 – 0400 to 0800	18	5	23
3 – 0800 to 1200	24	5	29
4 – Command (Master & Chief Engineer)	12	4	16
5 – Operational Day Workers	14	8	22
6 – Steward	17	11	28
Total N =	**103**	**38**	**141**

The BII was collected from all participating mariners; the logbook was collected on ships 2 through 8, and the RAI on ships 3 through 8. Table 4 provides a summary of the numbers of observations collected for each of these instruments.

Table 4. Number of Observations for Each Data Collection Instrument

Number of Logbook Days	Number of BII's	Number of RAI's
2,038	141	98

5.0 FINDINGS AND DISCUSSION

This section describes the research results, accompanied by interpretation and discussion. Before addressing the individual findings, it is beneficial to review the primary variables of interest.

Section 4.0 describes the data collection instruments: the mariner logbook, the RAI, and the BII. Each of these instruments provides data that can be evaluated in terms of the major independent variables: type of ship, time of day, and type of watch. Type of ship and time of day are straightforward variables — in this study there were five tankers and two freighters; time of day is analyzed in terms of the 24-hour clock and duration of a watch.

Watch type, discussed briefly in Section 4.4, is defined under six categories based on our findings regarding work and sleep patterns. The first three categories consist of watches 1, 2, and 3 (midnight to 0400, 0400 to 0800, and 0800 to 1200). Personnel were included in these categories if they regularly worked one of these watchstanding schedules. The fourth category consisted of *command* personnel, and included masters and chief engineers. These personnel were included in their own category because of the specific legal requirements that masters and chief engineers be on duty during particular portions of a voyage (e.g., navigating restricted waters). This leads to a somewhat irregular sleep pattern and would skew averages of sleep duration and timing if they were analyzed with another group. The fifth category of personnel includes dayworkers who do not stand watches — this includes crew members such as able-bodied seamen and unlicensed engineers. The sixth work category included the steward department.

The data are presented below in a series of analyses designed to address the two objectives of this research: (1) defining the nature and extent of sleep disruption-induced fatigue, and (2) defining the impact of watch duration on fatigue. Sleep durations are reported in terms of hours and fractions of hours (e.g., 7.5 hours is equivalent to 7 hours and 30 minutes); sleep times are reported in terms of hours and minutes (e.g., 2200 is equivalent to 10:00 p.m.). Different statistical procedures were employed to determine if a result was significant (i.e., not due to error). Findings discussed in the following sections are based on tests yielding a 95% or greater probability that the result did not occur by chance. Details of individual tests are specified in accompanying footnotes.

5.1 The Nature and Extent of Sleep Disruption and Fatigue in Mariners

5.1.1 Do Mariners Differ in Sleep Behavior at Home?

In order to determine the extent to which sleep disruption induces fatigue among mariners, it is first necessary to evaluate whether mariners differ in the amount and timing of sleep they obtain when not working aboard ship. The BII indicated that the average reported sleep duration at home is 7.98 ± 1.7

hours. Analysis showed no difference between work categories for the average reported sleep duration at home[1]. Similarly, the timing of the main sleep episode showed no differences between the watch categories, with the average go-to-bed time at 23:17 hours, ± 16 minutes.[2] Analysis of BII question 48 indicated that, overall, workers consider themselves more "evening types" than "morning types," but this cannot be attributed to a particular set of worker categories.[3] Data from the RAI showing alertness fluctuations over the day also showed no differences between watch categories.[4] Thus, it can be concluded that the personnel who experience dramatically different work-rest schedules aboard ship do not differ in the timing and duration of their sleep at home. Any observed differences in shipboard sleep behavior can therefore be attributed to the work schedule.

The next step in evaluating the impact of work-rest schedules on shipboard sleep behavior is to determine the extent to which a *sleep debt* is incurred; this is essentially the difference between the reported duration of sleep at home for individual mariners and the average sleep duration at sea obtained from the logbooks. This analysis showed a significant effect of sleep location, such that an average sleep debt of 1.3 hours per night is incurred aboard ship.[5] Table 5 summarizes the data concerning sleep duration at sea and at home.

Table 5. Descriptive Statistics for At-Home and At-Sea Sleep Durations.

Average Time of Sleep Onset at Home	Average Sleep Duration at Home (hrs)	Average Sleep Duration at Sea (hrs)	Sleep Debt (hrs)
23:17	7.9	6.6	1.3

The BII requested that mariners indicate whether they ever felt tired, fatigued, or a decrease in alertness during a watch. While there was no significant difference between the work categories,[6] it is noteworthy that 38 percent of the mariners indicated that they *did* experience fatigue or decreased alertness during watch. This is a substantial proportion, and is a similar proportion to previous reports of workers actually falling asleep on the job. Analysis of watch categories in terms of chronic fatigue (BII question 50) indicated that workers were within the range of previously reported values for this scale, with no differences between watch categories.[7]

It appears that mariners who work in the different categories of work-rest schedule are drawn from the same biological population (i.e., they do not differ in their basic circadian rhythms of sleep timing and duration, nor does there appear to be a preponderance of morning/evening types or chronic fatigue in the

[1] One factor analysis of variance (ANOVA) (watch type, 6 levels); $F = .406$; $df = 5, 130$; $p > .844$

[2] One factor ANOVA (watch type, 6 levels); $F = 1.43$; $df = 5,130$; $p > .217$

[3] Pearson chi-square = 17.12, $df = 15$; $p > .311$

[4] Two factor ANOVA (watch type, 6 levels by time of day, 24 levels (repeated measures); $F = 1.52$; $df = 5, 83$; $p > .19$

[5] Paired sample t-test, $t=6.61$, $df = 95$, $p < .001$

[6] Pearson chi-square = 8.02, $df = 5$, $p > .16$

[7] One factor ANOVA (watch type, 6 levels); $F = 1.52$; $df = 5,74$; $p > .19$

worker categories). It is evident from gross comparison of the at-home sleep duration with sleep duration aboard ship that a sleep debt of 1.3 hours per night is incurred at sea.

5.1.2 Do Mariners Differ in Sleep Behavior Aboard Ship?

The results presented above suggest that there is a substantial difference between the duration of sleep obtained aboard ship and that obtained at home. This section addresses the patterns and durations of sleep episodes obtained by mariners in their work environment, and is based on data obtained by means of the logbook. The analyses were conducted on average sleep durations for a 24-hour period; the averages are composed of data obtained over a 10 to 30-day period for each mariner.

The first approach to evaluating data of this sort is to visually inspect the patterns of sleep shown by mariners in the different watch types. Figure 6 shows the individual sleep records for all mariners in the different watch categories across the 24-hour period. In this figure the filled portions represent sleep periods; open space is awake time during which watchkeeping or other activities take place.

A notable feature in this figure is the regularity of timing of the sleep episodes – generally in proximity to the work periods. For example, mariners on the midnight to 0400 watch sleep in two episodes, one of which is initiated at 0430 and the other taking place from 2000 to 2330. A similar pattern is shown for the 0400 to 0800 watch. The 0800 to 1200 watch personnel go to sleep shortly after midnight, with a supplemental nap later in the day. Several of these mariners appear to take three sleep episodes per day. Command personnel sleep during what are considered "conventional" hours, but also show considerable variation for daytime sleep episodes based on the requirements to work all night in restricted waters. Dayworkers also sleep during "conventional" hours, and show similar variation in daytime sleep episodes. This may be attributed to all-hands calls for port activities and other variable aspects of their work schedule. The steward department shows the most regular pattern of sleep-wake behavior; this can be attributed to the fixed times of meal preparation and service.

One other feature of this figure warrants mention. That is the apparent sleep of some individuals during what would otherwise be their work periods. This is due largely to the ship being in port, and the shift in work activities that takes place, particularly for freight ships. Personnel on these ships are not as highly engaged during port calls as tanker personnel, and therefore may sleep at times of day that would otherwise conflict with their work schedules at sea. For this reason, we have analyzed the data in terms of location of the ship when the sleep episodes are recorded — either at sea or in port.[8]

---

[8] Average sleep durations per 24 hour period were computed for individuals by adding individual sleep episodes in a single 24 hour period, and averaging across days. Individual 24 hour periods were discarded if they exhibited extreme values, i.e., less than 3 hours or greater than 11.5 hours. These comprised less than 4% of the data set, and are attributable principally to logbook errors.

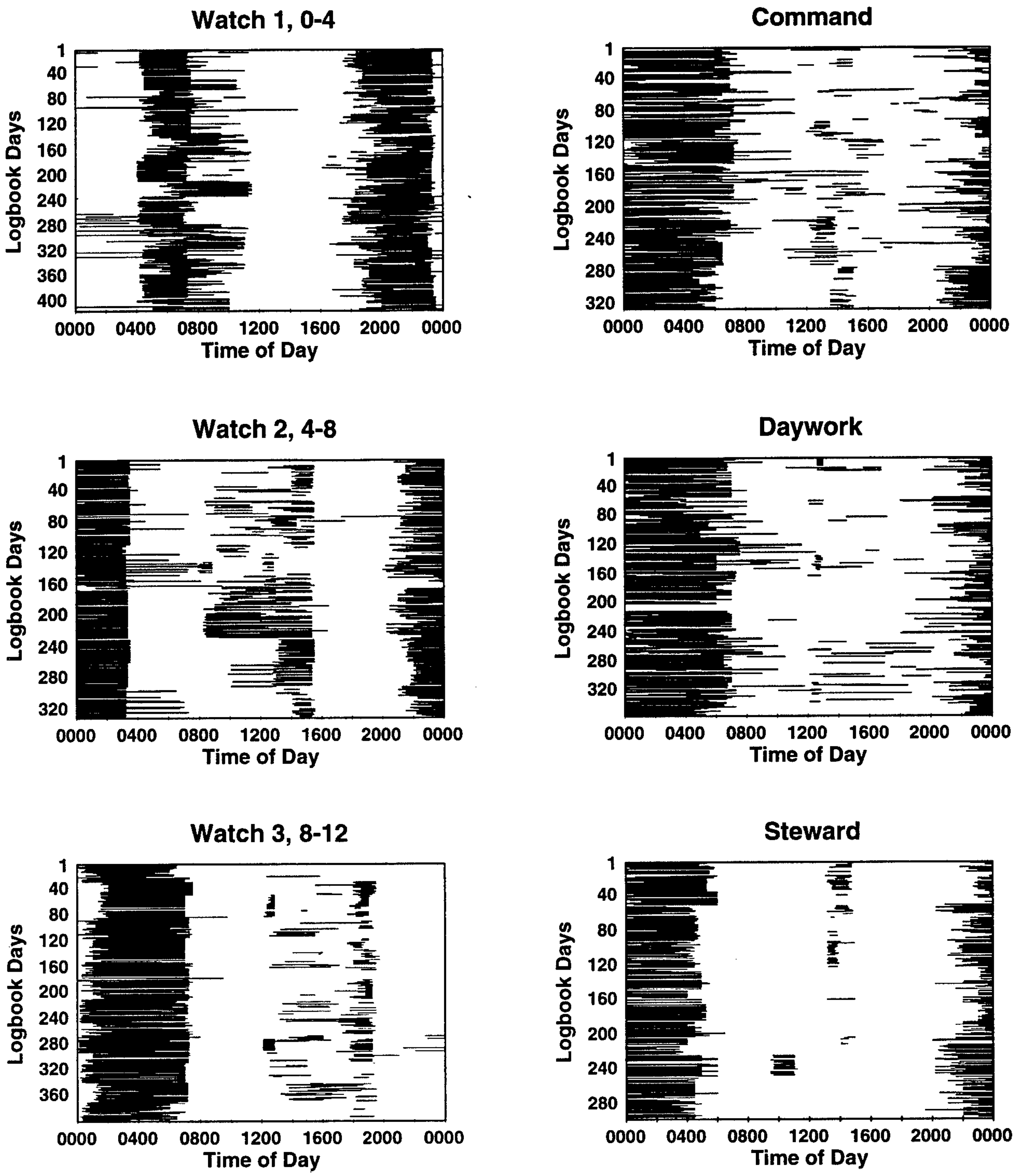


Figure 6. Sleep Patterns Over a 24-hour Period for Individual Logbook Days. (Lines indicate sleep episodes, white space indicates waking periods.)

The analysis indicated that watch type significantly influences sleep duration,[9] and is dependent on the type of ship.[10] Figure 7 presents the average sleep durations for the different watch types aboard freighters and tankers. There are several notable features in this figure. First, the average sleep duration for all types of workers and ships is 6.63 hours per 24-hour period — this is substantially lower than the values reported previously by Rutenfranz, et al. (1988). The average values in their study were on the order of 7.5 hours. It is notable that the Rutenfranz, et al. study showed much higher variances than the present work; this suggests that their data contained extreme values. Further analysis described below indicates that it is quite important to consider the phase of the voyage when analyzing mariner sleep data.

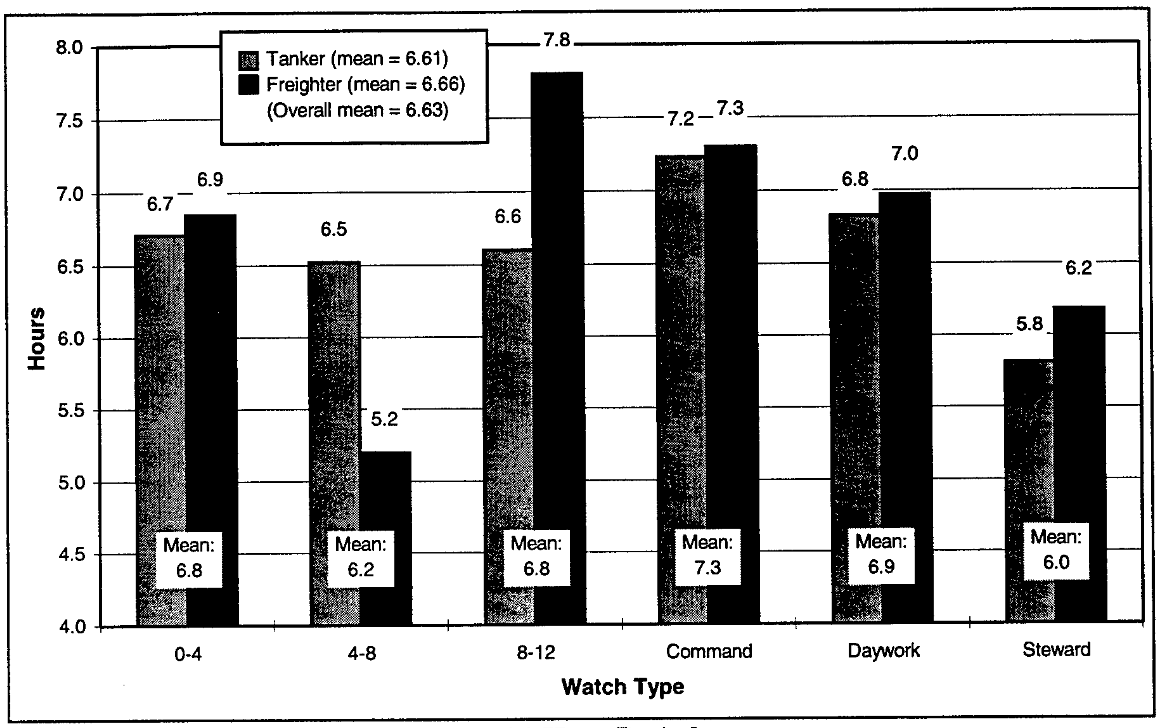


Figure 7. Average Sleep Durations per 24-Hour Period.

A second feature to point out in these data is that there is no significant difference between sleep durations on tankers and freighters, averaged across all categories of watch types. The difference between ship types is seen in the 0400 to 0800 and 0800 to 1200 watches; on tankers, the 0400 to 0800 watch obtained 6.5 hours of sleep whereas 5.2 hours were obtained on the freighter.[11] The opposite pattern occurs for the 0800 to 1200 watch: tanker personnel obtained 6.6 hours whereas freighter personnel obtained 7.8 hours.[12] All other categories are not significantly different.

---

[9] Two factor ANOVA (watch type by ship type); $F = 7.327$; $df = 5, 83$; $p < .0001$

[10] Two factor ANOVA (watch type by ship type); $F = 3.03$; $df = 5, 83$; $p < .014$

[11] One factor ANOVA (ship type, 2 levels); $F = 14.004$; $df = 1, 12$; $p < .003$

[12] One factor ANOVA (ship type, 2 levels); $F = 9.1$; $df = 1,15$; $p < .009$

The third feature to note from Figure 7 is that two watch types obtained significantly shorter sleep durations.[13] Across vessel types, personnel on the 0400 to 0800 watch obtained 6.2 hours of sleep per 24-hour period and personnel in the steward department obtained 6.0 hours of sleep, on average. The steward department sleep durations were shorter than all other watch types, and the 0400 to 0800 watch personnel on freighters slept less than the midnight to 0400 and 0800 to 1200 watches.

Since the duration of sleep in mariners appears to be substantially lower than previously reported, and lower than sleep obtained at home, it is important to consider the *patterning* of sleep. This can give a sense of the overall quality and restorative value of the sleep obtained. Figure 8 illustrates the number of sleep episodes taken per 24-hour period for the different watch types. It can be seen that the watchstanding personnel generally obtain their sleep in two or more separate episodes. Command personnel, dayworkers, and steward department personnel show a preponderance of single episode sleeps per 24-hour period. This situation changes substantially when in-port logbook days are considered. In this case, considerably lower percentages of watchstanding personnel take sleep in two episodes. Although the pattern of sleep changes in port, the overall duration does not.[14] This is driven largely by the tanker personnel in the data, who are engaged in cargo operations when in port. Additionally, the mates on two tankers in this sample shifted from a conventional 4-on, 8-off watch system at sea to a 6-on, 6-off system in port.

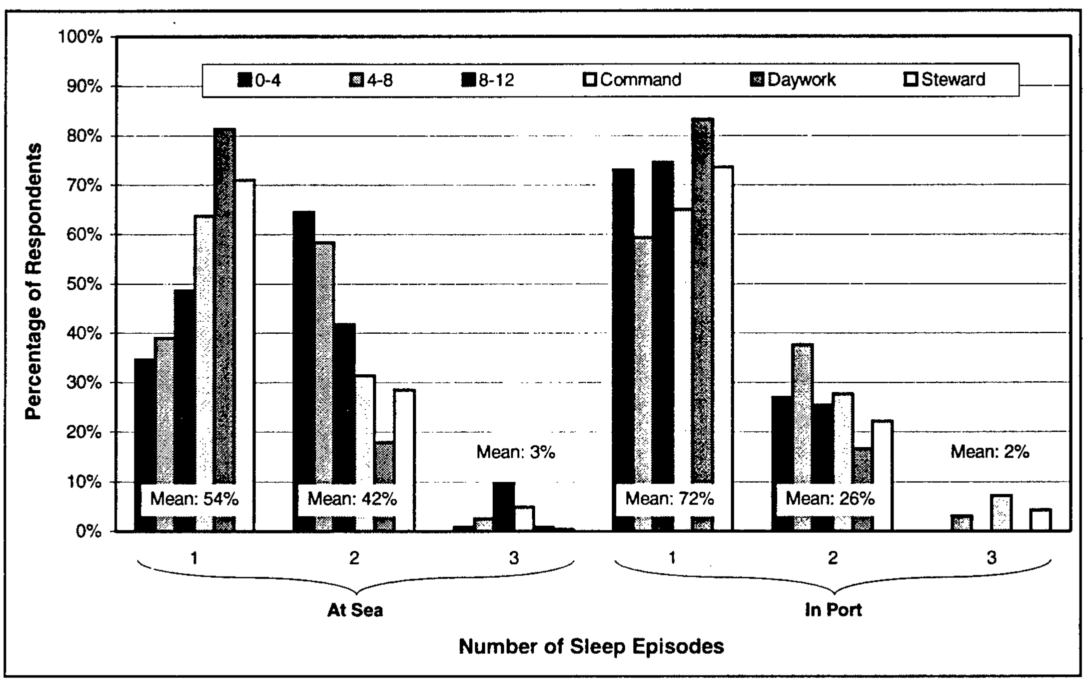


Figure 8. Percentage of Mariners in each Watch Type Taking 1, 2, or 3 Sleep Episodes per 24-hour Period at Sea and in Port.

[13] Least significant difference test, $p < .05$

[14] Three factor ANOVA (watch by ship type by voyage phase - repeated measures (at-sea, in-port)); $F = .07$; $df = 1,72$; $p > .79$.

5.1.3 Mariner Sleep Quality

In addition to duration of sleep periods, the restorative value of particular sleep episodes can be evaluated by considering the quality of the sleep obtained. A quality measure was obtained in the mariner logbook for each sleep episode recorded; the quality measure consisted of responses to five rating scales addressing ease of falling asleep, ease of arising, how rested the mariner felt upon arising, the depth of sleep, and sufficiency of sleep. A sum of the responses to these scales was used as the basic sleep quality metric; higher scores indicate better quality sleep. In the following analyses, sleep duration was used as a covariate to remove its influence from the statistical effects.

The results from this analysis are shown in Figure 9. The figure shows that watchstanders generally obtain lower quality sleep than personnel sleeping "conventional" hours.[15] There is also a distinction within watches, such that personnel on the 0800 to 1200 watch report lower quality ratings than the other five groups, and the dayworkers report the best quality sleep.[16] Finally, the 0400 to 0800 and 0800 to 1200 watch personnel report better sleep during naps than the main sleep episode. The opposite pattern is observed for dayworkers and stewards.

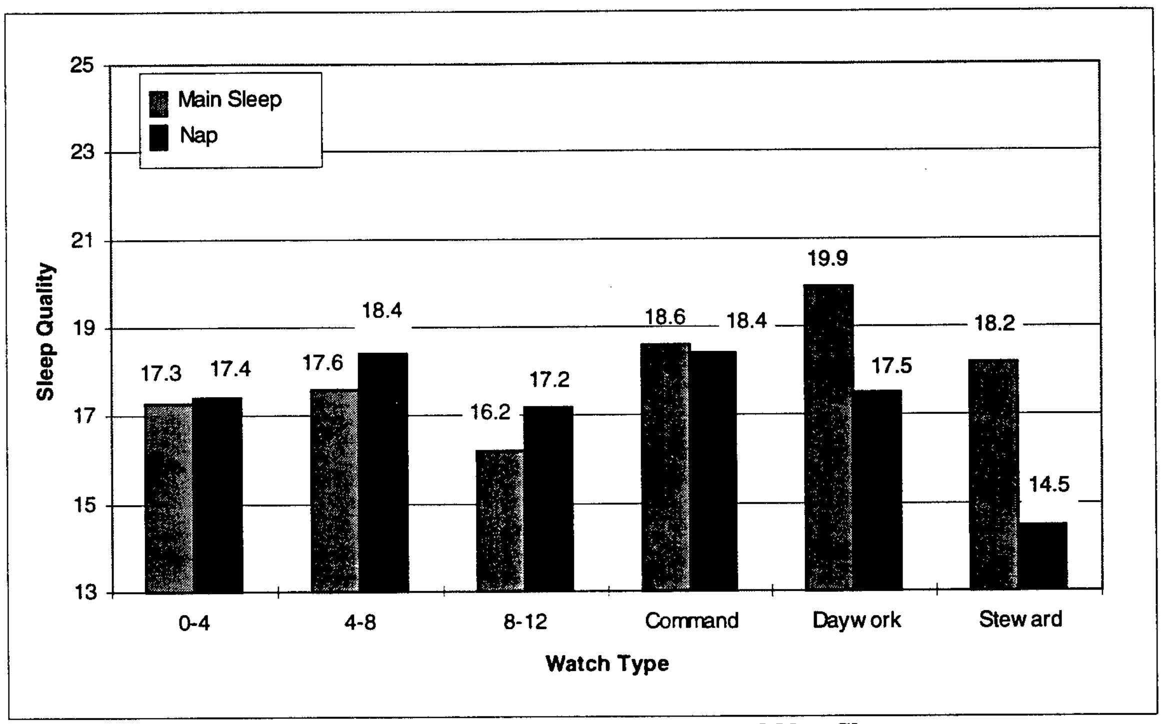


Figure 9. Average Sleep Quality Ratings for Main Sleep and Nap Sleep.

The results obtained from the sleep quality measures essentially confirm what was shown by Rutenfranz, et al. (1988). It is not surprising that personnel in command, daywork, and steward departments show higher sleep quality ratings — they sleep during the time period most consistent with human physiology.

---

[15] Two factor ANOVA (watch by sleep type (main sleep, nap sleep)); $F = 2.65$; $df = 5,77$; $p < .03$

[16] Least Significant Difference test, $p < .05$

It is somewhat surprising that the 0800 to 1200 watch personnel show the lowest sleep quality ratings, since their sleep onset shortly after midnight is the most similar to the sleep patterns of "conventional" hours. It is possible that this result is due to the opposite of sleep inertia (i.e., the difficulty in waking up following sleep). These workers may be experiencing "work inertia" (i.e., an inability to go to sleep following a period of work). This may also be somewhat true of the personnel on the midnight to 0400 watch — they usually take their main sleep immediately following the watch. The 0400 to 0800 watchstanders take their main sleep following the end of the 1600 to 2000 watch. The results suggest the possibility of providing a longer period of time between watches to provide a transition to more restorative sleep. This would seem particularly necessary in view of the adverse time periods in which this sleep is obtained.

5.1.4 Impact of Watch Schedule on Hours Worked

In Section 5.1.2, a variety of analyses illustrated the impact of watch schedule on the number of hours slept during a 24-hour period at sea. Similar analysis can be done with respect to the number of hours worked in order to identify any potential overload problems that may be affecting sleep and alertness on the job.

The data upon which this analysis is based are taken from the mariner logbook, and represent a similar volume of data to that used for analyzing sleep behavior. Figure 10 presents the findings for the six types of watch and two types of ship. A number of patterns are evident in this figure. The most obvious result is the impact of the type of ship upon the average number of hours worked: tankers averaged 11.64 hours in a 24-hour period, whereas freighters averaged 10.93 hours.[17] Watch types also differ significantly from each other,[18] and vary in hours worked, depending on the type of ship.[19] Average work hours show a significant *inverse* correlation with average sleep duration.[20]

Further evaluation of the hours worked aboard tankers indicates that the 0400 to 0800 and 0800 to 1200 watch categories work somewhat longer hours than the command category, and the steward department works significantly longer hours than all watch types except the third watch.[21] On freight ships, the midnight to 0400 and 0400 to 0800 watches work significantly longer hours than the dayworkers.[22] As with the sleep data, the phase of voyage (at sea or in port) did not significantly affect hours worked per day.[23]

---

[17] Two factor ANOVA (ship type by watch); $F = 7.903$; $df = 1,87$; $p < .009$
[18] Two factor ANOVA (ship type by watch); $F = 3.626$; $df = 5, 87$; $p < .005$
[19] Two factor ANOVA (ship type by watch); $F = 3.22$; $df = 5,87$; $p <.01$
[20] Correlation = -0.5, $df = 91$, $p < .001$.
[21] Least Significant Difference Test, $p < .05$
[22] Least Significant Difference Test, $p < .05$
[23] Three factor ANOVA (voyage phase (repeated measures) by ship type by watch); $F = .15$; $df = 1,66$; $p > .7$

The pattern of results shown here is maintained when the type of mariner is taken into account (i.e., licensed or unlicensed); thus, the principal driver of the work hour differences in the data appears to be the work schedule, and associated responsibilities. The results correspond to what we have learned about the factors influencing work practices. For example, the steward department on some tankers has recently undergone manning reductions; therefore it is natural that the remaining personnel work longer hours to take up the slack. The overall difference between tankers and freighter appears to be driven by the somewhat lower work hours of the dayworkers — this could be the result of electing not to engage in overtime.

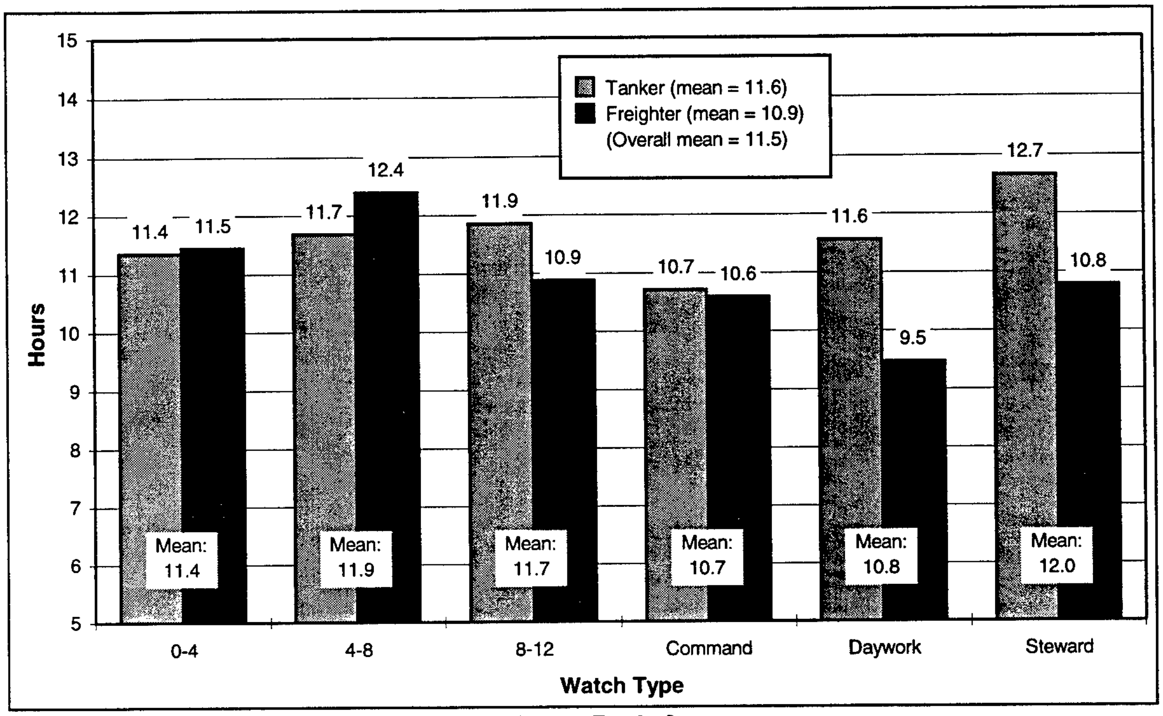


Figure 10. Average Work Hours per 24-Hour Period.

5.1.5 Indicators of Critical Fatigue in Mariners

The preceding sections have documented the existence of substantial sleep disruption among mariners. These sleep disruptions are known to reduce alertness during waking periods. What do these data tell us about the nature and extent of the fatigue problem in the maritime industry? In the following analyses we focus on the concept of *critical* fatigue (i.e., fatigue associated with impaired performance and imminent sleep).

The definition of fatigue is a very difficult issue — one which has led more than one investigator to suggest abandoning the concept completely (Muscio, 1921). All definitions of fatigue are ultimately of an operational nature (i.e., based on some type of measure). Among the more traditional measures are sleep latency in laboratory settings and sleepiness ratings on standard scales. The few studies that have been conducted of restricted sleep, in distinction to total sleep deprivation, have found subjects to exhibit increased ratings of sleepiness (Herscovitch and Broughton, 1981) and decreased sleep latencies on days following a restricted sleep regime (Roth, et al., 1989). For example, reducing sleep by half the amount normally obtained has been shown to result in significant changes in both physiological and psychological measures.

Given these findings, it is plausible to examine the data collected in this study for indicators of acute critical fatigue. Of the data we have collected, there are three measures that can be assessed: (1) the proportion of 24-hour periods in which total sleep was between 3 and 4 hours (3 hours was the lower cutoff for extreme values resulting from logbook errors), (2) the proportion of logbook alertness ratings of 3 (sleepy) or less, and (3) the proportion of sleep latencies (i.e., time between going to bed and falling asleep) of five minutes or less as reported in the logbook. Research has shown that relatively small sleep reductions have a detrimental impact on performance (Gillberg, 1995). Further, alertness ratings in the lower third of the scale have been shown to correspond to the onset of slow eye movements — an unambiguous symptom of physiological sleepiness (Akerstedt and Folkard, 1995). Reduced sleep latencies are routinely observed following total or partial sleep deprivation (Roth, et al., 1989).

Table 6 shows the incidence of these three critical fatigue indicators as percentages of the total sample obtained in the logbook. That is, for each sleep period, 24-hour period, and work period, the proportion of logbook entries meeting the aforementioned criteria were determined. The results indicate that 21 percent of all sleep episodes occur with a bed-to-sleep latency of less than 5 minutes. For all 24-hour periods recorded in the logbook, 8 percent were associated with total sleep durations less than 4 hours. For all work periods rated, 11 percent of the alertness ratings equivalent to "sleepy" to "fighting sleep" were obtained.

Table 6. Incidence of Critical Fatigue Indicators as a Proportion of Total Logbook Sample.

Sleep latencies less than 5 minutes	24 hour periods with total sleep between 3 and 4 hours	Work periods with alertness ratings ≤ 3
21%	8%	11%

Figure 11 presents the results of Table 6 by personnel watch categories to determine if there is a preponderance of critical fatigue indicators among the various workers. For sleep latencies of less than 5 minutes, the 0400 to 0800 and 0800 to 1200 watchstanders show the highest incidence.[24] Seventy-eight of the 121 respondents (64%) showed reduced latencies at some point during the study.

Total sleep durations of less than 4 hours per 24-hour period are overwhelmingly represented by the 0400 to 0800 watch personnel.[25] This is likely to be a result of personnel waking up to go on duty at 0400 and simply staying awake — not taking advantage of the opportunity for a nap. Across the entire sample, 50 individuals (39%) showed restricted sleep at some point during the study. Opportunities for recovery sleep (i.e., ≥ 8 hours) were less than the proportion of restricted sleep episodes — 5.2%. These episodes

[24]Pearson chi square = 165.31, $p < .00001$

[25]Pearson chi square = 136.19, $p < .00001$

occurred almost exclusively for command, daywork and steward department personnel. Recovery opportunities for watchstanders were virtually non-existent.

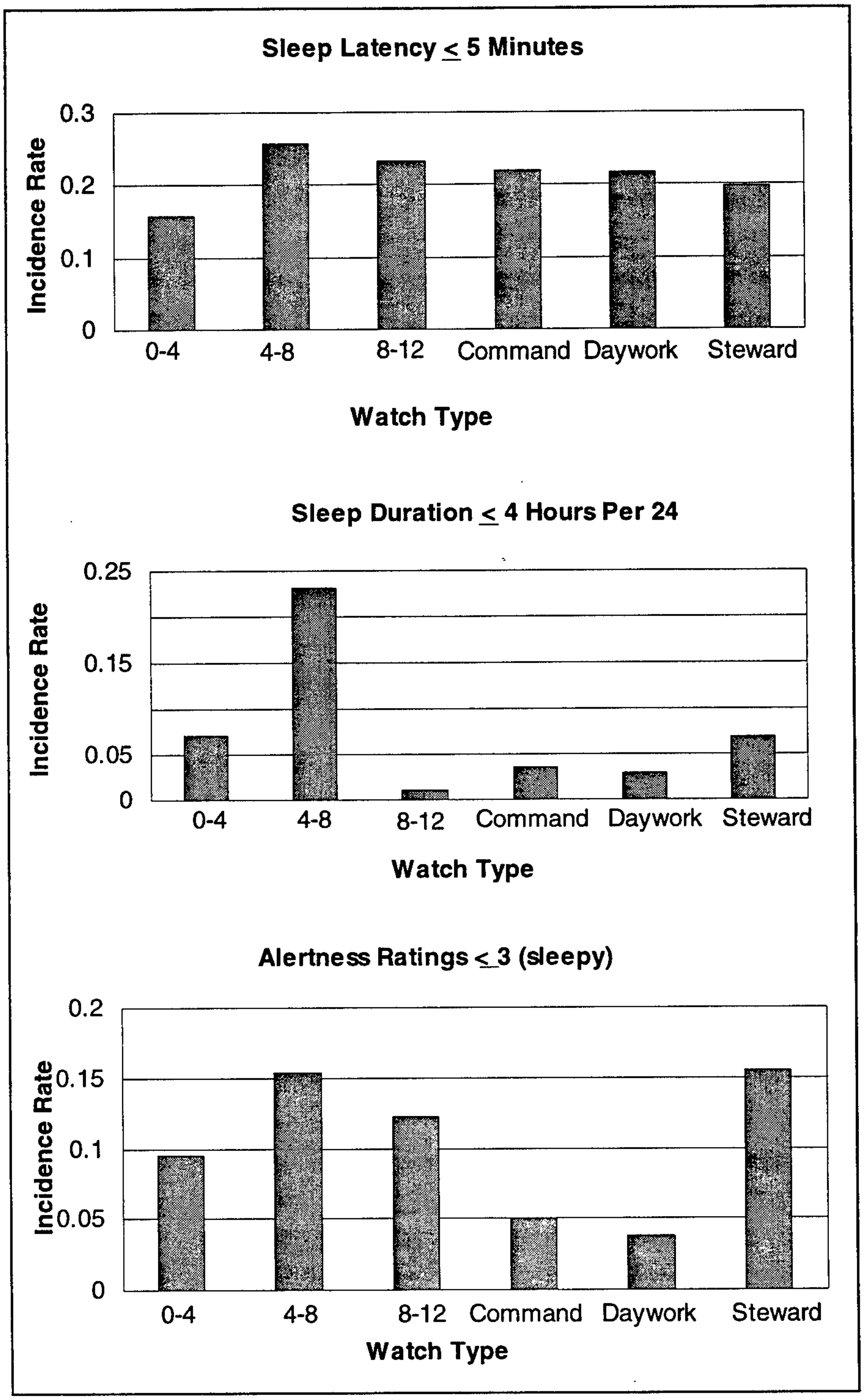


Figure 11. Incidence of Critical Fatigue Indicators in Each Watch Category.

Alertness ratings equivalent to the "sleepy" to "fighting sleep" range are also highly represented by the watchstanders and the steward department, and very little by command and dayworkers.[26] It should be noted that these proportions represent alertness ratings either before or after work; both were counted to determine the overall incidence of severe fatigue ratings. Twenty five mariners (20% of the sample) showed critical levels of alertness at some point during the study.

The data presented above indicate that if scientifically accepted measures are employed, the incidence of critical fatigue can range from 8 to 21 percent, depending on the measure. Analysis of fatigue symptoms reported in the logbook indicates that, overall, 28 percent of the work periods recorded are associated with one or more symptoms. The indicators discussed in this section represent a wide range of fatigue incidence, as would be expected with a multidimensional concept such as fatigue. Notwithstanding this range, it does appear that the incidence of critical fatigue in the maritime industry is substantial. Alternative scheduling or rest strategies may help to reduce the incidence of critical fatigue.

5.1.6 The Nature and Extent of Fatigue in Mariners: Summary

The focus of this section is to describe fatigue data in the U.S. maritime industry in terms of the incidence and nature of the problem. Prior reports have often anecdotally referred to fatigue as an issue, but little hard data exist to determine how often it occurs or why. In the absence of such information, little progress can be made toward policy and operational practice that can help alleviate the problem.

The data described in this section suggest that fatigue is indeed a problem of fairly widespread magnitude in the U.S. maritime industry. On the basis of a simple survey question, 38 percent of the respondents reported feeling fatigued at some point during their watch or duty period. More refined analyses of mariner sleep durations per 24-hour period indicate that the average sleep duration is 6.6 hours per night, with some categories of worker averaging as little as 5.2 hours per night. The sleep of watchstanders is fragmented because of work scheduling, which further reduces the restorative value of sleep.

Workdays are much longer than in similar research reported in Europe, and in several cases the mariners who sleep the least work the most. Watchstanders obtain significantly lower quality sleep than dayworkers, even when the watchstander (i.e., the 0800 to 1200 watch) sleeps in a physiologically adaptive period. Finally, on various measures of critical fatigue, the overall incidence varies from 8 percent for severely restricted sleep to 21 percent for very short sleep latencies. Of all work periods reported, 11 percent are associated with critically low levels of alertness at some time during the watch. The watchstanders account for the largest proportion of cases showing critical fatigue levels.

The data indicate that the critical factors contributing to mariner fatigue are (1) fragmented sleep periods, (2) sleeping at physiologically inappropriate times of day, and (3) insufficient time between work periods to obtain restorative sleep. Controlled laboratory studies show consistent relationships between these

---

[26] Pearson chi square = 317.82, $p < .00001$

factors and alertness and performance. The following section of the report discusses mariner alertness during work periods in relation to watch length, time of day, and sleep obtained prior to the work period.

5.2 *Relationship of Watch Duration, Alertness, and Fatigue*

The second objective of this work is to address the relationship of watch duration to mariner alertness. This relationship is important because of the prospect for increased watch durations associated with changing work practices and work-rest schedule regulations. Additionally, international changes in bridge manning practices, such as ongoing trials in Europe with one-man bridges, increase our need to better understand the fluctuations in alertness over the course of a watch. This section describes the findings related to alertness variations over the course of the 4-hour watch in the early and latter portions of the 24-hour period.

5.2.1 Comparison of Alertness Patterns at Home and at Sea

Analyses reported in the previous section indicated that mariners do not differ among the watch categories when considering alertness fluctuations over the day when they are at home. This indicates that mariners who work in different watch categories have basically the same circadian rhythms outside the work environment. However, there is considerable variation of this measure for the different watch categories within the work environment.

Figure 12 illustrates the alertness patterns at each hour of the day for mariners in each watch category (time periods during which people are usually sleeping contain no data points). The first feature to note from this figure is the similarity of alertness patterns in the "at-home" data, which has been confirmed statistically. The second feature to note is the disparity between the "at-home" and "at-sea" data. There are clear differences in peak alertness between home and sea ratings (in the case of the midnight to 0400 and 0400 to 0800 groups, work occurs when sleep usually occurs at home). The most striking effect is seen in the 0400 to 0800 watch during the early afternoon period — there is a very pronounced alertness decline for these workers, which is of greater magnitude and occurs earlier in the day when at sea. The 0800 to 1200 watch shows a bi-phasic alertness profile in the "at-sea" ratings, with a peak just before noon, and another at 2100. This dual peak profile is mirrored by two "dips" — one early in the afternoon and the other just following the dinner hour.

The utility of this type of comparison is that it provides a quick means (by use of the RAI) to compare the alertness profiles of different work-rest schedules with alertness profiles that are not constrained by specific work periods. Such a comparison can identify potential "trouble spots" during the course of the workday. For example, a person who regularly works the 0400 to 0800 watch has substantially reduced alertness in the early afternoon periods, and it is probable that risk is increased if he is working during this period.

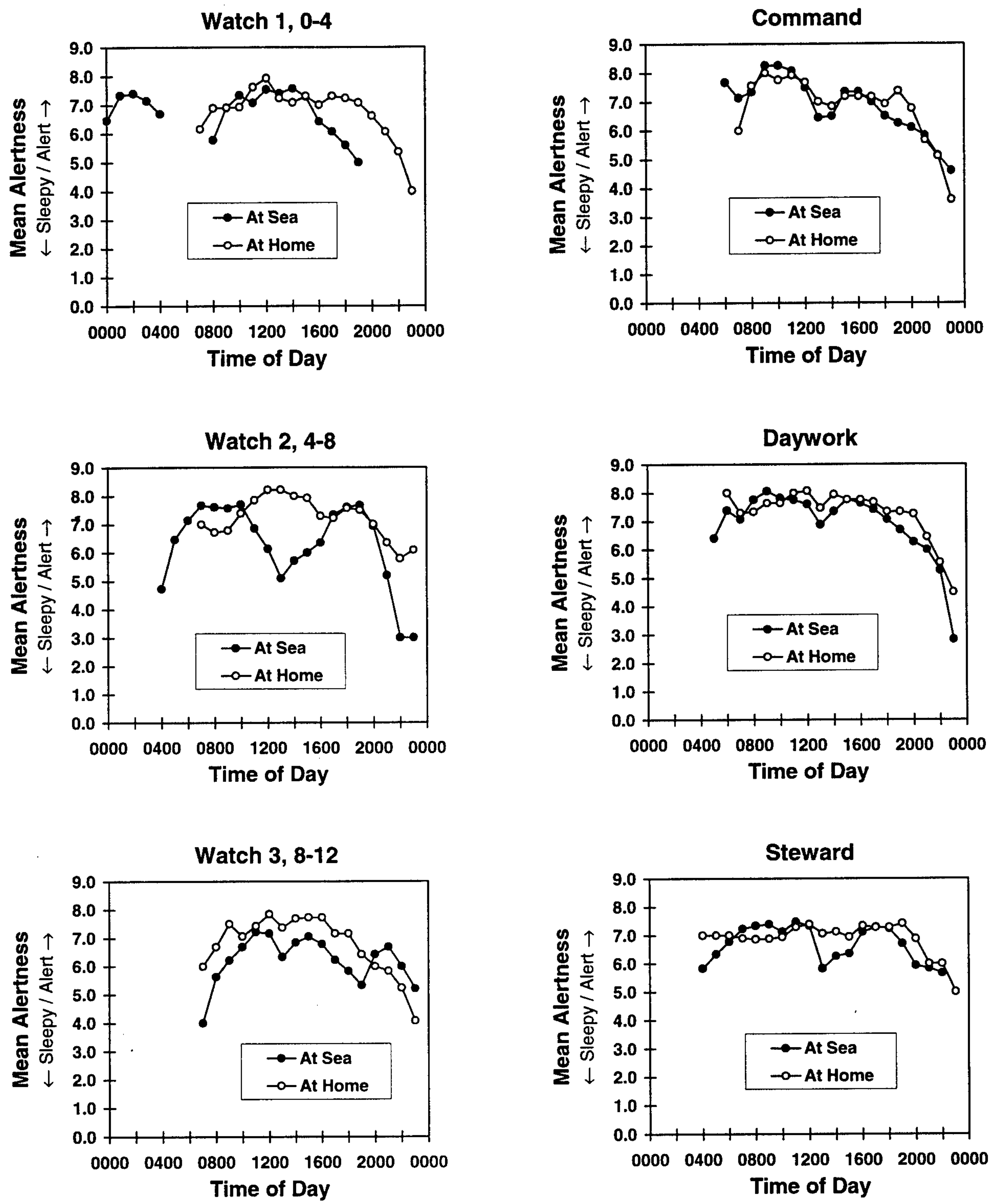


Figure 12. Alertness Profiles at Home and at Sea for Mariners at each Waking Hour of the Day. Data are from the Retrospective Alertness Inventory.

5.2.2 Time Course of Alertness Over the Watch

In addition to comparing alertness patterns between work and home settings, the data from the RAI and logbook permit an assessment of alertness variations over the course of a watch. This type of analysis is important to determine the extent to which there may be problem areas in the existing watch structure, and the impact of potential changes, such as lengthening or restructuring watches. The analyses reported in this section focus on the watchstanding personnel because they would be the most directly affected by any alteration of work structure. Logbook alertness values were scored on a 1 - 9 scale based on the position indicated on the visual analog scale.

Figure 13 presents data from the RAI and logbook that illustrate the average fluctuations in mariner alertness over the time course of each watchstanding period. The first feature to note from this figure is the similarity of data obtained from the logbook and the RAI. Correlational analysis reveals that both the individual and average ratings are significantly correlated.[27] The midnight to 0400 watch appears to

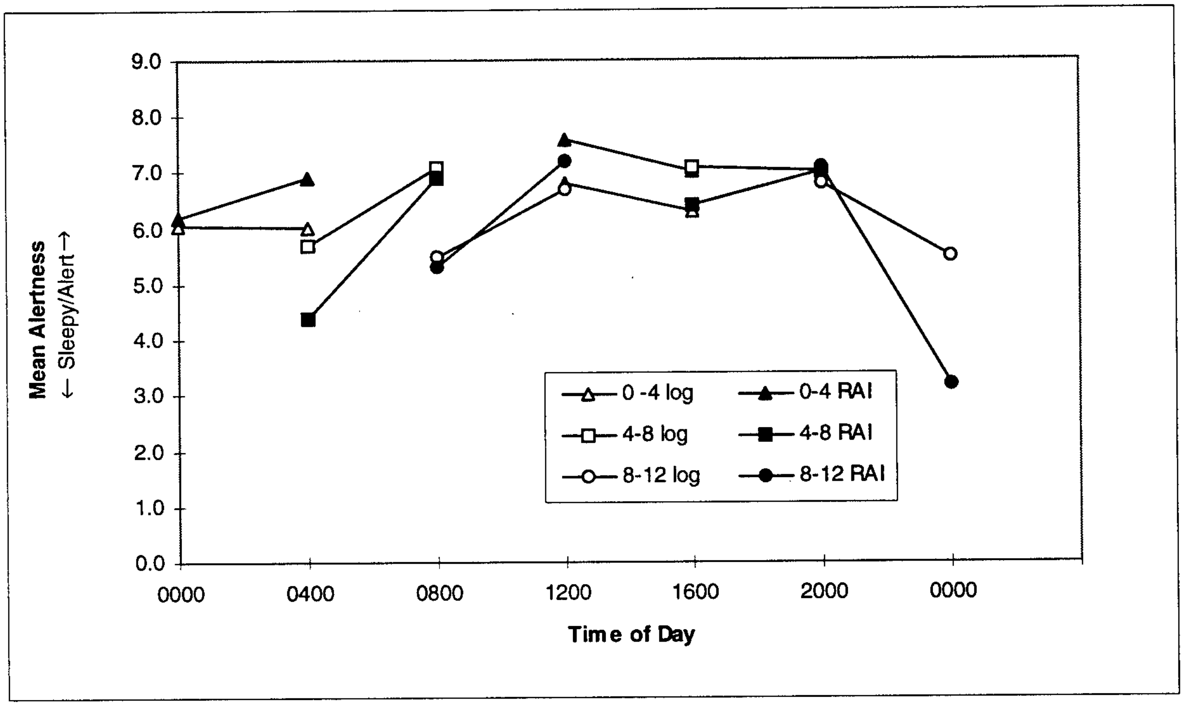


Figure 13. Time Course of Alertness over the Watch Period for Midnight to 0400, 0400 to 0800, and 0800 to 1200 Watchstanders, Obtained from Logbook and RAI.

[27] The cross correlations between RAI and logbook for each watch group are as follows: midnight to 0400 watch, r=.27, df=54, p<.05; 0400 to 0800 watch, r=.66, df=57, p<.0001; 0800 to 1200 watch, r=.61, df=56, p<.0001. The averaged data shown in Figure 13 show a correlation of r=.76, df=11, p<.004.

overestimate alertness by means of the RAI. In general, the results indicate that the RAI is a useful tool for estimating the average alertness of watchstander groups who work from early morning to late evening; its utility for assessing the level of alertness for the midnight to 0400 watch is questionable.[28]

Both the RAI and logbook yielded similar results in the analysis of alertness variations during the course of the watch.[29] The nature of the relationship between watch, time of day of watch, and time-into-watch is complex — all factors interact. Figure 13 helps us understand this interaction. The most parsimonious way to characterize the interaction is that each watch type shows a different alertness profile over the time course of the watch, and that this profile is different from morning to afternoon periods. For example, the midnight to 0400 watch shows relatively little change in alertness in the midnight to 0400 period, whereas the 0400 to 0800 watch shows a dramatic increase in alertness and the 0800 to 1200 watch shows a moderate increase in alertness during their first watches of the day. In the afternoon, the patterns reverse: the midnight to 0400 personnel show a modest decline in alertness, the 0400 to 0800 personnel show a modest increase, and the 0800 to 1200 personnel show a substantial drop in alertness.

The results indicate that the current work-rest scheduling for watchstanders does not allow the circadian rhythm of alertness to adapt to the work schedule. Adaptation would result in a more consistent and higher level of alertness throughout the workday. Figure 13 shows indications of early morning (i.e., 0400) reduced alertness, a post-lunch dip, and a decline in alertness in the late evening. The logbook results suggest that the midnight to 0400 personnel are working at a lower level of alertness than they would estimate, based on the disparity between logbook and RAI ratings. These expected variations in alertness are superimposed on multiple peaks and valleys in the watchstanding alertness profile based on the frequent changes of personnel at different times of day. It would be desirable to have a higher and more consistent alertness profile over the 24-hour period than portrayed in this figure; crew and watch changes are typically times during which problems can develop (Journal of Commerce, 1996).

5.2.3 Sleep Duration and Quality and Alertness During Work Periods

The results described in preceding sections suggest that we have accurately measured mariner sleep duration, quality, and alertness fluctuations during the work periods. The patterns indicate that watchstanders are generally at greater risk for disrupted or reduced sleep and lower main sleep episode quality. The alertness data indicate relatively poor adaptation of their circadian rhythm to the late night

---

[28] A three factor analysis of variance (time of watch [a.m., p.m.] by time-into-watch [before, after] by type of measure [RAI, logbook] showed a number of significant interactions involving the measures factor, including watch by measures by time of day ($F=4.35$, $df=2,29$, $p<.02$), watch by measures by time-into-watch ($F=3.94$, $df=2,29$, $p<.03$), and measures by time of day by time-into-watch ($F=7.3$, $df=1,29$, $p<.01$). The results indicate different patterns of measure sensitivity.

[29] Three factor repeated ANOVA (watch by time of day [early, late] by time-into-watch [hour 1,4] on RAI scores for watch segments yielded interactions between watch and time of day ($F=3.46$, $df=2,32$, $p<.04$), watch and time-into-watch ($F=8.22$, $df=2,32$, $p<.001$), time of day and time-into-watch ($F=29.95$, $df=1,32$, $p < .0001$) and watch, time of day and time-into-watch ($F=5.58$, $df=2,32$, $p<.008$). An identical analysis conducted on the before and after watch logbook alertness scores yielded a main effect of time of day ($F=5.82$, $df=1,49$, $p<.02$), an interaction between watch and time of day ($F=4.47$, $df=2,49$, $p<.02$), an interaction between time of day and time-into-watch ($F=27.2$, $df=1,49$, $p<.0001$) and an interaction between watch, time of day and time-into-watch ($F=4.73$, $df=2,49$, $p<.01$). The most important result is the 3-way interaction, obtained in both analyses.

and early morning schedules. In view of these findings, it would be desirable to predict alertness during any particular work period based on sleep duration and quality of the immediately preceding sleep episode. This type of information could be useful in warning mariners of potential alertness reductions, and developing means for managing these problems.

Our approach to alertness prediction was to use multiple regression as an "exploratory" data analysis tool — essentially to establish the feasibility of using data of the type we have collected for predicting alertness. Because the data set is quite large and very complex, we used the entire data set, without analyzing the impact of time of day of sleep, or time of day the alertness rating was obtained. The multiple regression computations were made on individual subject alertness values in the work period immediately following a sleep period (i.e., values obtained from the logbook). The general findings of these analyses are described below.

Two sleep variables — (1) total duration of the sleep period and (2) total quality of that sleep — were entered as predictors into three separate stepwise multiple regression analyses. For alertness at the beginning of the work period, $R = .61$, accounting for 37 percent of the variance. For alertness at the end of the work period, $R=.43$, accounting for 19 percent of the variance. Average alertness during the work period was computed based on the beginning and end of work period values; for this measure, $R=.57$, accounting for 33 percent of the variance.

Of particular interest in these analyses is the finding that total sleep quality was by far the main predictor of alertness in the work period. Adding duration of the sleep period to the model accounted for 1 percent of additional variance. Inserting additional terms to the model that account for time of day of rating and time of day of the sleep period can increase the variance accounted for by 3 percent. The results suggest that predicting individual alertness levels is complex, and probably requires a more elaborate time-series procedure.

5.2.4 Applicability of Modeling Techniques

The previous section described alertness modeling based on the data set collected in the maritime work environment. Modeling of alertness based on sleep data is an area where researchers are making progress toward developing tools to evaluate the potential impacts of various work-rest schedules. For example, Akerstedt and Folkard (1995) have developed a model that incorporates circadian rhythm components, and is applicable to *averaged* data within a group. It is likely that the ability to predict mariner alertness can be improved by aggregating individual data in ways that allow the influence of watch and time of day variables to be manifest. However, model development at this level is beyond the scope of the current project.

For the interim, the Akerstedt and Folkard (1995) approach is the most fully developed model for analyzing the impact of sleep patterns on subsequent alertness. This model is most useful for evaluating the impact of reduced sleep on personnel who sleep at "conventional" hours (i.e., between 2300 and

0700). Based on the model, it can be predicted that an 0800 to 1200 watchstander who wakes up at 0700 and does not take a nap during the day would experience reduced alertness toward the end of his watch in the evening (i.e., around 2300 or 2400 hours). This pattern was seen in the alertness ratings of the 0800 to 1200 watchstanders in our data, confirming the model prediction. In its present form, the model is most applicable to night sleepers for evaluating the impact of varying periods of wakefulness. Further developments to include the restorative value of sleep at different times within the 24-hour period, the impact of naps, and the impact of restricted major sleep episodes will make the model more useful for assessing mariner alertness.

In another project being conducted under the U.S. Coast Guard Human Factors Program Research and Development (Human Factors in Casualty Investigations), a predictive model of fatigue was developed. This model was based on the outcome of casualty investigations (i.e., whether mariner fatigue contributed to a casualty). In this project, data similar to the current study were collected, including sleep duration in the past 72-hour period, work duration in the last 72-hour period, and reports of fatigue symptoms. In the casualty investigation project, the model correctly classified 80 percent of the casualty cases in terms of their fatigue contribution (i.e., fatigue or other). Development of a similar model from the data collected in this study would be useful in comparing data across studies, and evaluating the potential risks of various work-rest schedules.

A different approach to modeling applied to maritime operations has been developed in a separate project under the Coast Guard Human Factors Research and Development Program (Minimum Manning Standards). The Crew Size Evaluation Model (CSEM) is designed to determine the number of personnel required to perform a given task within the constraints of work hour regulations and other voyage characteristics. Various analyses suggest that CSEM would be a useful means for evaluating alternative work-rest schedules. The model is currently well-suited to predict average and peak workloads in relation to existing work hour regulations. With modest further development, this model would be useful for determining the impact of work schedule changes. For example, the question of what tasks might need to be redistributed if work scheduling changed needs to be addressed. CSEM is an appropriate way to reduce the complexity of this question to a manageable level, and therefore is an important tool for use in the design of alternative schedules.

The general outlook for modeling applicability to mariner fatigue should be cautious but optimistic. The current alertness modeling capability applies to a limited set of maritime work schedules. Further development of regression models from our data set would likely improve prediction capability. Similarly, reconciling some of the differences in procedure between the casualty project and this study would likely result in a model capable of predicting fatigue as an outcome of particular work-rest schedules and sleep disruption immediately preceding the work period. From the standpoint of policy making and operational implementation, models will be useful tools for assessing the potential impact of new rules and work-rest schedules; for any particular intervention, it should be possible to predict the impact on mariner alertness and fatigue, and to assess the complexity and cost of implementation by the use of CSEM.

5.2.5 Relationship of Watch Duration, Alertness, and Fatigue: Summary

The focus of this section has been to characterize alertness fluctuations over the time course of individual 4-hour watches, and to determine the extent to which sleep duration and quality can be used to predict alertness in a work period. This type of knowledge will be useful in designing alternative watch structures and work-rest scheduling, and in evaluating their impacts.

Comparison of alertness profiles between the "at home" ratings and "at sea" indicates clear differences in peak alertness for certain watchstanders, particularly the midnight to 0400 and 0400 to 0800 groups. These groups are working at the most ill-suited times based on their circadian rhythms at home. The "at sea" data provide a useful profile of the various groups over the course of the workday. For example, the 0400 to 0800 watch personnel show a very pronounced "alertness decline," which would appear to put them at risk if they were working during this period.

Analysis of the time course of alertness over the watch periods indicates that there is a general circadian rhythm structure in alertness, upon which a variety of "peaks and valleys" are superimposed. These fluctuations are due to watch changes, which regularly begin at reduced levels of alertness. This finding suggests that longer watches may be appropriate, since they would be associated with higher and more consistent levels of alertness. A further finding from this analysis is that the midnight to 0400 watch personnel consistently overestimate their alertness levels, according to a comparison of the logbook and RAI data. This indicates that personnel who work during the circadian rhythm "low points" may be candidates for immediate training in means to recognize fatigue symptoms, and strategies to reduce it.

Assessment of mariner alertness by means of multiple regression modeling accounted for 37 percent of the variance in the data, without taking time of day and other work and sleep factors into account. Quality of the sleep episode immediately preceding the work period is the most significant predictor. The CSEM manning model appears to have high potential utility for evaluating the operational impact of alternative schedule designs. This approach, coupled with further model development from the data collected in this study, should be useful in assessing both the alertness and fatigue effects of different work structures and schedules, and the cost and complexity of change.

6.0 CONCLUSIONS

This project is the first comprehensive quantitative study of sleep and alertness patterns in U.S. mariners. Prior work in Europe contained limited samples from which to generalize, and reported sleep and work time values that do not accurately characterize the U.S. mariner population. The work reported here is sufficiently comprehensive to address the objectives of the project: (1) characterizing the nature and extent of the fatigue problem in the U.S. maritime industry, and (2) evaluating the relationship between fatigue, alertness, and watch duration.

Review of the literature indicates that performance declines occur in persons experiencing the sleep disruption similar to that found in the present study (see Appendix 3). *A variety of studies of chronic sleep deprivation show that the voluntary ability to direct attention to the environment is reduced* — this is one of the key factors in effective vigilance performance and in maintaining safe navigation (Blagrove, et al., 1995; Herscovitch and Broughton, 1981; Friedmann, et al., 1977).

The following sections review the main findings of the study in terms of the project objectives. This is followed by a series of recommendations for action to reduce the fatigue problem in the maritime industry.

6.1 Nature and Extent of the Fatigue Problem

The results of this research show that there is a fatigue problem in the U.S. maritime industry. The incidence of critical fatigue indicators such as severely restricted sleep durations per 24-hour period, sleep latencies of less than 5 minutes, and critically low alertness levels suggests that fatigue regularly occurs. The overall incidence rate is difficult to quantify because of the many different aspects of fatigue; however, the data support the following conclusions about the nature and extent of the fatigue problem:

- Critical levels of fatigue occur between 8 and 21 percent of the time, driven primarily by personnel on the 4-on, 8-off schedule. Recovery sleep periods do not occur.
- Mariners sleep an average of 6.6 hours per 24-hour period while on shipboard duty — this is 1.3 hours less than average sleep duration at home. Sleep debt is known to be cumulative and to reduce performance.
- Watchstanders generally obtain less total sleep than other personnel, and the sleep is of lower quality due to fragmentation and physiologically inappropriate sleep times.
- The steward department on tankers and the 0400 to 0800 watch on freighters have the shortest sleep durations of all watch and ship type combinations.
- Port activities significantly alter the timing of sleep; previous reseach has shown that changes in sleep timing can reduce alertness and performance levels.
- Tanker personnel generally work longer days than freighter personnel.

The research identified and quantified a variety of risk factors contributing to fatigue, including:

- reduced total sleep time per 24-hour period compared to home values (sleep debt)
- fragmented sleep
- sleep at physiologically inappropriate times of day
- insufficient time between shifts
- reduced quality main sleep
- long work days

Table 7 compares the categories of shipboard personnel against these risk factors.

Table 7. Level of Fatigue Risk Factors for Different Watch Categories.

	Fatigue Risk Factors					
Shipboard Categories	**Critically Reduced Sleep Durations**	**Fragmented Sleep**	**Sleep at Non-Adaptive Time**	**Reduced Time Between Work Periods**	**Long Work Days**	**Reduced Quality Main Sleep**
1 – 0 to 4	Moderate	High	High	High	High	High
2 – 4 to 8	High	High	Moderate	High	High	High
3 – 8 to 12	Low	Moderate	Low	High	High	High
4 – Command	Low	Low	Low	Low	Moderate	Moderate
5 – Day	Low	Low	Low	Low	Moderate	Low
6 – Steward	Moderate	Low	Low	Low	High	Moderate

The levels on the fatigue risk factors shown in Table 7 are generally higher for watchstanding personnel than command, daywork, and steward department personnel. For example, the 0400 to 0800 watch personnel exhibit a high incidence of critically reduced sleeps per 24-hour period (i.e., sleep less than 4 hours). One of the reasons for this is that it is easier just to stay up during the day once an alert state has been achieved; mariners often mentioned the impact of sleep inertia from naps taken prior to afternoon work. A similar paradox is seen in the 0800 to 1200 personnel; while they sleep during the hours of 0030 to 0700, the quality of sleep is poor, and there are consistent reports of difficulty falling asleep because of "work inertia" (i.e., the carryover stress from the work period just ended).

The nature and distribution of these risk factors indicate that the work schedule of the watchstanders is the primary contributor to the fatigue problem. Several possibilities exist for mitigating the problem through manipulation of the work-rest schedule. These possibilities are discussed further below.

6.2 Fatigue, Alertness, and Watch Duration

Understanding the relationship of watch duration, alertness, and fatigue is important for two reasons: (1) to identify existing problems that can be influenced by quick response approaches, and (2) to establish a baseline against which to compare conceptual changes (either regulatory or operational) in work structure or scheduling.

The important findings from this part of the study include:

- inconsistent levels of alertness over the watchstanding period
- a substantial drop in alertness on the 2000 to 2400 watch
- significant decline in 0400 to 0800 watch personnel alertness
- overestimating of alertness by midnight to 0400 watch personnel
- no data indicating watch durations should be fixed at four hours.

Inconsistent levels in the watchstanding alertness profile are attributable to the watch changes throughout the day. The 2000 to 2400 watch is the only watch that shows a substantial drop in alertness from beginning to end — this is because the time period corresponds to the onset of a physiological "low point" of the day for personnel on this shift. They go to bed soon after the watch is over, but paradoxically obtain the poorest quality sleep of all personnel aboard the ship. This latter finding is probably based on the "work inertia" of the immediately preceding watch. The overestimates of alertness by the midnight to 0400 watch personnel are cause for concern — immediate training related to fatigue symptoms of personnel in this group may be appropriate. Bearing these two findings in mind, there is no compelling evidence to suggest that watch durations need to be fixed at four hours. Increases in duration to facilitate longer rest periods should be considered, as well as shorter watches to facilitate scheduling.

Modeling to predict alertness in a watch period faces several difficulties, given the current state of model development. First, existing models do not account for sleep taken at different times of day, naps, or fragmented sleeps. Yet these are the factors that contribute to mariner fatigue. Second, existing models focus on sleep duration as the main predictor; however, this study indicates that *sleep quality* is a major predictor of alertness at the individual level. A potentially more fruitful approach is to develop predictive models from the data collected in this study, including long-term time series data, and to apply the CSEM manning model to evaluate alternative work schedules.

6.3 Recommended Courses of Action: Fatigue Reduction Approaches

The results of this study indicate that a fatigue problem exists in the U.S. maritime industry, and by implication, internationally. The research points to sleep disruption, insufficient time between watches, fragmented sleep, and long workdays as principal contributors to the problem. Analysis of alertness profiles during watchstanding periods indicates the desirability of a higher and more consistent level of alertness throughout the 24-hour period than is currently the case. These basic results suggest several courses of action for fatigue reduction, falling into the general categories of (1) work and rest period guidance and policy, (2) government-industry educational programs, and (3) design and evaluation of alternative work-rest schedules. The courses of action described below are intended as complementary and parallel activities.

6.3.1 Work-Rest Period Guidance and Policy

As described in the introduction, maritime work-rest period policies are at odds with our knowledge of human rest requirements. The existing U.S. minimum rest period of 9 hours does not translate into 9 hours of sleep; in the case of watchstanders, the average sleep duration per 24-hour period is 6.6 hours. Two of the three watches obtain this sleep in two episodes, which erodes the restorative value of the sleep.

As a first step toward moving the maritime industry toward more adaptive rest periods for mariners, it is recommended that the U.S. consider presenting the topic of *consecutive* rest periods as an issue in appropriate international forums. This would raise the issue in the international community, which is of considerable importance at this time, given the many other changes occurring in the maritime industry. An additional step is to seek industry input on the work-rest scheduling issue through publication in the Federal Register to initiate a public dialogue process. This is similar to the plan for obtaining industry response to the Prevention Through People implementation plan. A final step in this process would be the publication of a Coast Guard advisory bulletin (e.g., a Navigation and Inspection Circular or Commandant letter) suggesting to industry that continuous sleep periods are advisable for purposes of fatigue reduction. The National Aeronautics and Space Administration (NASA) published a similar advisory circular for the airline industry concerning the beneficial effects of strategic napping. Engaging in an international and public dialogue process will open the issue to informed analysis. Currently, the fatigue issue tends to be used as a bargaining chip between industry and labor, with no quantitative basis.

Both of the aforementioned approaches are U.S. government initiated, but do not constitute regulation. Instead, they use the visibility of the Coast Guard to raise the issue in an appropriate forum. This obviously nonregulatory approach to policy is based on the assumption that developing a regulation to cover the myriad possibilities for work-rest scheduling will be extremely difficult. The consequences of OPA '90 represent a good example: maximum workdays are capped at 15 hours for all tanker crews, but these mariners still suffer sleep disruption that is induced by the work-rest schedule.

6.3.2 Government-Industry Educational Programs

The maritime industry is a very tradition-oriented business. Practices that have been developed over periods of literally hundreds of years maintain a strong hold on the personnel who manage and operate ships. For example, the 4-on, 8-off work schedule for watchstanding has its roots in the Georgian navy of the 18th century. However, what may have been appropriate for that time period bears re-examination as technology and industry practices evolve.

One approach to improving the fatigue problem is to change existing beliefs through education and training. Industry management often believes that no problems exist because accidents related to fatigue have not been reported. Conversely, personnel aboard the ship may improperly estimate the extent of their own fatigue, as shown by the disparity between the daily and retrospective ratings of the midnight to 0400 watch. Educational programs that clearly convey the impacts of human physiological and psychological circadian rhythms, the impact of sleep debt and fragmentation, and the influence of sleeping at various times of day would help to establish a common understanding of fatigue in the maritime industry. Practical information for these programs could be obtained through improved casualty investigation procedures, as discussed by McCallum, Raby and Rothblum (1996).

There is a precedent for such a training program in the form of the NASA Fatigue Countermeasures Program. As part of this program for the aviation industry, NASA offers training in the fundamental aspects of fatigue and human performance. A number of maritime personnel have attended this class and report that it was very helpful for increasing their understanding of fatigue. A straightforward course of action from the present study would be to develop a specific "maritime fatigue training module" that focuses on the unique aspects of shipboard work schedules. This training module could be offered either as a supplement to maritime personnel attending the NASA program, or could form a core basis for a specific marine industry fatigue training program. In either case, using the extensive data collected in this study would be very useful both for establishing credibility with industry personnel and for illustrating specific points about fatigue and maritime work schedules.

6.3.4 Design and Evaluation of Alternative Work-Rest Schedules

The results obtained in this study indicate that the current 4-on, 8-off work-rest schedule leads to reduced sleep times for watchstanders, lower sleep quality, and an increased incidence of critical fatigue indicators. Since the work-rest schedule is the primary contributor, a logical course of action is to develop alternative schedules. This section discusses a research and development process to address this objective.

Development and testing of alternative watchstanding schedules for maritime work has been accomplished several times in the past 50 years (see Colquhoun, 1995 for review). These studies involved both military and commercial ships. The general finding is that circadian rhythms adapt well to the new schedules, and that sleep duration and quality are improved. However, operational difficulties were encountered in the commercial ship studies — the mates found it somewhat difficult to accomplish their extra duties (Fletcher, et al.,1988). The results suggest that while there are beneficial effects to be realized from alternative watchstanding systems, more attention to overall shift design and personnel utilization might reduce the operational difficulties. This is a very important issue from the standpoint of shipping company management — any change in operations needs to be developed with attention to cost and operational impact.

The third course of action recommended is to conduct a research effort to develop alternative watchstanding systems that reduce the fatigue risk factors inherent in the 4-on, 8-off system. Elements of this work would include:

- identifying alternative watchstanding systems currently in place (e.g., 12-on, 12-off)
- defining opportunities for alternative schedules in selected trade routes
- engaging shipboard personnel in the design process

- use of the CSEM model for computer-aided schedule design and evaluation
- trial implementation and evaluation of alternative watchstanding systems

Two of the key aspects of this approach are to selectively focus the design effort on selected trade routes and to involve shipboard operational personnel in the design process. The earlier work of Fletcher, et al. (1988) involving the "close" 6-on, 2-off watch system showed considerable merit in terms of providing a prolonged period of off-duty time for a single sleep. However, the system was designed without adequate consideration of operational questions, such as when watchstanders would accomplish their non-watchstanding duties.

New schedule design efforts should capitalize on the work of previous researchers, which considered the timing and placement of meals, prolonged off-time periods, etc. In addition, direct design input from working mariners and impact evaluation by means of the CSEM manning model are necessary. This type of process will ensure that operational questions are considered because the entire set of shipboard tasks will serve as a criterion; if some of these tasks cannot be accomplished, the new schedule would require modification. This type of process will permit consideration of a variety of potential manning and schedule design issues, such as:

- the use of second riding mates for strategic relief during longer watch periods
- the use of shore-based support for shipboard tasks that can be transitioned
- the prospect of enhancing the skill-base of selected unlicensed personnel to provide watch mate relief

Potential conflicts with Title 46 of the U.S. Code part 8104(d), which requires a three watch system on merchant vessels, will need to be considered as well. With advances in technology driving shipboard watchstanding practices, such as the controversial one-man bridge operation concept, these issues are increasingly important.

6.4 Implementing Recommended Courses of Action for Fatigue Reduction

These three recommended courses of action are the core elements of a process; each is an important aspect of addressing the maritime fatigue problem in a comprehensive way. The process is composed of complementary elements, designed to be carried out in parallel. For example, international policy development needs a technical basis for fatigue reduction (i.e., alternate work schedules). Similarly, raising the general level of awareness through a maritime-specific educational program will lead to more informed decisionmaking and operational practice. The courses of action described above will provide information that can guide international policy and practice for watchstanding in the current and future generation of commercial ships.

7.0 REFERENCES

Akerstedt, T. (1995). Work hours, sleepiness and the underlying mechanisms. *Journal of Sleep Research*. 4 (Supplement 2): 15-22.

Akerstedt, T. and Folkard, S. (1995). Validation of the S and C components of the three-process model of alertness regulation. *Sleep*. 18(1): 1-6.

Blagrove, M.; Alexander, C.; and Horne, J.A. (1995). The effects of chronic sleep reduction on the performance of cognitive tasks sensitive to sleep deprivation. *Applied Cognitive Psychology*. 9: 21-40.

Carskadon, M.A. and Roth, T. (1991). Sleep restriction. In T.H. Monk (Ed.). *Sleep, Sleepiness and Performance*. New York: John Wiley and Sons, Inc., pp. 155-168.

Colquhoun, W.P. (1995). Shiftwork at sea: Studies of watchkeeping. In Colquhoun, Costa, Folkard and Knauth (Eds.). *Shiftwork: Theory and Practice*. Frankfurt am Main: Peter Lang.

Dinges, D.F. and Kribbs, N.B. (1991). Performing while sleepy: effects of experimentally-induced sleepiness. In T. H. Monk (Ed.). *Sleep, sleepiness and performance*. New York: John Wiley and Sons, Inc.. pp. 97-128.

Fletcher, N.; Colquhoun, W.P.; Knauth, P.; DeVol, D.; and Plett, R. (1988). Work at sea: A study of sleep, and of circadian rhythms in physiological and psychological functions, in watchkeepers on merchant vessels - VI. A sea trial of an alternative watchkeeping system for the merchant marine. *Occupational and Environmental Health, 61,* 51-57.

Folkard, S. (1995). Effects on performance efficiency. In Colquhoun, Costa, Folkard and Knauth (Eds.). *Shiftwork: Theory and Practice*. Frankfurt am Main: Peter Lang.

Folkard, S.; Spelten, E.; Totterdell, P.; Barton, J.; and Smith, L. (1995). The use of survey measures to assess circadian variations in alertness. *Sleep*. 18(5): 355-361.

Friedmann, J.; Globus, G.; Huntley, A.; Mullaney, D.; Naitoh, P.; and Johnson, L. (1977). Performance and mood during and after gradual sleep reduction. *Psychophysiology*. 14(3):245-250.

Gillberg, M. (1995). Sleepiness and its relation to the length, content and continuity of sleep. *Journal of Sleep Research*. 4 (Supplement 2): 37-40.

Gillberg, M.; Kecklund, G; and Akerstedt, T. (1994). Relations between performance and subjective ratings of sleepiness during a night awake. *Sleep*, 17(3): 236-241.

Herscovitch, J. and Broughton, R. (1981). Sensitivity of the Stanford sleepiness scale to the effects of cumulative partial sleep deprivation and recovery oversleeping. *Sleep*, 4(1): 83-92.

Journal of Commerce (1996). Study of seafaring personnel... Longer handover periods could trim marine claims. April 12, p. 8A.

Kecklund, G. and Akerstedt, T. (1995). Effects of timing of shifts on sleepiness and sleep duration. *Journal of Sleep Research*. 4 (Supplement 2): 47-50.

Lauber, J.K. and Kayten, P.J. (1988). Sleepiness, Circadian Dysrhythmia, and Fatigue in Transportation System Accidents. *Sleep*, 11 (6): 503-512.

McCallum, M.C.; Raby, M.; and Rothblum, A.M. (1996). Procedures for Investigating and Reporting Human Factors and Fatigue Contributions to Marine Casualties. Battelle Seattle Research Center Technical Report.

Mitler, M.M.; Carskdon, M.A.; Czeisler, C.A.; Dement, W.C.; Dinges, D.F.; and Graeber, R.C. (1988). Catastrophes, sleep, and public policy: Consensus report. *Sleep*, 11(1): 100-109.

Muscio, B. (1921). Is a fatigue test possible? *British Journal of Psychology*. 12: 31-46.

National Commission of Sleep Disorders Research. (1993). *Wake up America: A National Sleep Alert.* U.S. Department of Health and Human Services.

Pollard, J.K.; Sussman, E.D.; and Stearns, M. (1990). Shipboard crew fatigue, safety and reduced manning. U.S. Department of Transportation Technical Report: DOT-MA-RD-840-90014.

Rosekind, M.R.; Gander, P.H.; Miller, D.L.; Gregory, K.B.; Smith, R.M.; Weldon, K.J.; Co, E.L.; McNally, K.L.; and Lebacqz, J.V. (1994). Fatigue in operational settings: Examples from the aviation environment. *Human Factors.* 36(2): 327-338.

Roth, T.; Roehrs, T.A.; Carskadon, M.A.; and Dement , W.C. (1989). Daytime sleepiness and alertness. In M.H. Kryger, T. Roth, and W.C. Dement (Eds). *Principles and Practice of Sleep Medicine.* Philadelphia: W.B. Saunders Company. pp. 14 - 23.

Rutenfranz, J.; Plett, R.; Knauth, P.; Condon, R.; DeVol, D.; Fletcher, N.; Eickhoff, S.; Schmidt, K.H.; Donis, R.; and Colquhoun, W.P. (1988). Work at sea: A study of sleep, and of circadian rhythms in physiological and psychological functions, in watchkeepers on merchant vessels - II. Sleep duration, and subjective ratings of sleep quality. *Occupational and Environmental Health, 60,* 331-339.

United Kingdom P&I Club. (1992). Analysis of Major Claims. United Kingdom Mutual Steam Ship Assurance Association (Bermuda) Limited. London: U.K.

APPENDIX 1

Scenarios for Fatigue Measurement in Maritime Operations

SCENARIOS FOR FATIGUE MEASUREMENT IN MARITIME OPERATIONS

INTRODUCTION

The purpose of this paper is to present a comprehensive list of approaches to measuring fatigue in maritime settings. The document is prompted by the need to collect converging types of data in a program aimed at characterizing factors related to alertness and fatigue in marine operations.

The approach taken in this document is a variant of "brainstorming" — listing all potential measurement scenarios (that we know of) and delineating the advantages and disadvantages of each. Such a list will allow us to evaluate the tradeoffs involved in collecting human performance and self-report data, and the generalizability of results. A variety of potential measurement scenarios and approaches are discussed, including at-sea measurements, surrogates for large-ship operations (e.g., ferries), and simulators. Only those approaches that have surface feasibility are discussed; certain operations, such as tug-barge tows, offer no prospect of introducing performance tests because of the minimum manning employed and the distraction of performance testing from other pilot house work. Further, only those approaches that seem likely to yield a sufficient density of data are discussed; certain options, such as measuring large-ship crews while in port, would appear to offer little prospect for gathering the number of observations required for reliable data.

The overriding question that is considered in delineating these approaches is this: To what extent do commercial maritime sleep/work schedules, such as 4-on, 8-off, affect attention and vigilance among personnel responsible for control of the ship? Subsidiary questions that need to be considered in selecting a research approach include: (1) the need for statistical significance of results, (2) the need for self-report and performance data obtained from the same subjects (i.e., significant correlation between self-report and performance data), and (3) the extent to which lines of evidence from different research approaches can be combined to make a convincing case.

AT-SEA OPERATIONS

1. **Whole crew around the clock measurement:** This approach is essentially the one tested by project researchers aboard the *ARCO Anchorage* in March 1995. The basis of this approach is self-report and performance measurement before and after watches for watchstanders (ideally, 6 times a day), and at multiple times during the work day for dayworkers.

Advantages: The principal benefit of this approach is that it closely monitors real operations. The self-report and performance measures presumably reflect the impact of ongoing operations, sea states, and work schedules.

Disadvantages: Our field experience suggests that the before-after watch regime is relatively intrusive, even with short duration tests. The combination of setup time, test time, and transition from bunk or workplace can add as much as 72 minutes to a 12-hour workday. In the case of tankers, this can impinge on the Oil Pollution Act of 1990 work hour limitations; for both freight and tankships, the protocol impinges on sleep. An additional limitation here is that to control data collection costs, only a single voyage segment (i.e., port - port) is measured. This precludes observing patterns of fatigue that may accumulate over a longer period (e.g., 30 days).

2. **30-day sleep and alertness rating log:** As a way to gather data over a longer period and minimize intrusiveness of the procedure, a 30-day log was developed. The log contains two pages for sleep behavior (time in bed, duration of sleep, etc.) and ratings, and three pages of alertness rating scales (before and after the first, second, and third work periods of a 12-hour day). Additionally, the log contains a "symptom checklist" adapted from prior studies of the physical and cognitive effects of fatigue, and a "critical incident" type recording form for use at the end of the day. The log is carried in the breast pocket of shirt or coverall, and filled in at appropriate times throughout the day.

Advantages: The procedure is relatively unobtrusive and covers a long period of time.

Disadvantages: There is no linkage of the self-report data to psychological task performance. The log may also not be filled out according to our instructions (e.g., it may be filled out from memory).

3. **Installation of performance tests on shipboard computers:** Delta or other tests would be installed on computers located either in the office or quarters of selected individuals. Tests would be taken according to a schedule prescribed by the researchers.

Advantages: Tests could be conveniently taken in the privacy of personal offices or quarters.

Disadvantages: Small numbers of subjects for each ship (on most ships, probably chief mate and chief steward with predictable schedules). Potential operational problems with software.

4. **Single subject round the clock:** This approach uses the methods described above in approach #1 (measure before and after watch) with a single subject who is devoted to the research protocol. This subject would be specially hired, and would follow a sleep schedule identical to when he or she works as an integral crew member. Some type of reduced activities would need to be developed for this crew member in order to preclude monotony and to approximate the work requirements of the full-duty crew.

Advantages: At-sea data collection could take place without disrupting the work and sleep schedule of full-duty mariners.

Disadvantages: While statistically significant within-subject correlations may be demonstrated, such a design would not meet the scientific requirements usually thought necessary to conclude that the effect is general.

5. **Cadets:** In this scenario, the methods described above in approach #1 would be employed with cadets on tour. We assume that with appropriate modifications to the protocol to involve more student participation, the work could be introduced as an aspect of the sea tour project activity. Students would take their personal 486 computers on the sea tour and complete the performance testing and self-report measures on the pre-watch/ post-watch schedule described above.

Advantages: Since cadets are on a learning tour, it should be possible to introduce performance testing into their routines without disrupting the operation of the ship. Further, it may be possible to follow them for a full 60 days, during which time schedule changes could be introduced. A variety of ship platforms and operating conditions could also be assessed.

Disadvantages: Cadets have relatively little sea experience compared to working mariners, and so may show larger fatigue effects because of a lack of adaptation. However, this might also be considered an advantage, since it would provide a relatively "pure" measure of fatigue without the masking effects of adaptation. For example, experienced mariners who are "adapted" to fatigue may perform quite well at routine operations, but poorly during unexpected or emergency events due to lack of spare capacity.

ALTERNATIVE AT-SEA OPERATIONS

6. **Ferry boats:** This approach would utilize the natural break in piloting operations to obtain performance data from selected individuals aboard commuter ferries in Puget Sound. These ferries maintain routine schedules at five locations in the Seattle area that are easily accessible. The boats load and unload at regular intervals, varying from 20 to 55 minutes. During these "down times" it may be feasible to gather human performance data from mates and captains who are not otherwise occupied with the ship's business. The data collection protocol would necessarily follow the ferry boat schedule, which covers 5:00 a.m. to 3:00 a.m.

Advantages: This approach would be logistically easy, given the locations of the boats. Researchers could be dispatched to particular boats for specified periods. Either short or long duration (e.g., one day or multiple days) testing could take place, and baseline data would be easily obtained because of regular days off. Frequent testing could be performed because of the rapid turn-around of boats, thus yielding better temporal resolution and more quickly eliminating practice effects. Large numbers of subjects could be obtained in a fairly short period of time. Since vigilant piloting and rapid decision making for small course corrections are performed routinely in this job, the results would directly address the impact of fatigue on bridge watchstanding performance.

Disadvantages: Since the research protocol would be based on the boat schedule, the issue of sleep fragmentation in 4-on, 8-off watchstanders would not be directly addressed. It could also be argued that any fatigue effect would not be directly generalizable to large ships because of the vastly different operations.

SHORE-BASED APPROACHES

7. Harbor assist tugs or Ship Escort Response Vessel System (SERVS): These vessels provide escort service for ships either entering port and docking (harbor assist) or for laden tanker vessels departing Valdez Terminal (SERVS). The crews of these vessels live aboard for their duty tour (14 days or more), and spend non-escort time tied up at the dock. The research protocol for this scenario would involve administering performance tests at frequent intervals throughout the times during which the vessel is tied up, attempting to cover as much of the 24-hour period as possible. This type of operation also offers the prospect of before and after escort operation testing.

Advantages: The shore-based operation provides ready access to crew members from several vessels simultaneously, thus increasing the density of data available within a particular time frame. Numerous crew members would be available during the inactive periods (which in Alaska can be considerable), thus facilitating larger sample sizes. Finally, the before-after testing would permit statements to be made regarding the impact of operations on fatigue.

Disadvantages: As with the ferry boat approach described above, the research protocol would be based on the boat and crew schedule, and the issue of sleep fragmentation in 4-on, 8-off watchstanders would not be directly addressed. Further, most data would be gathered during inactive periods, and it could be argued that monotony plays a significant role in test performance.

8. Pilots: This approach would be based on measuring pilot performance during their on-duty periods of inactivity (i.e., waiting for an assignment, and immediately before and after work periods). Researchers could be stationed at the pilot house and gather data regularly from pilots during their waking periods.

Advantages: Substantial numbers of seasoned mariners would be available in a single location for testing. Since there is very little to do while waiting for an assignment, cooperation would be high. Baseline data would be easily obtained, and large numbers of pilots could be tested within a 2-week duty period. The design would be particularly good for establishing relationships between self-report and performance measures at various times of day.

Disadvantages: Since pilots land at diverse locations throughout their assignment area, before-after measurement is not feasible unless a very focused location such as Valdez is used. Additionally, there is little predictability of sleep schedules, so a direct assessment related to 4-on, 8-off could not be achieved. Sleep disruption of performance is more likely toward the end of an assignment, when we would be unable to measure.

SIMULATION-BASED APPROACHES

9. Laboratory comparison of schedules: This would involve a controlled study of mariners recruited to follow a sleep and performance regime established to specifically address the impact of sleep disrupted by a 4-on, 8-off schedule on bridge watchstander performance. The design would necessarily entail a laboratory situation, in which multiple crews (run sequentially) simulated the schedule typical of large merchant ships. Sleeping quarters would be provided, as well as meals and other support during the test period. The test period would be established to evaluate the acute effects of sleep disruption induce by this schedule (i.e., on the order of several days).

Watchstanders would be required to perform typical bridge duties during their "work" periods, which would be accomplished by using a low fidelity simulator, such as Officer of the Watch (OOW). Additionally, the reaction time and other attention tests would be administered multiple times during the waking period.

Advantages: The design would permit a direct assessment of the 4-on, 8-off schedule on basic measures of attention, and on operational measures of performance derived from OOW. Explicit relationships could be established between self-report, basic attentional performance, and simulated operational performance.

Disadvantages: The design would be relatively high-cost, both in terms of facilities and researcher time, and subject time. The sleep schedule would take place outside of the motion on the ship and other unanticipated activities (i.e., the scenario is fairly "sterile").

10. Simulation of performance data: This scenario would not involve collection of performance data. Instead, it would entail using existing simulation programs that incorporate data concerning sleep duration and disruption, combined with circadian factors (developed by Folkard and Ackerstedt). Sleep log data obtained from mariners at sea over a 30-day period (see approach #2) would serve as inputs to the program. Using performance baselines established in previous studies, the program would be used to simulate the task performance impacts of actual sleep schedules as described by long-term sleep log data.

Advantages: This approach would capitalize on the best available information from two sources: (1) logs of actual mariner activity, and (2) established performance parameters from controlled studies. The linkages that are logistically difficult to establish in a field study would be addressed through modeling. The accuracy of the model could be assessed by comparing actual self-report ratings with those predicted by the model. To the extent that there is a good fit, the credibility of the performance data predictions would be enhanced.

Disadvantages: Simulated performance data lack the credibility of actual performance. The extent to which the modeling program parameters would be sensitive to maritime schedule sleep disruptions is not clear, since the model was developed on the basis of more typical sleep disruptions, such as sleep deprivation and conventional shifts (i.e., morning, afternoon, and night).

DISCUSSION

The research approaches described above offer a number of different possibilities for gathering human performance data related to maritime operations. They span the range of "ecological validity" from at-sea performance in conjunction with watches (the difficulties of which we now appreciate) to modeling of performance data based on sleep and activity logs.

Because of the various disadvantages described above with the at-sea approaches, this author suggests further evaluation of at-sea surrogates such as ferry boats, or shore-based maritime operations such as SERVS vessels. These offer the face validity of being "real" maritime operations, and as such would lend credibility to any model that might be developed on the basis of simulated performance data. Thus, my recommendation at this point would be to pursue three related lines of research: (1) long-duration sleep log and rating study at sea (approach #2), (2) either a ferry boat or shore-based (harbor tug or SERVS) collection of performance data, and (3) modeling of the performance effects of at-sea sleep schedules. This latter activity could be initiated in parallel with the at-sea sleep log study, and subsequent model runs could incorporate actual sleep log data.

This combined approach to self-report and performance data collection appears to be comprehensive, and would provide the basis for a plausible discussion of the effects of fatigue on bridge watchstander vigilance.

APPENDIX 2

Data Collection Instruments

MARINER'S

DAILY LOG

1996

The mariner's logbook was designed to collect sleep/work schedule information over a 10-day period. Each logbook contained a personal profile summary, a welcome note, and a set of instructions, as well as 10 identical data collection sections, each representing one day. Each section contained sleep and nap logs, work period logs, and end of day comments. Each of these is illustrated and detailed further in the next pages.

SLEEP AND NAP LOG

Voyage phase	Sea conditions
☐ In port	☐ Calm (0-4 ft)
☐ Restricted water	☐ Medium (5-18 ft)
☐ At sea	☐ Heavy (19-45 ft)

Date in bed ________ (mm/dd/yy)	Time (2400)
Time you went to bed	
Time you fell asleep	
Time you woke up	
Time you got up	
Sleep duration	
Number of awakenings at night ☐	

Rate Your Sleep

	Least (1)				Most (5)
Ease of falling asleep	1	2	3	4	5
Ease of arising	1	2	3	4	5
Was this sleep period sufficient?	1	2	3	4	5
How deep was your sleep?	1	2	3	4	5
How rested do you feel?	1	2	3	4	5

The Mariner's Logbook was divided into 10 identical sections, each section representing one day. In each section, there were three identical sleep and nap logs. The mariner could report as many as three sleep/nap periods in a 24-hour period.

In addition to the timing of the sleep episodes, mariners recorded voyage phase, sea conditions, and quality of sleep.

FIRST WORK PERIOD

Voyage phase	Sea conditions
☐ In port	☐ Calm (0-4 ft)
☐ Restricted water	☐ Medium (5-18 ft)
☐ At sea	☐ Heavy (19-45 ft)

☐ Normal duty ☐ Extra duty

Before work Date ________ (mm/dd/yy) Time________

Put a mark on the line to indicate how you feel right now

very sleepy |————————————————| very alert

After work Date ________ (mm/dd/yy) Time________

Put a mark on the line to indicate how you feel right now

very sleepy |————————————————| very alert

Did you experience any of the following during this work period?

☐ forgetfulness	☐ sore muscles
☐ distracted	☐ heavy eyelids
☐ difficulty focusing attention	☐ desire to sit or lay down
☐ less motivated	☐ itchy eyes
☐ did things at the wrong time	☐ difficulty focusing my eyes
☐ difficulty concentrating	☐ clumsy

Additional comments: ____________________

Each of the 10 sections contained three identical work period logsheets, enabling the mariner to record as many as three work periods per 24 hours. Each work period logsheet had three subdivisions: 1) summary of voyage phase and sea conditions; 2) alertness ratings before and after the work period; and 3) checklist of fatigue symptoms.

END OF DAY

Date________________
(mm/dd/yy)

Please note anything that occurred today that you could attribute to being tired or fatigued.

Did it happen to you? ☐ yes ☐ no

Another person? ☐ yes ☐ no

A group of people? ☐ yes ☐ no

When did it happen? From ________AM/PM

To ________AM/PM

What happened?______________________

____

____

What contributed to it?

____

____

____

What can be done to prevent it?

____

____

____

Additional comments:

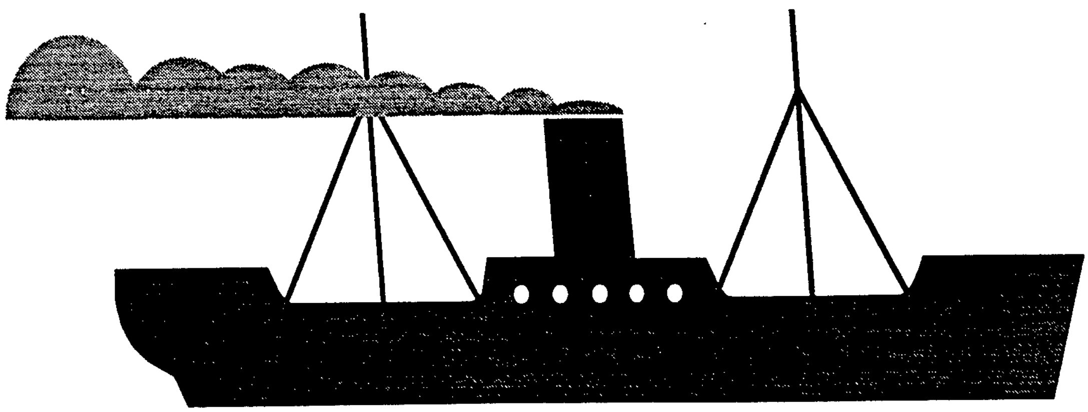
____

____

____

At the end of each one of the 10 sections, mariners could provide comments on this "End of Day" page as well as on the reverse side, which was blank and entitled "Additional Comments." The End of Day page asked the mariner to summarize any event or circumstances that occurred on that day and could have been attributed to being tired or fatigued.

ID # ____________



BACKGROUND INFORMATION INVENTORY

1996

INTRODUCTION

This questionnaire is an attempt to better understand and provide strategies to increase the safety and efficiency of merchant marine operations.

Please read each question carefully and mark the response which ***BEST*** reflects your feelings. Do not spend a lot of time on each one, your ***FIRST*** answer is usually the best. Most of the questions have no right or wrong answers. It is important that you answer each question even if you are unsure. ***Your identity and responses to the questionnaire will be completely protected. Do not place your name on the inventory and mark all answers in the space provided.*** Remember, the questions should NOT be discussed with anyone else, and the entire inventory should be completed without interruption if possible.

Your responses are valuable to provide safer and more productive work environments for yourself and fellow crew members. Your participation is greatly appreciated!!

GENERAL INFORMATION

1) Today's date: _____ Day _____ Month _____ Year

2) What is your age in years? _____

3) What is your sex? ☐ Male ☐ Female

4) What is your height? _____ feet _____ inches

5) What is your weight? _____ lbs.

SEA EXPERIENCE

6) How long have you worked as a merchant mariner? ____ years ____ months ____ weeks

7) How long have you worked for the current company? ____ years ____ months ____ weeks

8) Including this trip, how long have you worked on this vessel? ____ years ____ months ____ weeks

9) What is your present **rate** or **rank**? ***(e.g. chief mate, steward, wiper, etc.)*** ________________

10) How long have you been in your present **rate** or **rank**? ____ years ____ months ____ weeks

WORKING SCHEDULE

11) On average, how long are your tours? ***(enter number of days)*** ______ days

12) On average, how many days off do you have following a tour? ***(enter number of days)*** ______ days

13) How many days have you been on your present tour? ***(enter number of days)*** ______ days

14) What is the last day you went ashore? day ______ month______ time______

15) How long were you ashore? days ______ hours ______

16) On a typical day, what is your watch/duty schedule? ***(check one)***

a) ☐ 4 hours on/8 hours off
b) ☐ 6 hours on/6 hours off
c) ☐ 12 hours on/12 hours off
d) ☐ Other (specify) ________ hours on/________ hours off

17) What hours do you stand watch (***use military time - 2400 clock***)? 1) from ____ to ____
2) from ____ to ____

18) How long have you been on your **present** watch schedule?____ years ____ months ____ weeks

19) Given your schedule, what time do you consider as the beginning of your day? (U*se military time - 2400 clock*)?__________

20) If you could, would you change your watch schedule? ☐ No ☐ Yes

If Yes, what would the new schedule be? ________ hours "**on**" _________ hours "**off**"

Why?____

____

21) In general, how acceptable or unacceptable is your **present** watch schedule to you? (***check one***)

Very unacceptable	**Moderately unacceptable**	**Slightly unacceptable**	**Slightly acceptable**	**Moderately acceptable**	**Very acceptable**

22) On average, how many **days** do you work per week? _____ days

23) On average, how many **hours** do you work each week excluding overtime?_____ hours

24) On average, how many **hours** of overtime do you work each week? _____ hours.

SLEEP BEHAVIOR *ON THE SHIP*:

25) In a typical 24-hour period, how many sleep periods (***sleeps greater than 1.5 hours***) do you take? (***check one***)

a) ☐ 1 sleep period
b) ☐ 2 sleep periods
c) ☐ 3 or more sleep periods

26) At what time(s) do you take your sleep? (***fill in blanks in military time - 24 hour clock***)

1st sleep period: Go to sleep: _______ Get up: _______

2nd sleep period (if applicable): Go to sleep: _______ Get up: _______

3rd sleep period (if applicable): Go to sleep: _______ Get up: _______

27) How much **sleep** do you feel you get? (***check one***)

Too little		**Enough**		**Too much**

28) Do you take **naps** (***sleep less than 1.5 hours***)? (***check one***) ☐ Yes ☐ No

If **YES**, how often do you take them? (***check one***)

	5 days a week
	4 days a week
	3 days a week
	2 days a week
	1 day a week
	Less than 1 day a week

29) In a typical 24-hour period, how many naps do you take (***enter number***) _____ naps and on average how long do you nap for? (***enter in minutes***) _____ minutes.

30) On average, how long does it usually take you to **fall asleep**? _____ hours _____ minutes

31) On average, how many times do you **wake up** during a typical sleep period? _____

32) How often do you: (***check the appropriate box***)

	Not at all	**A little**	**Quite a bit**	**Almost always**
Have difficulty falling asleep?				
Have difficulty staying asleep?				
Wake up during sleep?				
Have difficulty getting up?				
Have restless or disturbed sleep?				
Disturb the sleep of other people?				
Wake up confused, disoriented, irritable?				

33) How often is your sleep **disrupted** or sleep onset delayed because of: (***check the appropriate box***)

	Never	**Almost never**	**Quite seldom**	**Quite often**	**Almost always**	**Always**
Heat or cold?						
Light?						
Noise?						
Quality of bed?						
Ship motions?						
Some other environmental factor?						
People?						
All hands call?						
Emergencies?						
Others?						

SLEEP BEHAVIOR *AT HOME*:

34) In a typical 24-hour period, how many sleep periods (***sleeps greater than 1.5 hours***) do you take at home? (***check one***)

a) ☐ 1 sleep period
b) ☐ 2 sleep periods
c) ☐ 3 or more sleep periods

35) At home, at what time(s) do you take your sleep? (***fill in blanks in military time***)

1st sleep period: Go to sleep: _______ Get up: _______

2nd sleep period (if applicable): Go to sleep: _______ Get up: _______

3rd sleep period (if applicable): Go to sleep: _______ Get up: _______

36) How much **sleep** do you feel you get at home? (***check one***)

Too little		**Enough**		**Too much**

37) What is your ideal sleep length? _______hours _______ min.

38) Do you take **naps** (***sleep less than 1.5 hours***) at home? (***check one***) ☐ Yes ☐ No

If **<u>YES</u>**, how often do you take them? (***check one***)

	5 days a week
	4 days a week
	3 days a week
	2 days a week
	1 day a week
	Less than 1 day a week

39) In a typical 24-hour period, how many naps do you take at home (***enter number***) _____ naps and on average how long do you nap for? (***enter in minutes***) _____ minutes.

40) On average, how long does it usually take you to **<u>fall asleep</u>** at home? _____ hours_____ minutes

41) On average, how many times do you **<u>wake up</u>** during a typical sleep period at home? _____

42) At home, how often do you: (***check the appropriate box***)

	Not at all	**A little**	**Quite a bit**	**Almost always**
Have difficulty falling asleep?				
Have difficulty staying asleep?				
Wake up during sleep?				
Have difficulty getting up?				
Have restless or disturbed sleep?				
Disturb the sleep of other people?				
Wake up confused, disoriented, irritable?				

43) At home, how often is your sleep **disrupted** or sleep onset delayed because of: (***check the appropriate box***)

	Never	Almost never	Quite seldom	Quite often	Almost always	Always
Heat or cold?						
Light?						
Noise?						
Quality of bed?						
Ship motions?						
Some other environmental factor?						
People?						
Emergencies?						
Others						

HEALTH ISSUES

44) Which response best describes you present **general health**? *(Check one)*

Poor	Fair	Good	Excellent

45) Are you **presently** being treated for any illness, injury, or mental health problem? ☐ Yes ☐ No

If **YES**, please specify the **problem** and any **medication** you have taken as treatment. ***(please print)***

____

____

46) How would you rate your own overall **physical fitness** level? (***check one***)

Poor	Fair	Good	Excellent

47) How often do you experience **sea sickness**? (***check one***)

Never	Less than once a month	Once or twice a month	Once a week	Two or three times a week	About every day

48) One hears about "**Morning" and "Evening**" types of people, which **ONE** of these types do you consider yourself to be? (***check one***)

Definitely 'Morning'	More 'Morning' than 'Evening'	More 'Evening' than 'Morning'	Definitely 'Evening'

49) The following questions are concerned with your daily habits and preferences. Please indicate what you prefer to do, or can do, and not what you may be forced to do by your present work schedule or routine.

Please work through the questions as quickly as possible. It is your immediate reaction to the questions that we are interested in, rather than a carefully deliberated answer. There are no "right" or "wrong" answers to any of the questions. For each questions we simply want you to indicate which of the five alternatives best describes you or your preferences by placing a ***check*** in the appropriate answer box.

	Almost Never	**Seldom**	**Some-times**	**Usually**	**Almost Always**
If you are feeling drowsy can you easily overcome it if you have something to do?					
Do you find it fairly easy to get to sleep whenever you want to?					
Can you miss a sleep period without too much difficulty?					
If you had to do a job in the middle of the night, do you think you could do it almost as easy as at a more normal time of day?					
Do you find it easy to "sleep in" in the morning if you got to bed very late the previous night?					
Can you easily keep alert in boring situations?					
Do you enjoy working at unusual times of day or night?					
If you have a lot to do, can you stay up late to finish it off without feeling too tired?					
Do you find it as easy to work late at night as earlier in the day?					
Can you easily go to sleep earlier than normal to "catch up" on lost sleep, e.g. after several late nights?					
Do you have **no** strong preferences as to when you sleep?					
Can you manage with only a few hours sleep for several days in a row without too much difficulty?					
Would you be just as happy to do something in the middle of the night as during the day?					
Do you go to parties or have evenings out with friends if you have to get up early?					

50) The following items relate to how **<u>you generally feel</u>**, please **<u>check the boxes</u>** which indicate the degree to which the following statements apply to your own normal feelings. ***(check one box for each item)***

	Not at all		Somewhat		Very much
I generally feel I have plenty of energy					
I usually feel drained					
I generally feel quite active					
I feel tired most of the time					
I usually feel full of vigor					
I usually feel rather lethargic					
I generally feel alert					
I often feel exhausted					
I usually feel lively					
I feel weary much of the time					

51) Here are some questions regarding the way you behave, feel, and act. Try to decide which response best represents your ***<u>typical</u>*** way of acting or feeling. There are no right or wrong answers to any of the questions: your **<u>immediate reaction</u>** is what we want. Please check that you have answered all of the questions. ***(check one box for each)***

	Almost never	Quite seldom	Quite often	Almost always
Do you like plenty of excitement and bustle around you?				
Does your mood go up and down?				
Are you rather lively?				
Do you feel 'just miserable' for no good reason?				
Do you like mixing with people?				
When you get annoyed, do you need someone to talk to?				
Would you call yourself happy-go-lucky?				
Are you troubled about feelings of guilt?				
Can you let yourself go and enjoy yourself a lot at a lively party?				
Would you call yourself tense or 'high strung'?				
Do you like practical jokes?				
Do you suffer from sleeplessness?				

52) Do you use tobacco products? ***(check one)*** ☐ Yes ☐ No
If **YES**, how much tobacco do you **use** per day *(enter amount in the appropriate box(es))?*

	At Home	**On Watch**	**Off Watch**
Number of cigarettes	cigarettes	cigarettes	cigarettes
Number of cigars	cigars	cigars	cigars
Pipes of tobacco	pipes	pipes	pipes
Dips/chew of tobacco	dips/chew	dips/chew	dips/chew

53) On average, how many caffeinated beverages do you drink per day? Cup size is equal to a 12 oz. can of soda ***(please enter zero if you do not use)***

	At Home	**On Watch**	**Off Watch**
Coffee	cups	cups	cups
Cola	12 oz. cans	12 oz. Cans	12 oz. cans
Tea	cups	cups	cups
Hot chocolate	cups	cups	cups

FEELINGS AT WORK

54) Which of the following responses best describes your **typical state** during work? (***check one***)

Sleepy	**Somewhat sleepy**	**Somewhat alert**	**Alert**	**Very alert**

55) About how often do you feel **tired** at work? (***check one***)

Never	**Less than once a month**	**Once or twice a month**	**Once a week**	**Two or three times a week**	**About every day**

56) About how often do you feel **sleepy** at work? (***check one***)

Never	**Less than once a month**	**Once or twice a month**	**Once a week**	**Two or three times a week**	**About every day**

57) On a normal workday, how **physically tired** do you usually feel at the **end** of the work day? (***check one***)

Not at all	**A little**	**Quite a bit**	**Extremely**

58) On a normal workday, how **mentally tired** do you usually feel at the **end** of the work day? (***check one***)

Not at all	A little	Quite a bit	Extremely

59) On a normal workday, how **tense** do you usually feel at the **end** of the work day? (***check one***)

Not at all	A little	Quite a bit	Extremely

FEELINGS DURING WATCH

60) Do you feel **tired, fatigued**, and/or decreased **alertness** during watch? ☐ Yes ☐ No

If Yes, how long into a watch do you feel **tired, fatigued**, and/or decreased **alertness**? ***(fill in blanks)***
_____ hours _____ minutes

61) What do you do to combat the feelings of **tiredness, fatigue,** and/or decreased **alertness** and remain efficient? ***(rank your TOP three choices: 1 = highest, 2 = second highest, and 3 = third highest)***

______ a) Drink coffee/soda, or eat candy/snacks, etc.
______ b) Stretch, perform light exercise, isometrics, etc.
______ c) Take rest breaks, etc.
______ d) Try to keep busy, work on projects, training
______ e) Rotate among duties/tasks
f) Other ________________________________
______ g) I never feel performance decrements during watch

62) How much do the following factors contribute to feelings of **tiredness, fatigue,** and/or decreased **alertness**? ***(check one for each)***

	Not at all	A little	Quite a bit	Extremely
Length of time on task				
Length of tour				
Tour route				
Boredom				
Number of port stops				
Lack of sleep				
Weather				
Watch schedule				
Overtime work				
Maintenance activities				
Workload				
Sea state				
Time of day				
Port activities				

63) Do you feel your **performance** decreases during **watch**? ☐ Yes ☐ No

If Yes, how long into a watch do you feel your **performance** decreasing? ***(fill in blanks)***

_____ hours _____ minutes

If Yes, how severe does the **performance** decrease? ***(check one)***

Not at all	A little	Quite a bit	Extremely

If Yes, how are the following affected? ***(check one)***

	Not at all	A little	Quite a bit	Extremely
Trouble making decisions?				
Trouble with memory?				
Trouble with simple tasks (adding, spelling, etc.)?				
Trouble concentrating or maintaining attention?				
Body motions (hard to hold on)?				
Problems with "sense of balance?"				
Problems with hand coordination?				
Problems with vision?				
Feeling weak and shaky?				
Other:				

64) If you feel **performance** decreasing, what do you do to combat it and remain efficient? ***(rank your TOP three choices: 1 = highest, 2 = second highest, and 3 = third highest)***

_______ a) Drink coffee/soda, or eat candy/snacks, etc.
_______ b) Stretch, perform light exercise, isometrics, etc.
_______ c) Take rest breaks, etc.
_______ d) Try to keep busy, work on projects, training
_______ e) Rotate among duties/tasks
_______ f) Other ____
_______ g) I never feel performance decrements during watch

65) How much do the following factors contribute to decreases in **performance**? ***(check one for each)***

	Not at all	A little	Quite a bit	Extremely
Length of time on task				
Length of tour				
Tour route				
Boredom				
Number of port stops				
Lack of sleep				
Weather				
Watch schedule				
Overtime work				
Maintenance activities				
Workload				
Sea state				

	Not at all	A little	Quite a bit	Extremely
Time of day				
Port activities				

66) What are the **best features** of working in the merchant marines?
a)__________
b)__________
c)__________
d)__________
e)__________

67) What are the **worst features** of working in the merchant marines?
a)__________
b)__________
c)__________
d)__________
e)__________

68) Knowing what you know now, if you had to decide all over again whether to **join** the merchant marines, would you join? ***(check one)***

Definitely join	Have some second thoughts	Definitely not join

69) Knowing what you know now, if you had to decide all over again whether to accept your current job, what would you decide? ***(check one)***

Decide without hesitation to take the same type of job	Have some second thoughts	Decide definitely not to take this type of job

70) If you were to **leave** the merchant marines, what would be your **main** reason(s)? ***(rank your TOP three choices: 1 = highest, 2 = second highest, and 3 = third highest)***

_______ a) to change my job duties
_______ b) to have more opportunity for off the job activities
_______ c) to obtain an improved working environment
_______ d) to earn better pay
_______ e) better working hours
_______ f) better opportunity for promotion
_______ g) medical restrictions

71) How acceptable or unacceptable do you find the use of **this questionnaire** as a method to help evaluate your work environment? (***check one***)

Very acceptable	**Moderately acceptable**	**Slightly acceptable**	**Moderately unacceptable**	**Very unacceptable**

72) Please note anything related to your work, sleep, fatigue level, etc. that you feel is important, but has not been addressed by this questionnaire.

____

____

____

____

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE!!!!

Alertness Inventory

Dear Crew Member:

Thank you for volunteering to participate in this project. We would appreciate your assistance in completing this short questionnaire at your convenience in the next five days.

The purpose of this questionnaire is to obtain some information regarding your work schedule and how alert/sleepy you tend to be throughout the day. There are only seven items to answer and it should take you approximately 10-15 minutes to complete everything. Please read each question carefully and answer it to the best of your knowledge. Note that any information you provide will be treated in a confidential manner.

If you have any questions, do not hesitate to contact the researcher on board. Thank you very much for your cooperation.

Subject ID:______________________________ Date:_______________

1. What is your working schedule on a typical day? *(circle whether it is normal or extra duty)*
   a) first work period: from _________ to ___________ normal duty extra duty
   b) second work period: from _________ to ___________ normal duty extra duty
   c) third work period: from _________ to ___________ normal duty extra duty

2. Rate your workload level on each working period. *(put an "x" on the appropriate number)*

a) first work period	from____to____	1	2	3	4	5
b) second work period	from ____to____	1	2	3	4	5
c) third work period	from____to____	1	2	3	4	5
		Extremely light	**Quite light**	**Average**	**Quite heavy**	**Extremely heavy**

3. The pacing of the job is: *(put an "x" on the appropriate number)*

1	2	3	4	5
Entirely outside my control	**Somewhat outside my control**	**In between**	**Somewhat under my control**	**Entirely under my control**

4. On a typical day at sea, what is your typical sleep schedule?
   a) first **sleep** period: from _________ to ___________
   b) second **sleep** period: from _________ to ___________
   c) third **sleep** period: from _________ to ___________

5. In this next question, we would like to know how alert or sleepy you feel throughout the day.

Please rate how alert or sleepy you normally feel at one-hour intervals before, during, and after **an average work day** during a typical sea duty tour. Use the 0 rating to indicate your normal sleep periods.

	Very alert		Alert		Neither alert nor sleepy	Sleepy (but not fighting sleep)			Very sleepy (fighting sleep)	Usually sleeping
00:00	1	2	3	4	5	6	7	8	9	0
01:00	1	2	3	4	5	6	7	8	9	0
02:00	1	2	3	4	5	6	7	8	9	0
03:00	1	2	3	4	5	6	7	8	9	0
04:00	1	2	3	4	5	6	7	8	9	0
05:00	1	2	3	4	5	6	7	8	9	0
06:00	1	2	3	4	5	6	7	8	9	0
07:00	1	2	3	4	5	6	7	8	9	0
08:00	1	2	3	4	5	6	7	8	9	0
09:00	1	2	3	4	5	6	7	8	9	0
10:00	1	2	3	4	5	6	7	8	9	0
11:00	1	2	3	4	5	6	7	8	9	0
12:00	1	2	3	4	5	6	7	8	9	0
13:00	1	2	3	4	5	6	7	8	9	0
14:00	1	2	3	4	5	6	7	8	9	0
15:00	1	2	3	4	5	6	7	8	9	0
16:00	1	2	3	4	5	6	7	8	9	0
17:00	1	2	3	4	5	6	7	8	9	0
18:00	1	2	3	4	5	6	7	8	9	0
19:00	1	2	3	4	5	6	7	8	9	0
20:00	1	2	3	4	5	6	7	8	9	0
21:00	1	2	3	4	5	6	7	8	9	0
22:00	1	2	3	4	5	6	7	8	9	0
23:00	1	2	3	4	5	6	7	8	9	0

6. In this question, we would like you to do the same thing as above, but consider:
   a) a typical day at the **beginning** of a tour (i.e., when you first board the vessel after a vacation or a period of time off from work).

	Very alert		Alert		Neither alert nor sleepy	Sleepy (but not fighting sleep)			Very sleepy (fighting sleep)	Usually sleeping
00:00	1	2	3	4	5	6	7	8	9	0
01:00	1	2	3	4	5	6	7	8	9	0
02:00	1	2	3	4	5	6	7	8	9	0
03:00	1	2	3	4	5	6	7	8	9	0
04:00	1	2	3	4	5	6	7	8	9	0
05:00	1	2	3	4	5	6	7	8	9	0
06:00	1	2	3	4	5	6	7	8	9	0
07:00	1	2	3	4	5	6	7	8	9	0
08:00	1	2	3	4	5	6	7	8	9	0
09:00	1	2	3	4	5	6	7	8	9	0
10:00	1	2	3	4	5	6	7	8	9	0
11:00	1	2	3	4	5	6	7	8	9	0
12:00	1	2	3	4	5	6	7	8	9	0
13:00	1	2	3	4	5	6	7	8	9	0
14:00	1	2	3	4	5	6	7	8	9	0
15:00	1	2	3	4	5	6	7	8	9	0
16:00	1	2	3	4	5	6	7	8	9	0
17:00	1	2	3	4	5	6	7	8	9	0
18:00	1	2	3	4	5	6	7	8	9	0
19:00	1	2	3	4	5	6	7	8	9	0
20:00	1	2	3	4	5	6	7	8	9	0
21:00	1	2	3	4	5	6	7	8	9	0
22:00	1	2	3	4	5	6	7	8	9	0
23:00	1	2	3	4	5	6	7	8	9	0

b) a typical day at the **end** of a tour (i.e., as you are close to returning home for a vacation or time off from work).

	Very alert		Alert		Neither alert nor sleepy	Sleepy (but not fighting sleep)			Very sleepy (fighting sleep)	Usually sleeping
00:00	1	2	3	4	5	6	7	8	9	0
01:00	1	2	3	4	5	6	7	8	9	0
02:00	1	2	3	4	5	6	7	8	9	0
03:00	1	2	3	4	5	6	7	8	9	0
04:00	1	2	3	4	5	6	7	8	9	0
05:00	1	2	3	4	5	6	7	8	9	0
06:00	1	2	3	4	5	6	7	8	9	0
07:00	1	2	3	4	5	6	7	8	9	0
08:00	1	2	3	4	5	6	7	8	9	0
09:00	1	2	3	4	5	6	7	8	9	0
10:00	1	2	3	4	5	6	7	8	9	0
11:00	1	2	3	4	5	6	7	8	9	0
12:00	1	2	3	4	5	6	7	8	9	0
13:00	1	2	3	4	5	6	7	8	9	0
14:00	1	2	3	4	5	6	7	8	9	0
15:00	1	2	3	4	5	6	7	8	9	0
16:00	1	2	3	4	5	6	7	8	9	0
17:00	1	2	3	4	5	6	7	8	9	0
18:00	1	2	3	4	5	6	7	8	9	0
19:00	1	2	3	4	5	6	7	8	9	0
20:00	1	2	3	4	5	6	7	8	9	0
21:00	1	2	3	4	5	6	7	8	9	0
22:00	1	2	3	4	5	6	7	8	9	0
23:00	1	2	3	4	5	6	7	8	9	0

7. Finally, please do the same thing for a typical day **at home**.

	Very alert		Alert		Neither alert nor sleepy		Sleepy (but not fighting sleep)		Very sleepy (fighting sleep)	Usually sleeping
00:00	1	2	3	4	5	6	7	8	9	0
01:00	1	2	3	4		6	7	8	9	0
02:00	1	2	3	4	5	6	7	8	9	0
03:00	1	2	3	4	5	6	7	8	9	0
04:00	1	2	3	4	5	6	7	8	9	0
05:00	1	2	3	4	5	6	7	8	9	0
06:00	1	2	3	4	5	6	7	8	9	0
07:00	1	2	3	4	5	6	7	8	9	0
08:00	1	2	3	4	5	6	7	8	9	0
09:00	1	2	3	4	5	6	7	8	9	0
10:00	1	2	3	4	5	6	7	8	9	0
11:00	1	2	3	4	5	6	7	8	9	0
12:00	1	2	3	4	5	6	7	8	9	0
13:00	1	2	3	4	5	6	7	8	9	0
14:00	1	2	3	4	5	6	7	8	9	0
15:00	1	2	3	4	5	6	7	8	9	0
16:00	1	2	3	4	5	6	7	8	9	0
17:00	1	2	3	4	5	6	7	8	9	0
18:00	1	2	3	4	5	6	7	8	9	0
19:00	1	2	3	4	5	6	7	8	9	0
20:00	1	2	3	4	5	6	7	8	9	0
21:00	1	2	3	4	5	6	7	8	9	0
22:00	1	2	3	4	5	6	7	8	9	0
23:00	1	2	3	4	5	6	7	8	9	0

Thank you very much for your cooperation.

APPENDIX 3

Review of Scientific Literature

MEASUREMENT OF MENTAL FATIGUE IN MERCHANT MARINE PERSONNEL WITH HUMAN PERFORMANCE TESTS: REVIEW OF SCIENTIFIC LITERATURE

INTRODUCTION

Fatigue is a commonly reported problem among sea-going personnel, and is often attributed to long work hours, night work, disrupted sleep patterns, and poor weather. In order to establish the extent and magnitude of this problem, the U.S. Coast Guard has undertaken a study of fatigue and alertness among merchant marine crew members. The focus of this study is measurement of fatigue in the operational setting (i.e., at sea) in order to provide exposure to the various contributors mentioned above.

One approach to measuring fatigue is the use of human performance data. These data are generally of two types: (1) performance on some aspect of the operational task, such as steering the ship, safety incidents, or collision avoidance effectiveness, and (2) performance on a simpler task that is interpolated within the ongoing job activities of the worker. Since the purpose of the Coast Guard fatigue program is to assess fatigue across a wide array of operational settings and variables, interpolated performance measures are most appropriate for use in this work. Further, to our knowledge, the type of data that would reflect operational performance of mariners directly is simply not collected in any systematic way. Thus, performance tests that simulate aspects of the mariner's job and are relatively easy and quick to administer are required. This review selectively examines the performance tests that have been described as showing a relationship to fatigue, and focuses primarily on the duration of the test, since this has large practical consequences for field testing.

HISTORICAL BACKGROUND

The present-day approaches to fatigue measurement can be linked directly to the work of Bills (1931), who studied "mental fatigue" during the continuous performance of a number of cognitive tasks. Bills remarked upon earlier failures to find consistent performance decrements, and took a more detailed approach to measurement. In a number of tasks, including arithmetic, reversible perspective, color naming, opposites, and code substitution, Bills observed the distribution of individual responses over time. The results indicated that subjects showed "blocks" in their response patterns, which were defined as responses at least twice as long as the average response for a trial block. What is important for the current research are the following points (1) blocks occur across a variety of tasks, (2) practice decreases their frequency, (3) fatigue increases their frequency. Blocks were described by Bills as akin to a refractory period in which no response is possible, and a possible mechanism whereby the nervous system automatically recovers and prevents more deleterious forms of fatigue.

The relationship of exceedingly long reaction times (RT) to brain function was studied by Bjerner (1949). His experiments demonstrated the simultaneous occurrence of long RT and a change in the electroencephalogram (EEG) "consisting mainly in the disappearance of the alpha rhythm and appearance of slow waves." Bjerner introduced the term "lapse" to describe long RT characteristic of the "blocking" described by Bills (1931). Sleep deprivation increased the number of lapses, which were associated with alpha rhythm depression. Bjerner cautioned that research on fatigue and sleep "will be held back by the loose designation of electroencephalographic changes, unsupported by other criteria, as sleep." This sentiment is reflected 40 years later in the work of Ogilivie and Wilkinson (1988), which indicates that multiple criteria, including behavioral performance, are required for the comprehensive evaluation of fatigue effects.

PERFORMANCE TASK TAXONOMY

Many different types of tasks have been used in the study of fatigue. The contemporary approach to fatigue derives in part from the use of the sleep deprivation methodology. While the earlier work of Bills (1931) was aimed at articulating general principles of mental fatigue in the tradition of neurophysiology, more recent work is aimed at elucidating the impacts of continuous operations and the concomitant sleep loss on human performance. The tasks employed in contemporary (i.e., 1958 to present) research can be broadly categorized as follows:

- Reaction time - tasks in which sustained attention is required over a relatively brief period (e.g., 10 minutes) to respond to rapidly occurring signals.
- Vigilance - tasks in which sustained attention is required over a relatively long period (e.g., 30 minutes) to detect infrequently occurring signals.
- Memory - tasks which require subjects to learn and retrieve information.
- Cognitive - tasks which require subjects to make a logical decision.

The review of performance tasks uses this taxonomy as a way to organize the numerous scientific reports concerning the impact of sleep deprivation on the performance of tasks interpolated in the period of study.

REACTION TIME TASKS

Reaction time tasks come in many varieties, but have the following general characteristics:

- Operators are required to sustain attention to a display
- Rapid and accurate responses are required

These characteristics are similar to the duties required of shipboard watchstanders in collision avoidance activities, and suggest that various reaction time measures would be appropriate measures for assessing fatigue in sea-going personnel.

Williams, et al. (1959) report the use of a two-choice forewarned RT task in subjects undergoing 74 to 98 hours of sleep loss. A series of experiments illustrated that sleep loss is associated with increased mean RT, increased number of lapses (responses more than twice as long as the baseline mean), and an increased slowing of the 10 slowest responses. These effects were observed in RT tests as short as 10 minutes duration.

Wilkinson (1959) employed a five-choice serial RT test, and observed fewer correct responses and more lapses ("gaps") under sleep-deprived conditions than control. Brief rest periods did not eliminate these effects, and they were most pronounced during the last trial block of a 25-minute testing session. This effect was confirmed by Wilkinson (1961), who also demonstrated that knowledge of results can to some extent mitigate (but not eliminate) the decrements.

In a study of RTs and EEG obtained in a 10-minute vigilance test, Williams, et al. (1962) showed a negative correlation between EEG frequency and RT. The EEG was scored as the number of waves in the 1-second period prior to a critical signal. This can be interpreted to mean that the higher the EEG frequency, the shorter the reaction time. With increasing sleep deprivation, the correlation between EEG and RT extended to longer epochs of the EEG.

Lisper and Kjellberg (1972) used a simple RT paradigm (i.e., subject responds immediately to the unwarned occurrence of a signal) to evaluate the effects of sleep deprivation on the distribution of RTs. Within a 10-minute block of trials, they showed that RT increases linearly across all percentiles of response speed (25^{th}, 50^{th}, and 75^{th}). However, the increase is greatest for the longest RTs, and is exacerbated by sleep deprivation. Analyses of separate time epochs within the 10-minute test indicated that the effects of sleep deprivation become evident in as short a time as 5 minutes. Since the effects of sleep deprivation were seen across all response speeds, the result indicates that sleep deprivation induces a generalized response slowing, as well as the more visible lapses.

The generalized slowing of responses in the fastest 25 percent of the RT distribution was also observed by Tharp (1978). Additionally, Tharp utilized the additive factors method to determine that sleep deprivation specifically affects the response selection aspect of RT performance (as distinct from stimulus encoding and categorization).

RT and several other performance tests (vigilance, Wisconsin card sort, and anagrams) were employed by Herscovitch and Broughton (1981) in an assessment of partial sleep deprivation. Subjects experienced a 40 percent sleep reduction for one night. Additionally, the Stanford sleepiness scale was administered at regular intervals on the day following sleep loss. Analysis indicated the Stanford sleepiness scale to be sensitive to the partial sleep deprivation, although correlational analysis of sleepiness ratings with performance was nonsignificant. The presentation of the results does not discuss the effect of sleep deprivation on the performance metrics, per se. However, it might be concluded that the Stanford sleepiness scale is more sensitive to smaller degrees of sleep loss than the performance measures.

A more detailed analysis of task factors was reported by Sanders, et al. (1982), who showed that sleep deprivation interacts with task variables in choice RT. Specifically, there is little effect of sleep deprivation on RT to undegraded stimuli. However, sleep deprivation substantially increases RT to degraded stimuli compared with the increase seen in rested subjects. This result indicates that the perceptual aspects of human information processing are also diminished by sleep deprivation.

Tilley and Wilkinson (1984) used a simple unprepared RT task to assess the effects of sleep deprivation in the first or second half of the night. Mean RTs were longer in the sleep-deprived conditions, and worse on the second night of deprivation than the first night, indicating a cumulative effect on performance. RT did not differ for sleep restrictions in the first or second halves of the night, indicating that response decrement is due to sleep loss per se, rather than a change in the composition of sleep. Response variability was not evaluated in this study.

In a study of continuous operations, Angus and Heslegrave (1985) employed a self-paced serial RT task as part of a larger battery of tests. They presented results showing that the number of responses per minute in this task declines significantly over a three-day command and control simulation. This pattern was mirrored by other performance tests, and by increased ratings of self-reported fatigue. Additionally, the pattern of decrement on the abstract performance tasks was mirrored by performance metrics extracted from the command and control simulation; specifically, message processing time increased signficantly over the three-day period. This result provides a type of job-relevant criterion validation for the performance tests.

Bonnet (1986) reports a study of sleep fragmentation using simple RT as one method of assessment. In this study, subjects were awakened after each minute of sleep by an audio signal. The resulting sleep period was severely fragmented, and performance testing on the subsequent day revealed increased mean RTs (1/RT to remove the skewness). Interestingly, in a subsequent study, Bonnet (1989) used median RTs to assess the impact of a fragmentation regime, and observed no effects (although other performance tests were sensitive to sleep loss). This result indicates the need to properly treat RT data in order to observe the impact of fatigue on performance.

The impact of nap sleep was evaluated by Dinges, et al. (1985) through the use of RT and other cognitive measures. Using the RT reciprocal to eliminate the effects of skewed distributions, this group demonstrated that naps under conditions of sleep deprivation are more immediately restorative (i.e., have less detrimental effect on performance upon awakening) when they are shorter and occur at the circadian temperature peak. It was further suggested that naps should be avoided after 36 hours of sleep deprivation since the detrimental effects on performance upon awakening are exacerbated. The performance results were paralleled by ratings on self-reports of fatigue obtained upon awakening. This study illustrated the utility of using RT and other performance methods to assess nap timing and placement.

Lisper, et al. (1986) used a secondary simple RT task to assess drowsiness while driving. In a detailed analysis of the RTs, it was shown that increased duration of the driving session was associated with significantly increased RTs, and that the increase in RT during pre-endurance sessions was signficantly correlated (-.72) with time to falling asleep at the wheel. The results suggest the potential use of RT changes over time as an index of susceptibility to fatigue.

RT was used to assess the impact of differing sleep conditions by Lavie, et al. (1987). In this complex study, subjects either attempted or resisted sleep for 7 minutes out of every 20 for a 36-hour test period. During the remaining 13 minutes, subjects performed a Fitt's law RT task. The results indicated that while there were no differences in sleep across the two conditions, performance was worse in the "resisting sleep" condition. Further, movement time (but not RT) was significantly correlated with total sleep time, suggesting a potentially sensitive index of sleep deprivation impairment.

In a study of operational flight crews, Dinges, et al. (1990) employed a simple reaction time task during in-flight operations. It was shown that mean RT, number of lapses, and the speed of optimum response increased significantly across the flight. The results were attributed to an increasing inability to sustain attention over the course of the flight. In a more recent review of RT and fatigue, Dinges and Kribbs (1991) describe the robust nature of the RT lapse phenomenon, and recommend the use of this type of task for field assessments of fatigue in operational settings.

A recently reported study by Gillberg, et al. (1994) used simple visual RT and a visual vigilance task (a computer version of a Mackworth clock) in conjunction with the Karolinska sleepiness scale (KSS), a visual analogue scale (VAS) of fatigue, and a newly developed scale called Accumulated Time with Sleepiness (ATS). This latter scale focused on symptoms of fatigue, including heavy eyelids, difficulty focusing attention, and periods when the subject was fighting sleep. Subjects were kept awake all night and tested in 55-minute blocks at 2200, 0200, 0400 and 0600 hours. The scales were administered several times during the 55-minute block. The performance data showed significant declines in RT and percentage of hits throughout the night. These effects were paralleled by significant increases in reported sleepiness and fatigue on all scales. The correlations between scales was between .65 and .86; performance was also well correlated with the rating scales. The results suggested that the ATS scale may be the best for predicting performance.

VIGILANCE TASKS

The general characteristics of a vigilance task are as follows:

- The operator is required to detect signals over a relatively long period of time (the "watch").
- Signals are intermittent, unpredictable, and infrequent.

These characteristics are similar to those encountered by mariners in standing watch in the deck or engineering department, and thus make the vigilance task an appropriate model for the study of fatigue effects in marine operations.

As part of their large-scale study of sleep loss, Williams, et al. (1959) employed three types of vigilance tasks: visual, auditory, and vibratory. Sleep deprivation effects were seen for each of these tasks, and it was noted that in the severely sleep deprived (e.g., 54 to 70 hours), a significant number of errors occurred during the first 2 minutes of the vigil. Knowledge of results improved performance in small and inconsistent ways.

In an experiment evaluating sleep deprivation in the context of continuous work, Wilkinson (1964) employed a 30-minute visual vigilance task, during which time 16 signals occurred. Performance on this low signal rate task was not different from control measurements following the first night of sleep deprivation, but declined precipitously following two night to 34 percent of control performance. During the last half of the vigil, performance fell to 5 percent of the control level.

Williams, et al. (1965) employed a 10-minute, high signal rate visual vigilance task that varied along the dimension of stimulus uncertainty (essentially they used highly predictable versus random signal conditions). Sleep loss showed the greatest impact on errors of omission for the random signal condition. Further analysis indicated that these effects manifested themselves within the first 3 minutes of testing after 55 hours of sleep loss. In comparison, 31 hours of sleep loss did not exhibit effects until 8 minutes into the 10-minute test session.

In an effort to assess the impact of sleep deprivation on the sensory and decision criterion factors in vigilance, Deaton, et al. (1971) employed a 30-minute high signal rate auditory vigilance task. Subjects were deprived of sleep for 33 hours following baseline testing. The results showed a significant decline in d' (the measure of perceptual sensitivity), with no decline on the decision parameter b (willingness to respond).

Bergstrom, et al. (1973) used a low signal rate visual vigilance task to assess the effects of sleep deprivation on stress. The experiment involved a 40-minute watch period, during which eight signals occurred. Sleep deprivation effects were evaluated at 6, 30, 54, 66, and 78 hours. Performance declined with increasing sleep deprivation, although the addition of a stress condition (random shocks to the leg) increased detection performance to near-normal levels. Thus, the study revealed that the capacity to perform is intact under sleep deprivation, and that it can be enhanced by stress.

In an assessment of altered sleep scheduling (habitual sleep, shifted sleep, extended sleep, and reduced sleep), Taub and Berger (1976) used a high signal rate auditory vigilance task of 45 minutes duration. The results indicated that under all conditions except habitual sleep, d' was significantly reduced. This result was mirrored by changes in self-reported measures of activation. These data illustrate the important point that performance is affected not only by the duration of sleep, but the placement of sleep in the circadian cycle. Thus, "recovery" sleeps of extended duration following sleep disruption may not have entirely beneficial effects on performance.

The sensitivity of the vigilance test to sleep deprivation was compared with several other performance tests and self-report ratings (Stanford Sleepiness Scale) by Glenville, et al. (1978). The vigilance test was a 60-minute watch with signals occurring regularly at 2-second intervals. Random presentation of targets occurred 40 times during the hour. Targets were of slightly shorter duration than background signals. The other tasks employed included a 10-minute auditory simple RT task, a four-choice serial RT task (self-paced by the subject), an auditory short-term memory test, and a writing reproduction test. The Stanford Sleepiness Scale was completed every 15 minutes. Subjects were deprived of sleep for 24 hours and tested the following morning. The results showed that the vigilance test was the most sensitive to sleep deprivation (percentage of hits showed the highest level of statistical significance); this was followed by the RT tasks, the writing task, and the Sleepiness Scale — all of which were equally sensitive, as defined by significance level. It is noteworthy that analysis of the simple RT data showed the effect of sleep deprivation within the first 5 minutes of testing. Subsequent analyses of the Stanford Sleepiness Scale in relation to performance showed this measure to be highly correlated (.5 - .69) with vigiliance performance and RT, but not with memory or writing reproduction (Glenville and Broughton, 1978). Further, the changes in Stanford Sleepiness Scale scores and percent differences in performance were highly correlated. This latter finding suggests the potential utility of self-report measures to predict performance level.

A subsequent study by Horne, et al. (1983) evaluated vigilance and signal detection parameters at multiple testing times throughout the day following sleep deprivation. The purpose of the study was to determine the extent to which there is a circadian variation in perceptual sensitivity (d'), independent of the willingness to respond (b). Subjects were tested five times throughout a 24-hour period over two days of sleep deprivation. The detection parameter d' showed a continuous decline over the testing period, but obvious circadian variation. Detection performance fell off markedly at night, and leveled off during the day. A similar pattern was observed for self-ratings of alertness, but no effect was obtained for b. This study shows the important of controlling testing times in vigilance/signal detection evaluations of fatigue.

The impact of incentive to perform in vigilance was assessed by Horne and Pettitt (1985). Using a 30-minute auditory vigilance task, it was shown that monetary incentive to perform can mitigate the effects of 24 hours of sleep deprivation on d', although b is decreased, indicating "riskier" decisions. Following a second day of sleep deprivation, d' fell to levels equivalent to the no incentive condition, while there was no further change in b. The data are interesting in that they suggest different time courses for the impact of sleep deprivation on decision parameters: high motivation, perceptual sensitivity will not be affected for the first 24 hours of fatigue (sleep deprivation), while the willingness to make false alarms (riskier decisions) is increased.

In distinction to the studies of total sleep deprivation, Horne and Wilkinson (1985) used an auditory vigilance test to evaluate the chronic reduction of sleep to a total length of 6 hours, in contrast to a control group that averaged 7.5 hours. There were no significant effects on any vigilance or self-report measures of sleepiness. These results are contrasted with the findings of Webb and Agnew (1974), who found that restriction of sleep to 5.5 hours per day resulted in a steady reduction of hits and false alarms.

Sleep deprivation and sleep disruption were compared by Bonnet (1986) using a 30-minute vigilance task, an addition task, and a 10-minute simple RT task. Subjects in various groups were either totally sleep deprived or aroused following 1 minute, 10 minutes, or 2.5 hours of sleep. Vigilance and addition performance were severely disrupted in the total sleep deprivation and 1-minute disruption condition, and impaired in the other disruption conditions. The presentation of the RT data did not permit an assessment of impact other than concluding that total sleep disruption significantly reduces mean RT.

MEMORY TASKS

Experimental methods for assessing the quality of human memory that are applicable to field assessments of fatigue generally fall into the category of short-term memory processes. This means that to-be-remembered-information (TBRI) is given at some point prior to a fatiguing operation or shift, and the quantity of information recalled or recognized is measured. Subsequently, during or following a fatiguing shift or operation, similar TBRI is presented and memory is assessed. The difference between pre-fatigue and post-fatigue measures is taken as an index of memory impairment. Memory measures are appealing for evaluating fatigue because of the importance of memory for constantly evolving traffic situations in the marine environment, and because of the subjective sense of memory failure that we experience with increasing fatigue. It is worth noting here that many of the cognitive tests discussed in the next section involve substantial use of memory; the tests described here provide a more accurate index of memory impairment that is independent of other factors such as linguistic processing and response selection.

Williams, et al. (1959) employed an immediate and delayed recall task in their assessment of sleep loss. The procedure involved reading simple items of interest to the subjects (e.g., "Who was the first president to die in office") and then providing the answer. Immediate recall was assessed 10 minutes after the first presentation of the information. Immediate recall decreased in proportion to sleep loss. Delayed recall was not affected after 24 hours of sleep loss, but was impaired thereafter at a constant level. One day of recovery was sufficient to return memory performance to baseline levels. The memory test learning procedure is estimated to require 2.5 to 5.0 minutes (25 items at 5 to 10 seconds per item). The interval between testing and recall varies from 10 minutes (immediate recall) to 24 hours (delayed recall).

A subsequent study by Williams and Gieseking (1966) evaluated delayed memory for words by recall, and for pictures by recognition. Both learning procedures were accomplished in approximately 5 minutes (25 stimulus items presented at 5 to 10 seconds apiece). Following one night of sleep deprivation, delayed recall was impaired compared to baseline conditions. A second night of sleep deprivation resulted in further decrement in memory recall. A 24-hour sleep deprivation period did not result in significant impairment in recognition memory for pictures. This study illustrates the differential sensitivity of memory measures, and the relatively robust nature of recognition memory (i.e., we can typically recognize much more than we can recall).

Elkin and Murray (1974) report a study assessing immediate and delayed recall of digits by sleep deprived and control subjects. The procedure involved presenting strings of three digits through headphones, followed by a tone that signaled a memory "probe" digit. The subject's task was to decide whether or not the probe digit was included in the previous string. The probe digit was presented immediately after the TBRI, or delayed by 20 seconds. Each test session took 5 to 8 minutes. Sleep deprivation had two principal effects: (1) After 35 hours of sleep deprivation, there was a significant increase in the number of perceptual errors, and (2) delayed recognition was impaired with increasing levels of sleep deprivation. The results suggest that the ability to attend to information decreases with sleep deprivation, and that even if perception occurs, the ability to recall that information after even a brief period (20 seconds) is significantly impaired. A similar procedure was used by Polzella (1975), who found that recognition was impaired with sleep deprivation. A further finding from this study was that for all categories of response (hits, misses, correct rejections, and false alarms), there were significantly more RT lapses in the sleep deprived condition.

The use of memory measures in assessing fatigue effects on performance must account for variations in the memory load imposed at different testing times throughout the circadian cycle. This was demonstrated by Folkard, et al (1976) in a study that employed high and low memory loads in a visual search task administered throughout a variety of shifts. Temperature was also monitored. The results indicated that low memory load was associated with poor performance during the night shift; performance was correlated with body temperature in this condition. High memory load was best during the night shift, and negatively correlated with body temperature. This type of test was subsequently used by Monk and Embrey (1981) in a comparison of memory task performance, alertness and temperature data, and on-the-job performance. The results indicated a dissociation between alertness and memory performance, with low alertness during the early morning hours corresponding to higher levels of performance on the high memory load test. Measurement of on-the-job performance errors showed that the fewest errors occurred during the early morning hours, and the largest number during the day shift.

The impact of recovery sleep on memory processes was evaluated by Akerstedt and Gillberg (1979). Subjects were awakened three times during the night in a baseline condition, shown four playing cards, and allowed to go back to sleep. On subsequent awakenings, the subject was asked to recall the color and value of the cards shown earlier. Sleep deprivation for 64 hours ensued. During the recovery sleep night, an identical memory test procedure was used. The results showed that memory performance was significantly worse (about 25 percent of baseline) and that Stage 4 sleep was enhanced. The results suggest the potential impairment that might ensue if people are required to make critical decisions during periodic awakenings during recovery sleep, as often happens in the maritime environment.

Babkoff, et al. (1988) used a memory search paradigm similar to that of Folkard, et al. (1976), and obtained performance measurements every 2 hours over a 72-hour period of sleep deprivation. Signal detectability (d') decreased monotonically over the period, while showing rhythmic variations. Response criterion did not decrease, but showed rhythmic fluctuations throughout the circadian period. These results are similar to those obtained in the vigilance studies discussed previously (Horne, et al., 1983).

COGNITIVE TASKS

Cognitive tasks are those that involve multiple aspects of the human information processing system, including attention, perception, memory, decision, and response. From a psychological standpoint, they are relatively complex, when compared to RT, vigilance, and memory tasks. Examples of cognitive tasks include comparing two letters and deciding if they are the same or different according to physical or semantic criteria; substituting numbers for letters in a sequence; and performing mental arithmetic. This section selectively reviews the literature concerning sleep deprivation and fatigue on tasks of this type.

The original investigations of blocking (Bills, 1931) employed two tasks that would be considered cognitive according to the above description. The first of these was alternate addition and subtraction and the second was digit/letter code substitution. Both tasks exhibited an increase in the number of blocks (lapses) over the course of a trial block (7 to 10 minutes) and an increase in the duration of the blocks with time.

Williams, et al. (1959) also investigated mental addition and concept attainment tasks under sleep loss. They found that the number of problems attempted in mental addition decreased substantially after 48 hours of sleep loss, but accuracy remained equal to control group performance. Similarly, on a concept attainment task in which subjects were to reason about a grouping rule for cards with different features, accuracy was maintained, but the time per problem increased. Both of these tasks were completed in less than 5 minutes. Wilkinson (1964) also observed a decrease in card sorting speed, while accuracy was maintained by a sleep deprived group. Williams and Lubin (1967) employed an experimenter-paced addition task and observed a decrease in response speed with increasing sleep deprivation .

The addition task was employed by Donnell (1969) in a study of 48 hours of sleep deprivation. On the first day following sleep deprivation, the number of additions attempted decreased from baseline after 10 minutes of testing , and after 6 minutes on the second day. The accuracy measure was less sensitive, requiring 50 minutes to show decrements on the first day and 10 minutes on the second day.

Hockey (1970) employed a dual task that involved pursuit tracking and a subsidiary task of visual detection. The visual targets were of higher probability in the central display area. Sleep deprivation reduced time on target for the tracking task, and increased RT to central and peripheral signals. The results suggested that sleep deprivation reduces the tendency to attend to central, highly relevant aspects of a display, despite the higher probability of signals occurring in this region. A similar loss of attentional selectivity was shown by Norton (1970) based on a card sorting task that varied according to the amount of distracting information. Sleep loss resulted in slower response speeds to cards with higher amounts of irrelevant information.

Friedmann, et al. (1977) employed a number of cognitive and vigilance type tests, as well as self-report measures, to evaluate gradual reduction of sleep from an average of 8 hours to 4.5 to 5.5 hours per night. This experiment took place over an 18-month period, with gradual reductions such as 30 minutes of sleep time every 3 weeks. The performance tests showed no detrimental effects of this gradual restriction, although the self-report ratings indicated considerable fatigue. During an "ad-lib" sleep period of 1 year, the subjects slept 1 to 2.5 hours less than their pre-experimental levels, but their self-report ratings returned to baseline levels. The results suggest some dissociation between performance measurement sensitivity and self-report measures during acute restriction of sleep. It was also suggested that 4.5 hours may be an inherent sleep limit below which performance will suffer. A similar lack of performance effects on sleep restriction to 4.5 hours per night for five nights was observed by Herscovitch, et al. (1980).

Webb and Levy (1982) employed a number of cognitive tests and self-report measures in an assessment of age effects and sleep deprivation. The performance tests included addition, visual search, word memory, word detection, reasoning, numerical estimation, object uses, remote associates, auditory vigilance, and line length judgment. The statistical analysis indicated that self-report measures, addition, vigilance, object uses, visual search, and reasoning (number attempted) yielded significant effects. This study is important in illustrating that cognitive tests are variably sensitive, depending on their structure and task demands.

Angus and Heslegrave (1985) used an extensive series of self-report and cognitive measures to document the effects of sustained performance in a command and control simulation over a 54-hour period of wakefulness. The performance tests included four-choice RT, letter coding, subtraction, logical reasoning, digit span, vigilance, paired associate learning/recall, map plotting, and message processing. All self-report scales indicated increasing fatigue and sleepiness over the simulation; the performance tests that were sensitive were RT, letter coding, logical reasoning, and vigilance. Decrements in these measures were paralleled by diminished performance on the job-relevant measures of message processing time.

Nicholson, et al. (1985) evaluated a number of performance tests in the context of alternate evening and morning sleep sessions. The tests included code substitution, symbol copying, letter cancellation, logical reasoning, mental addition, simple reaction time, choice reaction time, visuo-motor coordination, critical flicker fusion, auditory vigilance, card sorting, divided attention, and digit span. Large effects were observed for visuo-motor coordination, letter cancellation, mental arithmetic, simple and choice RT, and code substitution. Code substitution appears to be the most consistent test in the battery, showing effects of both sleep deprivation (or napping) and time of day.

In a study of extended workdays, Rosa, et al. (1985) employed a battery of cognitive tests, including logical reasoning, word memory, time estimation, and simple and choice RT. Extended workdays were associated with increased self reports of fatigue and decrements on the grammatical reasoning and digit addition tasks.

Webb (1986) employed a reading comprehension test to assess the performance of sleep-deprived older subjects (age 50 to 60). Following two nights of sleep deprivation, there was no significant decrement in reading comprehension performance. However, 50 percent of the subjects failed to sustain their pre-deprivation levels of performance.

In an analysis of the impact of naps prior to sleep deprivation, Bonnet (1991) employed a number of performance tests and self-report measures. He evaluated the dose-response relationship between nap length and performance improvement, and found, in general, that longer naps resulted in better performance during a 52-hour continuous operation. The performance data were paralleled by self-report measures of fatigue (Profile of Mood States).

SUMMARY

This paper reviews four primary approaches to the use of interpolated performance tasks to assess the effects of fatigue and sleep loss in humans: (1) reaction time, (2) vigilance, (3) memory, and (4) cognitive tasks. Each of these tasks offers particular benefits, and each has certain limitations. This section summarizes the results of the review and discusses the benefits and limitations of each technique.

RT tasks have been shown to be sensitive to a wide range of sleep loss and fatigue-related problems. The majority of the studies reviewed confirm the lapse phenomenon and have shown the robust nature of the effect across numerous types of stimulus modes and types of reaction task (simple and choice). It is apparent that sleep loss effects can be seen in the first 5 minutes of a task, and that self-report data, when collected, show the same effects as the performance data. There appears to be a cumulative effect of sleep loss on RT performance, although correlational data are lacking — all of the studies were performed within the experimental model using hypothesis testing statistics (e.g., analysis of variance). RT may be sensitive to fatigue resulting from sleep restriction as well as total sleep deprivation. This is suggested by Bills (1931), who showed blocking with increased time on task, and increased duration of the blocks. It is also suggested by the results of Bonnet (1989), who showed an effect of sleep fragmentation in sleep loss situations, and by Dinges, et al. (1990), who showed increased lapses with increasing time on task during flight operations.

The principal advantages of the RT task are its simplicity — there are few practice effects and the duration of the test is short. A theoretical advantage is the fundamental nature of the RT psychological process (i.e., sustaining attention and responding to signals). These processes underlie virtually all more complex cognition, and lapses in these processes will undoubtedly impair "higher" cognitive processes. The sole disadvantage of the RT task is its relatively uninteresting nature — it may be difficult to motivate subjects to perform the task in situations requiring multiple measurements across the day. However, the short duration should offset this problem to some extent, and previous reports have not indicated this as a problem.

Vigilance tasks have also shown robust effects of sleep loss and fatigue. The assessment of vigilance has shown that d' is primarily affected by sleep loss, with little impact on b. This confirms that sleep loss and fatigue result in reduced perceptual capacity, uninfluenced by decision criteria or willingness to perform. Fatigue effects also seem to be cumulative on the vigilance task. In a comparison of performance tests, Glenville, et al. (1978) found that the vigilance test showed the greatest statistical sensitivity to sleep loss. This needs to be considered in lieu of the finding that high motivation to perform will mitigate the effect of sleep loss on vigilance for the first 24 hours. There are conflicting data regarding the dose-response relationship between fatigue/sleep loss and vigilance performance in less than total sleep loss situations. Six hours of sleep (when normal = 7.5) resulted in no effects (Horne and Wilkinson, 1985); 5.5 hours of sleep resulted in a reduction of hits and false alarms (Webb and Agnew, 1974). As with RT, vigilance tasks are sensitive to sleep fragmentation. Self-report data parallel the behavioral effects observed in vigilance tasks.

The vigilance task has the following advantages in testing for fatigue and sleep loss effects: (1) the task is similar to that of many jobs involving watchstanding, (2) measures can be taken that directly reflect decision criteria and sensitivity, and (3) the task shows the largest statistical effects. The principal disadvantage of the vigilance task is its duration: a true vigilance task requires long vigils with infrequent signals. Higher signal rate tasks have shown similar effects in shorter time periods, but these begin to approach identity with RT tasks.

Memory tasks present a somewhat more complex picture of sleep deprivation and fatigue effects. The general pattern of data indicates that both immediate and delayed recall are impaired following sleep deprivation; immediate recognition is not impaired, although after a 20-second delay, retention declines. Depending on the procedure employed, perceptual processing either remains at control levels or is impaired (this seems to depend primarily on methods used to ensure that the subject attends to the stimulus — i.e., verbal repetition versus copying). As shown by Folkard, et al. (1976), memory performance varies with memory load, and is dissociated from the performance that would be expected on the basis of circadian rhythms. The work of Monk and Embrey (1981) illustrated a dissociation between self-report measures of alertness and memory performance. The apparent sensitivity of memory measures to relatively small variations in experimental procedure, and its sometimes paradoxical relationships to time-of-day and alertness, suggest that such measures are more appropriate for laboratory investigations than field studies of fatigue and work hours.

The studies of numerous cognitive tasks and their relative sensitivities to sleep deprivation and fatigue show that the tasks of addition, logical reasoning, and code substitution show consistent effects across studies. It is quite difficult to make direct comparisons across studies because of the different methods employed, both for sleep deprivation conditions and how the experimental tasks were implemented. The use of selective attention and dual task procedures (Hockey, 1970) suggests that the effects of sleep deprivation and fatigue on cognitive tasks result from decreased selectivity of attention. The studies that present a more fine-grained analysis of cognitive performance data (e.g., Rosa, et al., 1985) indicate that lapses underlie performance decrements in some tasks, such as logical reasoning. Cognitive tasks have the advantage of showing the impact of sleep deprivation and performance on mental functioning that is more akin to aspects of on-the-job performance. However, the many different procedures for implementing these tasks have led to a proliferation of results that are difficult to interpret. Further, unless the task is relatively well-controlled in terms of the cognitive operations carried out, there are various strategies that subjects could use to accomplish the tasks and preclude the demonstration of fatigue effects (e.g., rote learning tasks).

Based on an extensive review of the various types of effects observed in short duration performance tasks, Dinges (1992) proposed a taxonomy for the effects of sleep loss. Table 1 shows this taxonomy, and provides a general guide for the selection of performance tests for application in field or laboratory settings.

Table 1. Taxonomy for Effects of Sleep Loss on Performance (after Dinges, 1992).

Effect type	Nature of Effect	Behavioral Consequence	Type of task
Cognitive response shift	Slowing on self-paced tasks, increased errors on work-paced tasks	Reduction in total number correct	1 to 5 min tasks (addition, subtraction, concept attainment, code substitution)
Memory problem	Increased variability in reporting TBRI	Decreased ability to retain and recollect new information	3 to 10 minute free-recall tasks; delayed recognition tasks
Time-on-task decrement	Increased rate of slowing in response time or increase in errors	Accelerated decline in average performance with increasing task duration	10 to 30 minute sustained attention tasks (RT, vigilance)
Optimum response shift	Reduction in speed of fastest response times	Diminution of best psychomotor effort	10 to 30 minute high response rate RT tasks
Lapse (block, gap, pause)	Periods of very delayed responding or of nonresponding	Increased performance variability and increased errors of omission	5 to 30 minute tasks requiring sustained responding
False response	Increase in number of false responses during high signal load tasks	Decreased reliability of response inhibition and increased errors of commission	10 to 30 minute high response rate RT tasks

CONCLUSIONS AND RECOMMENDATIONS

Measurement of fatigue effects on human performance has been amply demonstrated in a variety of laboratory, and to a lesser extent operational, settings. The performance task that offers the most promise for application to fatigue measurement in mariners working aboard commercial ships is the RT task. Because of its simplicity, practice effects will be minimal, and it appears possible to show an effect of fatigue within 5 minutes of testing. Sleep deprivation does not appear to be a sine qua non for obtaining fatigue effects, as shown by the time-on-task and cross-session results of Bills (1931) and Dinges, et al. (1990). The RT task employed must save single-trial level data (e.g., exact RT, whether response was correct or incorrect), and must be administered at multiple points throughout the day. Concomitant alertness ratings on a scale such as the Stanford Sleepiness Scale would be desirable as well. It appears to be the case that well-controlled administration of self-report scales yields results that are highly correlated with performance (Glenville and Broughton, 1978; Bonnet, 1991; Gillberg, et al., 1994). It has been suggested that the timing of cognitive testing and self-report measurements influences the degree to which circadian rhythm effects are seen in self-report data (Babkoff, et al., 1991); thus, to be used as a predictor, self-report data should be obtained prior to cognitive testing. Finally, several reports have demonstrated the relationship of decrements in RT and other performance tests to impairment on the job for command and control (Angus and Heslegrave, 1985) and for driving (Lisper, et al., 1986). It is also known that RT lapses increase in frequency during the same time periods that the number of "microevents" indicative of sleep occur in commercial aircraft pilots (Graeber, et al., 1990). Thus, the validity of RT tasks in terms of job relevance is well-esablished.

Because it is risky to rely completely on a single measure, it is recommended that an additional short-duration task be used to complement RT. Based on the data reviewed above, and recent experience in field work, it appears that the code substitution task would be appropriate. Reliable results can be obtained in a 1.5 to 2 minute testing session, and RT can be collected for individual items as well as accuracy. The task is appropriate for a broad range of maritime personnel, unlike more complex cognitive tasks such as grammatical reasoning.

The combination of repeated RT and code substitution testing throughout a 24-hour period across a range of shipboard watchstanders and day workers is thus the basic design strategy for measuring mental fatigue in shipboard operations. These measures will be combined with detailed sleep and activity logs administered by on-board research personnel. Analyses will focus on time of day effects, differences between times of watch, impact of port operations, and the time course of measurements over an extended period (e.g., a week). Data of this type present considerable challenges in the analysis, since there are both gradual decrements and rhythmic influences. Thus, following initial assessment of patterns, consideration will be given to a variety of time-series techniques to elucidate the multiple effects likely to be present (Babkoff, et al., 1991).

REFERENCES

Åkerstedt, T. and Gillberg, M. (1979). Effects of sleep deprivation on memory and sleep latencies in connection with repeated awakenings from sleep. *Psychophysiology*, Vol. 16(1):49-52, The Society for Psychophysiological Research, Inc.

Angus, R.G. and Heslegrave, J. (1985). Effects of sleep loss on sustained cognitive performance during a command and control simulation. *Behavior Research Methods, Instruments, & Computers*, Vol. 17(1):55-67.

Babkoff, H.; Caspy, T.; and Mikulincer, M. (1991). Subjective sleepiness ratings: The effects of sleep deprivation, circadian rhythmicity and cognitive performance. *Sleep*, 14(6): 534-539.

Babkoff, H.; Caspy, T.; Mikulincer, M; and Sing, H.C. (1991). Monotonic and rhythmic influences: A challenge for sleep deprivation research. *Psychological Bulletin*, 109(3): 411-428.

Babkoff, H.; Mikulincer, M.; Caspy, T.; Kempinski, D.; and Sing, H. (1988). The topology of performance curves during 72 hours of sleep loss: a memory and search task. *The Quarterly Journal of Experimental Psychology*, 40A(4):737-756, The Experimental Psychology Society.

Bergström, B.; Gillberg, M.; and Arnberg, P. (1973). Effects of sleep loss and stress upon radar watching. *Journal of Applied Psychology*, Vol. 58(2):158-162.

Bjerner, B. (1949). Alpha depression and lowered pulse rate during delayed actions in a serial reaction test. *Acta Physiologica Scandinavia*. 19: 1 - 93.

Bills, A.G. (1931). Blocking: a new principal of mental fatigue. *American Journal of Psychology*, 43:230-245.

Bills, A.G. (1934). Some additional principles of mental fatigue. *Psychological Bulletin* 31, University of Chicago.

Bonnet, M.H. (1986). Performance and sleepiness as a function of frequency and placement of sleep disruption. *Psychophysiology*, May, Vol. 23(3):263-271, The Society for Psychophysiological Research, Inc.

Bonnet, M.H. (1989). Infrequent periodic sleep disruption: effects on sleep, performance and mood. *Physiology & Behavior*, Vol. 45:1049-1055, Pergamon Press.

Bonnet, M.H. (1991). The effect of varying prophylactic naps on performance, alertness and mood throughout a 52-hour continuous operation. *Sleep*, 14(4): 307-315.

Buck, L. (1975). Sleep loss effects on movement time. *Ergonomics*, Vol. 18(4):415-425.

Deaton, M.; Tobias, J.S.; and Wilkinson, R.T. (1971). The effect of sleep deprivation on signal detection parameters. *Quarterly Journal of Experimental Psychology*, 23:449-452.

Dinges, D.F.; Graeber, R.C.; Connell, L.J.; Rosekind, M.R.; and Powell, J.W. (1990). Fatigue-related reaction time performance in long-haul flight crews. *Sleep Research*, 19:117.

Dinges, D.F.; Orne, M.T.; and Orne, E.C. (1985). Assessing performance upon abrupt awakening from naps during quasi-continuous operations. *Behavior Research Methods, Instruments, & Computers*, 17(1):37-45. Psychonomic Society, Inc.

Dinges, D.F. and Powell, J.W. (1985). Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations. *Behavior Research Methods, Instruments, & Computers*, 17(6), 652-655, Psychonomic Society, Inc.

Dinges, D.F. and Kribbs, N.B. (1991). Performing while sleepy: effects of experimentally-induced sleepiness. In T. H. Monk (Ed.). *Sleep, sleepiness and performance*. New York: John Wiley & Sons. pp. 97 - 128.

Dinges, D.F. (1992). Effects of sleep loss on short-duration tasks. R.J. Broughton and R.D. Ogilivie (Eds.). *Sleep, Arousal and Performance.* Boston: Birkhauser. pp. 176 - 188.

Donnell, J.M. (1969.) Performance decrement as a function of total sleep loss and task duration. *Perceptual and Motor Skills*, Vol. 29:711-714.

Elkin, A.J. and Murray, D.J. (1974). The effects of sleep loss on short-term recognition memory. *Canad. J. Psychol./Rev. Canad. Psychol.* 28(2):192-198.

Folkard, S.; Knauth, P.; and Monk, T.H. (1976). The effect of memory load on the circadian variation in performance efficiency under a rapidly rotating shift system. *Ergonomics*, Vol. 19(4):479-488.

Friedmann, J.; Globus, G.; Huntley, A.; Mullaney, D.; Naitoh, P.; and Johnson, L. (1977). Performance and mood during and after gradual sleep reduction. *Psychophysiology*, Vol. 14(3):245-250, The Society for Psychophysiological Research, Inc.

Gillberg, M.; Kecklund, G.; and Akerstedt, T. (1994). Relations between performance and subjective ratings of sleepiness during a night awake. *Sleep*, 17(3): 236-241.

Glenville, M. and Broughton, R. (1978). Reliability of the Stanford Sleepiness Scale comparied to short duration performance tests and the Wilkinson auditory vigilance task. *Sleep Research*, 7: 149.

Glenville, M.; Broughton, R.; Wing, A.M.; and Wilkinson, R.T. (1978). Effects of sleep deprivation on short duration performance measures compared to the Wilkinson auditory vigilance task. *Sleep*, 1(2):169-170, Winter, Raven Press, New York.

Graeber, R.C.; Rosekind, M.R.; Connell, L.J.; and Dinges, D.F. (1990). Cockpit napping. *ICAO Journal*, October, 6 - 10.

Herscovitch, J. and Broughton, R. (1981). Sensitivity of the Stanford Sleepiness Scale to the effects of cumulative partial sleep deprivation and recovery oversleeping. *Sleep*, 4(1): 83-92.

Herscovitch, J.; Stuss, D.; and Broughton, R. (1980). Changes in cognitive processing following short-term cumulative partial sleep deprivation and recovery oversleeping. *Journal of Clinical Neuropsychology*, Vol. 2(4):301-319.

Hockey, G.R.J. (1970). Changes in attention allocation in a multicomponent task under loss of sleep. *Br. J. Psychol.*, Vol. 61(4):473-480.

Horne, J.A.; Anderson, N.R.; and Wilkinson, R.T. (1983). Effects of sleep deprivation on signal detection measures for vigilance: implications for sleep function. *Sleep*, 6(4):347-358, Raven Press, New York.

Horne, J.A. and Pettitt, A.N. (1985). High incentive effects on vigilance performance during 72 hours of total sleep deprivation. *Acta Psychologica*, 58:123-139, North-Holland Publishing Company.

Horne, J.A. and Wilkinson, S. (1985). Chronic sleep reduction: daytime vigilance performance and EEG measures to sleepiness, with particular reference to "practice" effects. *Psychophysiology*, Vol. 22(1):69-78, The Society for Psychophysiological Research, Inc.

Lavie, P.; Gopher, D.; and Wollman, M. (1987). Thirty-six hour correspondence between performance and sleepiness cycles. *Psychophysiology*, Vol. 24(4):430-438, The Society for Psychophysiological Research, Inc.

Lisper, H. and Kjellberg, A. (1972). Effects of 24-hour sleep deprivation on rate of decrement in a 10-minute auditory reaction time task. *Journal of Experimental Psychology*, Vol. 96(2):287-290.

Lisper, H.; Laurell, H.; and van Loon, J. (1986). Relation between time falling asleep behind the wheel on a closed track and changes in subsidiary reaction time during prolonged driving on a motorway. *Ergonomics*, 29(3): 445-453.

Monk, T.H. and Embrey, D.E. (1981). A field study of circadian rhythms in actual and interpolated task performance. *Advances in Biosciences*, Vol. 30:473-480, Night and Shift Work: Biological and Social Aspects.

Monk, T.H.; Knauth, P.; Folkard, S.; and Rutenfranz, J. (1978). Memory based performance measures in studies of shiftwork. *Ergonomics*, Vol. 21(10):819-826.

Naitoh, P. (1983). Signal detection theory as applied to vigilance performance of sleep-deprived subjects. *Sleep*, 6(4):359-361, Raven Press, New York.

Nicholson, A.N.; Pascoe, P.A.; Roehrs, T.; Roth, T.; Spencer, M.B.; Stone, B.M.; and Zorick, F. (1985). Sustained performance with short evening and morning sleeps. *Aviation, Space, and Environmental Medicine*, February, 56:105-114.

Norton, R. (1970). The effects of acute sleep deprivation on selected attention. *Br. J. Psychol.*, Vol.61(2):157-161.

Ogilvie, R.D. and Wilkinson, R.T. (1988). Behavioral versus EEG-based monitoring of all-night sleep/wake patterns. *Sleep*, 11, 139-155.

Polzella, D.J. (1975). Effects of sleep deprivation on short-term recognition memory. *Journal of Experimental Psychology, Human Learning and Memory*, Vol. 104(2):194-200.

Rosa, R.R.; Wheeler, D.D.; Warm, J.S.; and Colligan, M.J. (1985). Extended workdays: effects on performance and ratings of fatigue and alertness. Vol. 17(1):6-15.

Sanders, A.F.; Wijnen, J.L.C.; and van Arkel, A.E. (1982). An additive factor analysis of the effects of sleep loss on reaction processes. *Acta Psychologica* 51:41-59, North-Holland Publishing Company.

Taub, J.M. and Berger, R.J. (1976). The effects of changing the phase and duration of sleep. *Journal of Experimental Psychology: Human Perception and Performance*, Vol. 2(1):30-41.

Tharp, Jr., V.K. (1978). Sleep loss and stages of information processing. *Waking and Sleeping*, 2:29-33.

Tilley, A.J. and Wilkinson, R.T. (1984). The effects of a restricted sleep regime on the composition of sleep and on performance. *Psychophysiology*, Vol. 21(4):406-412, The Society for Psychophysiological Research, Inc.

Webb, W.B. (1986). Sleep deprivation and reading comprehension. *Biological Psychology*, 22:169-172, North Holland Publishing Company.

Webb, W.B. and Agnew, Jr., H.W. (1974). The effects of a chronic limitation of sleep length. *Psychophysiology*, 11:265-274.

Webb, W.B. and Levy, C.M. (1982). Age, sleep deprivation, and performance. *Psychophysiology*, Vol. 19(3):272-276, The Society for Psychophysiological Research, Inc.

Wilkinson, R.T. (1959). Rest pauses in a task affected by lack of sleep. *Ergonomics* Vol. 2:373-380.

Wilkinson, R.T. (1961). Interaction of lack of sleep with knowledge of results, repeated testing, and individual differences. *Journal of Experimental Psychology*, Vol. 62(3):263-271.

Wilkinson, R.T. (1964). Effects of up to 60 hours' sleep deprivation on different types of work. *Ergonomics*, Vol. 70:175-186.

Williams, H.L. and Gieseking, C.F. (1966). Some effects of sleep loss on memory. *Perceptual and Motor Skills*, 23:1287-1293, Southern Universities Press.

Williams, H.L.; Granda, A.M.; Jones, R.J.; Lubin, A.; and Armington, J.C. (1962). EEG frequency and finger pulse volume as predictors of reaction time during sleep loss. *Electroencephalography and Clinical Neurophysiology*, 14:64-70.

Williams, H.L.; Lubin, A.; and Goodnow, J.J. (1959). Impaired performance with acute sleep loss. *Psychological Monographs: General and Applied*, Vol. 73(14):1-26.

Williams, H.L.; Kearney, O.F.; and Lubin, A. (1965). Signal uncertainty and sleep loss. *Journal of Experimental Psychology*, Vol. 69(4):401-407.

Williams, H.L. and Lubin, A. (1967). Speeded addition and sleep loss. *Journal of Experimental Psychology*, 73, 313-317.