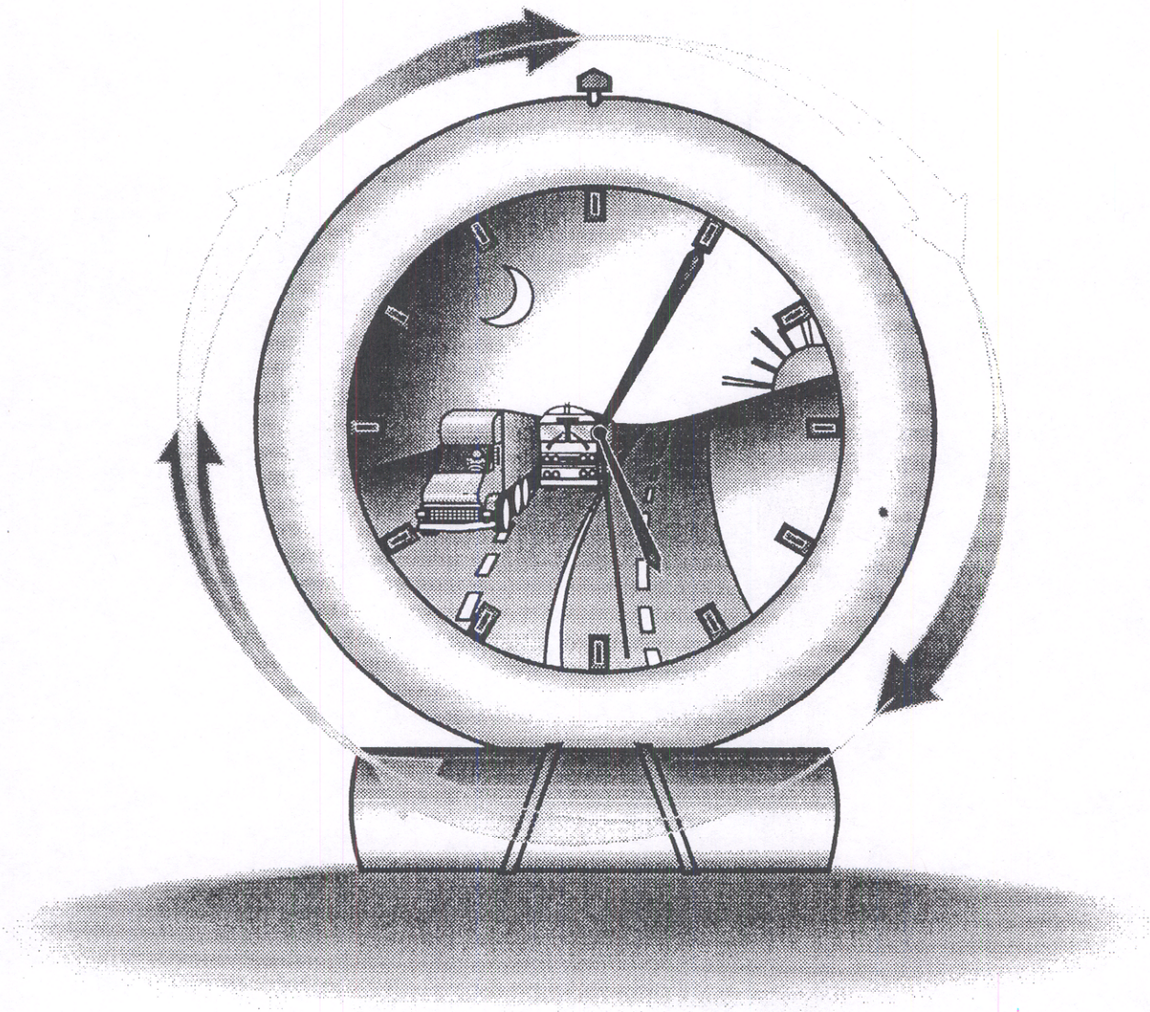
Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance



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16. Abstract

This project was comprised of two studies—a field study using wrist actigraphy to determine sleep duration and timing in long- versus short-haul CMV drivers over 20 consecutive days; and a sleep dose/response (SDR) laboratory study on CMV drivers to determine the effects of 3, 5, 7, and 9 hours time in bed (TIB) on performance (including simulated driving) over seven consecutive days. Findings from the latter (SDR) study were used to optimize the parameters of the Walter Reed Sleep Performance Model (SPM}—a mathematical algorithm to predict performance based on prior sleep and circadian rhythm. The SPM has been integrated into the current version oft e Sleep Watch Actigraph, a wrist-worn device for management of sleep and performance in the operational environment.

In Chapter 1, theoretical background on the nature of sleep loss-induced performance decrements is presented. Chapter 2 provides the methodology used in the SDR (laboratory) study, and the detailed results of that study. Chapter 3 provides the background for SPM development, and a detailed description of the SPM. Chapter 4 presents the methodology used in the field study, and the detailed results of that study. Chapter 5 provides an overview and synthesis of results, conclusions, and recommendations.

Results from the CMV Drivers field Study portion of the present project show that daily sleep duration is correlated with duration of off-duty time, and both long- and short-haul drivers average approximately 7 1/2 hours of sleep per night—which is within normal limits. However, there is significant day-to-day variability in sleep duration in both groups that is unrelated to work/rest schedule. Therefore, in addition to optimizing work/rest schedules, investigation of additional means for improving driver performance and alertness is advisable.

In the SDR laboratory study portion of the present project, sleep duration-related differences in daytime performance were evident, with even small differences in average nighttime sleep duration resulting in measurable performance decrements. Performance decrements were maintained across the entire 7 consecutive days of sleep restriction, suggesting that there was no compensatory or adaptive response to even mild sleep loss. Following more severe sleep restriction (e.g., the 3-hr TIB group) recovery of performance was not complete after three consecutive nights of recovery sleep (with 8 hours spent in bed each night). This suggests that full recovery from substantial sleep debt may require several days of extended recovery sleep.

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EFFECTS OF SLEEP SCHEDULES ON COMMERCIAL MOTOR VEHICLE DRIVER PERFORMANCE

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Ms. Rita Bontz of the Maryland Independent Truckers Association, whose support was instrumental in recruitment of the driver/volunteers.

The 116 drivers who participated in the two studies comprising this project—their considerable sacrifices and the effort they put forth in hope of improving the safety and efficiency of their industry reflected highly upon themselves, and the driving profession in general.

TABLE OF CONTENTS

EXECUTIVE SUMMARY …… ES-1

CHAPTER 1. A HISTORICAL AND METHODOLOGICAL OVERVIEW OF SLEEP AND PERFORMANCE ……..…..…… 1-1

A. Introduction …… 1-1

B. The Nature of Sleep-Loss Induced Performance Deficits …….. 1-1

C. Sleep Restriction …… 1-5

D. Possible Differences in the Recuperative Value of the Various Sleep Stages ……. 1-14

E. Implications for Development of a Sleep/Performance Model …… 1-22

CHAPTER 2. THE SLEEP DOSE/RESPONSE STUDY …… 2-1

A. Background …… 2-1

B. Methods ……. 2-5

C. Results …… 2-20

D. Discussion …….. 2-84

CHAPTER 3. THE SLEEP/PERFORMANCE MODEL ……. 3-1

A. Background: A Critical Review of Sleep/Alertness Models—Input Factors, Prediction Output, and Limitations ……. 3-1

B. The Walter Reed Sleep Performance Model (SPM)….……. 3-5

C. Parameter Estimation—Methods and Results ……... 3-10

D. Discussion ……. 3-18

CHAPTER 4. FIELD STUDY: ACTIGRAPHIC ASSESSMENT OF CMV DRIVERS OVER 20 CONSECUTIVE DAYS …….. 4-1

A. Overview and Study Objectives …… 4-1

B. Methods ……. 4-2

C. Results …… 4-6

D. Discussion …….. 4-47
E. Summary—Field Study …….. 4-63
F. Conclusions—Field Study …… 4-63
G. Recommendations—Field Study ……..… 4-64
H. Subtask: Interview of CMV Personnel …… 4-65

CHAPTER 5. GENERAL RESULTS, CONCLUSIONS, AND RECOMMENDATIONS ……..... 5-1
A. Field Study: Actigraphic Assessment of CMV Drivers …...……..… 5-1
B. Laboratory Study: The Sleep Dose/Response Study ……..……..… 5-2
C. Rationale for Modeling Psychomotor Vigilance Task (PVT) Performance in the Walter Reed Sleep Performance Model (SPM) ……..... 5-4
D. Refinements of the SPM ……. 5-6
E. Implications for Performance in the Operational Environment ……..... 5-7
F. Future Directions: The Sleep Watch Actigraph (SWA) as a Component of a Comprehensive Sleep/Performance-Management System …..…… 5-9

REFERENCES …… R-1

LIST OF FIGURES

CHAPTER 2

Figure 2-1 Mean total sleep time (sum of Stages 1, 2, SWS, and REM) in minutes across study days as a function of sleep group …… 2-22

Figure 2-2 Mean recuperative sleep time (sum of Stages 2, SWS, and REM) in minutes across study days as a function of sleep group …… 2- 24

Figure 2-3 Mean recuperative sleep time in minutes (sum of Stages 2, SWS, and REM) with Stage 1 amounts in minutes separately for each group across study days. Recuperative sleep time plus Stage 1 equals total sleep time ……. 2-26

Figure 2-4 Mean minutes of Stage 1 across study days as a function of sleep group ……. 2-28

Figure 2-5 Mean minutes of Stage 2 across study days as a function of sleep group ……. 2-29

Figure 2-6 Mean minutes of slow wave sleep (Stages 3 and 4) across study days as a function of sleep group ……... 2-30

Figure 2-7 Mean minutes of rapid eye movement (REM) sleep across study days as a function of sleep group …… 2-31

Figure 2-8 Scatter plot of baseline mean sleep latency scores for all subjects …...…. 2-33

Figure 2-9 Mean latency to sleep (collapsed across time of day) as a function of sleep group (all subjects included) across study days ……..... 2-34

Figure 2-10 Mean latency to sleep (collapsed across time of day) as a function of sleep group (for nonpathologically sleepy subjects—baseline mean latency > 5 min) across study days ……. 2-37

Figure 2-11 Relative number of microsleeps across days as a function of sleep group…...…… 2-44

Figure 2-12 Relative maximum duration of microsleeps (seconds) across study days as a function of sleep group ……. 2-45

Figure 2-13 Relative total amount of microsleep (seconds) across study days as a function of sleep group ……. 2-46

Figure 2-14 Mean sleepiness scores across study days (collapsed across time of day) as a function of sleep group …….. 2-47
Figure 2-15 Serial addition/subtraction accuracy (percent correct) across study days as a function of sleep group …… 2-49
Figure 2-16 Serial addition/subtraction speed (1/RT) across study days as a function of sleep group …….. 2-50
Figure 2-17 Serial addition/subtraction throughput (speed * accuracy) across study days as a function of sleep group ……. 2-51
Figure 2-18 Wilkinson 4-Choice reaction time accuracy across study days as a function of sleep group …….. 2-53
Figure 2-19 Wilkinson 4-Choice reaction time speed across study days as a function of sleep group ……. 2-54
Figure 2-20 Wilkinson 4-Choice reaction time throughput across study days as a function of sleep group …… 2-55
Figure 2-21 10-choice reaction time accuracy across study days as a function of sleep group ……. 2-57
Figure 2-22 10-choice reaction time speed across study days as a function of sleep group …… 2-58
Figure 2-23 10-choice reaction time throughput across study days as a function of sleep group …… 2-59
Figure 2-24 Mean speed (1/RT) on the psychomotor vigilance task (simple reaction time task) across study days by sleep group. …… 2-61
Figure 2-25 Mean number of response times greater than 0.5 seconds, on the psychomotor vigilance task across study days by sleep group …….. 2-62
Figure 2-26 Synthetic work task (SYNWORK) total score across study days as a function of sleep group …… 2-64
Figure 2-27 Simulator-driving mean speed averaged over all 55-mi/h (88.5-km/h) zones (top) and all 35-mi/h (56.3-km/h) zones (bottom), across study days by sleep group …….. 2-65
Figure 2-28 Standard deviation of speed averaged over all 55-mi/h (88.5-km/h) zones, across study days by sleep group …..……..….. 2-67

Figure 2-29 Standard deviation of speed averaged over all 35-mi/h (56.3-km/h) zones, across study days by sleep group ……. 2-68
Figure 2-30 Mean lane position (in feet to the left of the lane center) averaged over all scenario segments, across study days by sleep group …… 2-70
Figure 2-31 Standard deviation of lane position averaged over all scenario segments, across study days by sleep group ……. 2-71
Figure 2-32 Standard deviation of lane position for Scenario Segments 1 through 7, across study days, for the 3-hour sleep group …….. 2-72
Figure 2-33 Mean number of accidents per 45-minute simulation, across study days by sleep group ……. 2-74
Figure 2-34 Oculomotor FIT pupil diameter across study days as a function of sleep group …… 2-76
Figure 2-35 Oculomotor FIT saccadic velocity across study days as a function of sleep group …… 2-78
Figure 2-36 Mean tympanic temperature (centigrade) by day and time of day, separately as a function of sleep group ……. 2-80
Figure 2-37 Absolute speed on Serial Addition/Subtraction versus number of test sessions ……..…. 2-94

CHAPTER 3

Figure 3-1 Initial fit of predicted values (dashed lines) to group daily means (solid lines) using parameter values derived from the 3-hour group's data using a simple iterative search technique (decrement constant 0.55 percent per hour, recovery constant 0.06) ……..…….. 3-13
Figure 3-2 (a) Initial fit of predicted values (dashed lines) to group daily means (solid lines) using parameter values derived from the 3-hour group's data using particle-swarm optimization (decrement constant 0.4204 percent per hour, recovery constant 0.0366) …….. 3-14

Figure 3-2 (b) Initial fit of predicted values (dashed lines) to group daily means (solid lines) using parameter values derived from all four groups' data using particle swarm optimization (decrement constant 0.4766 percent per hour, recovery constant 0.0477) 3-15
Figure 3-3 Convergence of the prediction error during Particle Swarm Optimization 3-17
Figure 3-4 (a, b) Observed and predicted performance for 3-hour and 5-hour sleep groups 3-21
Figure 3-4 (c, d) Observed and predicted performance for 7-hour and 9-hour sleep groups 3-22
Figure 3-5 Percentage of subjects with various levels of error. The height of each bar represents the percentage of subjects with a percent error in each 5 percent error bin 3-23
Figure 3-6 (a, b) Observed and predicted performance for subjects whose data were predicted by the model very well (Subject 518) versus very poorly (Subject 544) 3-24

CHAPTER 4

Figure 4-1 Off-duty time spent sleeping as a function of hours off-duty per 24-hour period, short-haul drivers 4-8
Figure 4-2 Frequency distribution of off-duty durations per 24-hour period, short-haul drivers 4-9
Figure 4-3 Frequency distribution of off-duty sleep durations per 24-hour period, short-haul drivers 4-10
Figure 4-4 Off-duty time spent sleeping as a function of hours off-duty per 24-hour period, long-haul drivers 4-11
Figure 4-5 Frequency distribution of off-duty durations per 24-hour period, long-haul drivers 4-12
Figure 4-6 Frequency distribution of off-duty sleep durations per 24-hour period (includes sleeper-berth time), long-haul drivers 4-13

Figure 4-7 Mean daily sleep per 24-hour period obtained off-duty, short-haul versus long-haul drivers …… …….. 4-14
Figure 4-8 Type B times spent sleeping per 24-hour period as a function of Type B hours, short-haul drivers …….. 4-16
Figure 4-9 Frequency distribution of Type B sleep durations per 24-hour period, short-haul drivers …….. 4-17
Figure 4-10 Frequency distribution of Type B durations per 24-hour period, short-haul drivers, excluding 24-hour periods off-duty ….…….. 4-18
Figure 4-11 Type B time spent sleeping per 24-hour period as a function of Type B hours, long-haul drivers ……..…….. 4-20
Figure 4-12 Frequency distribution of Type B sleep durations per 24-hour period, long-haul drivers ……..…….. 4-21
Figure 4-13 Frequency distribution of Type B durations per 24-hour period, long-haul drivers ……..……. 4-22
Figure 4-14 Mean sleep obtained during Type B time per 24-hour period, short-haul versus long-haul drivers ……..… 4-23
Figure 4-15 Sample actigraph records with corresponding Driver's Record of Duty Status (RODS): inconsistency between actigraph and RODS ……..… 4-24
Figure 4-16 Frequency distribution of total sleep times per 24-hour period (summed across all possible duty statuses), short-haul drivers …….. 4-25
Figure 4-17 Frequency distribution of total sleep times per 24-hour period (summed across all possible duty statuses), long-haul drivers …… 4-26
Figure 4-18 Mean total sleep off-duty and during Type B time per 24-hour period, short-haul versus long-haul drivers ……. 4-27
Figure 4-19 Cumulative percentage distribution of total sleep durations per 24-hour period for short-haul and long-haul drivers …… 4-28
Figure 4-20 Sleep-bout duration for the first actigraphically identified sleep bout of each 24-hour period as a function of time of day of sleep-bout onset, short-haul drivers …….. 4-30
Figure 4-21 Frequency of first sleep bouts per 24-hour period as a function of onset time, short-haul drivers …….. 4-31

Figure 4-22 Sleep-bout duration for subsequent actigraphically identified sleep bouts of each 24-hour period as a function of time of day of sleep-bout onset, short-haul drivers …….. 4-32
Figure 4-23 Frequency of subsequent sleep bouts per 24-hour period as a function of onset time, short-haul drivers ……. 4-33
Figure 4-24 Sleep-bout duration for the first actigraphically identified sleep bout of each 24-hour period as a function of time of day of sleep-bout onset, long-haul drivers …….. 4-34
Figure 4-25 Frequency of first sleep bouts per 24-hour period as a function of onset time, long-haul drivers …… 4-35
Figure 4-26 Sleep-bout duration for subsequent actigraphically identified sleep bouts of each 24-hour period as a function of time of day of sleep-bout onset, long-haul drivers …… 4-36
Figure 4-27 Frequency of subsequent sleep bouts per 24-hour period as a function of onset time, long-haul drivers ……. 4-37
Figure 4-28 Frequency of first sleep bouts per 24-hour period as a function of onset time, short-haul versus long-haul drivers …….. 4-38
Figure 4-29 Frequency of subsequent sleep bouts per 24-hour period as a function of onset time, short-haul versus long-haul drivers …….. 4-39
Figure 4-30 Daily total sleep time per each 24-hour period across all 20 study days for three short-haul drivers (drivers with high/medium/low variability in daily total sleep times) ……. 4-44
Figure 4-31 Daily total sleep time per each 24-hour period across all 20 study days for three long-haul drivers (drivers with high/medium/low variability in daily total sleep times) ……. 4-45
Figure 4-32 SPM predicted performance based on actigraphically recorded sleep per 24-hour period for short-haul driver H7076 (ranked high on daily variability in total sleep time relative to the other short-haul drivers studied) ……..…… 4-54

Figure 4-33 SPM predicted performance based on actigraphically recorded sleep per 24-hour period for long-haul driver B6828 (ranked high on daily variability in total sleep time relative to the other long-haul drivers studied) ……..…….. 4-55

Figure 4-34 SPM predicted performance based on actigraphically recorded sleep per 24-hour period for long-haul driver Z2911 (ranked medium on daily variability in total sleep time relative to the other long-haul drivers studied) . ……..…….. 4-56

Figure 4-35 SPM predicted performance based on actigraphically recorded sleep per 24-hour period for short-haul driver C2979 (ranked medium on daily variability in total sleep time relative to the other short-haul drivers studied) ……..…….. 4-57

Figure 4-36 SPM predicted performance based on actigraphically recorded sleep per 24-hour period for short-haul driver T5452 (ranked low on daily variability in total sleep time relative to the other short-haul drivers studied) ……..…….. 4-58

Figure 4-37 SPM predicted performance based on actigraphically recorded sleep per 24-hour period for long-haul driver K9113 (ranked low on daily variability in total sleep time relative to the other long-haul drivers studied) ……..…….. 4-59

CHAPTER 5

Figure 5-1 The Sleep Watch Actigraph (SWA) showing fuel-gauge-type current performance capacity read-out …… 5-10

LIST OF TABLES

CHAPTER 2

Table 2-1	Daily schedule of testing ……	2-7
Table 2-2	Stanford Sleepiness Scale items …….	2-12
Table 2-3	Mean (stderr) total sleep in minutes ……..…….	2-23
Table 2-4	Mean (stderr) recuperative sleep in minutes ..…….	2-25
Table 2-5	Break-out by Sleep Group, Study Phase, and Time Preceding Crashes: Number and percentage of simulator-driving accidents preceded by microsleep up to 1 minute prior to accidents …..……..…..	2-39
Table 2-6	Break-out by Sleep Group and Day: Number and percentage of simulator-driving accidents preceded by microsleep up to 1 minute prior to accidents …….	2-40
Table 2-7	Summary: Number and percentage of simulator-driving accidents preceded by microsleep up to 1 minute prior to accidents …..…….	2-41
Table 2-8	Break-out by Sleep Group and Duration of Microsleeps: Number and percentage of simulator driving accidents preceded by microsleep up to one minute prior to accidents ……..……..	2-41
Table 2-9	Break-out by Sleep Group and Day: Number and percentage of simulator-driving accidents preceded by microsleep up to 2 s prior to accidents ……..……..	2-42
Table 2-10	Summary: Number and percentage of simulator-driving accidents preceded by microsleep up to 2 s prior to accidents ……..	2-43
Table 2-11	Mean (stderr) systolic blood pressure (mm/Hg) by day and time of day ……...	2-82
Table 2-12	Mean (stderr) diastolic blood pressure (mm/Hg) by time of day …….	2-83

CHAPTER 3

Table 3-1 Particle-swarm optimization parameter values ……..……... 3-16

CHAPTER 4

Table 4-1 Mean daily (per 24-hour period) total sleep time (averaged across all available participation days) for each short-haul driver ……. 4-41

Table 4-2 Mean daily (per 24-hour period) total sleep time (averaged across all available participation days) for each long-haul driver …….. 4-42

APPENDICES

Appendix 1	Phase 2 Study Criteria and Recruitment Forms ..……..	A1-1
Appendix 2	Driver Demographic Information ……..…….....	A2-1
Appendix 3	Driving Simulator Scenario Specifications……..…	A3-1
Appendix 4	Analysis of Variance Tables, Phase 2 Dependent Measures …….	A4-1
Appendix 5	Phase 1 Recruitment Forms ……..…….	A5-1
Appendix 6	Monitoring Sleep And Predicting Performance Using Actigraphy With Embedded On-Line Sleep Scoring and Performance Prediction Algorithms/Outputs (Sleepwatch-Actigraph) …….	A6-1
Appendix 7	Subtask: Interview of CMV Personnel: Amount of Time Professional Drivers Spend Sleeping ……	A7-1

LIST OF ABBREVIATIONS, ACRONYMS, AND DEFINITIONS

Acrophase …….….. Highest point of a circadian rhythm

ANOVA ……..…. Analysis of Variance

APC ……..… Amplitude of Pupil Constriction

ASICs ……..…. Application Specific Integrated Circuits

BAC ……..… Baseline Alertness Curve

CDL …..……... Commercial Driver License

Circadian rhythm ……..… Any pattern of biological events that recurs every 24 hours. Biological events displaying circadian rhythmicity are thought to be driven by an internal clock but influenced by external factors

CL ……..... (Pupil) Constriction Latency

CMV ……... Commercial Motor Vehicle

CPAP……... Continuous Positive Airway Pressure

DSP …….……. Digital Signal Processing

DSST …… Digit Symbol Substitution Test

DST ……..… Daylight Savings Time

EEG .…….……..….. Electroencephalogram or Electroencephalography

EKG ……..… Electrocardiogram or Electrocardiography

EMG ……..…..… Electomyogram or Electromyography

EOG ……..…… Electrooculogram or Electrooculography

FHWA ……..… Federal Highway Administration

FMCSA…… Federal Motor Carrier Safety Administration

FIT ……... Fitness Impairment Tester

GCRC …….. (Johns Hopkins Bayview) General Clinical Research Center

HOS ……..… Hours of Service (Regulations)

HR …… Heart Rate

IND ……...…. Initial Pupil Diameter

JND ……..…..… Just Noticeable Difference

K-complex …….…… EEG event characterized by high-amplitude negative voltage followed by positive voltage (total negative-to-positive amplitude = 75 microvolts) then negative voltage, with a total signal duration of at least 0.5 s. One marker of Stage 2 sleep but also often seen after external stimulation

KSS ……..…… Karolinska Sleepiness Scale

Microsleep……..…….. Brief EEG event characterized by the occurrence of Stage 1 sleep for a period of 1 to 15 seconds in an otherwise awake individual

MSLT ……..…....… Multiple Sleep Latency Test—series of 4 to 5 bi-hourly tests generally starting at 0800 hours in which the latency to fall asleep is determined under sleep-conducive conditions. Individuals showing sleep latencies faster than 5 minutes are considered pathologically sleepy

Nadir ……..……. Lowest point of a circadian (24-hour) rhythm

NREM ……..…… Non-rapid-eye-movement sleep (i.e., Stages 1, 2, 3, and 4)

NTSB ……..……. National Transportation Safety Board

OMCHS …….. Office of Motor Carrier and Highway Safety

OSA ……. Obstructive Sleep Apnea

PAB ……..……. (Walter Reed) Performance Assessment Battery

PERCLOS ……..…… Percent Eye Closure (alertness monitoring device)

PLM ……..…. Periodic Limb Movements (During Sleep)

POMS ……..……. Profile of Mood States

Process C ……..…… Hypothetical process accounting for circadian rhythmicity in observed sleep/wake behavior. Mathematically, Process C is often described as a sinusoidal function with a peak (acrophase) in the evening and a nadir in the morning.

Process S ……. Hypothetical process accounting for changes in observed sleep/wake behavior as a function of time awake and time asleep. Mathematically, Process S is usually described as an exponential function during waking.

PSG ……..…… Polysomnogram or Polysomnography

PSO …… Particle Swarm Optimization

PVT …… Psychomotor Vigilance Task

r …… correlation coefficient (Pearson *r*)

Rebound effect ……. significantly increased levels of a particular stage of sleep relative to baseline (occurs following sleep restriction/deprivation)

Recuperative sleep ..…… Total sleep time (TST - see below) that does not include Stage 1; same as TST-stg1 (see below)

REM ……..… ……..… Rapid eye movement sleep

SDR …… Sleep Dose Response (study)

SEM …… Standard error of the mean

Sleep fragmentation ……. naturally occurring or stimulus-induced interruption of an ongoing sleep stage such that a lighter stage ensues

Sleep inertia ……..…….. observable phenomenon occurring immediately upon awakening and lasting approximately 20 minutes in which performance and alertness improve across time

Sleep spindle …..…… EEG event characterized by low-amplitude, 12- to 14-hertz activity of 0.5- to 2.0-s duration. One marker of Stage 2 sleep

SLT ……..…...……. Sleep Latency Test—modified version of the MLST in which less than the number of prescribed tests is administered, the interval between tests is different from the prescribed 2 hours, or the test is modified in some other way

SPM ……..…… (Walter Reed) Sleep Performance Model

SRT ……..…… (Tukey's) Studentized Range Test

Stage 1 sleep …….sleep stage characterized by low amplitude mixed-frequency EEG activity and considered the transition stage between wakefulness and other sleep stages

Stage 2 sleep ……..……. sleep stage characterized by the appearance of sleep spindles and K-complexes in the EEG

Stage 3 sleep ……. sleep stage characterized by high amplitude delta waves occurring in 20-49% of an epoch

Stage 4 sleep …… sleep stage characteriazed by high amplitude delta waves in 50% or more of an epoch

Stage REM ……..…… sleep stage characterized by low amplitude, mixed frequency EEG, reduced muscle tonus, and intermittent rapid eye movements

stderr …….. ….. standard error (of the mean)

STISIM ……..…… Systems Technology, Inc., Simulator (driving simulator)

SV …… Saccadic Velocity

SWA …… Sleep Watch Actigraph

SWS …… Slow-wave sleep—sum of Sleep Stages 3 and 4

TIB …… Time In Bed

TST ……..…… Total Sleep Time (sum of Stages 1, 2, slow-wave sleep, and rapid eye movement or REM sleep)

TST-stg1 ……..……..… Total sleep time that does not include Stage 1

Type B Sleep …..……. sleep taken at times other than off-duty, including sleeper berth Time

Ultradian Rhythm ….……. Biological rhythm that occurs with a frequency faster than 24 hours (e.g., 12-hour biological rhythm)

VAS ……..…… Visual Analog Scale

VEOG ……..… Vertical EOG (electrooculogram)

WASO ……..……. Wake (time) After Sleep Onset

WAVT ……..…… Wilkinson Auditory Vigilance Task

WRAIR ……..……. Walter Reed Army Institute of Research

WRF ……..…… Work-Related Fatigue (Model)

EFFECTS OF SLEEP SCHEDULES ON COMMERCIAL MOTOR VEHICLE DRIVER PERFORMANCE

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EFFECTS OF SLEEP SCHEDULES ON COMMERCIAL MOTOR VEHICLE DRIVER PERFORMANCE

EXECUTIVE SUMMARY

May 2000

INTRODUCTION

The project entitled "Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance" was comprised of two studies—a field study and a laboratory study. In the field study, wrist actigraphy was used to determine amounts of sleep in long- versus short-haul commercial motor vehicle (CMV) drivers over 20 consecutive days, continuously, during and outside the work shift. Results from this study revealed the extent to which inadequate sleep constitutes a potential problem for these two subpopulations of CMV drivers. In the laboratory study, the effects of 3, 5, 7, and 9 hours of nightly time in bed (TIB) on subsequent performance (on a variety of psychomotor tasks, including simulated driving), were measured across 7 consecutive days in CMV drivers. Results from this study were used to optimize the parameters of the Walter Reed Sleep Performance Model (SPM). The SPM, along with a sleep scoring algorithm, has been integrated into the current version of the Sleep Watch Actigraph (SWA), a wrist-worn device for management of sleep and performance in the operational environment.

PROJECT PARTICIPANTS

This was a collaborative project, performed by the Division of Neuropsychiatry, Walter Reed Army Institute of Research, with funding from the Department of Transportation (DOT) Federal Motor Carrier Safety Administration (formerly the Office of Motor Carriers of the Federal Highway Administration), the Federal Aviation Administration, and the Federal Railroad Administration. The General Clinical Research Center/Johns Hopkins Bayview Medical Center provided both the venue and staff for conduction of the laboratory (Sleep Dose/Response) study.

BACKGROUND

Under current U.S. Federal Hours of Service (HOS) regulations, CMV drivers are restricted to a maximum of 10 hours of driving (and/or 15 hours on-duty time) after 8

consecutive hours off-duty; and a maximum of 60 hours on-duty time over 7 consecutive days (or a maximum of 70 hours over 8 consecutive days for those who operate 7 days per week). However, the HOS regulations do not necessarily prevent significant sleep debt and sleepiness-related performance deficits in CMV operators. This is because: (a) under HOS regulations, driving may occur in the early morning hours; (b) the HOS regulations do not prohibit backward–rotating or highly irregular work/rest schedules; and (c) a minimum off-duty period of 8 hours may not be long enough to ensure adequate sleep (since drivers would also be expected to eat, shower, etc., during this period). The field study was designed to assess, using wrist actigraphy, the relative amounts of sleep obtained by short- and long-haul CMV drivers over 20 consecutive days continuously, both on-duty and off-duty.

Although it is known that sleep debt impairs performance on a variety of tasks (including driving-related measures), the relationship between hours of sleep and subsequent performance during wakefulness has never been adequately *quantified*. Therefore, although it is known that greater sleep debt results in greater deficits, the likely consequences of a particular level of sleep debt for performance and safety in an operational environment has not yet been specified. This is partly due to the fact that relatively few well-controlled studies have investigated the effects of restricted sleep over multiple consecutive days. The lack of such studies is particularly problematic because it is most likely that sleep restriction (i.e., inadequate daily sleep), rather than total sleep deprivation (the complete absence of sleep), accounts for most daytime sleepiness in CMV drivers (and workers in all other occupations, as well). In addition, adaptive mechanisms—for example, changes in sleep architecture that could enhance the minute-by-minute recuperative value of recovery sleep—may be induced during sleep restriction. Thus, full explication of the relationship between sleep and subsequent performance requires studies involving the parametric manipulation of total sleep times across multiple days. The latter was the purpose of the laboratory (Sleep Dose/Response) study. Quantification of the relationship between total sleep time across multiple days and subsequent performance will allow the construction of a sleep/performance model—a requisite for optimally effective management of sleep and performance in the operational environment.

STUDY OBJECTIVE I:
FIELD STUDY—ACTIGRAPHIC ASSESSMENT OF THE SLEEP OF CMV DRIVERS OVER 20 CONSECUTIVE DAYS

METHOD

Subjects

Subjects were 50 CMV drivers (men and women), aged 21 to 65, holding a valid Commercial Driver License (CDL). Twenty-five of the drivers maintained driving schedules that enabled them to return home at the end of most work periods to sleep and thus were categorized as "short-haul" drivers. The other 25 drivers maintained schedules that did not always allow them to return home at the end of work periods to sleep; they were categorized as "long-haul" drivers. Subjects were not asked to restrict their use of tobacco or caffeine during the study. All subjects signed an informed consent form and were paid $300 for participation.

Design

The study was designed to assess the sleep/wake schedules of CMV drivers in a naturalistic and minimally intrusive manner. Subjects were provided a wrist actigraph and instructed to wear it at all times, except when bathing/showering.

Measures

Wrist actigraphy was used to objectively measure the timing and duration of sleep periods over a 20-day period. Drivers were also given sleep logs to fill out on each of the 20 consecutive study days. These sleep logs were used to gather subjective information on sleep times, sleep latency, arousals during sleep, alertness upon awakening, napping (number and duration), and self-reported caffeine, alcohol, and drug use. Initially, long-

haul drivers were asked to provide copies of their daily logs corresponding to study dates, and short-haul drivers were asked to keep track of their on-duty and off-duty times across the 20 days of the study. Because of noncompliance in the short-haul group (mainly attributed to drivers forgetting to keep track of duty times), all drivers were then given Driver's Daily Log sheets (identical to those normally used by drivers as part of Department of Transportation requirements). These were filled out on each of the 20 consecutive study days.

Data Analysis

Data from each actigraph were downloaded to a personal computer and scored for daily sleep periods by visual inspection of the actigraph records. For each 24-hour period, total sleep within that period was identified and categorized as either: (a) off-duty sleep (sleep obtained during the primary, or longest, off-duty period during the 24-hour day) or (b) sleep taken during Type B time (which includes sleep taken at all other times). The amount and timing of daily sleep was calculated for each group of drivers, and the correlations between daily sleep and off-duty time were determined.

Strengths and Limitations of the Methodology

Strengths:

1. Actigraphic measures are minimally intrusive, objective measures.
2. Combined information from actigraph records and driver logs increases reliability and specificity of the sleep data.

Limitations:

1. Actigraphy does not allow scoring of sleep stages, which may be differentially restorative.
2. The reliability of actigraphy in a moving motor vehicle (e.g., when a driver is sleeping in a sleeper berth of a moving vehicle) is currently unknown.
3. The reliability of subjective reports (e.g., subject logs) is typically low.

RESULTS AND DISCUSSION — CMV DRIVERS FIELD STUDY

In the CMV drivers field study, it was found that both long- and short-haul drivers averaged approximately 7.5 hours of sleep per night, which is within normal limits for adults. Time off-duty was positively correlated with total sleep time for both groups, but the short-haul drivers were more likely to consolidate their daily sleep into a single, work-shift sleep period. Long-haul drivers obtained almost half of their daily sleep during work-shift hours (mainly sleeper-berth time), which suggests that they spend a significant portion of the work shift in a state of partial sleep deprivation—i.e., until the opportunity to obtain on-duty recovery sleep presents itself.

In both groups, however, there was no off-duty duration that guaranteed adequate sleep—for example, one driver obtained no sleep during a 20-hour off-duty period. Likewise, large day-to-day variations in total sleep time were evident for drivers in both groups, with some individuals showing a pattern suggesting chronic sleep restriction with intermittent bouts of extended recovery sleep. Based on these findings, it is suggested that although work/rest schedules can be devised to help minimize CMV driver sleep debt, optimal enhancement of driver alertness and performance will require additional approaches.

STUDY OBJECTIVE II:
LABORATORY STUDY — THE SLEEP DOSE/RESPONSE (SDR) STUDY

The cause-effect relationship between sleepiness and impaired performance is well established, but the relationship has not been quantified parametrically—a necessary step toward determining, for example, how much sleep is necessary to perform subsequent daytime tasks with nominal efficiency and safety. Therefore, the primary objectives of the SDR study were as follows:

1. Determine the effects of four sleep/wake schedules on alertness and performance, and
2. Develop an algorithmic model to predict performance on the basis of prior sleep parameters.

METHOD

Subjects

Sixty-six subjects participated in the SDR study: 16 females ages 24 to 55 with a mean and median age of 43 years, and 50 males ages 24 to 62 with a mean age of 37 and median age of 35 years. All subjects held a valid CMV driving license, but subjects differed in terms of years of experience and the types of trucks or buses driven. All subjects signed an informed consent form and were paid $4,000 for participating.

Design

Subjects spent 14.5 days in the laboratory: 3 days of training/baseline performance with 8 hours time in bed (TIB) each night; followed by 7 consecutive days of performance testing during which subjects were allowed either 3, 5, 7, or 9 hours TIB each night. This was followed by a 4-day recovery period during which performance testing was continued and subjects again obtained 8 hours TIB each night. Wake-up time was held constant at 0700 hours across all conditions (to minimize disruption of circadian rhythms), and all performance tests and physiological measures were conducted at the same times of day across all phases of the study.

Measures

A wide variety of measures were used, including psychomotor tasks [e.g., various tasks from the Walter Reed Performance Assessment Battery (PAB), the Systems Technology, Inc., Simulator (STISIM) driving simulator, the Psychomotor Vigilance Task (PVT)] and physiological measures [e.g., oculomotor measures from the Fitness Impairment Tester (FIT) device, vital signs, and the sleep latency test (SLT)]. Sleep/wake state was measured and recorded 24 hours per day with portable EEG recorders.

Data Analysis

Data were generally analyzed using a three-way mixed Analysis of Variance (ANOVA) for TIB group (3, 5, 7, or 9 hours/night), day (11 days; Baseline 1 to Recovery 3), and time of day, with repeated measures on the latter two factors. Number of levels for the time-of-day factor depended on the daily sampling rate for a given task (for example, four levels for STISIM, which was administered at 0730, 1030, 1330, 1930 hours). Main effects for sleep group, day, and time of day, as well as their interactions, were analyzed. The interaction of TIB Group x Day is most relevant to this report; thus, this interaction (if significant) was further analyzed using simple-main-effects ANOVAs. Greenhouse-Geisser corrections were applied to all repeated-measures tests. Post-hoc comparisons among means were conducted using the Tukey HSD test. Results were deemed significant at $p < .05$. Analyses were conducted using commercially available statistical packages (SAS, SPSS, and BMDP).

Strengths and Limitations of the Methodology

Strengths:

1. The wide variety of performance and physiological measures used in the SDR study provide a comprehensive overview of the effects of sleep restriction.
2. The long duration of this residential study [3 baseline/training days followed by 7 days with 3, 5, 7, or 9 hours TIB (time in bed) per night, and ending with 4 days of recovery sleep] allows evaluation and quantification of TIB Group x Day interactions. These interactions reveal the relative extent to which habituation or accommodation to various levels of sleep restriction occurs.

Limitations:

1. The trade-off for using a wide variety of measures was that the number of daily administrations for each particular measure was restricted—precluding evaluation of circadian rhythms in the SDR study.
2. Subjects were heterogeneous with respect to age, which may have contributed to error variance in performance measures.

RESULTS AND DISCUSSION—THE SDR LABORATORY STUDY

Results from the CMV drivers field study portion of this project show that daily sleep duration is correlated with duration of off-duty time, and both long- and short-haul drivers average approximately 7 1/2 hours of sleep per night—which is within normal limits. However, there is significant day-to-day variability in sleep duration in both groups, and long-haul drivers obtain almost half of their daily sleep during work-shift hours (from which it can be inferred that they spend a significant portion of their on-duty hours with a significant sleep debt). Therefore, in addition to optimizing work/rest schedules, investigation of other means for improving driver performance and alertness is advisable.

In the SDR laboratory study portion of the present project, the focus was on quantification of the relationship between nighttime sleep duration and subsequent performance across 7 consecutive days—a necessary first step for effective management of alertness and performance in the operational environment. It was found that the 3-, 5-, 7-, and 9-hour TIB groups averaged 2.87, 4.66, 6.28, and 7.93 hours of sleep, respectively, across the 7 days—and that group-related (i.e., sleep dose-dependent) differences in subsequent daytime performance were evident (and quantifiable) for several measures.

Of particular interest were the findings that even a relatively small reduction in average nighttime sleep duration (i.e., to 6.28 hours of sleep—the average amount of sleep obtained by the 7-hour group) resulted in measurably decremented performance (e.g., on the PVT). This decrement was maintained across the entire 7 consecutive days of sleep restriction, suggesting that there was no compensatory or adaptive response to even this mild degree of sleep loss. It was also found that following more severe sleep restriction (e.g., the 3-hour group), recovery of performance was not complete after 3 consecutive nights of recovery sleep (with 8 hours spent in bed on each night). This suggests that full recovery from substantial sleep debt requires recovery sleep of extended duration. It further suggests that the extant level of daytime alertness and performance capacity is a function not only of an individual's circadian rhythm, time since the last

sleep period, and duration of the last sleep period, but is also a function of his/her sleep history, extending back for at least several days.

Also, it was found that the temporal concordance between EEG-defined lapses in alertness and accidents on a simulated driving task was low—indicating that sleepiness-induced performance decrements most often occur in the absence of visually observed electrophysiological evidence of impaired alertness.

Of the various performance measures from the SDR study available for modeling [i.e., that could serve as the predicted variable in the Walter Reed Sleep/Performance Model (SPM)], the Psychomotor Vigilance Task (PVT) was deemed optimal. This was because: (a) there were no apparent learning effects with this measure during the experimental phase of the study; (b) the measure was sensitive to the experimental manipulation (i.e., there was adequate separation in mean performance levels between the various sleep groups); and (c) although fatigue might affect PVT performance (and account for some of its sensitivity to sleep loss), it is a short-duration task (10 minutes)—thus, fatigue would be expected to account for a relatively small portion of the variance. Therefore, the SPM parameters were optimized using PVT data.

The SPM predicts performance capacity based on a combination of the subject's sleep debt and circadian rhythms. Sleep debt calculations take into account the amount of sleep obtained over the past few days, time elapsed since the last sleep period, and the predicted recuperative value of the last sleep period as a function of its duration and continuity. The SPM includes a charging function for recuperation during sleep (with a 5-minute "delay of recuperation" function, which is implemented after each arousal or awakening, to account for the reduced recuperative value of fragmented sleep), a discharging function that represents a linear decline in performance while awake, and a circadian-rhythm-modulating function with the acrophase (highest point of the circadian rhythm) occurring at 2000 hours. Integration of the SPM with other on-line measures of performance in the operational environment would allow: (a) performance data feedback to the SPM so that the model parameters could be optimized to the individual on an ongoing basis; and (b) better-informed decision making regarding the likelihood of impending performance failure or the need for countermeasures on an individual

basis. Integration of the SPM with other on-line measures of performance could be a subject for additional research.

1. A HISTORICAL AND METHODOLOGICAL OVERVIEW OF SLEEP AND PERFORMANCE

A. INTRODUCTION

In this chapter, background information is provided to enhance the reader's understanding of the theoretical and practical issues that surround the current effort of the Walter Reed Army Institute of Research to model the relationship between sleep and subsequent performance. Discussion of the nature of sleep-loss-induced performance deficits is provided, including a description of the underlying physiological basis of these performance deficits and the nature of potentially interactive factors such as external stimulation and motivation level. It is asserted that sleep-loss-induced performance deficits are the result of an overall reduction in performance capacity that constitutes a steady (albeit reversible) state characterized by: (a) an increased level of concentrated effort to maintain nominal performance levels on a variety of tasks, which eventually or intermittently results in: (b) frank impairment of performance. Frank performance deficits are sometimes the result of "lapses" in attention or alertness; however, it is shown that lapses do not account for all of the performance deficits that result from sleep loss. Next, the "sleep restriction" literature is critically reviewed, and it is suggested that the effects of chronic sleep restriction may not be equivalent to those of total sleep deprivation—with the possibility that some physiological and/or psychological accommodation may occur during chronically restricted sleep. Finally, the literature addressing the potentially differential recuperative effects of the various sleep stages is discussed, along with the implications for efforts to model the effects of sleep loss on performance using input from wrist actigraphy.

B. THE NATURE OF SLEEP-LOSS-INDUCED PERFORMANCE DEFICITS

Human performance is determined by multiple factors, including: the traits of the individual performing the task (e.g., intellectual, physical, and psychomotor capabilities), the state of the individual (in terms of motivation, attention, effort level, fatigue, and mood, to name a few) and various aspects of the task being performed (e.g., the extent to which task performance requires perseverance, creativity, foresight, and planning; the extent to which the

task has been learned; and the extent to which it involves physical vs. mental effort, etc.). In some instances, task performance itself can impact the performer's state (e.g., sleepiness may be unmasked during performance of extended, boring tasks—see Carskadon & Dement, 1982). Also, deficits in one aspect of brain function (e.g., sleepiness caused by sleep loss) can sometimes be partially (and temporarily) offset by extra effort or increased motivation (e.g., Percival et al., 1982). For example, nominally adequate driving performance in a sleep-deprived individual might be maintained through "force of will" for some period of time—although performance could not be maintained this way indefinitely. Therefore, human performance is the product of a complex interaction involving the performer's internal milieu of traits and states and the nature of the task being performed.

Ultimately, the capacity to perform a particular task depends on the underlying capacity and readiness of the brain to perform that task. Normal performance over extended periods of time typically reflects and signifies a normal underlying level of brain functioning (e.g., normal alertness levels, an absence of pathologies). Also, normal performance typically involves some variability—with circadian, as well as ultradian, rhythmicity evident for most performance measures. But poor performance does not necessarily reflect compromised brain functioning. This is because performance deficits can result from, for example, inattentiveness due to boredom, reduced mood, momentary distractions, thirst, or pain—there is an infinite number of events and circumstances that could affect performance outcome, although they do not impact brain function, nor do they reflect the underlying capacity of the brain to perform the task at hand.

In those cases in which brain functioning is actually compromised, the average performance level will typically be reduced to an extent that corresponds to the extent of the underlying brain dysfunction. Again, the correspondence may not be perfect or linear since compensatory mechanisms such as increased focussing of concentration and effort may help maintain performance at nominally adequate levels, at least temporarily. But extended monitoring of performance (or more extensive probing of performance capacity with challenging tasks) will typically reveal deficits that reflect the compromised brain state.

Sleepiness constitutes one such state of compromised brain functioning. It has long been known that sleep deprivation has a generally negative effect on performance (the first scientific study of sleep deprivation on human performance was conducted in 1896 by Patrick and

Gilbert). But it has also been demonstrated that all tasks are not equally sensitive to sleep loss (e.g., Wilkinson, 1965). In general, tasks involving mental performance are especially sensitive, whereas tasks requiring mostly physical performance (e.g., measures of strength and endurance) are much less sensitive.[1]

THE LAPSE HYPOTHESIS

Furthermore, within the realm of mental performance, sensitivity to sleep loss varies from task to task. Wilkinson (1965) showed that relatively uninteresting, complex, long-duration (30 minutes or longer) tasks are especially affected by sleep loss. This may be because such tasks are themselves sleep-conducive—i.e., likely to unmask underlying sleepiness and possibly lead to frank sleep onset. (This hypothesis would also help explain why tests of physical performance are relatively unaffected by sleep loss—performance of these tests is antithetical to sleep onset by virtue of the stimulation that these activities provide). In fact, it has been hypothesized (e.g., Williams et al., 1959; Lubin, 1967) that *all* sleep-loss-induced performance deficits are the result of "lapses" in performance—perhaps due to brief episodes of EEG-defined sleep, and that performance between lapses (i.e., during EEG-defined wakefulness) may be unaffected by sleep loss. However, Kjellberg's (1977) review of the literature suggests that performance degradation during sleep loss cannot be explained solely by lapses. Also, Valley and Broughton (1983) found that narcoleptics show performance decrements even in the absence of EEG-defined lapses in alertness; and Thomas et al. (1998) more recently found that most "crashes" during simulated driving by normals under conditions of chronic sleep restriction were not associated with any visually discernable EEG indicators of drowsiness. Similarly, it has been shown that most "crashes" in a driving simulator following total sleep deprivation are not associated with any visually discernable EEG indicators of drowsiness (Welsh et al., 1998; Peters et al., 1998).

Gillberg and Akerstedt (1998) performed an extensive electrophysiological investigation of performance on a visual vigilance task during 64 hours of continuous wakefulness, for the

[1] Most attempts to demonstrate an effect of sleep loss on physical performance (e.g., strength and endurance) have failed to do so. And although there are some recent studies showing mildly reduced performance on tests of muscular strength following sleep loss (Reilly and Piercy, 1994), the extent to which these changes reflect true reductions in muscular capacity versus changes in effort/motivation to perform the task is not clear.

express purpose of determining the nature of sleep-loss-induced performance deficits. They found that electrophysiologically defined sleepiness was not evident during any misses occurring during the first 24 hours of continuous wakefulness (although subjective sleepiness increased and was inversely correlated with performance over this time period). The number of misses associated with electrophysiologically defined sleepiness did gradually increase over the remainder of the study (i.e., from 24 to 64 hours of wakefulness). Some of these misses were associated with movement artifact in the EEG and EOG signals (perhaps indicating inattention to the task), frequent blinking, and inadequate tracking of the visual stimulus, but misses also occurred while sleepy subjects were apparently tracking the visual stimulus with no motion artifacts, no excessive blinking, and no electrophysiologically defined sleepiness—i.e., during what, by objective criteria, was apparently normal wakefulness.

REGIONAL BRAIN FUNCTION AND PERFORMANCE DURING SLEEP LOSS

Horne (1988) showed that tasks of higher-order mental abilities (i.e., those abilities mediated by prefrontal cortex) are also especially sensitive to sleep loss in normals. Tests of higher-order cognitive abilities (e.g., reasoning, judgment, creativity) can be relatively stimulating and challenging, and are therefore probably not sleep-conducive in the same way that those tasks identified by Wilkinson (1965) are. In these tests, lapses might be expected to increase response time, but would not be expected to impact the actual ability to perform the task. Therefore, while it is most certainly the case that brief periods of non-performance during EEG-defined lapses in alertness can and do decrement performance on a variety of tasks, these lapses do not account for all of the variance associated with sleep loss-induced performance deficits.

Sleep loss results in a *state* of impaired alertness and performance capacity—a reduced mean level of functioning around which alertness and performance levels fluctuate on a moment-to-moment basis. Previous work in the Walter Reed laboratory (Thomas et al., 1998) has established that this reduced state of alertness and performance capacity is characterized by reduced brain activation (i.e., hypometabolism), with global reductions of about 7 percent following 24 hours of continuous wakefulness. However, the brain hypometabolism that results from sleep loss is not homogeneous. Regions most affected include the thalamus and anterior

cingulate cortex (which, in addition to other functions, mediate general arousal level and the focussing of attention), as well as heteromodal association areas[2] in prefrontal and parietal cortices (which also mediate some aspects of attention, as well as higher-order mental abilities such as foresight, planning, problem solving, and perseverance; see Mesulam, 1985). Thus, it is possible that the sensitivity to sleep loss of long-duration, boring tasks (i.e., the types of tasks identified by Wilkinson) largely reflect hypometabolism in the thalamus and anterior cingulate (i.e., difficulty maintaining attention and alertness), whereas deficits in higher-order mental abilities (such as those identified by Horne, 1988; and Feuerstein et al., 1997) reflect sleep-loss-induced hypometabolism in the prefrontal and parietal heteromodal association cortices. Viewed in this way, sleep loss constitutes a physiological state characterized by heterogeneous, regional deficits in brain activation—and the sensitivity of various performance measures to sleep loss is a function of the extent to which performance depends upon activation of those brain regions most affected by sleep loss.

C. SLEEP RESTRICTION

Operationally, sleep loss can be defined as reduced daily total sleep time (TST), relative to typical daily TST. *Total* sleep deprivation is defined as a period of continuous wakefulness that extends beyond the average daily duration of wakefulness (of about 16 to 18 hours for a normal adult; Williams et al., 1974). Sleep restriction differs from total sleep deprivation in that some sleep is obtained, but not enough sleep to restore alertness and performance to normal (non-sleep-deprived) levels. Acute sleep restriction refers to a short-term reduction in total sleep time (e.g., a single night). For the purpose of this discussion, the term "sleep restriction" refers to those studies and other situations in which shortened sleep periods are obtained over multiple consecutive nights.

[2] The highest order of information integration in the brain occurs in the cortex, and within the cortex there is a hierarchy in terms of the complexity of the information processing accomplished: Primary sensory regions perform the initial registration of sensory stimuli; this information is then passed to and processed by unimodal association cortex, where the presence or absence of relevant features of the stimulus is determined; before this information is, in turn, fed to heteromodal association cortex, where the ultimate meaning of the information is determined [i.e., in terms of associated mental imagery, emotional relevance (assessed with input from limbic and paralimbic areas), relationship to abstract concepts, etc.]

There has been little evidence that the sleepiness and performance deficits that accrue from sleep restriction are qualitatively different from the sleepiness and performance deficits that accrue from total sleep deprivation. It is perhaps, then, for the sake of efficiency, that previous studies in which the nature of sleep-loss-induced performance deficits were investigated have generally employed total sleep deprivation methods rather than sleep restriction methods—although sleepiness in the real world is undoubtedly most often the result of sleep restriction rather than total sleep deprivation.

Sleep restriction studies have typically been conducted to determine the extent to which (a) adaptation to restricted sleep schedules occurs, (b) the costs (in terms of daytime alertness and performance) associated with restricted sleep, (c) the nature of any adaptive processes resulting from chronic sleep restriction (e.g., changes in sleep architecture that might signify an adaptive response to shortened sleep), and (d) the extent to which restricted sleep schedules are volitionally maintained. However, there have been few published long-term (multiple-day) sleep restriction studies conducted for the express purpose of systematically quantifying the relationship between total sleep times and performance.

VOLITIONAL SLEEP RESTRICTION

There are indications that volitional sleep restriction might be pervasive in the general population of Americans today: Bliwise et al. (1992) found that the average nightly self-reported total sleep time (TST) is currently 7.0 to 7.9 hours in normal, healthy individuals aged 50 to 65 years old, significantly less than the average of 8.0 to 8.9 hours that was found in the 1950s. Although the reasons for this reduction in self-reported TST are unclear (and would be unavoidably speculative), it is safe to assert that the average, physiologically based sleep need probably has not changed over this time period.

Naturally Short Sleepers

There is significant inter-individual variability with respect to nightly TST. Naturally short sleepers—i.e., those who appear to require much less than normal total daily sleep amounts compared to appropriate (e.g., similarly aged) cohorts but who have no complaints of

insomnia—have been studied in an effort to determine whether there are any characteristics (especially sleep architecture differences) that imbue these people with the ability to function normally despite their relatively abbreviated sleep. Meddis et al. (1973) reported the case history of a 70-year-old woman who was found to average only 66.8 minutes of polysomnographically determined sleep per night across the 5 consecutive nights that she spent in the laboratory (the range equaled 0 to 204 minutes of sleep per night). The percentage of total sleep time spent in Stages 3 and 4 (see Rechtschaffen and Kales, 1968) across these nights was elevated for a 70-year-old female at 32.6 percent (see Williams, et al., 1974, p. 65) while the percentage of REM sleep was close to normal at 16.5 percent.

Jones and Oswald (1968) polysomnographically measured the sleep of two adult males who each reportedly slept only 3 hours per night. One was studied over 4 consecutive nights and 3 non-consecutive nights. The other was studied over three consecutive nights on two separate occasions—and average TSTs were verified to be less than 3 hours for each subject. For each of these subjects, the percentage of Stages 3 and 4 sleep was elevated (averaging approximately 50 percent of TST), and the percentage of stage REM sleep was normal (averaging 23 percent of TST). Therefore, higher-than-average percentages of Stages 3 and 4 sleep—but normal percentages of Stage REM sleep—consistently characterize the sleep architecture of naturally short sleepers.

Acute Sleep Restriction

Because Stage 3-4 sleep (or slow wave sleep (SWS)) tends to predominate during the first half of the sleep period while stage REM (rapid eye movement) sleep tends to occupy more of the latter half of the sleep period (e.g., Hauri, 1982), a single night of reduced sleep typically results in selective reduction in Stages REM and 2, with relative preservation of absolute amounts of SWS (Johnson & Macleod, 1973; Webb & Agnew, 1965; 1975).

Devoto et al. (1999) conducted a study using six male subjects in a cross-over design in which TIB was limited to 5, 4, 3, 2, or 1 hours (versus 8 hours on baseline nights) on nonconsecutive nights separated by at least 1 week. Thus, each subject served as his own control in a dose-response study of the effects of acute sleep restriction on next-day performance (Wilkinson Auditory Vigilance Task—WAVT), subjective ratings of alertness (visual analog

scales), and objectively measured sleepiness (multiple sleep latency test—MSLT). Generally, it was found that subjective alertness and performance declined linearly as nighttime sleep durations were reduced. The only exception was a sharp increase in the percentage of false positive responses on the WAVT in the 1-hour TIB condition—the condition that also resulted in the least SWS. Devoto et al. (1999) reported that changes in TST accounted for more of the variance in next-day performance (on the WAVT) and alertness (on the MSLT) than did changes in SWS amounts—a finding that they interpreted as suggesting that TST is generally a better predictor of next day functioning than SWS amount. However, their results may be due to the fact that SWS amounts varied relatively little across the various sleep restriction conditions, compared to total sleep times.

Chronic Sleep Restriction

The sleep architecture of normal sleepers who voluntarily reduce the number of hours of sleep obtained per night is quite similar to that of naturally short sleepers. Webb and Agnew (1974) recruited 15 male adults with normal nightly sleep durations (of 7 to 8 hours) to participate in one such study. After four baseline nights in the laboratory, sleep was restricted to 5.5 hours per night for 60 consecutive nights. Although these subjects slept at home and were therefore trusted to restrict their sleep voluntarily, sleep was also polysomnographically monitored once per week in the laboratory. Several performance measures and subjective rating scales were administered once per week, in conjunction with the polysomnographic monitoring of nighttime sleep. Initially, absolute amounts of Stage 4 (deep) sleep were increased, and Stage REM amounts were decreased, although average REM latency (i.e., the duration from sleep onset to the first epoch or REM sleep) was reduced under the restricted sleep schedule. Stage REM sleep remained reduced for the duration of the study, while Stage 4 amounts returned to their initial values (a finding that could indicate some adaptive process or could indicate that compliance to the sleep restriction schedule may have declined across the 60-day study period). The only performance measure significantly affected was an auditory vigilance task—there was a steady decline in performance on this task across the study period. But it was reported that unsolicited self-reports of drowsiness gradually declined to below baseline levels. Although the once-a-week sleep architecture data suggest the possibility of some sort of adaptive process over

the course of the study, and the decline in self-reported drowsiness during this period is consistent with the possibility of adaptation (or at least habituation), caution must be exercised in drawing conclusions from this study since the subjects' adherence to the sleep restriction schedule was not monitored.

Similar effects of sleep restriction on performance and sleep staging were reported by Friedmann et al. (1977); and Mullaney et al. (1977). After 3 weeks of baseline measures, several married couples agreed to gradually reduce their total sleep times to 4.5 to 5.5 hours per night. It was found that, even after 6 to 8 months of restricted sleep, performance on several tests (including Williams Word Memory, Digit Span, Wilkinson Auditory Vigilance, and Wilkinson Addition), as well as body temperature rhythms, were unaffected (i.e., remained comparable to measurements taken at baseline). However, subjective ratings of sleepiness were increased, and average sleep-onset latencies were reduced by sleep restriction. In this study, EEG data were collected at the subjects' homes using modified FM recorders 3 nights per week. These recordings revealed that the restricted sleep contained less Stage 2 and REM, and increased (in terms of both percentage and absolute amounts) Stage 4 (deep) sleep. Extremely short REM latencies (less than 10 minutes) were occasionally found during sleep periods shorter than 6.5 hours.

Studies in which sleep times were more rigorously controlled and monitored showed little evidence of adaptation to restricted sleep schedules, but these studies were typically conducted over fewer days. Carskadon and Dement (1981) studied the sleep of 10 young adults over 12 consecutive nights—3 baseline nights, 7 nights in which sleep was restricted to 5 hours, and 3 recovery sleep nights. They found that Multiple Sleep Latency Test scores decreased steadily across the 7 sleep-restricted nights and returned to baseline following the first night of recovery sleep. Subjective sleepiness, as measured with the Stanford Sleepiness Scale (SSS) stabilized after the fourth night of sleep restriction. Restricted sleep contained reduced absolute amounts of Stages 2 and REM, but absolute amounts of Stages 3 and 4 were not significantly affected.

The relationship between sleep restriction and Stage 3-4 (deep) sleep rebound was examined by Dement and Greenberg (1966), who studied four subjects on two sleep restriction schedules using a crossover design. On one schedule, the subjects slept in the laboratory for 7 consecutive nights—3 baseline, 3 nights of sleep reduced by 2½ to 3 hours, and 1 recovery sleep night. On the other schedule, subjects slept in the laboratory for 13 consecutive nights—6

baseline, 6 restricted sleep, and 1 recovery sleep night. Although Stage 3 and 4 sleep amounts were maintained at baseline levels during the sleep restriction nights, a Stage 4 rebound effect (i.e., significantly increased Stage 4 sleep relative to baseline), was evident on the recovery sleep nights. This suggests that: (a) increased pressure to sleep resulted from the sleep-restriction-mediated reductions in Stage 2 and REM sleep amounts; and (b) Stage 4 sleep may therefore have relatively greater minute-by-minute recuperative value than Stage 2 and REM, since no rebound effect was evident for these stages, despite the fact that they were the only stages reduced by the sleep restriction procedure. Similar results were subsequently reported by Webb and Agnew (1975).

More recently, Dinges et al. (1999) conducted a study in which TIB was restricted to either 4, 6, or 8 hours for 14 consecutive days and nights in the laboratory, in 35 normal adult subjects. Preliminary analyses indicated that daytime performance (measured at 2-hour intervals) declined across the 14 sleep restriction days in a dose-dependent manner [i.e., in the 6- and 4-hour TIB conditions, relative to the 8-hour TIB (control) condition]. Performance measures that were affected included: frequency of lapses of the Psychomotor Vigilance Task (PVT); duration of lapses on the PVT; number of correct responses on the Digit Symbol Substitution Test (DSST); and throughput on the Walter Reed Serial Add/Subtract Test. Dinges et al. indicated that on Day 13 of sleep restriction, performance in the 4-hour TIB group was essentially equivalent to that seen in a comparable group of subjects after 2 days of total sleep deprivation. In the 5-hour TIB group, performance at Day 5 of sleep restriction was at the level seen following 1 day of total sleep deprivation. Also, "uncontrolled sleep attacks" occurred in 23 percent of the 6-hour TIB group, and 46 percent of the 4-hour TIB group after the sixth day of sleep restriction (versus no uncontrolled sleep attacks in the 8-hour TIB group). Despite these clear and robust effects on performance and alertness, most subjective measures of mood and alertness showed no TIB group differences, including the Stanford Sleepiness Scale (SSS), the Karolinska Sleepiness Scale (KSS), the Profile of Mood States (POMS), and the Visual Analog Scale (VAS). This suggests that self-assessment abilities themselves may be impacted by sleep restriction.

Preliminary sleep data from that study—consisting of conventional sleep stage scoring and spectrally analyzed EEG data for 10 subjects from the 4-hour TIB group and five subjects from the 8-hour TIB (control) group—were presented by Von Dongen et al. (1999). Not

surprisingly, TST in the 4-hour TIB group increased across the sleep restriction period, from a mean of 3.4 hours of sleep to a mean of 3.9 hours of sleep. (That is, by the end of the sleep restriction period, the efficiency with which subjects utilized their nightly 4-hour opportunity for sleep had increased). It was expected that the sleep architecture of the 4-hour TIB group would be characterized primarily by increasing absolute amounts and percentages of Stage 3-4 sleep during the sleep restriction phase—which would be consistent with findings from studies of naturally short sleepers (reviewed earlier), as well as findings from the recovery nights following total sleep deprivation (e.g., Berger and Oswald, 1962). However, Von Dongen et al. reported that the "dominant feature" of restricted sleep architecture in this study was increased Stage REM sleep—a finding that they surmised may be a time-of-night effect (sleep was allowed from 0330 to 0730 hours). Neither conventionally scored Stage 3-4 sleep nor slow wave energy (a spectral analysis-derived measure of slow wave activity in the EEG) were increased (versus baseline) on the first night of recovery sleep following sleep restriction. This was surprising since the behavioral data indicate a significantly increased sleep debt, and recovery sleep following total sleep deprivation typically results in increased Stage 3-4 sleep.

The Dinges et al./Von Dongen et al. (1999) results are preliminary (sleep analyses include data from only 15 of the 35 subjects, and sleep data from Recovery Nights 2 and 3 are not yet available). Nevertheless, these data suggest that recovery from extended sleep restriction might not proceed in the same manner as recovery from total sleep deprivation, with perhaps those processes that mediate habituation (and possibly some sort of adaptation or accommodation) to sleep restriction affecting the course of recovery sleep.

Implicit in the sleep deprivation literature is the presupposition that the full satisfaction of sleep debt—for example, the attainment of 1 or more nights of subjectively and objectively satisfying recovery sleep following acute sleep deprivation—restores alertness to some immutable, pre-deprivation optimum level. However, the sleep restriction literature contains at least some suggestion that an accommodative[3] response to longer-term sleep restriction may

[3] In this discussion, "accommodation" refers to an extended-sleep-restriction-induced change in the alertness level "set point"—a hypothetical construct that describes/defines the level of alertness that could be considered normal or average for an individual. Accommodation is therefore contrasted from "adaptation"—which would refer to a process (e.g., a change in sleep architecture that increases the recuperative efficiency of sleep) that directly counteracts the effects of sleep restriction. Likewise, accommodation is conceptually distinct from "habituation"—which, in this context, would refer to the process by which a sleep-restricted individual may become psychologically inured to a reduced alertness level.

occur. That is, it is possible that the homeostatic "set point" for alertness and performance may be reduced as a result of long-term exposure to a restricted sleep schedule.

For example, as reviewed earlier, Webb and Agnew (1974) found that initial increases in slow wave sleep were reversed over a 60-day sleep restriction period, along with spontaneous reports of excessive sleepiness, while performance on a vigilance task remained decremented and Stage REM sleep amounts remained low. Similarly, Von Dongen et al. (1999) reported that 14 days of sleep restricted to 4 hours resulted in no increases in the percentage of SWS during the restricted sleep periods and no SWS rebound on the first night of recovery sleep (data from subsequent recovery sleep nights are not yet available)—although, as reported by Dinges et al. (1999), performance declined across this 14-day sleep restriction period, and there was some evidence of at least subjective habituation (though no true adaptation) to the reduced alertness levels that resulted from the sleep restriction. These results conflict with those of Friedmann et al. (1977) and Mullaney et al. (1977), who found consistently increased SWS along with subjectively reduced daytime alertness across 6 to 8 months of sleep restriction although they found performance on a variety of tasks to be unaffected by sleep restriction.

Clearly, findings from previous sleep restriction studies are inconsistent and sometimes contradictory—potentially due to differences in sleep restriction levels, the durations of studies, the subject populations sampled, and the dependent measures used in the various studies. Additionally, the extent to which sleep duration was actually controlled and monitored varies from study to study. Therefore, the extent to which findings from these previous studies should be considered valid and reliable is proportional to the extent of the experimental control over daily sleep duration that was exercised in each.

COMPARISON OF THE EFFECTS OF SLEEP PATHOLOGIES AND SLEEP RESTRICTION ON PERFORMANCE

Bonnet has conducted a series of studies (e.g., 1985, 1987, 1989) suggesting that the recuperative value of sleep depends upon both the duration and continuity of that sleep. However, in their review and reanalysis, Wesensten et al. (1999) argue that reductions in total recuperative sleep time invariably accompany sleep disruption, and that it is the duration of total recuperative sleep—not the continuity of the sleep per se—that most likely determines its

recuperative value. If Wesensten et al. (1999) are correct, then certain sleep pathologies such as obstructive sleep apnea (OSA) and Periodic Limb Movements During Sleep (PLMs) can provide insight into the consequences of extended sleep reduction.

Feuerstein et al. (1997) found that several frontal-lobe mediated cognitive abilities were impaired in sleep apnea patients, who—compared with matched normal controls—made more perseverative errors (i.e., performance deficits resulting from failure to appropriately initiate new cognitive strategies when problem solving); showed deficits in both verbal and visual learning; and had relatively reduced memory spans. Following four to six months of CPAP (continuous positive airway pressure) treatment of sleep apnea, most cognitive performance deficits were reversed. However, short-term memory deficits were not improved by the CPAP treatment—suggesting the possibility that some aspects of neurocognitive deficits that result from sleep apnea result from the impact of the disorder on the patient's sleep, while other deficits may be the result of the hypoxemia that results from the disorder (for a discussion, see Roth, Roehrs, and Rosenthal, 1995).

SUMMARY—FINDINGS FROM SLEEP RESTRICTION STUDIES

Based on previous studies, it is clear that sleep restriction results in reduced performance on a variety of measures. It is also clear that sleep architecture changes in response to sleep restriction, although the specific sleep stages affected are not always consistent across studies, and the implications of these changes for possible adaptation, habituation, or some other accommodation to sleep restriction are unknown. Missing from previous sleep restriction studies—and what the present study accomplishes—is the quantification of the relationship between multiple levels of sleep restriction and subsequent performance over several consecutive days of restricted sleep.

D. POSSIBLE DIFFERENCES IN THE RECUPERATIVE VALUE OF THE VARIOUS SLEEP STAGES

THE HETEROGENEOUS NATURE OF SLEEP

Although sleep can be characterized behaviorally as a homogeneous state of quiescence and reduced responsivity to sensory stimuli, it is physiologically dynamic with intermittent/phasic changes in brain (as well as endocrine, peripheral nervous system, and perhaps immune system) activity. The notion that sleep may be comprised of physiologically distinct stages was initially proposed by Loomis et al. (1937), who noted that behavioral responsivity during sleep varied as a function of EEG characteristics such as signal amplitude and frequency. After the discovery of REM sleep by Aserinsky and Kleitman (1953), it was generally recognized that sleep was essentially comprised of two physiologically distinct states of consciousness—REM and non-rapid-eye-movement (NREM) sleep. In fact, based on their review of the physiology of sleep, Snyder and Scott (1972) suggested that REM sleep is as different from NREM sleep as sleep itself is from wakefulness.

SLEEP STAGES

In the sleep scoring system currently accepted as the standard (Rechtschaffen & Kales, 1968), sleep is divided into five stages—Stages 1 to 4 and REM. Stage 1 is characterized by low-amplitude, mixed-frequency EEG activity and is considered a transitional state between wakefulness and the deeper (and more recuperative) NREM Sleep Stages 2, 3, and 4 (Johnson, 1973). Stage 2 is characterized by the appearance in the EEG of sleep spindles (12- to 14-hertz "sigma" activity occurring in 0.5 to 2.0-s "bursts") and K-complexes (a sharp negative excursion followed by a slower positive excursion—and often quickly followed by a sleep spindle). High-amplitude delta or "slow" waves (slower than 2 hertz with a peak-to-peak amplitude of at least 75 microvolts) can emerge during Stage 2 sleep. When delta waves comprise 20 to 49 percent of an epoch (epochs are typically 30 s long in human sleep studies, as in the present study), then that epoch is scored as Stage 3 sleep. Epochs comprised of 50 percent or more delta wave activity are scored as Stage 4. Stage REM sleep is characterized by a low-amplitude, mixed-

frequency EEG (similar to that seen during Stage 1), reduced muscle tonus (relative to the other sleep stages, as well as to wakefulness), and intermittent rapid eye movements (or REMs). REM is the sleep stage during which most dreaming occurs.

Sleep-Stage-Related Differences in Recuperation: Experimental Evidence

This section contains a critical review of studies conducted for the express purpose of determining differences in the recuperative value of the various sleep stages. Studies concerned solely with the effects of selective deprivation of REM sleep are excluded (for reviews of this literature, see Dement, 1972; Greenberg and Pearlman, 1974; and Vogel, 1968). In general, these studies show that REM deprivation does not result in large increases in sleepiness (Dement, 1964; 1965a; 1965b). In fact, REM deprivation may actually cause "heightened arousal," especially in nonhumans (Vogel, 1968; Webb 1969). Selective deprivation of REM sleep has been found to be so innocuous that Dement (1972) has suggested that the main purpose of REM sleep may be to maintain sleep while NREM (SWS) mechanisms "rest." Though this view is difficult to reconcile with phenomena such as "REM rebound" following deprivation, it reflects the lack of impressive findings from REM deprivation studies.

In one of the earliest studies in which sleep stage functions were compared, Agnew et al. (1967) deprived six subjects of Stage 4 sleep for 7 nights while six other subjects were deprived of REM sleep. Tests during the day included grip strength, pursuit rotor ability, experimenter-paced addition, MMPI, Pensacola 2 scale, Taylor Manifest Anxiety scale, and Cattell's 16 PF test. Of these tests, only addition has been shown to be sensitive to sleep loss (e.g., see Hord et al.,1976; Lubin et al., 1974; and Webb & Levy, 1982). However, grip strength has been shown to be sensitive to "sleep inertia" effects (Jeanneret and Webb, 1963). (For a description of "sleep inertia" effects, see Lubin et al., 1974.)

Neither deprivation procedure resulted in significant deficits on any performance test. However, data from the personality tests given the following day indicated that REM deprivation caused subjects to become "less well integrated and less interpersonally effective," while Stage 4 deprivation appeared to make the subjects "withdrawn, less aggressive, and physically uncomfortable." Though no measures of sleepiness were taken per se, it was reported that sleepiness was the chief complaint for both groups. During the deprivation procedures, the

nocturnal sleep structure was differentially affected. Stage 4 deprivation resulted in a sharp increase in the amount of Stage 2 sleep, while REM deprivation resulted in a small decrease in amount of Stage 2 and a sharp increase in the amount of Stage 1 sleep. Total sleep times were not reported, but it was indicated that the percentage of "awake time" was only slightly elevated in each group. Also, the number of stimulus presentations (200 ms, 5 to 15 microamperes electric shock) required to prevent SWS was four times as great as the number required to prevent REM.

On the basis of the intensity of stimulation required to prevent SWS, Agnew et.al. (1967) suggested that Stage 4 sleep may be the most critical stage. However, any conclusions regarding the relationship between sleep stage and recuperative value are mitigated by the fact that sleep was more severely disrupted (four times as many arousals) in the group deprived of Stage 4 sleep. Furthermore, because the sleep stages are differentially distributed throughout the sleep period, it is possible that the psychological effects found by Agnew et al. (1967) were a function of "time of night" of awakenings rather than deprivation of SWS versus REM. These findings might also have been due to the differential effects that the deprivation procedures had on Stage 2 amounts.

Ideally, when comparing SWS and REM, sleep periods containing only REM should be compared to periods containing only SWS. However, since REM sleep usually appears only after 90 minutes of NREM sleep, it is very difficult to obtain sleep periods that isolate REM sleep in normals. It is therefore difficult to design studies that convincingly attribute specific recovery functions to REM versus NREM sleep. Billiard (1976) took advantage of the fact that narcoleptics often enter REM sleep only minutes after sleep onset, allowing comparison of the recuperative value of naps containing mostly REM to those containing mostly NREM sleep.

In Billiard's (1976) study, performance measures and subjective rating scales were used to determine whether REM or NREM sleep had greater recuperative value in narcoleptics. For 2 days, narcoleptic subjects were allowed to sleep according to one of two schedules. One group (n=8) was allowed ad libitum sleep on Day 1. After each spontaneous awakening, an addition test and a seven-point rating scale on the recuperative value of the nap were administered. On Day 2 these subjects were again allowed to sleep ad libitum but were awakened and tested 10 minutes after sleep onset. Subjects in Group 2 were required to maintain wakefulness from 0700 hours to 2230 hours on Day 1. On Day 2 they were placed on a fixed schedule consisting of five

test sessions spaced throughout the day (0900 to 1945 hours). Each session consisted of 30 minutes of testing (addition, serial alternation tests), followed by a 15-minute nap, then an additional 30 minutes of testing. Stanford Sleepiness Scales and mood scales were administered every 15 minutes throughout the day, except during the 30-minute test sessions. Five normal (non-narcoleptic) subjects served as a control group and followed the same schedule as Group 2.

For Group 1, the recuperative value of the naps was rated significantly lower on Day 2 than on Day 1. This finding may be related to the fact that the mean duration of naps on Day 2 was reduced to 10 minutes from a mean duration of 67 minutes, 18 seconds on Day 1. No other differences were significant for this group, including ratings of REM versus NREM naps. It was reported, however, that narcoleptic subjects fell asleep most often during testing when the preceding nap consisted of mostly REM sleep. When considered in conjunction with the findings of Mitler et al. (1982)—who reported that the likelihood of obtaining REM-onset naps in narcoleptics is reduced when instructions on the MSLT are changed to "try to stay awake"—it appears that REM sleep may not be as efficient as NREM sleep for the reversal or prevention of sleepiness.

For Group 2, improvement on the serial alternation task followed NREM sleep. No other differences were statistically significant. However, all nonsignificant trends were in the same direction, indicating that NREM sleep may have more recuperative value than REM sleep. All control subjects performed "at peak" at all times, suggesting that subjects in this group were not sleepy at any time during the testing. Though it is tempting to conclude from this study that NREM sleep has more recuperative value than REM sleep, there are problems with generalizing findings from narcoleptic subjects to normal populations. Narcoleptics suffer from an intractable sleep disorder, which may involve some REM dysfunction (e.g., see Broughton and Mamelak, 1976).

One of the best-designed studies investigating possible stage-related performance deficits was conducted by Lubin et al. (1974). They were interested in assessing the recovery function of REM versus Stage 4 sleep on various performance measures after total sleep deprivation. Twelve subjects spent 10 consecutive nights in the laboratory. The first 4 were baseline nights, followed by 2 nights of total sleep deprivation, 2 nights of "partial recovery," then 2 nights of full recovery sleep. For four subjects, sleep was interrupted whenever signs of SWS appeared during the "partial recovery" nights. This was done in an effort to eliminate or reduce the

amount of SWS obtained. Four other subjects had REM sleep disrupted in a similar manner, while the remaining subjects obtained uninterrupted sleep during this phase of the experiment. Several measures were obtained from each subject at approximately the same time each day. These included the Williams Word Memory Test, the Wilkinson Addition Test, the Plus Seven Test, the X-Crossout Test, a counting test, and an auditory vigilance test. A mood scale was also administered, and a sleepiness test was constructed from those items in the mood test judged by the authors to be positively correlated with sleepiness.

Slow wave sleep percentages were reduced from 14 percent during baseline to 1 to 2 percent during partial recovery (for the SWS-deprived group). However, to keep subjects from immediately returning to SWS following an arousal, Lubin et al. found that it was necessary to maintain wakefulness for 30 to 60 s. Because of the relative difficulty in distinguishing REM sleep from wakefulness or Stage 1, the REM deprivation procedure was less successful, resulting in a reduction from baseline levels of 26 percent to 5 percent during the partial recovery phase (in the REM-deprived group).

It was found that all groups showed decrements in performance following sleep loss, but none of the groups differed from one another with respect to rate of recovery during the partial-recovery phase. Lubin et al. (1974) concluded that recovery sleep containing reduced-percent REM, reduced-percent SWS, or the uninterrupted mixture of the sleep stages are all equally effective in reversing performance deficits.

Similar conclusions were derived in a second study by Johnson et al. (1974). They deprived seven subjects of Stage REM sleep and seven subjects of Stage 4 sleep for 3 consecutive nights, followed by 1 night of total sleep deprivation. It was hypothesized that one type of stage deprivation would potentiate the effects of total sleep loss to a greater extent than the other. However, it was found that neither type of deprivation differentially exacerbated the effects of subsequent total sleep deprivation on a wide range of tasks. In fact, a comparison of the performance of these subjects to those in the Lubin et al. (1974) study revealed that, following 1 night of total sleep loss, stage-specific deprivation resulted in significantly less decrement (and actually improved performance in some cases) on the addition and word memory tests. Considering both the Lubin et al. (1974) and Johnson et al. (1974) studies together, it was concluded that amount of sleep time, and not amount of a particular sleep stage, is the critical factor in determining deficits in performance.

However, there are alternative explanations for their failure to find sleep stage-related differences. It is likely that Stage 2 sleep is effective in reversing sleep-deprivation-induced performance decrements, though it may not be as efficient as some other stages (e.g., SWS). Since approximately 50 percent of the total sleep time during recovery was comprised of Stage 2 sleep for all groups, any subtle differences due to reductions in REM versus SWS may have been obscured. Another explanation may be that the stage-deprivation procedures were only partially successful; targeted sleep stages were reduced but not eliminated. REM deprivation was particularly difficult because there were problems with quickly identifying it as it occurred. Therefore, if REM or SWS is important for the reversal of deprivation-induced performance decrements, it is possible that a significant portion of this recuperative effect is realized with relatively brief exposures to the critical stage. Related to this possibility are the findings of Haslam (1982), who sleep-deprived her subjects for 90 hours, causing substantial decrements in performance on several tasks. At the end of the 90 hours, subjects were allowed 4-hour daily naps as the sole sleep for the next several days. These naps were found to be effective in reversing the performance decrements, since performance levels were restored to near-baseline values (at least for the afternoon testing session). It should be noted that these naps contained high percentages of SWS.

From this brief review, it is apparent that more experimental work is needed to establish whether the various sleep stages differentially reverse sleepiness. Non-experimental indications that SWS may be integral to the recovery function are suggestive, but the only experiment to date that tends to confirm this notion was performed on narcoleptics (Billiard, 1976), and the conclusions from this study therefore suffer from restricted generalizability. Most experiments with normals (i.e., those of Lubin et al., 1974; and Johnson et al., 1974) have failed to uncover differential stage-related recovery functions. An exception was the study by Carskadon and Dement (1977) in which subjects were kept on a 30-minute sleep/60-minute awake schedule for several days. However, in that study, it was found that naps containing SWS actually exacerbated sleepiness (as measured on the Stanford Sleepiness Scale)—a finding perhaps attributable to "sleep inertia."

Questions regarding the extent to which sleep stages are differentially recuperative are obviously important when attempting to quantify the relationship between sleep and subsequent performance. However, as the preceding brief review illustrates, previous experiments have

failed to discern stage-dependent differences in the rate at which recuperation accrues during sleep. This does not mean that sleep-stage-related differences do not exist. Rather, it is apparent from the review that the lack of experimental control over sleep stages has precluded definitive comparisons (i.e., studies have generally failed to compare sleep periods that are equivalent in all potentially relevant respects except for the sleep stages of interest).

In fact, there are very good reasons (albeit non-experimental) to hypothesize that SWS has greater recuperative value than the other sleep stages. First, it is known that Stage 3-4 (SWS) sleep tends to predominate during the first half of the night, whereas Stage REM occupies more of the latter half of the night—an order that suggests that SWS may be the relatively more important stage of sleep. Furthermore, the finding that even relatively brief sleep periods (e.g., a 4-hour daily nap following 90 hours of continuous wakefulness) can restore performance to near-normal (pre-sleep deprivation) levels on some tasks (e.g., Haslam, 1982) suggests that the recuperative benefits of sleep are, to a significant extent, "front-loaded"—in much the same way that SWS is itself front-loaded within a typical sleep period. Finally, recovery sleep (i.e., sleep following significant sleep loss) is typically characterized by increased (or "rebound") SWS—both in terms of the percentage and the absolute amounts of SWS obtained. Since normal performance levels are restored following recovery sleep periods that include much less sleep time than the amount that was actually "lost," the implication is that is that SWS is likely to be the most "restoratively efficient" sleep.

Sleep Fragmentation

The recuperative value of sleep for maintaining alertness and performance is determined by its duration. Sleep duration, in turn, is determined by actual total sleep time and by the continuity (or alternatively, fragmentation) of sleep. The amount of time scheduled for sleep (time spent in bed) is a weak predictor of sleep duration. Sleep fragmentation consists of either naturally occurring or stimulus-induced interruptions of an ongoing sleep stage such that a lighter stage ensues. These interruptions, or arousals, are defined as an increase in EEG frequency with or without a concomitant increase in muscle tone, heart rate, respiration, etc. (American Sleep Disorders Association, 1992). Neither a full awakening nor a complete stage shift is required for indication of an arousal.

In a recent review of several studies of experimental sleep fragmentation (usually induced by presentation of auditory stimuli during sleep) it was found that the most consistent effect of fragmentation on sleep is to increase amounts of Stage 1 sleep (the stage of sleep intermediate between relaxed wakefulness and Stage 2 sleep) (Wesensten et al., 1999). For example, Bonnet (1985) found that reaction time, addition, and Digit Symbol Substitution were impaired following nights of fragmented sleep. In the Bonnet (1985) study, it appeared that TST did not differ from baseline to fragmentation Nights 1 and 2. However, Bonnet's (1985) reported TST included Stage 1. When Stage 1 amounts were subtracted from total sleep time (TST minus Stage 1 or "TST-stg1"), it could be seen that the fragmentation procedure reduced TST-stg1 considerably.

Likewise, higher rates of sleep fragmentation destroy the recuperative value of sleep more so than lower rates. As would be expected, Stage 1 is increased to a greater extent with higher fragmentation rates (Levine et al., 1987). Magee et al. (1987) also found greater reductions in TST-stg1 and greater increases in Stage 1 when sleep was fragmented at higher rates. Next-day latencies to sleep were decreased accordingly. These results indicate a good correspondence between TST-stg1 and next-day sleepiness (Wesensten et al., 1999). Such studies indicate that Stage 1 has little or no recuperative value in terms of sustaining alertness or performance. In fact, Bonnet (1986a) showed that subjects who accumulated only Stage 1 performed no better than subjects who were totally sleep deprived, and next-day sleep latencies were comparably reduced in both groups. It is notable that, in those previous studies in which Stage 1 was included in TST calculations, no correlation was found between TST and next-day sleepiness (sleep latency) and/or performance (e.g., Bonnet, 1986b). However, significant, positive correlations have been found between Stage 1 amounts and next-day sleepiness (e.g., Magee et al., 1987). These findings are also consistent with the hypothesis that Stage 1 has little or no recuperative value and imply that TST-stg1 is a better predictor of performance and next-day alertness than TST (which typically includes Stage 1 amounts).

The reviewed studies further suggest that fragmentation rates faster than approximately 1 every 4 minutes of sleep are required to substantially increase amounts of Stage 1 (Magee et al., 1987) and thus reduce TST to the point where recuperation is also reduced. However, the relationship between fragmentation rate and decreased TST-stg1 is not invariant. This relationship changes both within a night of fragmentation and across multiple fragmentation

nights. Within and across nights, faster rates of fragmentation (and/or louder disrupting stimuli) are required to achieve the same level of sleep disruption (Badia et al., 1985; Balkin et al., 1985). These effects are presumably due to mounting sleep deprivation. Accumulating sleep deprivation, in turn, results in higher arousal thresholds, even within the same EEG-defined stage of sleep.

Thus, sleep fragmentation procedures that increase the amount of Stage 1 and/or wakefulness cause next-day sleepiness and performance impairments. Fragmentation procedures that do not increase Stage 1 do not impair next-day performance and/or alertness. These findings indicate that Stage 1 "sleep" has relatively little or no recuperative value in terms of maintaining alertness and performance. These findings also suggest that Stage 1 sleep amounts should be subtracted from total sleep time to more accurately reflect recuperative sleep time.

E. IMPLICATIONS FOR DEVELOPMENT OF A SLEEP/PERFORMANCE MODEL

Although the accuracy of a model describing the relationship between sleep and subsequent performance could be enhanced if the relative recuperative powers of the various sleep stages were known and quantified, the current state of uncertainty with respect to this issue does not preclude construction of such a model. The same properties of sleep that prevent a definitive SWS versus REM study (i.e., the predictable and characteristic effects that varying durations of continuous wakefulness have on subsequent SWS amounts; and the relatively invariant timing of the various sleep stages within sleep periods), may obviate the need to specify the relative recuperative values of the various sleep stages. For example, if *X* hours of continuous wakefulness followed by a sleep period of *Y* hours reliably results in restoration of performance capacity to Level *Z* during subsequent wakefulness, the extent to which this outcome was due to an underlying, predictable, and characteristic sleep architecture would be of little consequence. On the other hand, if the nature of sleep was such that the timing and duration of the various sleep stages within a sleep period were random, then specification of the recuperative values of those stages could be critical for a modeling effort.

Therefore, the importance of determining the relative recuperative value of the various sleep stages is not deemed critical to the modeling effort at this time. Nevertheless, it is possible

that there are significant sleep-stage-specific differences in recuperative value, and specification of these differences at some point might improve the model's accuracy—especially for explaining potential differences in the sleep-mediated restoration of performance capacities in two individuals who obtain equivalent amounts of total sleep time.

It is important to note that input to the Walter Reed Sleep/Performance Model (SPM, see Chapter 3) currently consists only of actigraphically determined sleep/wake scores—from which TST is determined and used (along with circadian rhythm information) to predict subsequent performance capacity. The decision to model the relationship between total sleep time and performance capacity therefore was based on a combination of theoretical and practical considerations, including: (a) the fact that TST is known to impact subsequent performance capacity, although the relationship has not previously been quantified (as reviewed earlier); (b) wrist actigraphy is a minimally invasive and valid means of determining TST in the operational environment, but sleep stage information cannot currently be derived from actigraphic data; and (c) the extent to which sleep stages are differentially recuperative (if, in fact, they are at all differentially recuperative) is unknown (as reviewed earlier). The laboratory portion of this project (described in detail in Chapter 2) was undertaken because, as discussed, relatively little is known about the effects of chronic sleep restriction on performance during intervening periods of wakefulness—information that is critical for modeling the effects of sleep on performance in a realistic military or commercial operational environment.

2. THE SLEEP DOSE/RESPONSE STUDY

A. BACKGROUND

SUMMARY—HISTORICAL BACKGROUND AND CURRENT STATE OF KNOWLEDGE

Over a 30-year period from the 1950s to the 1990s, self-reported daily total sleep obtained by adults aged 50 to 65 declined by 1 hour to about 7.1 hours per night (Bliwise et al., 1992) and recent studies suggest that the average amount of daily sleep obtained by adults in modern society is inadequate for maintenance of optimal alertness during waking hours (for review and discussion, see Bonnet and Arand, 1995). For long-haul truck drivers operating just within the current hours-of-service regulations, polysomnographically determined daily sleep time has been shown to average only 3.83 to 5.18 hours, depending on whether a 10- or 13-hour shift was worked and whether the shift involved nighttime driving (Mitler et al., 1997). Although there is some debate about the extent to which current sleep habits impact average daytime alertness levels and performance [Harrison and Horne (1995) suggest that the recuperative value of sleep is vanishingly modest as sleep duration is extended beyond 7.5 hours], it is generally agreed that widespread sleepiness constitutes a significant threat to general safety and an enormous encumbrance on the economy due to reduced work efficiency and increased accident rates. The National Commission on Sleep Disorders Research estimated that the cost to the economy of sleepiness-related accidents in 1988 was between $43 and $59 billion dollars (Leger, 1994)[1]. Likewise, the potential threat to public safety posed by sleepiness is clear in the conclusions of the consensus report by the Association of Professional Sleep Societies Committee on Catastrophes, Sleep, and Public Policy (Mitler et al., 1988). It was suggested that sleepiness probably played a significant role in several well-publicized disasters and near-disasters including the incidents at the Three Mile Island nuclear power plant in Pennsylvania in 1979; the Davis-Besse reactor at Oak Harbor, Ohio, in 1985; the Rancho Seco nuclear reactor in

[1] Although these figures have been disputed [Webb (1995) suggests that the National Commission on Sleep Disorders Research estimate might be inflated by a factor of as much as 50], there is general agreement that sleepiness constitutes a widespread and addressable problem.

California in 1985; the explosion of the NASA space shuttle "Challenger" in 1986; and possibly the meltdown at the nuclear power plant in Chernobyl in 1986.

SLEEPINESS AND DRIVING

The effect of sleepiness on performance is a concern in both military and commercial operational environments. Of particular interest is the impact of sleepiness on driving performance, since the trend toward 24-hours-per-day operations in all sectors continues to grow [a report by the U.S. Congress Office of Technology Assessment (1991) indicates that 20 percent of the workforce engages in shift work]. This results in ever-increasing numbers of drivers (both commercial drivers and commuters) on the roads during the circadian nadirs for performance and alertness and after having obtained less than normal amounts of daily sleep [shift workers average less-than-normal daily total sleep time—e.g., Frese and Harwich, 1984; Tepas and Carvalhais, 1990].

Like its impact on the economy at large, the extent to which actual driving accidents can be attributed to sleepiness is a matter of debate. Sleepiness has been estimated to account for as few as 1 to 3 percent of total accidents (Knipling and Wang, 1994—cited in U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-MC-97-002, 1996; and Lyznicki et al., 1998) to as many as 16 percent of total accidents (Horne and Reyner, 1995a). Also, driving accidents attributable to sleepiness may be more severe, accounting for as much as 31 percent of fatal-to-the-driver accidents involving commercial drivers (NTSB Safety Study Report No. SS90/01, cited in Philip et al., 1996). A recent update by Knipling ("Crash Problem Size Assessment Update" from the FHWA OMCHS—January, 1999) lists estimated ranges for percentages of large-truck crashes that are fatigue-related. Knipling estimated that 0.24 to 0.53 percent of 165,000 single-unit truck and 0.69 to 1.5 percent of 392,000 combination-unit truck crashes were fatigue related. To some extent, discrepancies between estimates may be due to differences in the criteria used to determine whether accidents were the result of sleepiness—e.g., whether mere suspicion versus actual evidence of frank sleep onset was required, or whether the possibility that sleepiness-related inattention, lane-drift, etc., without frank sleep onset were included in the tally (Webb, 1995; Thomas et al., 1995). Direct, objective evidence of the causal relationship between sleepiness and accidents is often lacking. In nonfatal crashes, evidence of

sleepiness consists almost solely of driver verbal reports (e.g., "I nodded off for a second"), whereas, in fatal crashes, only indirect evidence might be available (Pack et al., 1995). To a significant extent, attribution of sleepiness as the cause of vehicle crashes entails deductively ruling out other, more obvious causes.

Horne and Reyner (1995a) noted time-of-day effects similar to those cited by Dinges (1995)—e.g., early-morning and late-afternoon peaks in accidents, even after data were corrected for hourly variations in traffic density. Likewise, as reported by Dinges (1995), the temporal pattern of police-reported drowsy-driver accidents in both the United States and Europe is similar to that of industrial accidents, with elevations during the mid-afternoon and early-morning hours. Horne and Reyner (1995b) cited data indicating similar time-of-day effects in other countries.

If their numbers are correct, then even the 1 to 3 percent cited by Knipling and Wang (1994—discussed earlier) would translate to 100,000 to 300,000 sleepiness-related crashes per year. If even a small fraction of these involve sleepy CMV operators working in accordance with current FMCSA regulations, this suggests that the regulations may not be adequate to ensure alertness and nominally safe performance in a significant proportion of drivers. Since the current rules regulate off-duty time, the critical issue is whether off-duty time is sufficient to allow adequate sleep.

ASPECTS OF DRIVING PERFORMANCE THAT ARE SENSITIVE TO SLEEPINESS

Although the precise percentage of actual driving accidents caused directly or proximately by sleepiness cannot be known, the effects of sleepiness on psychomotor performance measures relevant to (or approximating) driving performance is well established. For example, among the driving-related dependent variables shown to be sensitive to sleepiness (induced by full or partial sleep loss, circadian factors, or a combination of these factors) are: standard deviation of lane position in driving simulators [e.g., Gillberg, Kecklund, and Ackerstedt (1996)]; lane deviations and steering-wheel corrections during actual driving (e.g., U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-MC-97-002, 1996; Siegmund et al., 1996; King et al., 1995); driving speed (e.g., Gillberg et al., 1996) and off-road accidents in a driving simulator (Thomas et al., 1995). [For a more complete

review of driving-related performance measures sensitive to sleep loss, see U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-MC-97-002 (1996) pages 2-34 to 2-36.]

Also, it should be noted that driving can share many of the properties of a vigilance task (of the sort found by Wilkinson, 1965, to be sensitive to sleep loss) such as monotony (Lisper et al., 1971), which may unmask sleepiness (Carskadon and Dement, 1982) and therefore exacerbate performance deficits and/or increase the likelihood of frank sleep onset.

RATIONALE FOR THE SLEEP DOSE/RESPONSE STUDY

Although the causal relationship between sleepiness and impaired performance is well established, there have been no previous attempts to quantify the relationship parametrically—a necessary step toward determining, for example, how much sleep is necessary to perform subsequent daytime tasks with nominal efficiency and safety.

GOALS OF THE SLEEP DOSE/RESPONSE STUDY

1. Determine the effects of four sleep/wake schedules on alertness and performance.
2. Develop an algorithmic model to predict performance on the basis of prior sleep parameters.
3. Evaluate technologies for their ability to predict performance degradation/failures and hence their potential as devices for on-line, real-time alertness monitoring.
4. Identify any physiological measures that correlate with recuperation during sleep.

HYPOTHESES:

1. Sleep durations resulting from 9-, 7-, 5-, or 3-hour times in bed on each of 7 consecutive nights will result in corresponding, ordered differences in subsequent daytime alertness and performance.
2. Sleep restriction will degrade performance across all measures, ranging from driving simulation, through less realistic synthetic work tasks, to more abstract cognitive performance tests.

3. The sleep/recovery curve, estimated from these data, will show a rapid rise early in the night's sleep and then an asymptotic approach to full recovery as sleep duration is extended.

B. METHODS

SUBJECTS

Subjects were recruited through advertisements in various motor-carrier-industry publications and newsletters, and through postings of fliers at truck stops. Those who passed an initial telephone-screening questionnaire (see **Appendix 1**) were subsequently screened for medical and sleep history, and were given a complete physical examination including blood and urine samples, an electrocardiogram (EKG), a visual acuity test, and a color vision test. Subjects were required to be in good health without diseases, disorders, or physical conditions that would endanger themselves or others or compromise the purpose of the experiment, as determined by the conditions of the protocol and the judgment of the examining physician (see Appendix 1 for a listing of diagnostic and exclusionary criteria). Among the exclusionary criteria were pregnancy; the use of tobacco, illicit drugs, and certain medications; caffeine consumption exceeding 400 mg per day; positive antibody test to HIV or hepatitis B; and evidence of alcohol, tobacco, or caffeine in the urine at any time during the experiment.

After passing the screen, the purpose and details of the experiment were explained both orally and in writing, and all subjects signed a voluntary consent form as per Army regulations AR 70-25 and AR 40-38. Those completing the 2-week study were paid $4,000—a flat fee of $140 for wearing the actigraph for 7 days prior to the in-house portion of the study, and an additional $3,860 for the in-house portion (equivalent to an hourly wage of $10.72).

The 66 participants who completed the study consisted of 16 females ages 24–55 with a mean and median age of 43 years, and 50 males ages 24 to 62 with a mean age of 37 and median age of 35 years. The ethnic composition of the subject population was 15 African-American, one biracial (black and white), 49 Caucasian, and 1 Hispanic. All subjects held valid CMV driving licenses but differed widely in the types of trucks or buses they drove and in their years of experience. A detailed listing of these statistics is provided in **Appendix 2**.

PROCEDURE

Subjects arrived at the Division of Neuropsychiatry (Silver Spring, Maryland) by 1000 hours Saturday. They were separated into groups of two to four, and were provided with a detailed description of all study procedures and rules.

Training Phase

Following the description of study procedures and rules, electrodes for polysomnography (described later) were applied. Subjects were then equipped with an Oxford Medilog 9200 ambulatory recorder (described later) and a wrist-worn activity monitor (described later), which they wore for the duration of the study. They then began training on the various performance tasks (described later). At 1800 hours, they were transported from the Division of Neuropsychiatry to the Johns Hopkins Bayview General Clinical Research Center (GCRC), where they spent the next 14 days. Once at GCRC, training on the performance tasks continued. Throughout the study, meals were served at approximately 0830, 1230, and 1730 hours, with snacks and beverages freely available. Subjects were not allowed to smoke or use nicotine or caffeine products throughout the study. Compliance was determined by periodic urine drug screens (the timing of which the subjects were unaware). Use of other drugs (e.g., acetaminophen for headache) was allowed at the discretion of the attending physician.

At 2300 hours on Saturday, subjects were allowed to sleep undisturbed until 0700 hours Sunday (8 hours in bed for all sleep groups). Due to a limitation of only two sleep chambers, two subjects of the same gender were assigned to each bedroom. Each subject slept in his/her own hospital-style bed. At 0700 hours Sunday, subjects were awakened and practiced performance tests. They retired at 2300 hours Sunday and awakened at 0700 hours Monday, at which time training continued.

Baseline/Experimental Phase

Baseline sleep (1 night) was obtained from 2300 hours Monday until 0700 hours Tuesday. Baseline day testing commenced on Tuesday morning, as per the schedule outlined in **Table 2-1**.

Table 2-1. Daily schedule of testing.

Test and (Duration)	Sleep Groups								
	All						7, 5, 3 *	5, 3 *	3 *
Vitals (5')	0705	1030	1330	1630	1930	2130	2220	0050	0250
FIT (5')	0730	1030	1330	1630	1930	2130	2220	0050	0250
STISIM (45')	0740	1040	1340		1940		2230	0100	0300
PAB (15')		0900	1200	1500		2100			
SYN (15')		0915	1215	1515		2115			
PVT (10')		0930	1230	1530		2130			
SLT (20'max)†		0940/ 1005		1540/ 1605			2140/ 2220		
PAB 2 (10')†		1005/ 0950		1605/ 1550					
ORG (30'max)				1645					
PAB 3 (10')								0000	0200
PVT (10')								0010	0210
Meals	0830		1240		1730		2315		
Shower					1800				

† *Slash indicates alternation of Subject Pair 1 and Pair 2* * *Experimental Days Only*

NOCTURNAL SLEEP TIME:
9-h group: 2200 – 0700
7-h group: 0000 - 0700
5-h group: 0200 – 0700
3-h group: 0400 – 0700

ABBREVIATIONS:
FIT = **F**itness **I**mpairment **T**est
STISIM = **S**ystems **T**echnologies **I**nc. **SIM**ulator
PAB = **P**erformance **A**ssessment **B**attery
SYN = **SYN**thetic Work Task
PVT = **P**sychomotor **V**igilance **T**ask
ORG = **Org**anizational Task

On Tuesday evening, subjects began following one of the four nocturnal sleep schedules (9, 7, 5, or 3 hours in bed per night), to which they adhered across the next 7 nights (Tuesday night until the following Monday night—a total of 7 nights). Daytime testing occurred according to the schedule outlined in **Table 2-1**. The last experimental day was Tuesday.

Recovery Phase

The last experimental day of testing (Tuesday) was followed by 3 nights of recovery sleep (Tuesday, Wednesday, and Thursday nights), during which all subjects were allowed 8

hours in bed (2300 to 0700 hours). Testing occurred on the days following recovery sleep (Wednesday, Thursday, and Friday). On Friday night, the subjects were allowed a final 8-hour period in bed. They were awakened Saturday morning; all electrodes and equipment were removed. They were then debriefed and released from the study.

TEST INSTRUMENTS AND MEASURES

This study employed a large number of physiological, psychophysiological, cognitive, and behavioral measures, which are listed here with brief descriptions. Additional details are given in the Results section for some measures, or in separate appendices, where appropriate.

Polysomnography

Polysomnography (PSG) served as the basis of several tests, including nocturnal sleep and objective alertness measures (sleep latency and microsleep). PSG included electroencephalography (EEG – C3 and C4), electrooculography (EOG – outer canthi of each eye), electromyography (EMG – mental/submental) and electrocardiography (EKG – just below left and right clavicle). These measures were recorded continuously throughout the study using a Medilog 9000-II magnetic cassette recorder (Oxford Instruments, Largo, Florida). EEG and EOG signals were referenced to contralateral mastoids. In addition, one pair of supra and sub-orbital electrodes was applied to measure vertical EOG (VEOG). Electrodes were applied using either collodion-soaked gauze (EEG) or surgical tape (EOG, VEOG, and EMG). All of the latter signals were recorded using tin-cup electrodes. Electrocardiogram (EKG) was recorded using button-type, stick-surface, chlorided silver electrodes. Electrode types, placement (Jasper, 1958), and application procedures followed current scientific practice. Impedance and adhesion were checked a minimum of six times per day, and electrodes were repaired or replaced as necessary.

Nocturnal Sleep

Actual versus targeted nocturnal sleep was scored from the recorded PSG data following the standard procedures of Rechtschaffen and Kales (1968). These analyses were performed on the Medilog recordings just mentioned using Oxford digitizing equipment and Eclipse software

(Stellate Systems, Westmont, Quebec) for baseline through recovery nights (B through R3). Each record was scored from lights out to lights on (total time in bed) in 30-s epochs, with each epoch assigned to one of the following stages: wake, 1, 2, slow-wave (SWS), and rapid-eye movement sleep (REM). From this information, total time spent in each sleep stage could be derived. These variables were then further converted into total sleep time (sum of Stages 1, 2, SWS, and REM). Since evidence suggests that Stage 1 may not sustain cognitive performance/alertness (see Chapter 1 review of sleep fragmentation), Stage 1 was not included in the calculation of another variable referred to as "recuperative sleep time" (sum of Stages 2, SWS, and REM). Inter-rater reliability was at least 85 percent, compared with scoring of an identical record by an investigator (TJB) holding a current board certification in sleep medicine.

ALERTNESS MEASURES

Objective Alertness—Sleep Latency

Sleep latency tests (SLTs) were given either twice or three times per day at 0940/1005, 1540/1605, and 2140/2205 hours, following a procedure modified from Carskadon and Dement (1981). A limitation of two sleep chambers required subjects to be tested in pairs, offset by 25 minutes. The SLT is widely accepted as a direct and objective measure of sleep propensity. Subjects were placed in bed in a quiet, darkened room and instructed to close their eyes and not resist the urge to fall asleep. EEG (C3 and C4), left and right EOG, and submental EMG leads from the subject were connected to both a bedside Medilog recorder and by cable to a Mentor computerized polygraph outside the bed chamber, where the signals were visually monitored in real time and also digitized and stored for later rescoring. The subject was awakened after two clear indicators of Stage 2 sleep (e.g., spindles or K-complexes) or after 20 minutes of elapsed time—whichever occurred first. Post hoc rescoring provided verification and also allowed the use of Stage 1 criteria following the conventional procedure of Carskadon and Dement (1981). The dependent variable analyzed for SLT was latency to the first 30 s of Stage 1 sleep.

Objective Alertness—Microsleep

The presence or absence of microsleep, and Rechtshaffen and Kales (1968)-defined sleep during simulator-driving performance was scored from the recorded PSG data. The criteria used for scoring microsleep was the occurrence of Stage 1 sleep, in the absence of artifact, with a duration of 1 to 15 s. Five PSG channels were used to score microsleeps as follows: EEG from C3 and C4 for scoring Stage 1 theta events, and left and right EOG and EMG for assessing the presence of muscle or movement artifact.

The term "microsleep" has been used to describe the observed phenomenon in which, in sleepy individuals, brief episodes of apparent sleep sometimes intrude into otherwise normal-appearing (by objective EEG criteria) wakefulness. It is clear that microsleep episodes, when they occur, can contribute to performance deficits. However, the extent to which microsleep episodes contribute to various types of performance deficits during sleep loss is a matter of some debate (see pp. 1-3 and 1-4). This may, in part, be due to the fact that there are no standard criteria for scoring microsleep. Some researchers use only EEG criteria, others use a combination of EEG and EOG criteria, while still others use purely behavioral criteria, such as failure to respond during performance demands (i.e., performance lapses; see Konowal et al., 1999). In this study, the operational definition of microsleep was based as closely as possible on the standard sleep stage scoring rules of Rechtschaffen and Kales (1968): A microsleep episode was scored when visual inspection of the EEG recording from Channel C3 or C4 revealed activity in the theta range (4.0 to 7.0 Hz—indicative of light, Stage 1 sleep), lasting from 1 to 15 s, in the absence of muscle or movement artifact (scored from EOG and EMG channels). Microsleeps were also scored with the appearance of EEG indicators of deeper sleep stages (i.e., sleep spindles, K-complexes, or delta waves), but this was exceedingly rare.

Microsleep and sleep associated with simulator-driving crashes. An analysis of the PSG records associated with STISIM drives in which vehicular collisions and/or off-road accidents occurred was performed as a *primary* analysis to determine the extent to which electrophysiologically defined events immediately preceded simulator-driving accidents. These PSG/crash records were scored for both microsleep and Rechtschaffen and Kales (1968)-defined sleep. This analysis included all STISIM drives for a given sleep group in which a crash occurred. Each PSG segment was scored by one experienced analyst, who scored the preceding

1minute to the time an accident transpired. This minute was broken down into 31 to 60 s, 11 to 30 s, 6 to 10 s, and 0 to 2 s before the accident. Microsleep *immediately* preceding an accident (i.e., close enough in temporal correspondence to the accident to be considered the cause of the accident) was defined as occurring 0 to 2 s prior to the accident and, in the case of Rechtschaffen and Kales (1968)-defined sleep, up to 30 s prior to the accident. The exact time of an accident was indicated by a crash signal on Channel 7 of the PSG record. If a file lacked crash signals, the crash time was calculated by adding the elapsed time (taken from the STISIM file) to the start time of the drive.

Microsleep during simulator-driving periods. An analysis of the PSG records corresponding to the STISIM test at 1340 hours (simulator drive) was performed as a *secondary* analysis to assess whether differences occurred in microsleep events during simulator-driving performance among the sleep groups. Rechtschaffen and Kales (1968)-defined sleep, including alpha activity, was not observed in the analysis of PSG records corresponding to accidents (see Results); therefore, this analysis was not performed for the PSG records associated with the STISIM drives at 1340 hours. The STISIM test at 1340 hours was selected for analysis because it corresponded with previously observed declines in alertness/performance in the early afternoon (Mitler et al., 1988). Also, this time point closely corresponded to a time point similarly analyzed in a prior study of the effects of total sleep deprivation on microsleep events and simulator-driving accidents using a 45-minute STISIM drive (Thomas et al., 1995).

Due to the enormous size of the STISIM 1340-hours PSG records data set, four technicians were assigned to score these records for microsleep after completing a training program and completing a reliability check. Each analyst scored approximately the same number of PSG records from each sleep group. Post hoc analysis of randomly selected PSG records revealed that inter-rater reliability of the microsleep analysts to the experienced scorer who performed the crash/PSG analysis was less than 50 percent[2]. The reanalysis of these PSG records indicated that the analysts consistently underscored the occurrence of microsleep.

[2] In the case of standard Rechtschaffen and Kales (1968) sleep scoring, an 85 percent inter-rater reliability is accepted as the minimum reliability for multiple scorers of a PSG data set. There are no such accepted inter-rater reliability standards for scoring microsleep. Given the difficulty of scoring microsleep (i.e., searching for and detecting infrequently occurring Stage 1 sleep events embedded in primarily awake EEG), the most important aspects of the analysis procedure employed here were that each scorer received an equivalent number of records from each sleep group and that the data were reported as relative, not absolute, values. See Discussion (section on Relationship between Simulated Driving Performance and Microsleep) for further comments regarding this issue.

Therefore, relative numbers, rather than absolute numbers, of microsleep parameters (i.e., relative number, relative maximum duration [seconds], relative total amount [seconds]) across the sleep groups were statistically assessed.

Subjective Alertness/Sleepiness

Self-ratings of alertness (or its converse, sleepiness) were obtained throughout each day at the beginning of each PAB administration (described below) using the Stanford Sleepiness Scale (Hoddes et al., 1973). For the Stanford Sleepiness Scale (SSS), subjects selected one of seven statements that best described their current state of alertness, as indicated in **Table 2-2**. The subject's actual sleepiness rating (1 through 7) served as the dependent variable analyzed for the SSS.

Table 2-2. Stanford Sleepiness Scale items.

Rating	Degree of Sleepiness
1	Feeling active, vital, alert, or wide awake
2	Functioning at high levels, but not at peak; able to concentrate
3	Awake, but relaxed; responsive but not fully alert
4	Somewhat foggy, let down
5	Foggy; losing interest in remaining awake; slowed down
6	Sleepy, woozy, fighting sleep; prefer to lie down
7	No longer fighting sleep, sleep onset soon; having dream-like thoughts

PERFORMANCE MEASURES

Performance instruments included a driving simulator, a synthetic work task, a battery of cognitive tests, and both simple and choice reaction time (RT) tasks.

Simple Reaction Time

Simple (as opposed to disjunctive or choice) RT tasks require responding as quickly as possible to the occurrence of a single stimulus. Such tasks can assess motor speed relatively isolated from higher cognitive functions, requiring only the detection of stimulus presence or absence without further discrimination. If the inter-stimulus intervals are long and/or variable, or the task duration is long, then such tasks may also assess attention and vigilance.
Simple reaction time was measured using the Psychomotor Vigilance Task (PVT) of Dinges and Powell (1985). This device is a programmable digital electronic modification of the Unprepared Simple Reaction Time task of Wilkinson and Houghton (1982). Both tasks have been shown to be sensitive to sleep deprivation effects (Dinges et al., 1987, Dinges et al., 1997, Wilkinson and Houghton, 1982). The test used a book-sized, hand-held device that has two response buttons and an LED four-digit numeric display. The subject was instructed to press a response button with the preferred thumb as quickly as possible after the display began counting. The counter then halted briefly, displaying the response time in milliseconds and then darkened during the subsequent inter-stimulus interval. Inter-stimulus intervals varied randomly from 2 to 10 s in 2-s increments. Each test administration lasted 10 minutes.

Choice RT and Cognitive Tasks

A subset of tasks from the Walter Reed Performance Assessment Battery (PAB) (Thorne et al., 1985) was administered four times per day to all groups. These tasks included Serial Addition and Subtraction, 10-Choice Reaction Time, Logical Reasoning, Running Memory, Code Substitution, Interval Production, the Stroop Test, and Delayed Recall. Only the first two are described and reported here.

Serial addition/subtraction is a mental arithmetic task requiring immediate/working memory, arithmetic processing, and sustained attention. Two single, random digits are flashed sequentially in the center of the screen, followed by either a plus or minus sign and then a question mark. The subject must add or subtract the numbers accordingly and enter the least significant digit of the answer as quickly as possible using the keypad. If the answer is negative, the subject must first add 10 and then enter the single positive digit that results. The digits and signs appear for only 250 ms each, separated by 200 ms, with the next trial following 300 ms

after the response. The task ran for 60 trials, typically taking between 2 and 3 minutes to complete. This task has some of the characteristics of a signal detection task, and a vigilance task without the usual time penalty. It has been shown to be sensitive to sleep deprivation and fatigue (Belenky et al., 1994, Gillooly et al., 1990, McCann et al., 1992, Newhouse et al., 1989, Newhouse et al., 1992, Neri et al., 1992, Penetar et al., 1994, Thorne et al., 1983) and has been used as the archetypal performance test for developing the Sleep Performance Model.

The **10-Choice Reaction Time** task presents single digits in the center of the screen, and the subject is to enter the same digit from the keypad as quickly as possible. The digit remains until the subject responds, with the next trial following 300 ms thereafter. The digits are the 60 "answer" digits from the preceding Serial Addition/Subtraction task of the same test session, presented in the same order (these differ randomly across sessions). This task is a classical RT task in its own right but also serves as additional practice on the keypad and as a motor-control task for Serial Addition/Subtraction.

Dependent measures analyzed for Serial Addition/Subtraction and 10-Choice Reaction Time were accuracy (percent correct), speed (reciprocal of reaction time), and throughput (product of speed and accuracy).

A second battery was given twice a day to all groups and consisted of two tasks, with the task of interest being **4-Choice Serial Reaction Time** (Wilkinson and Houghton, 1975). In this task, the screen displays four half-inch squares in a square array corresponding to four keys in the lower left corner of the keypad. A red dot appears in one square, and the subject is to press the corresponding key as quickly as possible. The red dot then jumps randomly to a different (or the same) square, and the subjects follow it. The task ran for 8 minutes or 999 responses, whichever occurred first. The duration of the task was selected partly to induce a degree of muscle and mental fatigue, believed to increase its sensitivity, and partly to compare and contrast with the simple RT task described above.

Finally, a third battery was given only to the 3- and 5-hour sleep groups to occupy their extra time awake, using tasks that would not interfere with the learning curve for the other two batteries common to all groups. These "filler" tasks will not be discussed here.

Synthetic Work Task

A synthetic work task is designed to occupy a position between single cognitive tests of component abilities presented sequentially (such as the PAB) and "part" simulators requiring time-sharing of resources, where the cognitive components are usually inseparable (Alluisi, 1967). SYNWORK1 (Elsmore, 1994) requires dividing attention among four concurrent cognitive tasks involving short-term memory scanning, mental arithmetic, visual monitoring, and auditory vigilance and discrimination. Each of the subtasks is displayed simultaneously in one quadrant of the screen, and the subject responds to each using a mouse. A small window in the center of the screen displays a composite score, which the subject is instructed to maximize.

The **memory scanning** task briefly presented six randomly selected letters at the beginning of the test session, which the subjects were to memorize. Thereafter, single probe letters were presented every 20 s, and the subject had 5 s in which to decide whether each was a member of the memory set or not, or if unable to do so, to look up the original list before responding.

The **mental arithmetic** task required adding two three-digit numbers and entering the answer by incrementing or decrementing each digit of a digital counter. Scratch pads were not allowed, and the subject had to hold intermediate sums and carries in memory while being frequently interrupted to attend to the other concurrent tasks.

The **visual monitoring** task resembled a panel meter or gauge with a needle that drifted slowly to the left or right of center. The subject was instructed to prevent the needle from reaching full scale by periodically clicking a reset button to recenter it; otherwise, points were subtracted from the composite score for every second the needle was "pegged."

The **auditory task** presented either 931 Hz or 1234 Hz beeps every 5 s. The subject had up to 5 s to decide which tone occurred and then to click a button if it was the less frequent higher tone, which occurred with a probability of 0.2.

Points were earned for correct responses to the individual subtasks and subtracted for errors. Points were also subtracted for errors of omission (e.g., missed signals, or for having to look up, rather than recall, the target letters in the memory task). Task duration was 15 minutes.

Driving Simulator

The driving simulator was STISIM Version 10 by Systems Technology Inc., Hawthorne, California. This simulator consisted of a 21-inch monitor displaying the computer-generated scenario, a speedometer, and a single rear-view mirror; a bench-mounted console with steering wheel, horn button, and turn-signal lever; and a floor-mounted pedal box with brake and throttle. The system was controlled by an 80486 100-MHz PC with the necessary peripheral boards and software to run the programmed scenario, to monitor and record the subject's performance, and to interactively generate the graphics display at 20 frames per second.

Vehicle acceleration, drag, and braking dynamics were set to approximate a "generic truck" with a four-speed transmission. The transmission was necessarily automatic, with shift points set at 25, 45, and 65 mi/h (40.2, 72.4, 104.6 km/h, respectively), purposefully straddling the 35- and 55-mi/h speed limits (56.3 and 88.5 km/h, respectively). Since it was impossible to provide proprioceptive or vestibular feedback of acceleration, simulated transmission noise rose and fell in loudness and pitch within each gear band to provide auditory feedback of speed and speed variation, to supplement that displayed visually by the speedometer and the passing scene. Brake screech and tire squeal were also sounded when appropriate. Steering dynamics employed real-time computation and force-feedback via torque motor to vary steering resistance with speed and turning radius.

The programmed scenario simulated a short haul between depots or terminals on the outskirts of two unseen cities, over urban roads onto rural roads, and passing through two small towns. Scenario length was 185,000 ft (approximately 35 mi or 56.4 km) with a nominal driving time of 45 minutes when observing speed limits and safe practices for de/accelerating. Although this would be a relative short drive in the real world, it is consistently reported as aversively long and boring in simulation, and particularly so with repetition. Experience indicated that a longer scenario would lead to motivational and compliance problems in a repeated-measures design such as this. The program included six-, four-, and two-lane roads; 35- and 55-mi/h (56.3- and 88.5-km/h, respectively) speed limits; curves and straight-aways; crossroads with cross traffic both with and without signal lights; oncoming cars in the opposite lanes, passing cars, and cars to be passed; buildings, trees, and roadside signs; and parked cars and pedestrians in the two towns. Specific details are provided in **Appendix 3**.

The scenario provided realistic opportunities for accidents and collisions, but all were avoidable by a normal, alert driver (for example, one could collide with a slow vehicle ahead or be rear-ended in passing it by failing to check the rear-view mirror). Upon the occurrence of an accident, brake screech and crash sounds were played through the subject's earphones, a series of cracks appeared in the windshield (or rear-view mirror), and the vehicle was halted on the side of the road. It was then necessary for the driver to pull back onto the road and reaccelerate through the low gears up to the speed limit, which slightly delayed the completion of the scenario. For purposes of maintaining motivation and attention, the mild punishment of this added effort and delay was deemed preferable to the simulator's alternative no-consequence option of continuing through the crash with the original speed and lane position.

Although the basic scenario remained the same each time it was driven, small but noticeable variations were introduced on an infrequent pseudo-random basis (e.g., whether a given traffic signal turned red, or a cross-traffic vehicle was on a potential intercept course, or a normally stationary car pulled out from a filling station). This was done to prevent subjects from essentially ignoring traffic signals and cross-traffic after memorizing the scenario through repetition, and it was a practical compromise dictated by the total number of drives and the time- and labor-intensive effort of designing and programming scenarios. In addition, at 10 slightly varied locations in each scenario, a divided-attention task was inserted. This consisted of a 10-s presentation of a left-pointing or right-pointing arrow in the upper left or upper right portion of the screen, requiring the subject to press the corresponding turn signal.

Subjects were fully informed of the design of the study and the purpose of the test. The limitations of the simulator were identified and acknowledged, but subjects were asked to take the simulation seriously and to do their best each time, regardless of the phase of the study. They were told that their job had three requirements: 1) to drive safely and observe all traffic regulations; 2) to maintain the current speed limit as exactly and consistently as possible; and 3) to stay centered in the right-most lane except when merging or passing. They were told that while the last two requirements might not be realistic in their workaday world, speed variation and lane deviation were known to be sensitive performance variables and were being recorded continuously. To aid them in each, they were specifically shown which visual cues indicated that the vehicle was centered in the lane, and which auditory and visual cues indicated speed variation. They were also told that if they maintained the current speed limit, they could usually

pass through most intersections without the signal light turning red and without colliding with cross traffic, but that there would be occasional exceptions to both rules. This information was disclosed from the start to hasten stability and reduce variability between subjects. The same individual gave all subjects the same instructions.

The elapsed distance and time of occurrence of all accidents were recorded continuously throughout the scenario and separately tallied as off-road accidents, vehicular collisions, or pedestrians struck. Data recorded for the 10 divided-attention trials included number correct, number in error, and number missed (lapses). Other performance data consisted of the means and standard deviations for speed, lateral placement, steering rate, and heading error. These statistics were recorded for seven 4,000-ft (1219-m) segments differing in lane numbers and speed limits, approximately symmetrical about the middle of the scenario. Symmetrical spacing was designed to allow an assessment of time-on-task effects (separated from sleep deprivation effects), not confounded by differences in speed limits or lane numbers. The position of each data-collection segment was selected so as not to confound performance measures with programmed events, as occurs in many driving simulations. Thus, speed variation would not be recorded when the scenario required the driver to slow for a car ahead, nor would lateral position be recorded when the scenario required the driver to merge (cross lanes) or pass. In order not to introduce spurious differences in speed variation due to occasionally forgetting the current speed limit, 35- and 55-mi/h (56.3- and 88.5 km/h, respectively) speed-limit signs were spaced at nominally equal time intervals rather than at equal distances.

OCULAR MEASURES

Oculomotor functions reflect coordinated neuronal activity in both brainstem and cortical areas. Voluntary control is exercised over direction of gaze and attempt to focus. Involuntary control determines pupil size and maximum speed of ocular movement. Because of the involvement of multiple neuronal systems, oculomotor measurements have been explored as a means of easily quantifying and tracking diffuse neuronal dysfunction. The Fitness Impairment Test (FIT, Pulse Medical Instruments, Inc., Rockville, Maryland) was used to measure four oculomotor parameters: initial pupil diameter (IPD), pupil constriction latency (CL), amplitude of pupil constriction (APC), and saccadic velocity (SV). A composite index combining IPD, CL,

APC, and SV has been shown to be sensitive to total sleep deprivation and to correlate with simulator-driving accidents. One or more oculomotor measures might be individually more sensitive to partial sleep deprivation and selectively correlate with driving accidents. If one of these measures is especially sensitive to the effects of partial sleep deprivation, then the identified measure may have applicability as an alertness assessment or monitoring tool. Two of these measures, pupil diameter and saccadic velocity, showed statistical significance with performance impairments and will be discussed in detail.

The FIT pupillometer is a self-contained, fully automated, computer-controlled optical tracking and recording system. Ocular measures were sampled six to nine times per day, but only the six time points (0735, 1030, 1330, 1630, 1930, and 2145 hours) common to all four sleep groups were used in the repeated-measures ANOVA. Results of the FIT analyses are reported in Appendix 4. Four oculomotor parameters were measured over a 30-s period with the FIT. In this task, the subject focused with his/her dominant eye on a light circle of low brightness displayed in the center of a monitor while a camera captured the initial pupil diameter. A flash of bright white light then stimulated the pupillary light reflex, in order to measure constriction latency, which is the time from flash to onset of pupil constriction. Amplitude of pupil constriction is derived from the difference between the IPD and the smallest after-flash diameter. Since the camera samples the pupil at a rate of 60 per second, changes as small as 0.05 mm (0.002 in) may be detected. Finally, a light flashed alternately between the far right and far left visual field (constant distance each iteration) with the subject directing his/her gaze at each flash. Saccadic velocity is measured as the speed of eye movement between the visual fields. The optical tracking device assesses eye movements at the rate of 900/s and can detect changes as small as 0.1 mm (0.004 in). These measures have been shown to be sensitive to sleepiness (Lowensten and Lowenfeld, 1951; Yoss, 1970).

HEALTH MEASURES

Standard physiological measures included **heart rate** (HR, measured from the electrocardiogram or EKG via the Oxford Medilog recorder), **systolic and diastolic blood pressure** (BP – IVAC VitalCheck 4200, IVAC Corp., San Diego California), and **tympanic temperature** (Thermoscan Pro-1, Thermoscan Inc., San Diego California) sampled periodically

throughout each day. These measures were taken primarily for purposes of verifying health status rather than for detecting sleep deprivation effects per se, or for tracking diurnal rhythms.

STATISTICAL ANALYSES

Unless otherwise specified in "Results," data were analyzed using a three-way mixed Analysis of Variance (ANOVA) for sleep group (3, 5, 7, or 9 hours in bed per night), day (11 days; baseline through Recovery Night 3), and time of day, with repeated measures on the latter two factors. Number of levels for the time-of-day factor depended on the daily sampling rate for a given task (for example, four levels for STISIM, which was administered at 0730, 1030, 1330, and 1930 hours). Main effects for sleep group, day, and time of day, as well as their interactions, were analyzed. The interaction of Sleep Group x Day is most relevant to this report; thus, this interaction was further analyzed using simple main effects ANOVAs. The first simple main-effect (simple effect of day for each sleep group) evaluated changes across days, separately within each sleep group. The second simple main effect (simple effect of sleep group at each day) evaluated sleep-group differences, separately for a particular day. Greenhouse-Geisser corrections were applied to the degrees of freedom associated with all repeated-measures tests. This correction (a conventional practice with use of repeated-measures designs) reduces degrees of freedom to adjust for possible violations of the assumptions upon which ANOVA is based (Kirk, 1982). Post hoc comparisons among means were conducted using the Tukey HSD test (Kirk, 1982). Results were deemed significant at an alpha level of less than .05 ($p < .05$). Analyses were conducted using commercially available statistical packages (SAS, SPSS, and BMDP).

C. RESULTS

NOCTURNAL SLEEP

Nocturnal sleep data were analyzed using a two-way mixed Analysis of Variance with sleep group (3, 5, 7, or 9 hours per night) and Night (11 nights; baseline through Recovery Night 3) as factors. The interaction of Sleep Group x Night is most relevant to this report; thus, this interaction (if significant) was further analyzed using simple main-effects ANOVAs. The first

simple main effect evaluated changes across nights, separately within each sleep group. The second simple main effect evaluated sleep group differences, separately for a particular night.

Total Sleep Time, Minutes

Total sleep time (TST) was calculated as the sum of minutes spent in Stages 1, 2, slow wave sleep (Stages 3 and 4), and REM sleep.

Figure 2-1 illustrates mean TST separately for each sleep group across baseline, experimental, and recovery sleep nights. **Table 2-3** lists mean TST by sleep group and night. Average TST during the experimental phase (mean of experimental days 1 through 7) for the 3-, 5-, 7-, and 9-hour TIB groups was 2.87, 4.66, 6.28, and 7.93 hours of sleep, respectively.

At baseline (8 hours in bed for all sleep groups), mean TST was similar among sleep groups (sleep group simple effect, NS). Total sleep time amounts differed significantly among sleep groups across experimental Days 1–7 (sleep group simple effects, *p*s < .05). Total sleep-time amounts were at near-baseline levels across all three recovery days, for all four sleep groups (sleep group simple effects, *p*s > .05). Regarding the pattern of TST change within a sleep group across baseline, experimental, and recovery days: first, from baseline to experimental phase, TST increased in the 9-hour sleep group, then decreased from experimental to recovery phase (night simple effect, $p < .05$). Total sleep time decreased in a predictable and dose-dependent fashion from baseline to experimental phase in the 7-, 5-, and 3-hour sleep groups; from experimental to recovery phase, TST returned to near-baseline levels in all three groups (night simple effects for 7-, 5-, and 3-hour groups, *p*s < .05). A significant Sleep Group x Night interaction confirmed these observations ($p < .05$).

Results of the above analyses are summarized in **Appendix 4.**

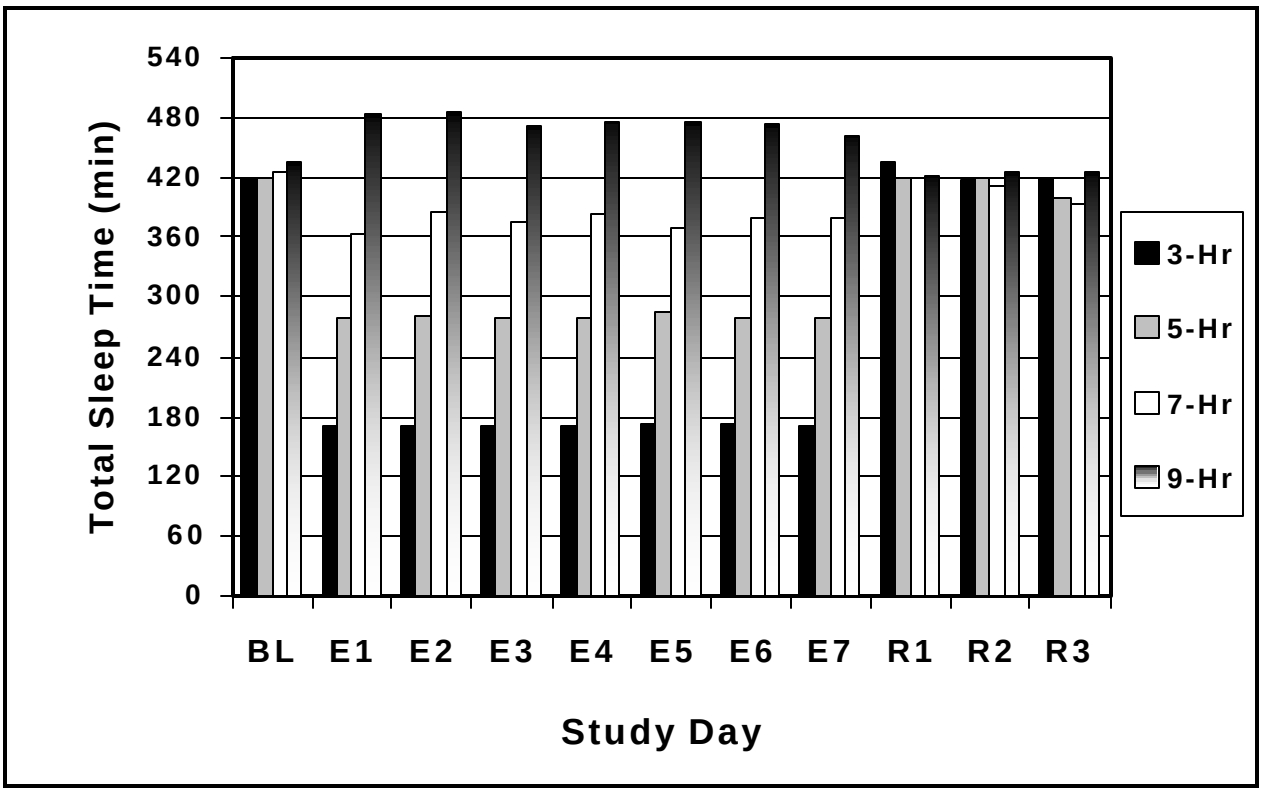

Figure 2-1. Mean total sleep time (sum of Stages 1, 2, SWS, and REM) in minutes across study days as a function of sleep group.

Table 2-3. Mean (standard error) total sleep in minutes.

DAY	GROUP			
	3-hr	5-hr	7-hr	9-hr
Baseline	420.48 (8.46)	419.12 (10.19)	425.39 (8.73)	435.26 (4.17)
E-1	170.47 (1.41)	277.70 (3.17)	364.00 (7.66)	483.14 (5.44)
E-2	171.09 (1.21)	281.04 (2.37)	384.63 (3.30)	485.66 (4.32)
E-3	172.19 (1.83)	278.83 (4.33)	374.68 (8.04)	472.61 (7.52)
E-4	171.67 (3.77)	278.11 (2.08)	383.63 (6.27)	476.64 (8.34)
E-5	173.60 (1.16)	284.75 (1.52)	369.54 (8.58)	475.48 (7.80)
E-6	173.39 (0.89)	278.74 (2.46)	379.34 (5.28)	473.95 (7.46)
E-7	170.78 (2.46)	279.93 (3.14)	379.70 (7.55)	462.38 (10.36)
R-1	434.45 (9.08)	418.17 (10.76)	418.40 (8.16)	422.10 (5.13)
R-2	416.33 (11.39)	418.89 (5.55)	411.62 (6.50)	425.76 (4.80)
R-3	418.61 (12.00)	398.70 (8.33)	394.00 (12.12)	425.98 (5.18)

Recuperative Sleep Time, Minutes

As noted in Methods, recuperative sleep time was calculated as the sum of minutes spent in Stages 2, SWS, and REM sleep—that is, Stage 1 was not included. This variable was calculated since evidence suggests that Stage 1 may not sustain cognitive performance/alertness (see Chapter 1 review of sleep fragmentation).

Figure 2-2 illustrates mean recuperative sleep time separately for each sleep group across baseline, experimental, and recovery sleep nights. **Table 2-4** lists mean recuperative sleep time by sleep group and night. For comparison, **Figure 2-3** illustrates recuperative sleep time co-plotted with total sleep time (see **Figure 2-1**). As seen, since total sleep time amounts included Stage 1, they were slightly greater than recuperative sleep amounts.

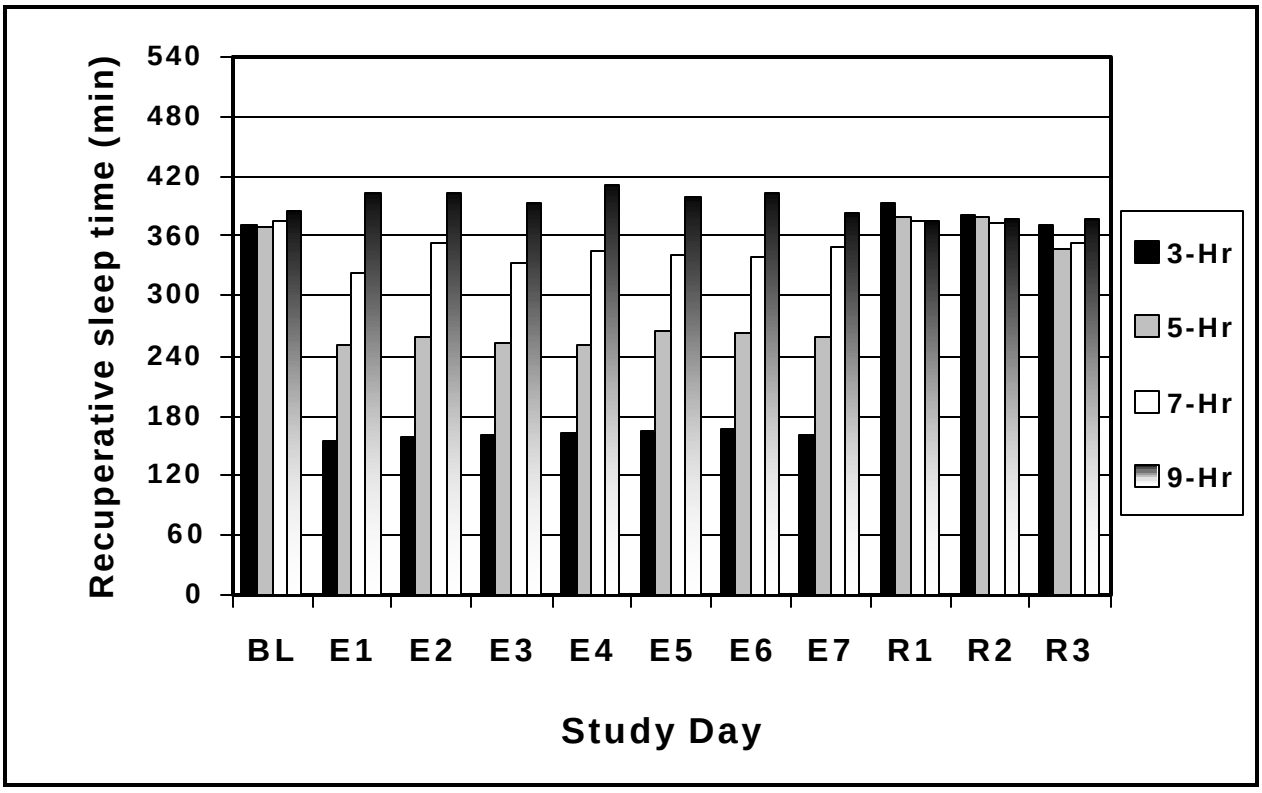

Figure 2-2. Mean recuperative sleep time (sum of Stages 2, SWS, and REM) in minutes across study days as a function of sleep group.

Table 2-4. Mean (standard error) recuperative sleep in minutes.

DAY	GROUP				
	3-hour	5-hour	7-hour	9-hour	Tukey HSD
Baseline	372.00 (8.88)	369.23 (11.10)	375.17 (12.19)	385.24 (5.37)	NS
E-1	155.57 (3.06)	249.88 (5.48)	322.96 (8.46)	404.34 (8.51)	31.01
E-2	159.02 (2.00)	258.97 (4.29)	354.36 (4.97)	403.74 (12.02)	32.08
E-3	160.06 (2.97)	254.26 (5.35)	333.40 (9.77)	394.27 (13.92)	41.51
E-4	162.08 (3.99)	250.96 (5.91)	346.70 (6.90)	412.08 (10.16)	32.96
E-5	165.53 (1.79)	264.66 (2.80)	340.64 (8.34)	399.29 (8.36)	27.83
E-6	166.86 (1.29)	262.93 (3.13)	339.88 (7.66)	404.50 (11.16)	31.93
E-7	160.53 (3.22)	259.39 (5.52)	348.84 (6.99)	383.75 (13.95)	39.06
R-1	394.92 (15.37)	380.30 (12.74)	375.73 (8.55)	374.53 (7.65)	NS
R-2	380.83 (12.03)	380.16 (4.54)	373.72 (7.77)	377.34 (6.95)	NS
R-3	371.15 (12.62)	347.27 (9.94)	354.03 (13.92)	378.43 (8.37)	NS
Tukey HSD	24.67	26.16	27.02	26.16	

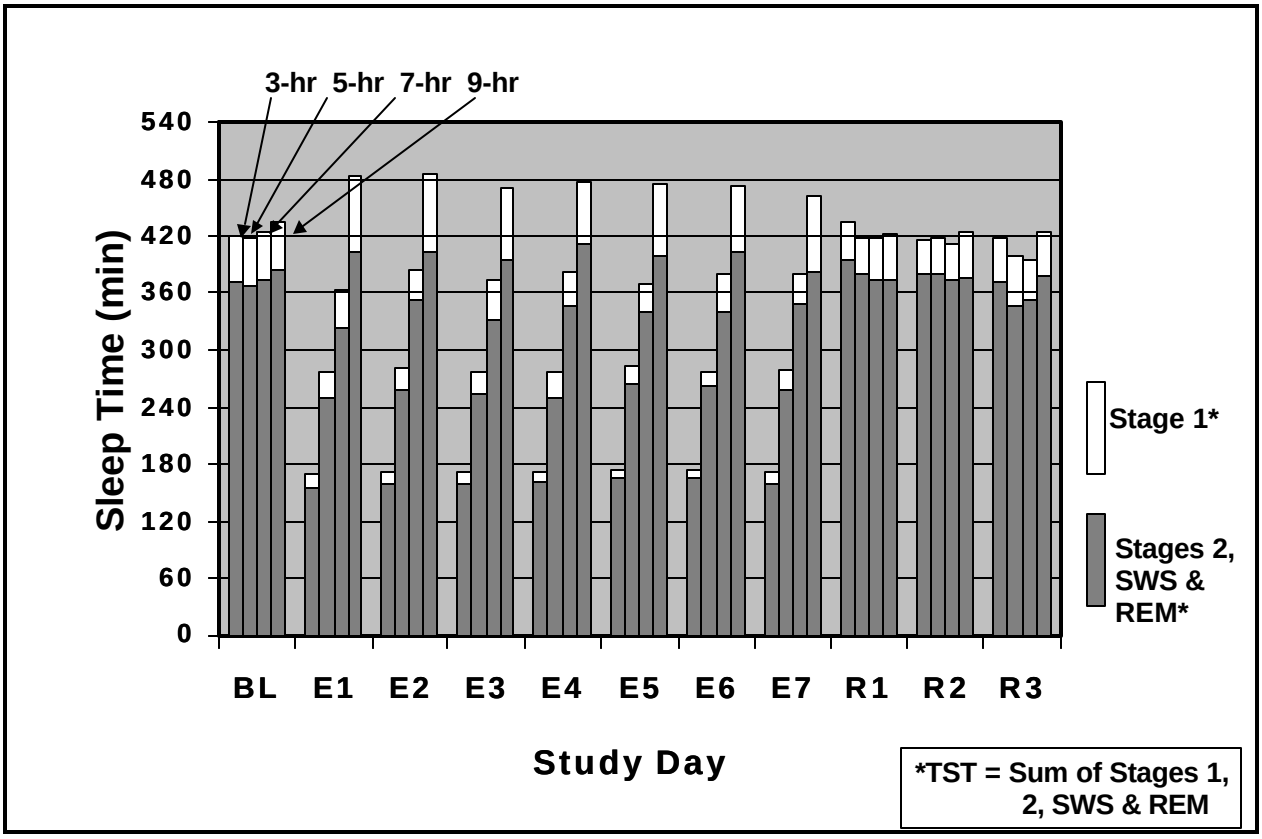

Figure 2-3. Mean recuperative sleep time in minutes (sum of Stages 2, SWS, and REM) with Stage 1 amounts in minutes separately for each sleep group across study days. Recuperative sleep time plus Stage 1 equals total sleep time.

At baseline (8 hours in bed for all sleep groups), mean recuperative sleep time was similar among sleep groups and averaged approximately 6.5 hours (group simple effect, NS). Average recuperative sleep time during the experimental phase (i.e., the mean of experimental days 1 through 7) for the 3-, 5-, 7-, and 9-hour TIB groups was 2.69, 4.29, 5.68, and 6.67 hours, respectively. Of greater interest, however, is the pattern of change in recuperative sleep time across experimental days for each sleep group. Recuperative sleep remained relatively constant in the 9-hour sleep group (approximately 6.5 hours per night) but did vary up to 1 hour across nights (night simple effect, $p < .05$). Recuperative sleep time decreased in a dose-dependent fashion in the 7-, 5-, and 3-hour sleep groups. Recuperative sleep decreased to just under 6 hours per night in the 7-hour sleep group (night simple effect, $p < .05$); to just over 4 hours in the 5-hour sleep group (night simple effect, $p < .05$); and to just under 3 hours in the 3-hour sleep group (night simple effect, $p < .05$). Recuperative sleep time returned to baseline levels

(approximately 6.5 hours per night) across the recovery phase (8 hours in bed per night) for all sleep groups (group simple effect, NS). A significant Sleep Group x Night interaction confirmed these observations ($p < .05$).

Simple effects for night indicated that recuperative sleep time varied across nights for all four sleep groups (night simple effects, ps $< .05$). Further, simple effects for group (used to determine whether differences existed among the four sleep groups on a particular night) were significant on all seven experimental nights (group simple effects, ps $< .05$), but not on the baseline night nor on any of the three recovery sleep nights (ps $> .05$). Results of the Tukey HSD comparisons are shown in **Table 2-4**.

Results of the above analyses are summarized in **Appendix 4.**

Individual Sleep-Stage Times

The following section describes results for minutes spent in each of the individual sleep stages (1, 2, slow-wave, and REM) across nights, as a function of sleep group.

Stage 1 Sleep Time, Minutes

Figure 2-4 illustrates mean time spent in Stage 1, separately for each sleep group across baseline, experimental, and recovery sleep nights.

Stage 1 amounts were similar among sleep groups on the baseline night (group simple effect, NS). Across the experimental nights, Stage 1 amounts increased in the 9-hour sleep group but decreased in the 5-hour and 3-hour sleep groups (night simple effects, *p*s < .05). Although Stage 1 amounts appeared to decrease in the 7-hour sleep group, this decrease was not significant (night simple effect, NS). Across the recovery nights, Stage 1 amounts returned to near-baseline levels in the 9-, 5-, and 3-hour sleep groups; no differences among sleep groups were found for Stage 1 amounts across any recovery night (group simple effects, NS). A significant Sleep Group x Night interaction confirmed these observations ($p < .05$).

Results of the above analyses are summarized in **Appendix 4.**

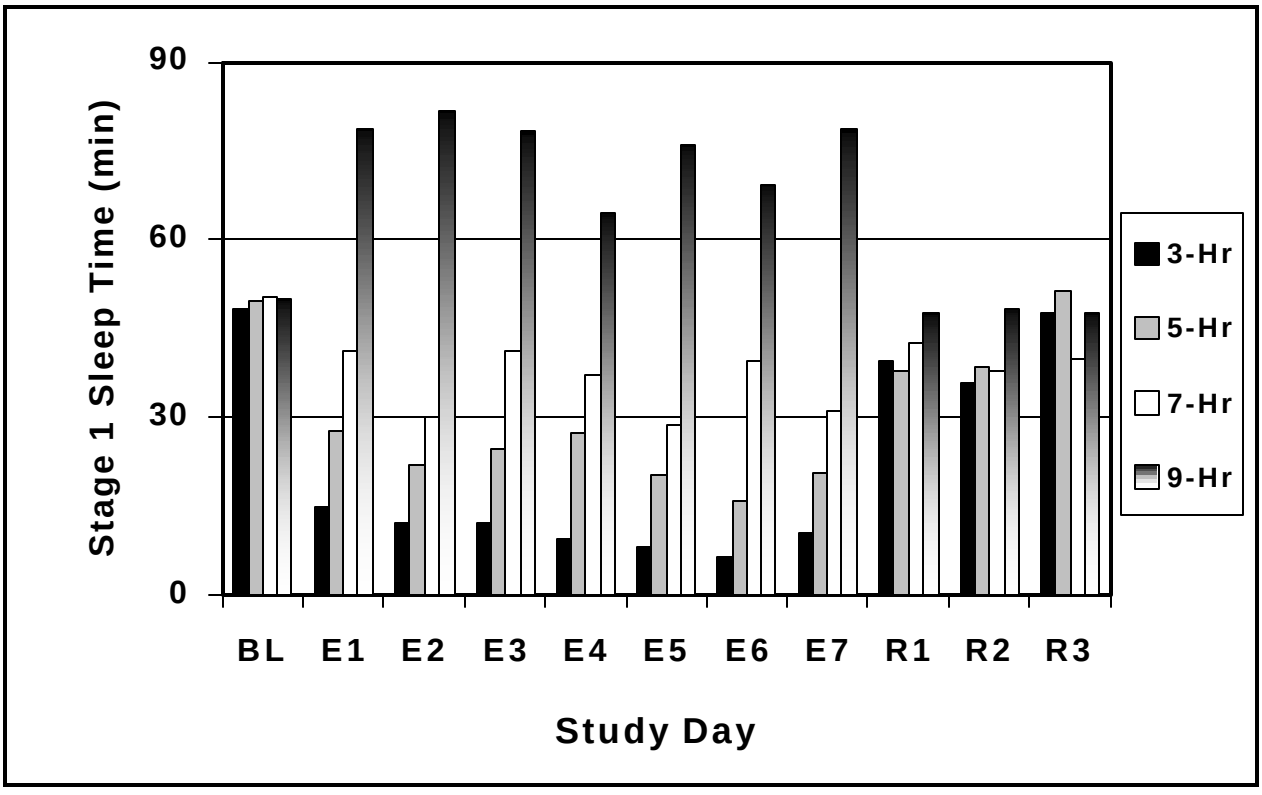

Figure 2-4. Mean minutes of Stage 1 across study days as a function of sleep group.

Stage 2 Sleep Time, Minutes

Figure 2-5 illustrates mean time spent in Stage 2 for each sleep group across baseline, experimental, and recovery sleep nights.

Stage 2 amounts were equivalent among sleep groups on the baseline night (group simple effect, NS). Across experimental nights, Stage 2 amounts appeared to increase slightly in the 9-hour sleep group, but this change was not significant (night simple effect, NS). Stage 2 amounts decreased in the other groups (night simple effects *p*s < .05) in a dose-dependent fashion, with greatest decreases in the 3-hour sleep group. During recovery, Stage 2 amounts returned to approximately baseline levels in all groups. No differences in Stage 2 amounts were found during the recovery phase (group simple effects, NS). A significant Sleep Group x Night interaction ($p < .05$) confirmed these observations.

Results of the above analyses are summarized in **Appendix 4.**

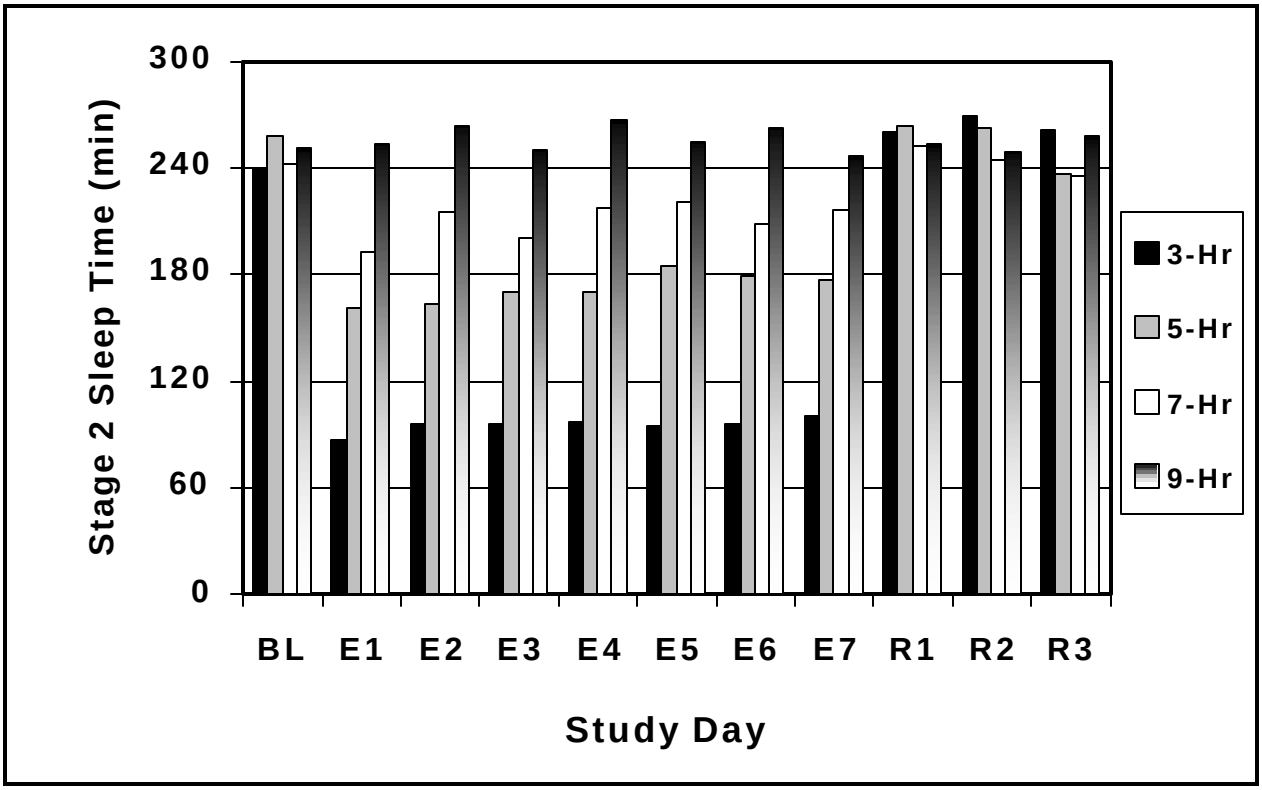

Figure 2-5. Mean minutes of Stage 2 across study days as a function of sleep group.

Stage SWS Time, Minutes

Figure 2-6 illustrates mean time spent in Stage SWS (Stages 3 and 4 combined) for each sleep group across baseline, experimental, and recovery sleep nights.

Stage SWS amounts were characterized by a high degree of variability within sleep groups—thus, many of the apparent differences between groups and across nights (see Figure 2-6) were not significant. Analyses of variance revealed a marginally significant main effect for Night ($p = 0.09$). Collapsed across groups, SWS amounts were highest on the baseline night (mean = 39.56 minutes), then decreased across experimental nights (mean = 38.41, 35.75, 38.69, 36.96, 36.28, 32.13, and 29.63 minutes across E1 through E7, respectively). A slight rebound was noted on the first recovery night (mean = 34.82 minutes), followed by a slight decrease across the second and third recovery nights (means = 30.76 and 32.04 minutes, respectively). Neither the Sleep Group main effect nor the Sleep Group x Night interaction was significant ($p > .05$).

Results of the above analyses are summarized in **Appendix 4.**

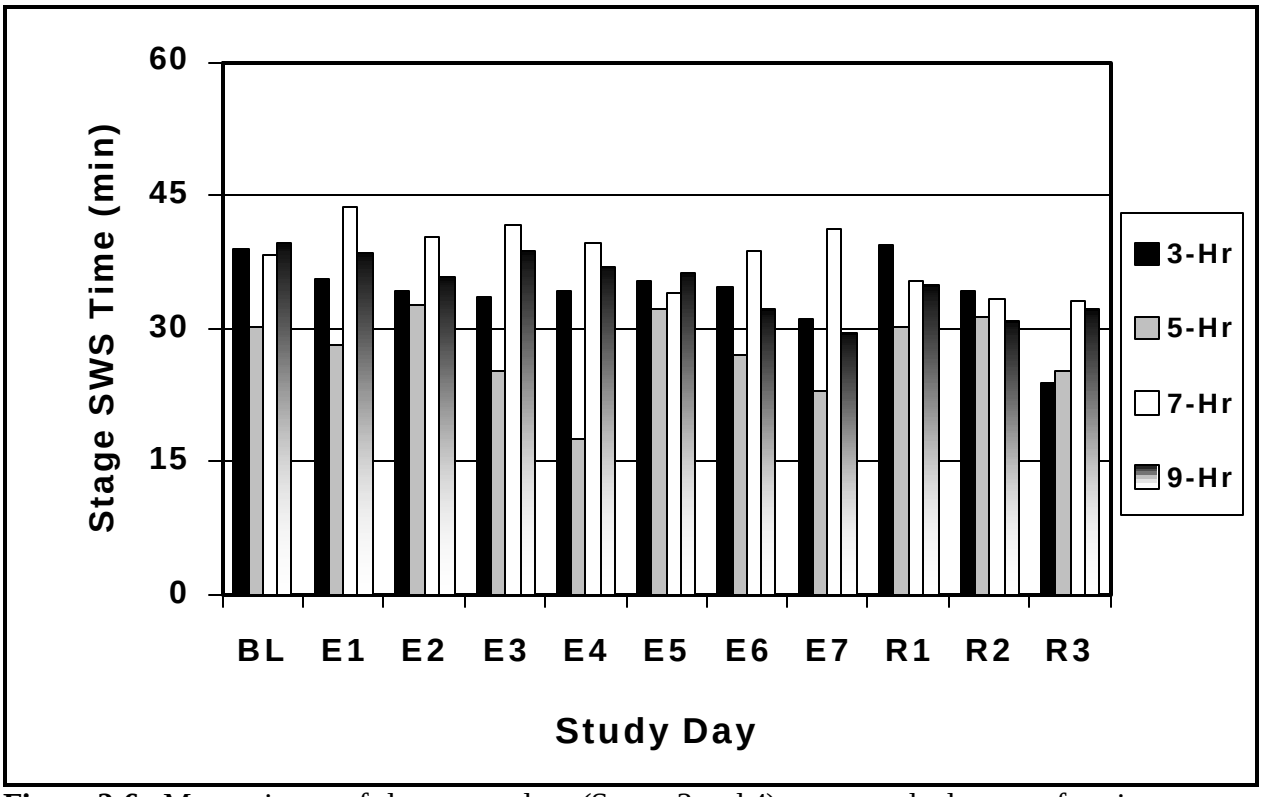

Figure 2-6. Mean minutes of slow wave sleep (Stages 3 and 4) across study days as a function of sleep group.

Stage REM, Minutes

Figure 2-7 illustrates mean time spent in Stage REM for each sleep group across baseline, experimental, and recovery sleep nights.

Stage REM amounts did not differ among sleep groups on the baseline night (group simple effect, NS). Across the experimental phase, REM amounts increased in the 9-hour sleep group (night simple effect, $p < .05$) and decreased in both the 5-hour and 3-hour sleep groups (night simple effects, ps $< .05$). REM amounts did not differ across nights in the 7-hour sleep group (night simple effect, NS). During the recovery phase, REM amounts appeared to return to baseline levels since the group simple effects on Recovery Nights 1 and 3 were not significant; however, the 3-hour sleep group displayed a marginal decrease in REM amounts on Recovery Night 2 (group simple effect, $p = 0.06$). A significant Sleep Group x Night interaction confirmed these observations ($p < .05$).

Results of the above analyses are summarized in **Appendix 4.**

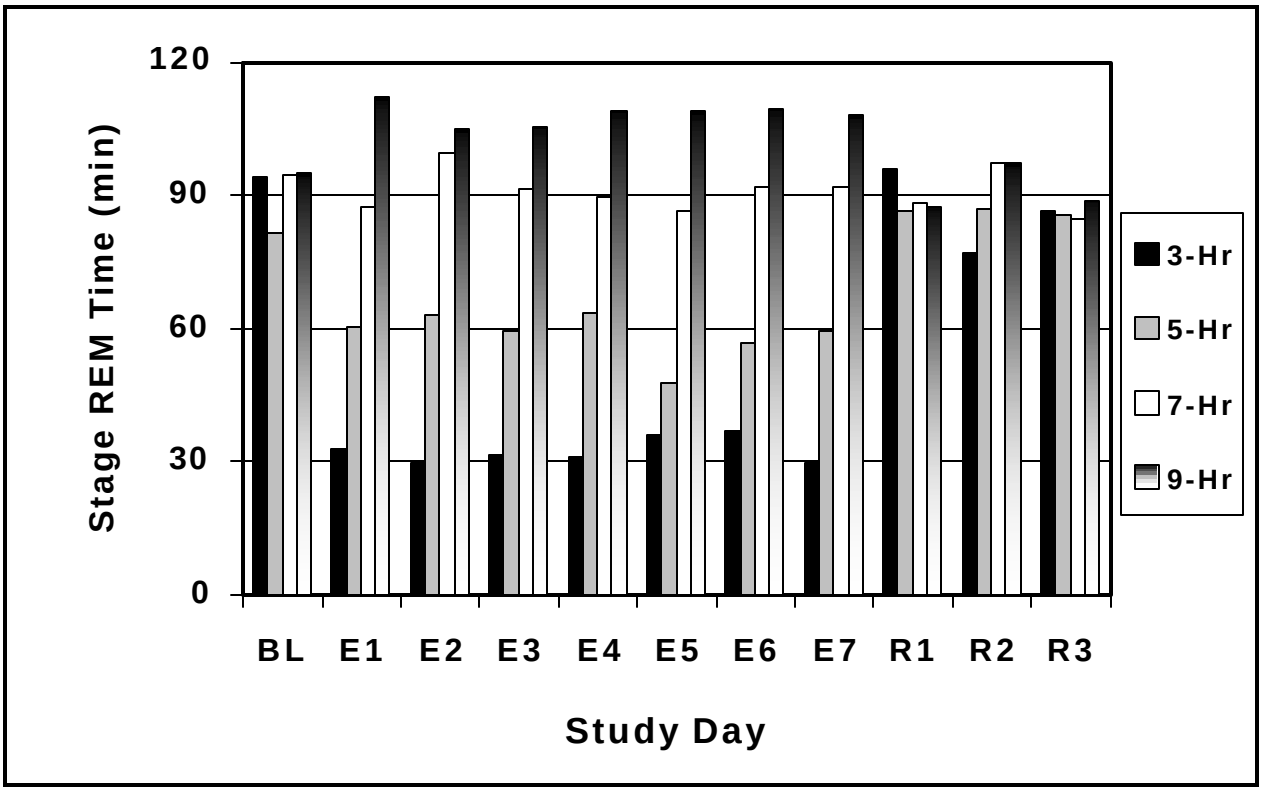

Figure 2-7. Mean minutes of rapid eye movement (REM) sleep across study days as a function of sleep group.

ALERTNESS

Objective Alertness: Sleep Latency

Daytime sleep latency (tests administered at 0940 and 1540 hours, common to all sleep groups) was analyzed using a three-way mixed Analysis of Variance (ANOVA) with sleep group (3, 5, 7, or 9 hours per night), day (11 days; B_1- R_3), and time of day (morning versus afternoon) as factors. For sleep latency, the interaction of Sleep Group x Day is most relevant to this report; thus, this interaction (if significant) was further analyzed using simple main-effects ANOVAs to evaluate sleep group differences, separately for a particular day.

A scatter plot of baseline mean sleep latency scores (average of morning and afternoon SLTs on the baseline day) is illustrated in **Figure 2-8**. An inspection of these baseline sleep latency scores revealed that 24 subjects could be considered pathologically sleepy by standard criteria (sleep latency less than 5 minutes, ASDA, 1992). Sleep latency scores in the "pathological" range were equally distributed among the sleep groups (n = 5, 5, 6, and 8 for 3-, 5-, 7-, and 9-hour sleep groups, respectively). Baseline sleep latency scores did not cluster around any one particular value, nor was there a clear separation of scores into "pathologically sleepy" and "not pathologically sleepy" categories. Rather, sleep latency scores were approximately evenly distributed along a continuum, ranging from a maximum of 20 minutes (n = 3; 20 minutes was the maximum time allotted for SLTs and indicates that subjects did not fall asleep) to a minimum of 1.05 minutes (n = 1). The latter score is within 30 s of test sensitivity limits.

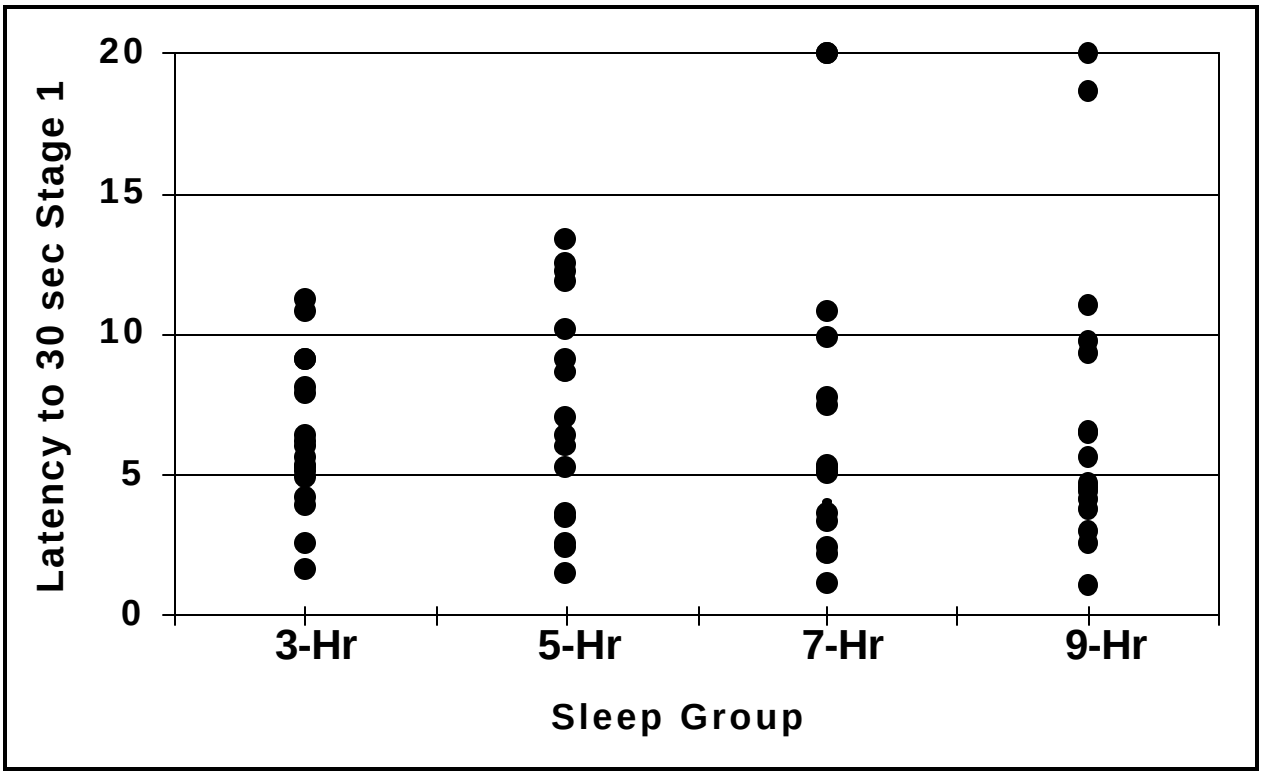

Figure 2-8. Scatter plot of baseline mean sleep latency scores for all subjects.

Because sleep latency scores were fairly evenly distributed along a continuum, a cutoff of "pathological" would have been arbitrary. Therefore, initial analyses were conducted on data from all subjects. Further analyses conducted on data from the subset of subjects whose sleep latency scores were categorized as not pathologically sleepy (as defined by published standards) are reported next.

Daytime Sleep Latency—All Subjects

Figure 2-9 illustrates mean daytime sleep latency (collapsed across morning and afternoon tests) separately for each sleep group across baseline, experimental, and recovery sleep days.

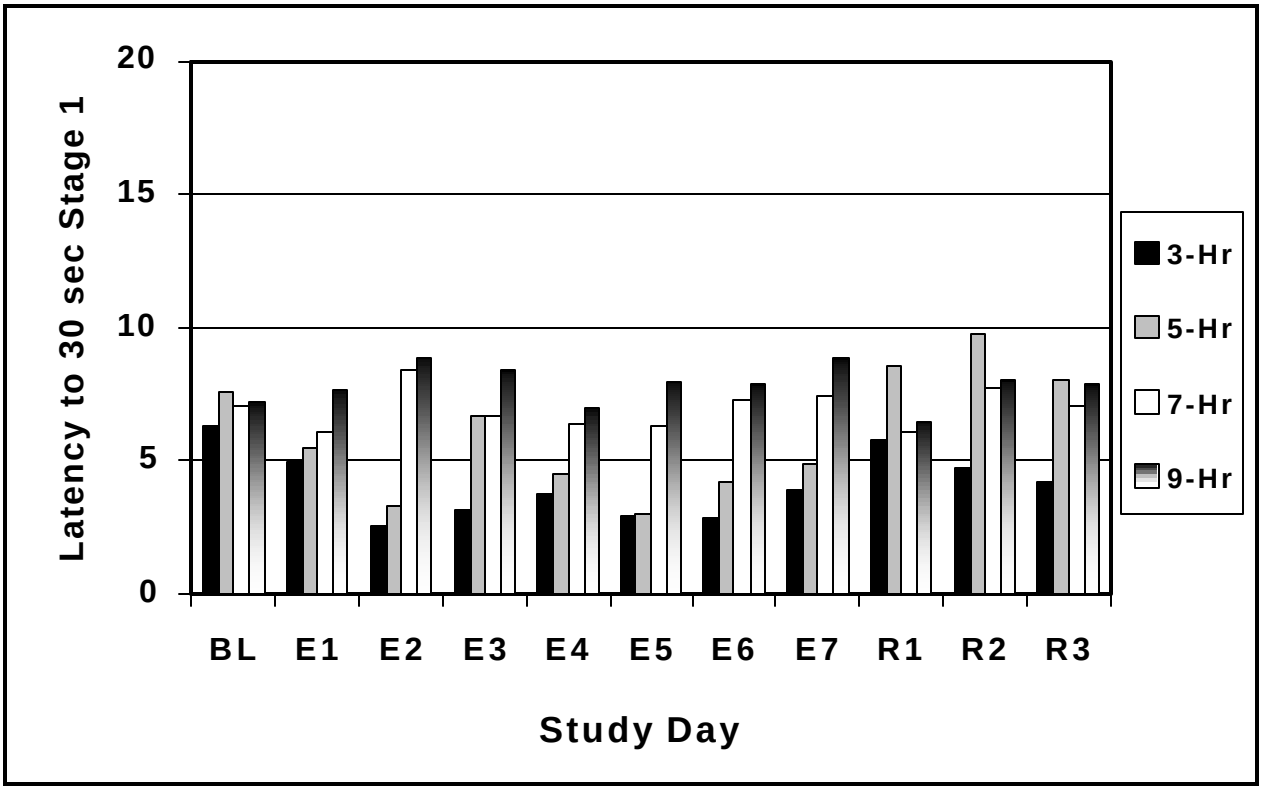

Figure 2-9. Mean latency to sleep (collapsed across time of day) as a function of sleep group (all subjects included) across study days.

At baseline, mean daytime sleep latency was similar among sleep groups. Sleep latency changed across experimental and recovery days in a dose-dependent manner (Sleep Group x Day interaction, $p < .05$).

Results of simple main-effects analyses of sleep group (separately for each day) are described next. Simple main-effects analyses of sleep group are used to determine whether differences existed among the four sleep groups on a particular day:

Sleep group effect on Baseline. No sleep-group differences were found on the baseline day (group simple effect, $p > .05$).

Sleep-group effect on E1. No sleep-group differences were found on experimental day 1 (group simple effect, $p > .05$).

Sleep-group effect on E2. Sleep latency was similar for the 3- and 5-hour groups and was shorter than latency for the 7- and 9-hour sleep groups (group simple effect, $p < .05$). The sleep latency difference between 3- and 5-hour versus 7- and 9-hour sleep groups was significant (3-hour = 5-hour < 7-hour = 9-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E3. Sleep latency for the 3-hour sleep group appeared to be shorter than sleep latency for the 5-, 7-, and 9-hour sleep groups (group simple effect, $p < .05$). However, only the difference between the 3- and 9-hour sleep group was significant (3-hour < 9-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E4. Sleep latency for the 3- and 5-hour sleep groups appeared to be shorter than latency for the 7- and 9-hour sleep groups (group simple effect, $p < .05$). Only the difference between the 3- and 9-hour sleep group was significant (3-hour < 9-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E5. Sleep latency for the 3- and 5-hour sleep groups was shorter than latency for the 7- and 9-hour sleep groups (group simple effect, $p < .05$). This difference between 3- and 5-hour versus 7- and 9-hour sleep groups was significant (3-hour = 5-hour < 7-hour = 9-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E6. Sleep latency for the 3- and 5-hour sleep groups was shorter than latency for the 7- and 9-hour sleep groups (group simple effect, $p < .05$). This difference between 3- and 5-hour versus 7- and 9-hour sleep groups was significant (3-hour = 5-hour < 7-hour = 9-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E7. Sleep latency for the 3- and 5-hour sleep groups appeared to be shorter than latency for the 7- and 9-hour sleep groups (group simple effect, $p < .05$). Latency for the 3-hour sleep group was significantly shorter than latency for the 7- and 9-hour sleep groups; also, latency for the 5-hour sleep group was significantly shorter than latency for the 9-hour sleep group (Tukey HSD, $p < .05$).

In short, during the experimental phase, although not always significant, the ordering of group mean sleep latency (from shortest to longest) remained consistent. Shortest sleep latency (indicating highest level of sleepiness) was consistently found in the 3-hour sleep group, followed by 5-, 7-, and 9-hour sleep groups, respectively.

Sleep-group effect on R1. No sleep group differences were found on Recovery Day 1 (group simple effect, $p > 05$).

Sleep-group effect on R2. Sleep latency for the 5-hour sleep group was longer than latencies for the other groups (group simple effect, $p < .05$). However, only the difference between the 5- and 3-hour sleep groups was significant (3-hour < 5-hour; Tukey HSD, $p < .05$).

Sleep-group effect on R3. Sleep latency for the 5-hour group was longer than latencies for the other groups (group simple effect, $p < .05$). Latency for both the 5-hour and 9-hour sleep groups was significantly longer than latency for the 3-hour sleep group (3-hour < 9-hour = 5-hour; Tukey HSD, $p < .05$).

Results of the previous analyses are summarized in **Appendix 4.**

Daytime Sleep Latency—Subjects Not Deemed Pathologically Sleepy

The following analyses were restricted to the subset of 42 subjects whose baseline average sleep latency scores (collapsed across time of day) were categorized as not pathologically sleepy by published criteria (sleep latency greater than 5 minutes—ASDA, 1992).

Figure 2-10 illustrates mean daytime sleep latency (collapsed across morning and afternoon tests) separately for each sleep group across baseline, experimental, and recovery sleep days.

At baseline, mean daytime sleep latency was similar among sleep groups. Sleep latency changed across experimental and recovery days in a dose-dependent manner (Sleep Group x Day interaction, $p < .05$).

Results of simple main-effects analyses of sleep group (separately for each day) are described next. Simple main-effects analyses of sleep group are used to determine whether differences existed among the four sleep groups on a particular day:

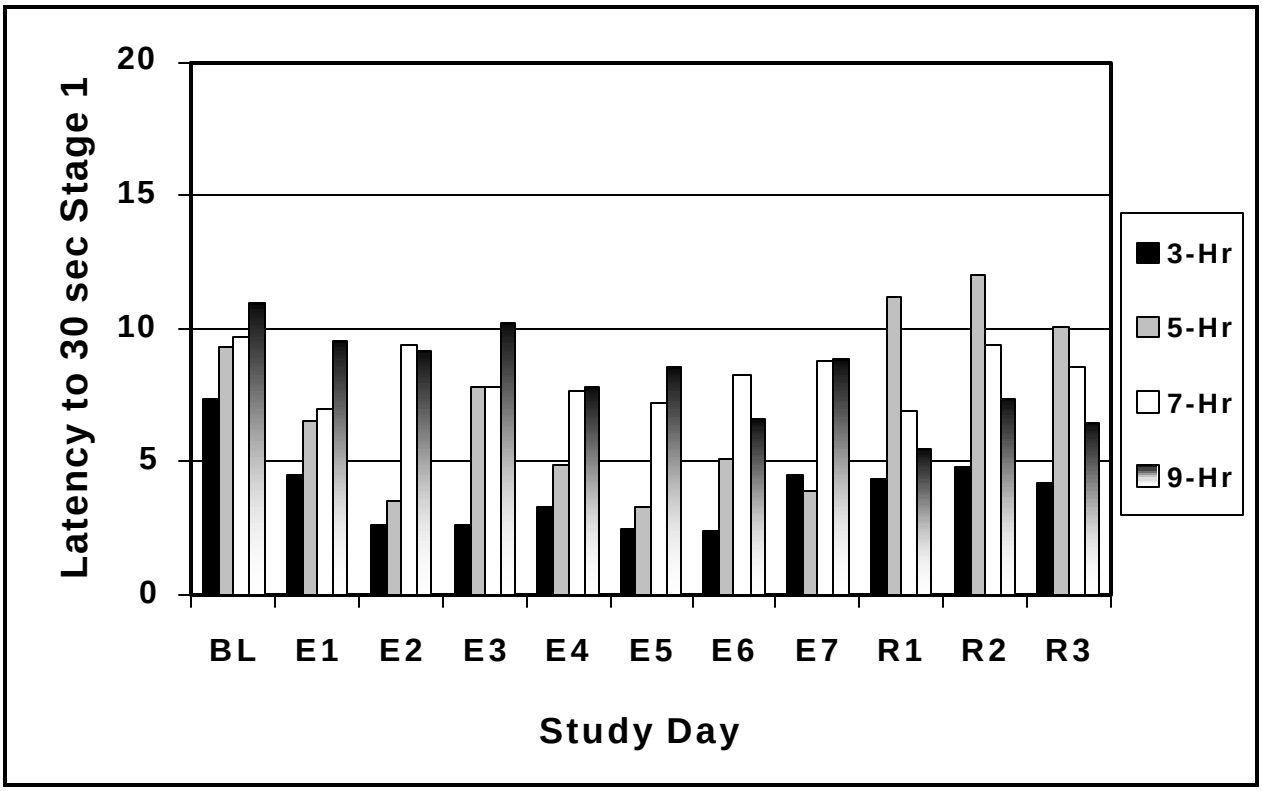

Figure 2-10. Mean latency to sleep (collapsed across time of day) as a function of sleep group (for nonpathologically sleepy subjects—baseline mean latency > 5 minutes) across study days.

Sleep-group effect on Baseline. No sleep-group differences were found on the baseline day (group simple effect, $p > 05$).

Sleep-group effect on E1. A marginal effect of group was found on E1 ($p = 0.49$). However, post-hoc Tukey HSD failed to reveal differences among groups ($p > .05$).

Sleep-group effect on E2. Sleep latency was similar for the 3- and 5-hour sleep groups and was shorter than latency for the 9- and 7-hour sleep groups (group simple effect, $p < .05$). The sleep latency difference between 3- and 5-hour versus 9- and 7-hour sleep groups was significant (3-hour = 5-hour < 9-hour = 7-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E3. Sleep latency for the 3-hour sleep group appeared to be shorter than sleep latency for the 7-, 5-, and 9-hour sleep groups (group simple effect, $p < .05$). However, only the difference between the 3- and 9-hour sleep group was significant (3-hour < 9-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E4. Sleep latency for the 3- and 5-hour sleep groups appeared to be shorter than latency for the 7- and 9-hour sleep groups (group simple effect, $p < .05$). Only

the difference between the 3- and 9-hour sleep groups was significant (3-hour < 9-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E5. Sleep latency for the 3- and 5-hour sleep groups was shorter than latency for the 7- and 9-hour sleep groups (group simple effect, $p < .05$). This difference between 3- and 5-hour versus 7- and 9-hour sleep groups was significant (3-hour = 5-hour < 7-hour = 9-hour; Tukey HSD, $p < .05$).

Sleep-group effect on E6. Sleep latency for the 3-hour sleep group was shorter than latency for the 9- and 7-hour sleep groups (group simple effect, $p < .05$; Tukey HDS, $p < .05$). The 3-hour sleep group did not differ from the 5-hour sleep group; likewise, the 5-hour sleep group did not differ from the 7- and 9-hour sleep groups (Tukey HSD, $p > .05$).

Sleep-group effect on E7. Sleep latency for the 5-hour sleep group was shorter than latency for the 7- and 9-hour sleep groups (group simple effect, $p < .05$; Tukey HSD, $p < .05$). Latency for the 3-hour sleep group did not differ from the 7- and 9-hour sleep groups (Tukey HSD, $p > .05$).

On all experimental days except E7, shortest sleep latency (indicating highest level of sleepiness) was found in the 3-hour sleep group. In contrast, ordering of group mean sleep latency (from shortest to longest) among the 5-, 7-, and 9-hour sleep groups varied across days.

Sleep-group effect on R1. Sleep latency for the 5-hour sleep group was longer than latencies for the other groups except the 7-hour sleep group (group simple effect, $p < .05$; Tukey HSD, $p < .05$). The 3-, 9-, and 7-hour sleep groups were not significantly different from each other (Tukey HSD, $p > .05$).

Sleep-group effect on R2. Sleep latency for the 5-hour sleep group was longer than latencies for the other groups except the 7-hour sleep group (group simple effect, $p < .05$; Tukey HSD, $p < .05$). The 3-, 9-, and 7-hour sleep groups were not significantly different from each other (Tukey HSD, $p > .05$).

Sleep-group effect on R3. Sleep latencies for the 5- and 7-hour sleep groups were longer than latency for the 3-hour sleep group (group simple effect, $p < .05$; Tukey HSD, $p < .05$). Latency was not different between the 3- and 9-hour sleep groups, nor among the 5-, 7-, and 9-hour sleep groups (Tukey HSD, $p > .05$).

Results of the above analyses are summarized in **Appendix 4**.

Objective Alertness: Microsleep

Microsleep and Sleep Associated with Simulator-Driving Crashes

A separate statistical analysis revealed a significant effect of sleep restriction on simulator-driving accidents (see Results section, Simulator-Driving [STISIM, Accidents, p. 2-73]). With respect to associated sleep events, Rechtschaffen and Kales (1968)-defined sleep episodes and alpha activity were not observed in the 1 minute prior to simulator-driving accidents. Microsleep events (as defined on p. 2-10), however, did occur.

Table 2-5 lists the number and percentage of simulator-driving accidents that were preceded by microsleep events up to 1 minute prior to the accidents, with the 1-minute period partitioned into bins corresponding to 31-60 s, 11-30 s, 6-10 s, and 0-2 s prior to the accident.

Table 2-5. Break-out by Sleep Group, Study Phase, and Time Preceding Crashes: Number and percentage of simulator-driving accidents preceded by microsleep up to 1 minute prior to accidents[1].

			Number / *Percentage*[2]				
Sleep Group[3]	**Study Phase**	**Total No. of Crashes**	**31-60 s**	**11-30 s**	**6-10 s**	**3-5 s**	**0-2 s**
3-h	Baseline	30	3 / *10.00*	4 / *13.33*	2 / *6.67*	0 / *0.00*	4 / *13.33*
3-h	Experiment	491	72/ *14.66*	60 / *12.22*	24 / *4.89*	19 / *3.87*	67 / *13.64*
3-h	Recovery	48	4 / *8.33*	5 / *10.42*	0 / *0.00*	0 / *0.00*	0 / *0.00*
5-h	Baseline	25	1 / *4.00*	1 / *4.00*	1 / *4.00*	0 / *0.00*	3 / *12.00*
5-h	Experiment	183	13 / *7.10*	13 / *7.10*	5 / *2.73*	9 / *4.92*	14 / *7.65*
5-h	Recovery	39	3 / *7.69*	3 / *7.69*	4 / *10.26*	5 / *12.82*	1 / *2.56*
7-h	Baseline	18	3 / *16.67*	2 / *11.11*	0 / *0.00*	2 / *11.11*	0 / *0.00*
7-h	Experiment	99	9 / *9.09*	4 / *4.04*	6/ *6.06*	2 / *2.02*	4 / *4.04*
7-h	Recovery	38	2 / *5.26*	2 / *5.26*	0 / *0.00*	1 / *2.63*	2 / *5.26*
9-h	Baseline	13	1 / *7.69*	2 / *15.38*	0 / *0.00*	1 / *7.69*	1 / *7.69*
9-h	Experiment	49	5 / *10.20*	5 / *10.20*	1 / *2.04*	3 / *6.12*	0 / *0.00*
9-h	Recovery	17	4 / *23.53*	1 / *5.88*	0 / *0.00*	1 / *5.88*	0 / *0.00*

[1]The simulator exposure or distance traveled was the same for all STISIM tests (185000 ft or ~35 mi/56 km).
[2] Percentages were calculated by dividing the total number of crashes preceded by microsleep up to 1 minute *per study phase* by the total number of crashes *per study phase*. [3]Subjects for the microsleep/sleep analyses numbered as follows: 3-h sleep group, n=17; 5-h sleep group, n=16; 7-h sleep group, n=16; and 9-h sleep group, n=16.

Table 2-6 lists the number and percentage of simulator-driving accidents that were preceded by a microsleep event up to 1 minute prior to the accidents for each study day. During the experimental sleep restriction phase (summarized in **Table 2-7**), 33 percent of driving accidents across all sleep groups were preceded by microsleep up to 1 minute prior to the accidents. This ranged from 49 percent to 29 percent, for the 3- and 9-hour sleep groups, respectively. When all days and accidents are considered across the sleep groups (**Table 2-7**), the total percentage remains approximately the same as the sleep restriction phase (33 percent).

Table 2-6. Break-out by Sleep Group and Day: Number and percentage of simulator-driving accidents preceded by microsleep up to 1 minute prior to accidents[1].

	Number and *Percentage*[2] Total Number of Crashes										
Sleep Group/Day	**B**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**R1**	**R2**	**R3**
3-h (n=17)	13 *43.33* 30	13 *38.23* 34	34 *54.84* 62	33 *49.25* 67	36 *50.70* 71	58 *50.88* 114	45 *49.45* 91	23 *44.23* 52	2 *16.67* 12	3 *17.65* 17	4 *21.05* 19
5-h (n=16)	6 *24.00* 25	10 *27.78* 36	9 *40.91* 22	6 *33.33* 18	4 *17.39* 23	9 *28.13* 32	6 *25.00* 24	10 *35.71* 28	6 *46.15* 13	5 *41.67* 12	5 *35.71* 14
7-h (n=16)	7 *38.89* 18	5 *41.67* 12	5 *50.00* 10	6 *33.33* 18	3 *17.65* 17	1 *6.67* 15	4 *30.77* 13	1 *7.14* 14	2 *18.18* 11	3 *27.27* 11	2 *12.50* 16
9-h (n=16)	5 *38.46* 13	1 *20.00* 5	5 *62.50* 8	1 *11.11* 9	2 *22.22* 9	0 *0.00* 2	3 *30.00* 10	2 *33.33* 6	2 *50.00* 4	3 *42.86* 7	1 *16.67* 6

[1]The simulator exposure or distance traveled was the same for all STISIM tests (185000 ft or ~35 miles/56 km).
[2]Percentages were calculated by dividing the total number of crashes preceded by microsleep *per day* divided by the total number of crashes *per day*.

Table 2-7. Summary: Number and percentage of simulator-driving accidents preceded by microsleep up to 1 minute prior to accidents[1].

	Number / *Percentage*[2] Total Number of Crashes	
Sleep Group/Phase	**Sleep Restriction Phase (Days E1-E7)**	**All Phases (Days B, E1-E7, R1-R3)**
3-h (n=17)	242 / *49.29* 491	264 / *46.40* 569
5-h (n=16)	54 / *29.51* 183	76 / *30.77* 247
7-h (n=16)	25 / *25.25* 99	39 / *25.16* 155
9-h (n=16)	14 / *28.57* 49	25 / *31.64* 79

[1]The simulator exposure or distance traveled was the same for all STISIM tests (185000 ft or ~35 mi/56 km).
[2]Percentages were calculated by dividing the total number of crashes preceded by microsleep up to 1 minute *per study phase* by the total number of crashes *per study phase*.

The maximum duration of microsleeps preceding accidents up to 1 minute ranged from 5.4 s for the 3-hour sleep group, 3.8 s for the 5-hour sleep group, 5.3 s for the 7-hour sleep group, and 2.9 s for the 9-hour sleep group. **Table 2-8** lists the number and percentage of microsleep events preceding accidents within 1 minute, partitioned into 1-s intervals corresponding to 1.0-1.9 s, 2.0-2.9 s, 3.0-3.9 s, 4.0-4.9 s, and 5.0-5.9 s. The majority of microsleep events were less than 3 s in duration.

Table 2-8. Break-out by Sleep Group and Duration of Microsleep: Number and percentage of simulator-driving accidents preceded by microsleep up to 1 minute prior to accidents.

Sleep Group	**Number of Crashes Preceded by Microsleeps**	**Number / *Percentage* Duration of Microsleep (in seconds)**				
		1.0-1.9	**2.0-2.9**	**3.0-3.9**	**4.0-4.9**	**5.0-5.9**
3-h (n=17)	264	136 / *51.52*	91 / *34.47*	29 / *10.98*	4 / *1.52*	4 / *1.52*
5-h (n=16)	76	34 / *44.74*	36 / *47.37*	6 / *7.89*	0 / *0.00*	0 / *0.00*
7-h (n=16)	39	25 / *64.10*	9 / *23.08*	4 / *10.26*	0 / *0.00*	1 / *2.56*
9-h (n=16)	25	16 / *64.00*	9 / *36.00*	0 / *0.00*	0 / *0.00*	0 / *0.00*

Table 2-9 lists the percentage of simulator-driving accidents preceded by microsleep up to 2 s prior to the accidents for each study day. Microsleep events did not immediately precede driving accidents on a frequent basis. During the experimental sleep restriction phase (summarized in **Table 2-10**), less than 7 percent of accidents across all 4 sleep groups were immediately preceded by microsleep. This ranged from 14 percent to 0 percent for the 3-hour and 9-hour sleep groups, respectively. When all study days and accidents are considered across the sleep groups (**Table 2-10**), the percentage is approximately the same as for the sleep restriction phase (less than 7 percent). Even when the entire 10 s prior to each accident is considered (see **Table 2-5**), only 110 (out of 491), or 22 percent, of simulator-driving accidents across the sleep restriction phase were preceded by microsleep for the 3-hour sleep group (the most severely sleep-deprived group).

Table 2-9. Break-out by Sleep Group and Day: Number and percentage of simulator-driving accidents preceded by microsleep up to 2 s prior to accidents[1].

	Number and *Percentage*[2] Total Number of Crashes										
Sleep Group/Day	**B**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**R1**	**R2**	**R3**
3-h (n=17)	4 *13.33* 30	2 *5.88* 34	9 *14.52* 62	10 *14.93* 67	9 *12.68* 71	15 *13.16* 114	17 *18.68* 91	5 *9.62* 52	0 *0.00* 12	0 *0.00* 17	0 *0.00* 19
5-h (n=16)	3 *12.00* 25	2 *5.56* 36	1 *4.55* 22	2 *11.11* 18	1 *4.35* 23	3 *9.38* 32	3 *12.50* 24	2 *7.14* 28	0 *0.00* 13	1 *8.33* 12	0 *0.00* 14
7-h (n=16)	0 *0.00* 18	2 *16.67* 12	2 *20.00* 10	0 *0.00* 18	0 *0.00* 17	0 *0.00* 15	0 0.00 13	0 *0.00* 14	0 *0.00* 11	1 *9.09* 11	1 *6.25* 16
9-h (n=16)	1 *7.69* 13	0 *0.00* 5	0 *0.00* 8	0 *0.00* 9	0 *0.00* 9	0 *0.00* 2	0 *0.00* 10	0 *0.00* 6	0 *0.00* 4	0 *0.00* 7	0 *0.00* 6

[1]The simulator exposure or distance traveled was the same for all STISIM tests (185000 ft or ~35 mi/56 km).
[2]Percentages were calculated by dividing the total number of crashes preceded by microsleep up to 2 s *per day* divided by the total number of crashes *per day*.

Table 2-10. Summary: Number and percentage of simulator-driving accidents preceded by microsleep up to 2 s prior to accidents[1].

	Number / *Percentage*[2] Total Number of Crashes	
Sleep Group/Phase	**Sleep Restriction Phase (Days E1-E7)**	**All Phases (Days B, E1-E7, R1-R3)**
3-h (n=17)	67 / *13.64* 491	71 / *12.48* 569
5-h (n=16)	14 / *7.65* 183	18 / *7.29* 247
7-h (n=16)	4 / *4.04* 99	6 / *3.87* 155
9-h (n=16)	0 / *0.00* 49	1 / *1.26* 79

[1]The simulator exposure or distance traveled was the same for all STISIM tests (185000 ft or ~35 mi/56 km).
[2]Percentages were calculated by dividing the total number of crashes preceded by microsleep up to 2 s *per study phase* by the total number of crashes *per study phase*.

Microsleep during Simulator-Driving Periods

The measures derived from the PSG scoring were: (a) relative number of microsleeps; (b) relative maximum duration of microsleeps; and (c) total relative amount of microsleep. The three measures were subjected to repeated-measures ANOVA with the 11 days as the repeated-measures factor since only one time period was used. There were 715 observations for the 65 subjects over 11 days.

The results of the ANOVA are summarized in **Appendix 4**.

Relative Number of Microsleeps. The repeated-measures ANOVA showed no significant differences between sleep groups or between days or Sleep Group x Day interaction for the relative number of microsleeps (see **Figure 2-11)**. Post hoc Tukey's means comparisons across days for between- and within-group differences, respectively, also indicated no significant differences.

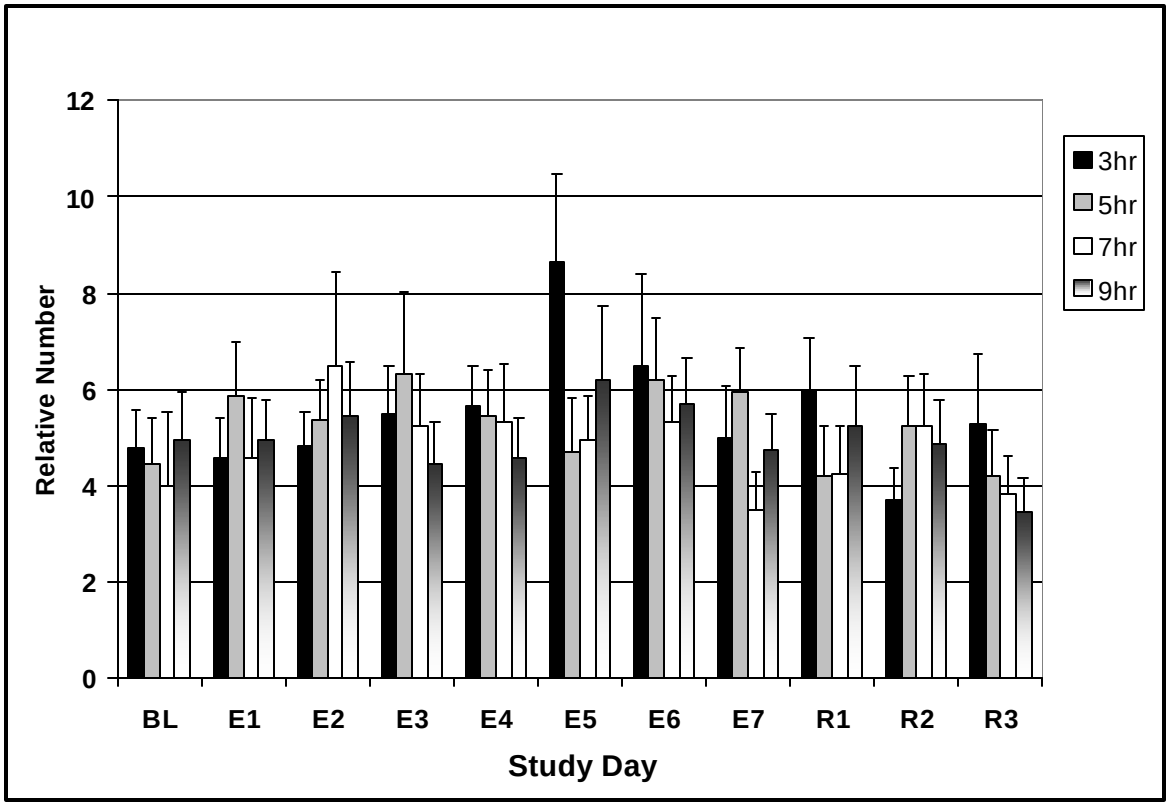

Figure 2-11. Relative number of microsleeps across days as a function of sleep group.

Relative Maximum Duration of Microsleeps. Similar to the analysis of relative number of microsleeps, ANOVA showed no significant differences between sleep groups, nor between days or Sleep Group x Day interaction for this measure (see **Figure 2-12**). Post hoc Tukey's means comparisons across days for between-group differences indicated significant difference on Experimental Day 5 between the 5-hour and 3-hour sleep groups. The within-group differences showed significance on only the 3-hour sleep group for Experimental Day 5, at which time the relative microsleep duration was greater during the second day of recovery (R2).

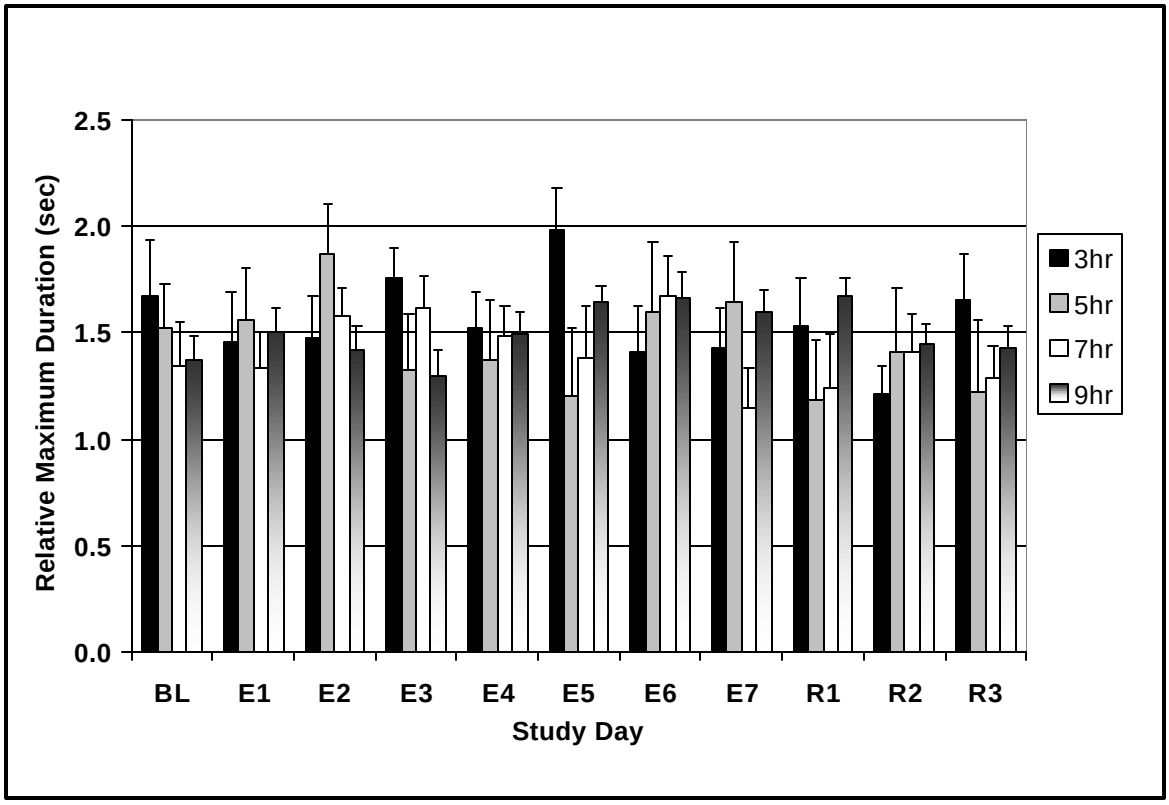

Figure 2-12. Relative maximum duration of microsleeps (seconds) across study days as a function of sleep group.

Relative Total Amount of Microsleep. The results of ANOVA for this measure were identical to that for relative number of microsleeps, with no significant differences between sleep groups, no between-days effects, and no Sleep Group x Day interaction for total relative amount of microsleep occurrence (see **Figure 2-13**). Post hoc Tukey's means comparisons across days for between- and within-group differences, respectively, also indicated no significant differences.

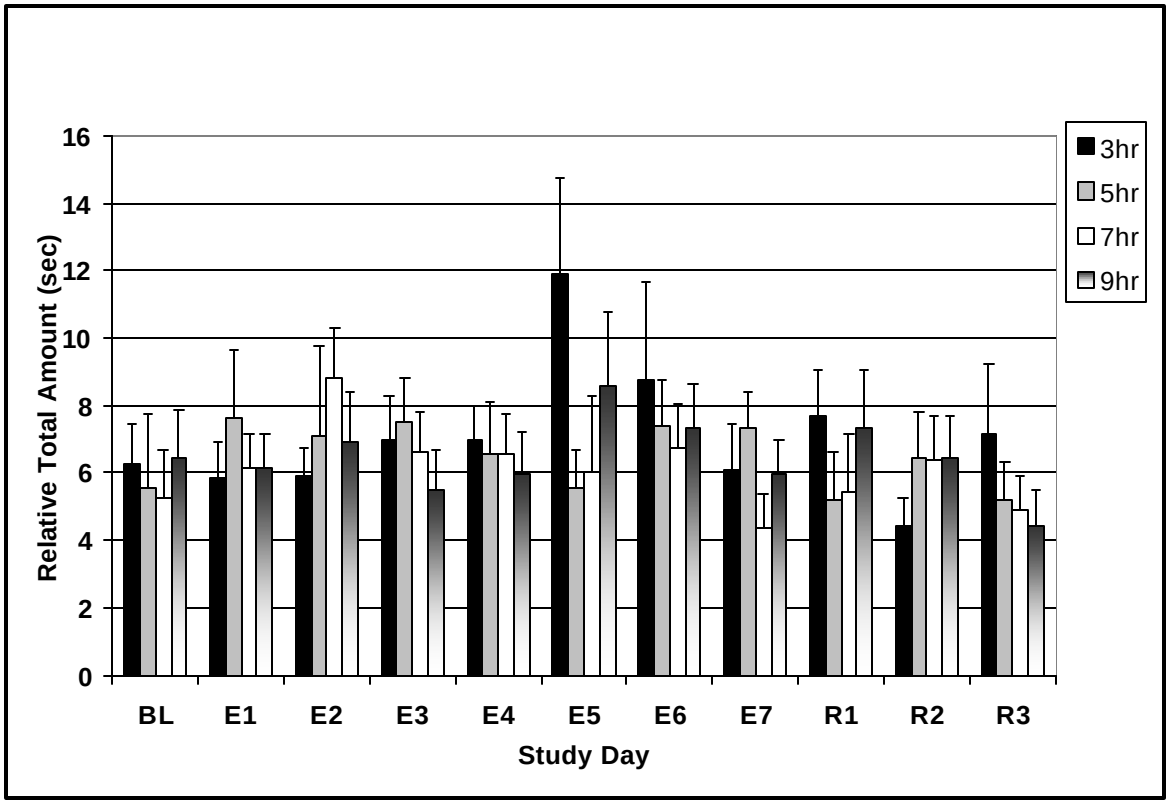

Figure 2-13. Relative total amount of microsleep (seconds) across study days as a function of sleep group.

Subjective Alertness: Stanford Sleepiness Scale

Daytime Stanford Sleepiness Scale (SSS) scores were analyzed using a three-way mixed Analysis of Variance (ANOVA) with sleep group (3-hour, 5-hour, 7-hour, 9-hour), day (11 days; B_1- R_3), and time of day (four levels—0900, 1200, 1500, and 2100 hours) as factors.

Figure 2-14 illustrates mean sleepiness scores for each sleep group across study days (collapsed across time of day).

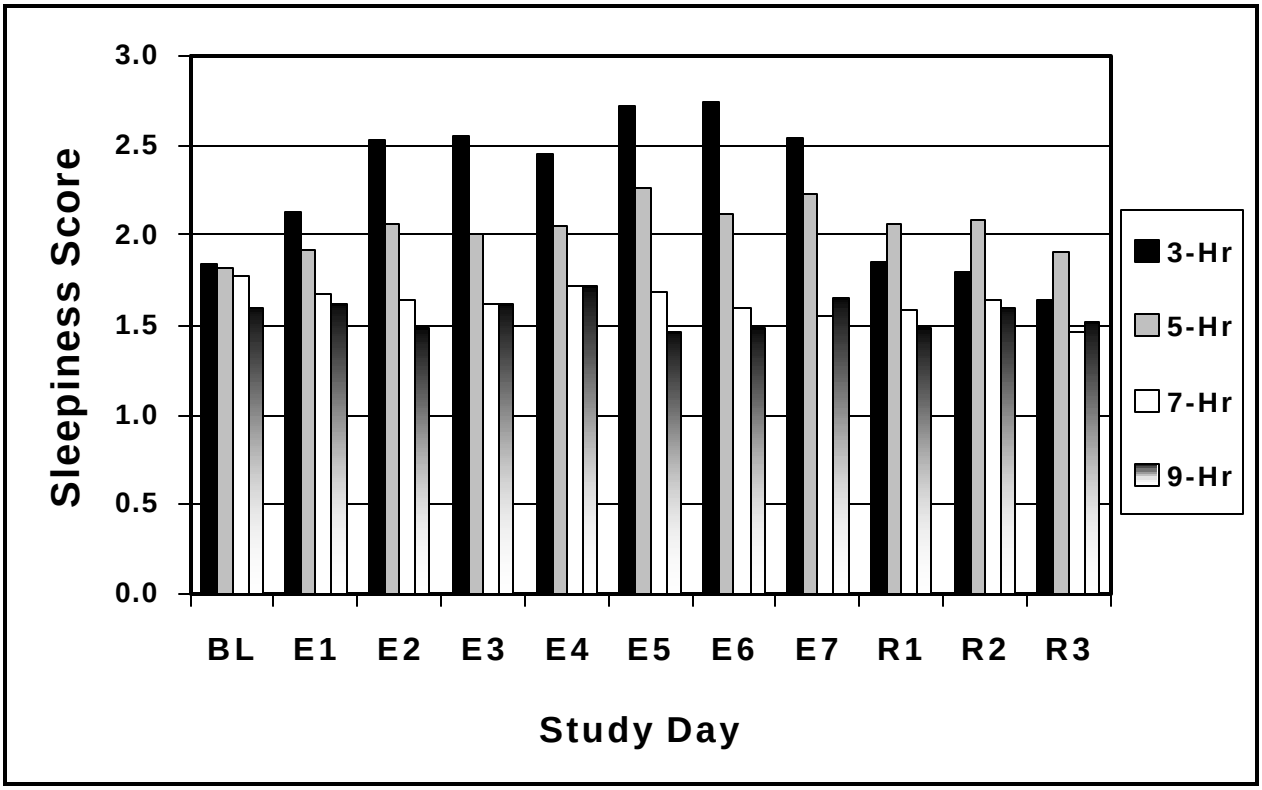

Figure 2-14. Mean sleepiness scores across study days (collapsed across time of day) as a function of sleep group.

Sleepiness scores differed significantly as a function of group (main effect, $p < .05$), day (main effect, $p < .05$), and time of day (main effect, $p < .05$). However, the main effects for group, day, and time of day also interacted (Day x Sleep Group, Day x Time of Day, and Time of Day x Sleep Group interactions, $p < .05$). Sleepiness scores for all groups increased across the baseline day. Across experimental days, mean daytime-sleepiness scores (collapsed across time of day) increased in the 3-hour sleep group, while sleepiness scores for the 5-, 7-, and 9-hour

sleep groups remained relatively stable. During the recovery phase, sleepiness scores for the 3-hour sleep group returned to those seen on the baseline day. The three-way Sleep Group x Day x Time of Day interaction was not significant ($p > .05$).

Results of this ANOVA are found in **Appendix 4**.

COGNITIVE PERFORMANCE

Serial Addition/Subtraction

The Serial Addition/Subtraction task generated three output measures: accuracy (percent correct), speed (reciprocal of reaction time), and throughput (speed * accuracy). These measures were analyzed separately. The task was administered at 0900, 1200, 1500, and 2100 hours each day during the study, thus providing four levels for the time-of-day factor. For this task, data were analyzed for 66 subjects over 11 days with four administrations per day and amounted to a total of 2,904 observations for each of the three test measures.

The results of the ANOVA are summarized in **Appendix 4**.

Accuracy. Response accuracy for serial addition/subtraction was not significantly different between sleep groups; however, differences among days ($F_{10,620} = 3.41$, $p = .0068$), and the interaction of Day x Sleep Group ($F_{30,620} = 2.47$, $p = .0028$), were significant. There were no significant time-of-day nor Time of Day x Sleep Group effects, but the Day x Time of Day interaction ($F_{30,1860} = 1.96$, $p = .0281$), was significant. The three-way interaction of Day x Time of Day x Sleep Group was not significant. Tukey's means comparisons showed, that with the exception of Experimental Days 1 and 2, accuracy of the 9-hour sleep group was greater than the other groups on a daily basis. Tukey's means comparisons for group differences within time of day reflect similar 9-hour sleep-group differences from the other sleep groups. **Figure 2-15** compares performance among the four sleep groups, as well as within group differences across the 11 days for this measure.

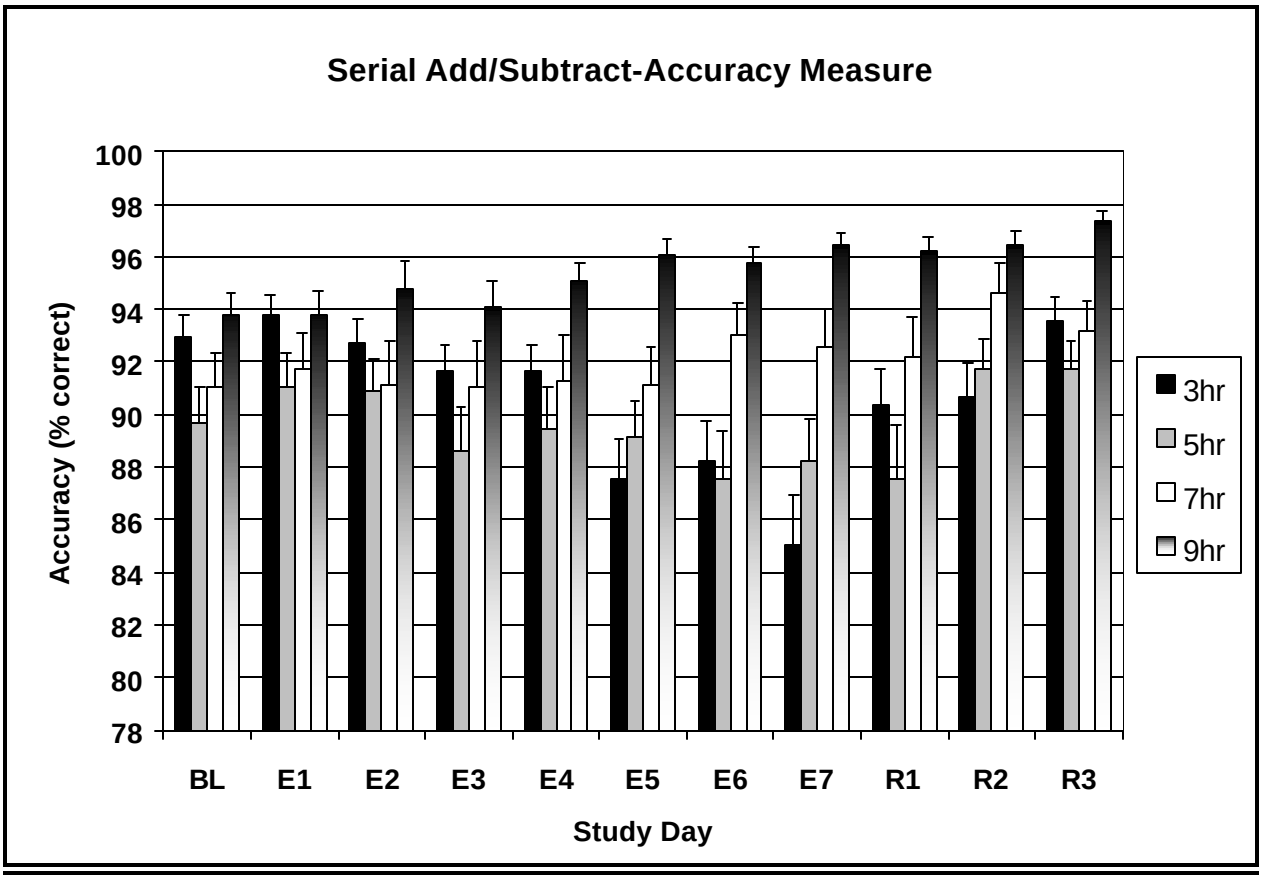

Figure 2-15. Serial addition/subtraction accuracy (percent correct) across study days as a function of sleep group.

Speed. Sleep groups did not differ with respect to mean speed; however, significant effects were evident for day ($F_{10,620} = 24.85$, $p < 0.0000$), Day x Sleep Group ($F_{30,620} = 2.82$, $p = 0.0001$), time of day ($F_{3,186} = 3.62$, $p = 0.0159$), and Day x Time of Day ($F_{30,1860} = 24.15$, $p < .0000$). The Time of Day x Sleep Group and Day x Time of Day x Sleep Group interactions were not significant. Tukey's group means comparisons showed no significant differences between groups only on the Baseline and first recovery days, while the differences among groups were significant for the other days. Tukey's means comparisons for group differences within time of day show no significant difference between sleep groups only at 0900 hours; otherwise, there were selective sleep-group differences. **Figure 2-16** compares performance among the four sleep groups, as well as within-group differences across the 11 days for this measure.

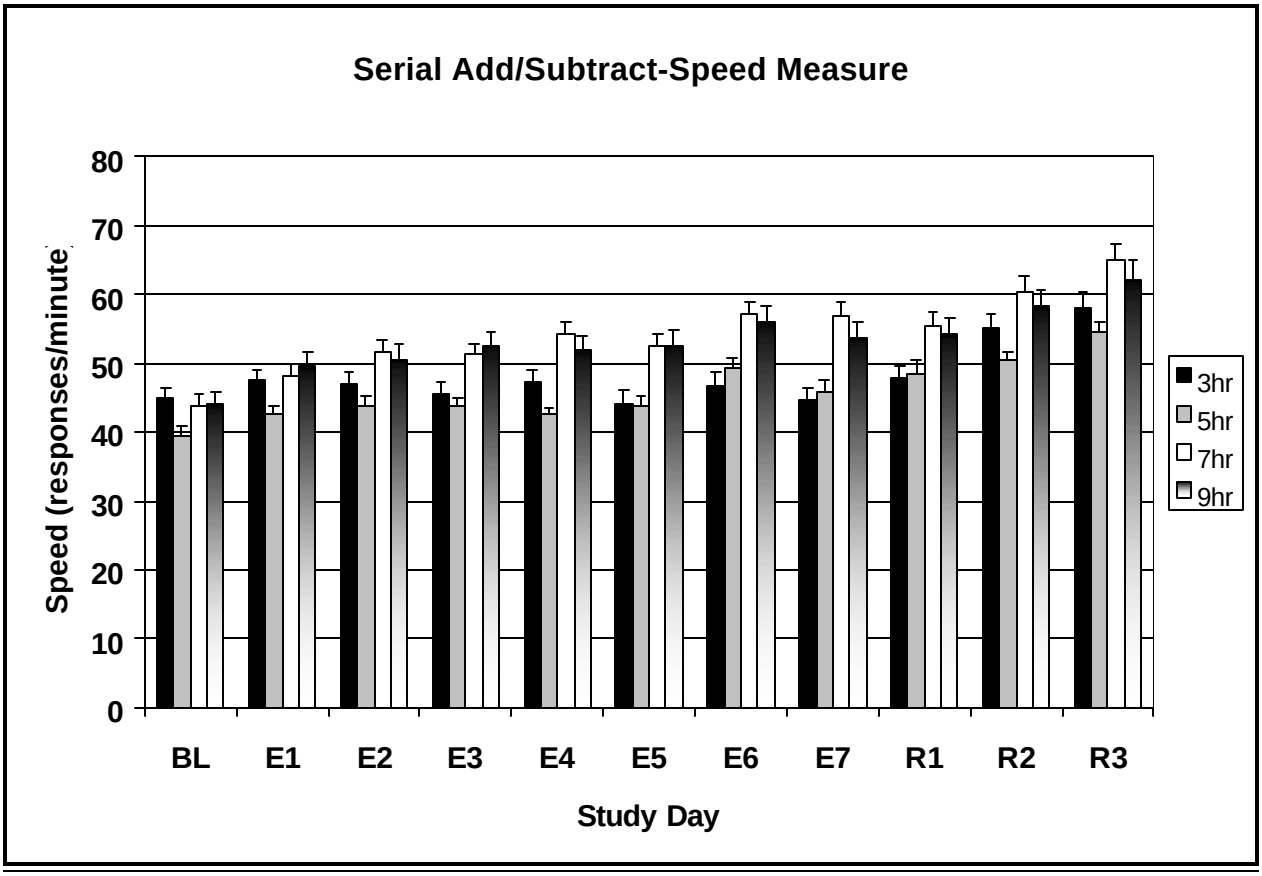

Figure 2-16. Serial addition/subtraction speed (1/RT) across study days as a function of sleep group.

Throughput. Because this measure is a composite of speed with accuracy, with speed being the greater influence, results of statistical analyses were comparable to that for speed. Consequently, no significant differences were found between sleep groups. However, significant differences were evident for day ($F_{10,620} = 23.95$, $p < 0.0000$), Day x Sleep Group ($F_{30,620} = 3.78$, $p < 0.0000$), time of day ($F_{3,186} = 5.01$, $p = 0.0027$), and Day x Time of Day ($F_{30,1860} = 25.86$, $p <$ .0000). The Time of Day x Sleep Group and Day x Time of Day x Sleep Group interactions were not significant. However, Tukey's means comparisons show significant differences daily between selective groups. Tukey's means comparisons for group differences within time of day also show significant differences between selective groups at each testing time. **Figure 2-17** compares performance among the four sleep groups, as well as within-group differences across the 11 days for this measure.

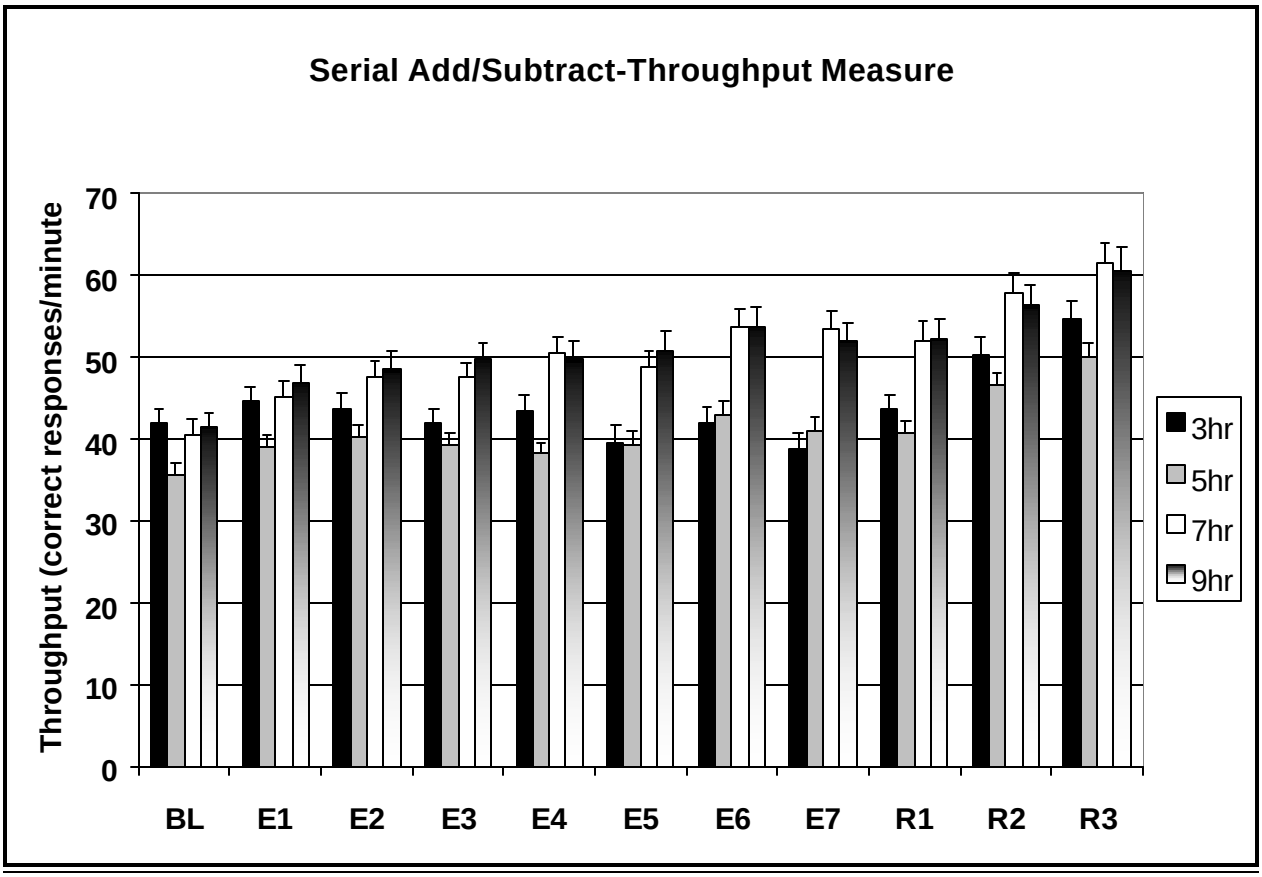

Figure 2-17. Serial addition/subtraction throughput (speed * accuracy) across study days as a function of sleep group.

4-Choice Reaction Time

The 4-Choice Reaction Time task also generated three output measures of accuracy, speed, and throughput and was administered at 1000 and 1600 hours each day during the study providing two levels for the time-of-day factor.

The results of the ANOVA are summarized in **Appendix 4**.

Accuracy. Response accuracy for this task was significantly different among sleep groups ($F_{3,62} = 2.86$, $p = .0438$) and between days ($F_{10,620} = 5.11$, $p = .0020$) while Day x Sleep Group interaction was not. Time-of-day effects were not significant, nor were any of the interactions. Tukey's means comparisons show no significant differences among groups for the Baseline, Experiment 1, Experiment 2, and Experiment 4 days, with selective group differences in the other days. Tukey's means comparisons for time-of-day differences reflect the partition of the 9- and 7-hour sleep groups differences from the 5- and 3-hour sleep groups for both test times. **Figure 2-18** compares performance among the four sleep groups, as well as within group differences across the 11 days for this measure.

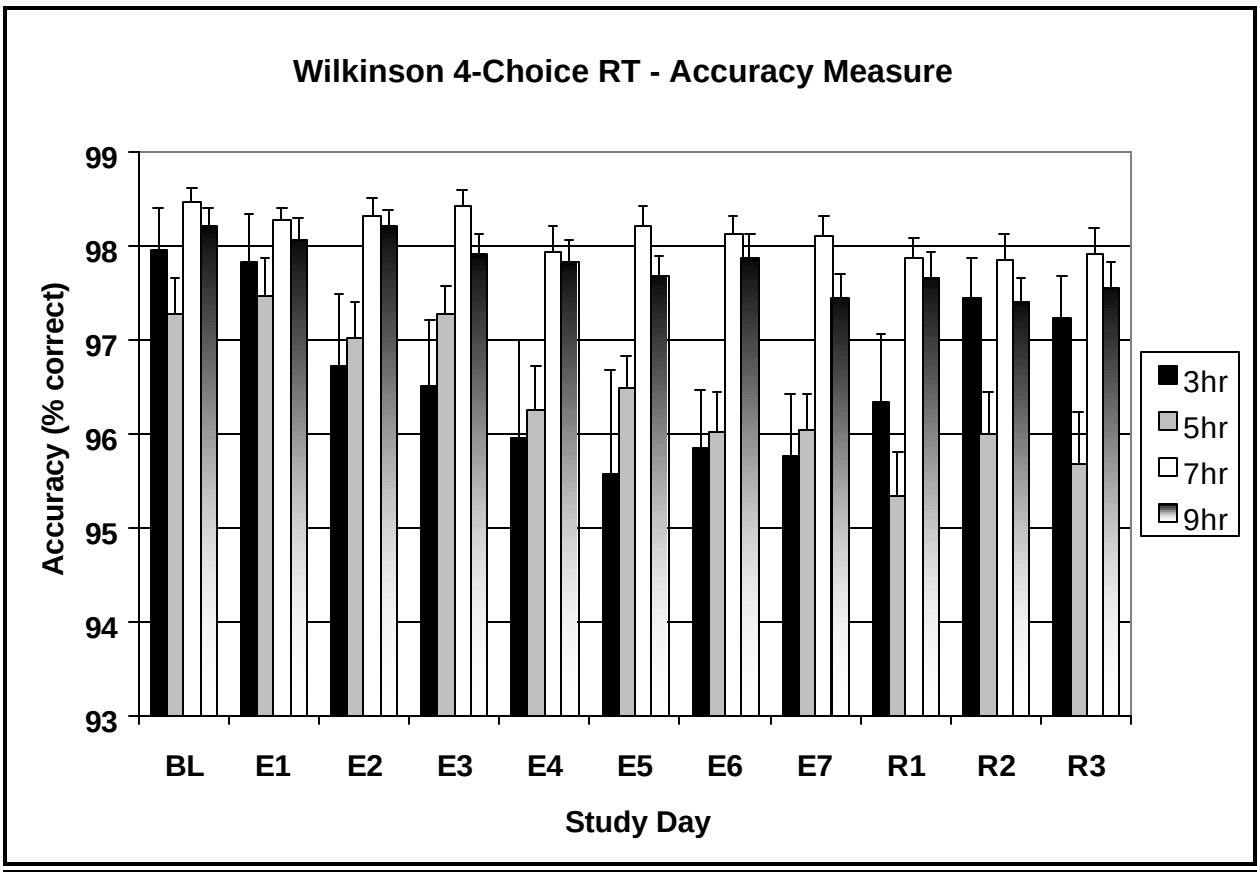

Figure 2-18. Wilkinson 4-Choice reaction time accuracy across study days as a function of sleep group.

Speed. Speed for this task was significantly different among sleep groups ($F_{3,62} = 6.18$, $p = 0.0010$), days ($F_{10,620} = 28.13$, $p < 0.0000$), and Day x Sleep Group ($F_{30,620} = 3.33$, $p = 0.0010$). The time-of-day effect was not significant, nor was the Time of Day x Sleep Group interaction. Interactions of Day x Time of Day ($F_{10,620} = 20.82$, $p < 0.0000$), and Day x Time of Day x Sleep Group ($F_{30,620} = 1.79$, $p = 0.0466$) were significant. Tukey's comparisons show significant differences between selective groups on all days. Tukey's means comparisons for group differences within time of day show significant differences between the 3-hour sleep group versus the other three sleep groups for both test times. **Figure 2-19** compares performance among the four sleep groups as well as within group differences across the 11 days for this measure.

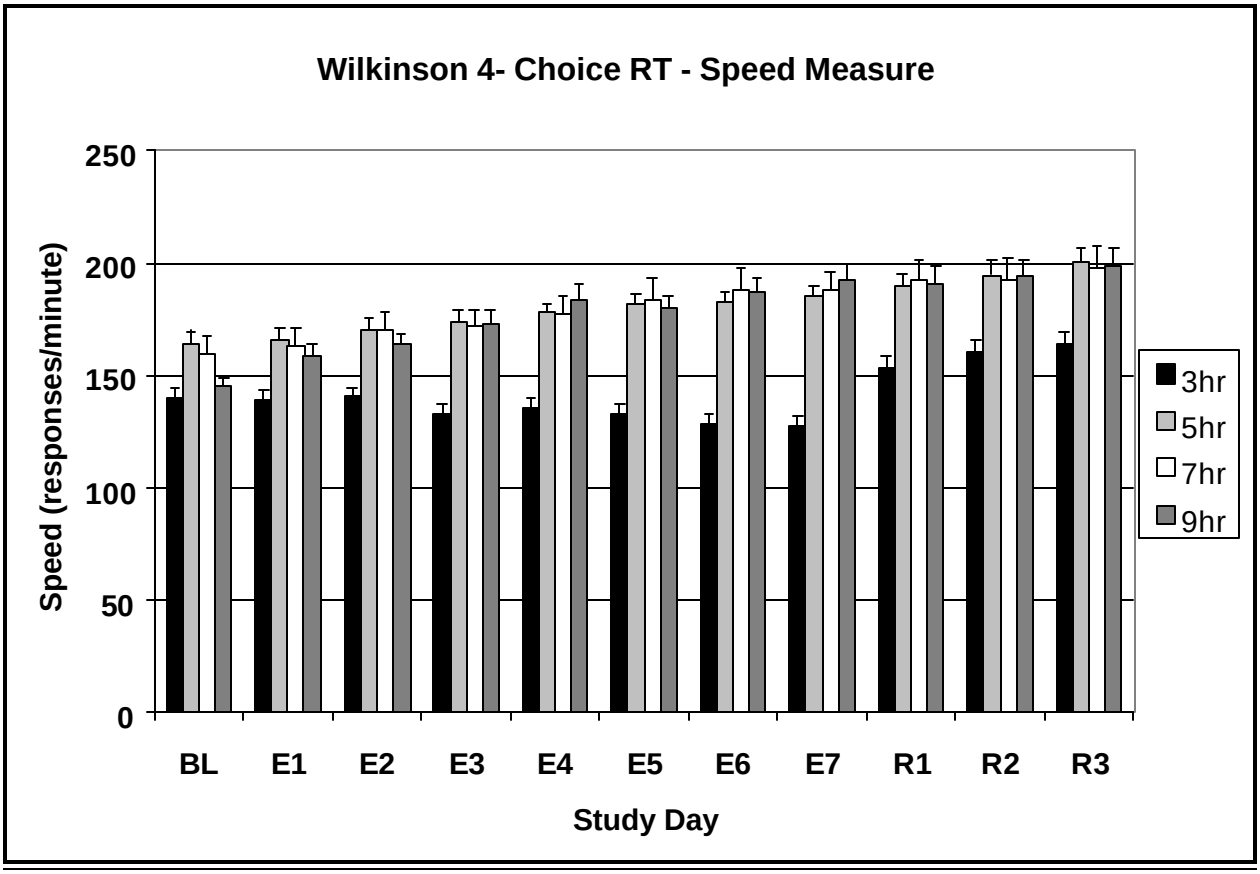

Figure 2-19. Wilkinson 4-Choice reaction time speed across study days as a function of sleep group.

Throughput. Results of statistical analysis for this measure paralleled those for mean speed. Significant differences were found among sleep groups ($F_{3,62} = 6.48$, $p = 0.0007$), days ($F_{10,620} = 24.48$, $p < 0.0000$), and for Sleep Group x Day ($F_{30,620} = 3.56$, $p = 0.0004$). Neither time of day nor Time of Day x Sleep Group effects were significant. However, Day x Time of Day ($F_{10,620} = 19.59$, $p < 0.0035$), and Day x Time of Day x Sleep Group ($F_{30,620} = 1.87$, $p = 0.0328$) were significant. Tukey's means comparisons within days and group differences for time of day show essentially the same daily significant differences between selective groups as for the speed measure. **Figure 2-20** compares performance among the four sleep groups, as well as within group differences across the 11 days for this measure.

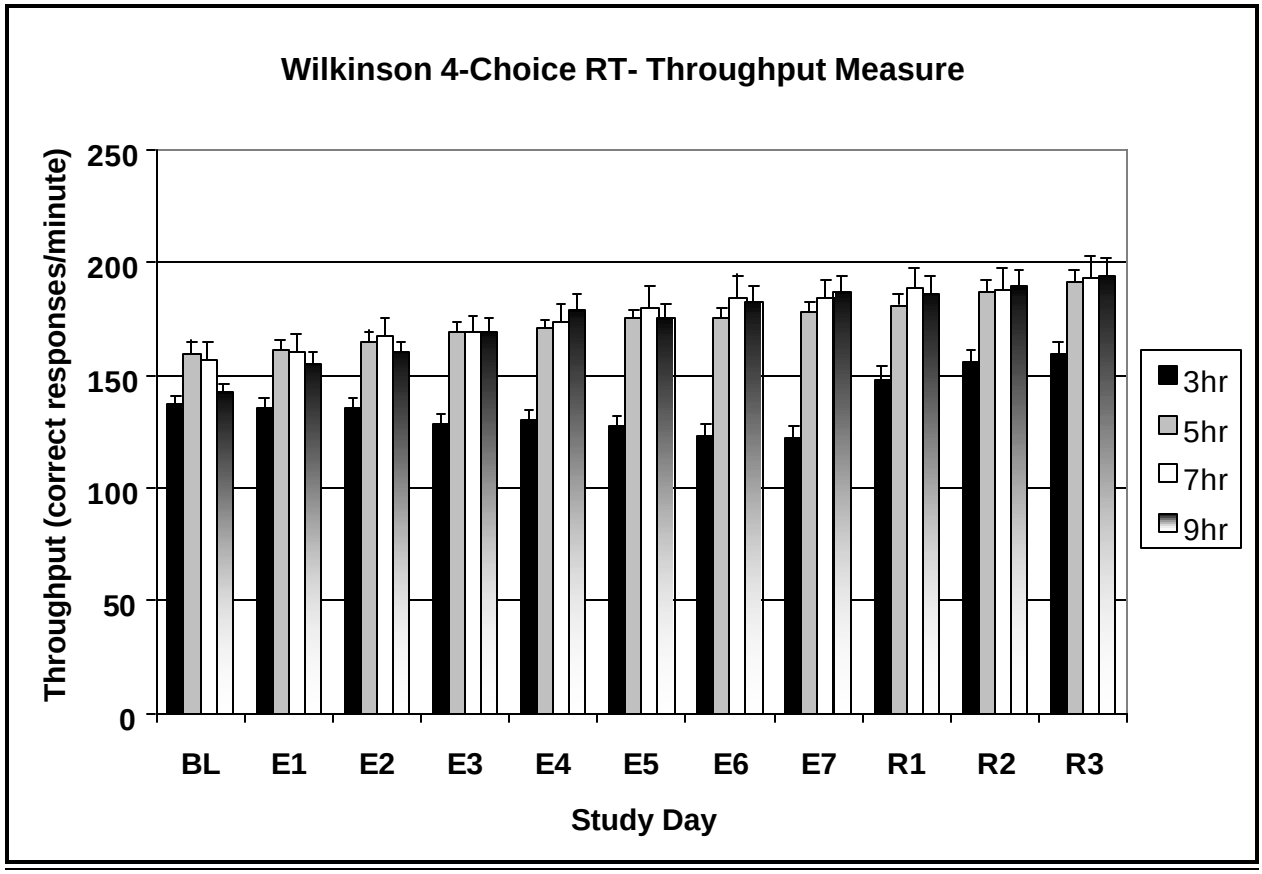

Figure 2-20. Wilkinson 4-Choice reaction time throughput across study days as a function of sleep group.

10-Choice Reaction Time

The 10-Choice Reaction Time task, like the previous two tasks, generated three output measures of accuracy, speed, and throughput and was administered during the same test sessions as the Serial Add/Subtract task at 0900, 1200, 1500, and 2100 hours each day during the study.

The results of the ANOVA are given in **Appendix 4**.

Accuracy. Response accuracy for this task was not significantly different among sleep groups or days; however, the Day x Sleep Group interaction ($F_{30,620} = 2.00$, $p = 0.0170$), and time of day ($F_{3,186} = 3.50$, $p = .0202$) were significant. No other interactions were significant. Tukey's means comparisons show no significant differences among groups for the Experiment 1, Experiment 2, and Recovery 3 days. Selective group differences were found on the other days, mainly of the 3-hour sleep group differences with the other three sleep groups. Tukey's means comparisons for time-of-day differences reflect the 9-hour sleep-group differences with the other three groups for all times of day and the 7-hour sleep-group difference from the 5-hour sleep group for the 0900- and 1500-hours test times. **Figure 2-21** compares performance among the four sleep groups, as well as within group differences across the 11 days for this measure.

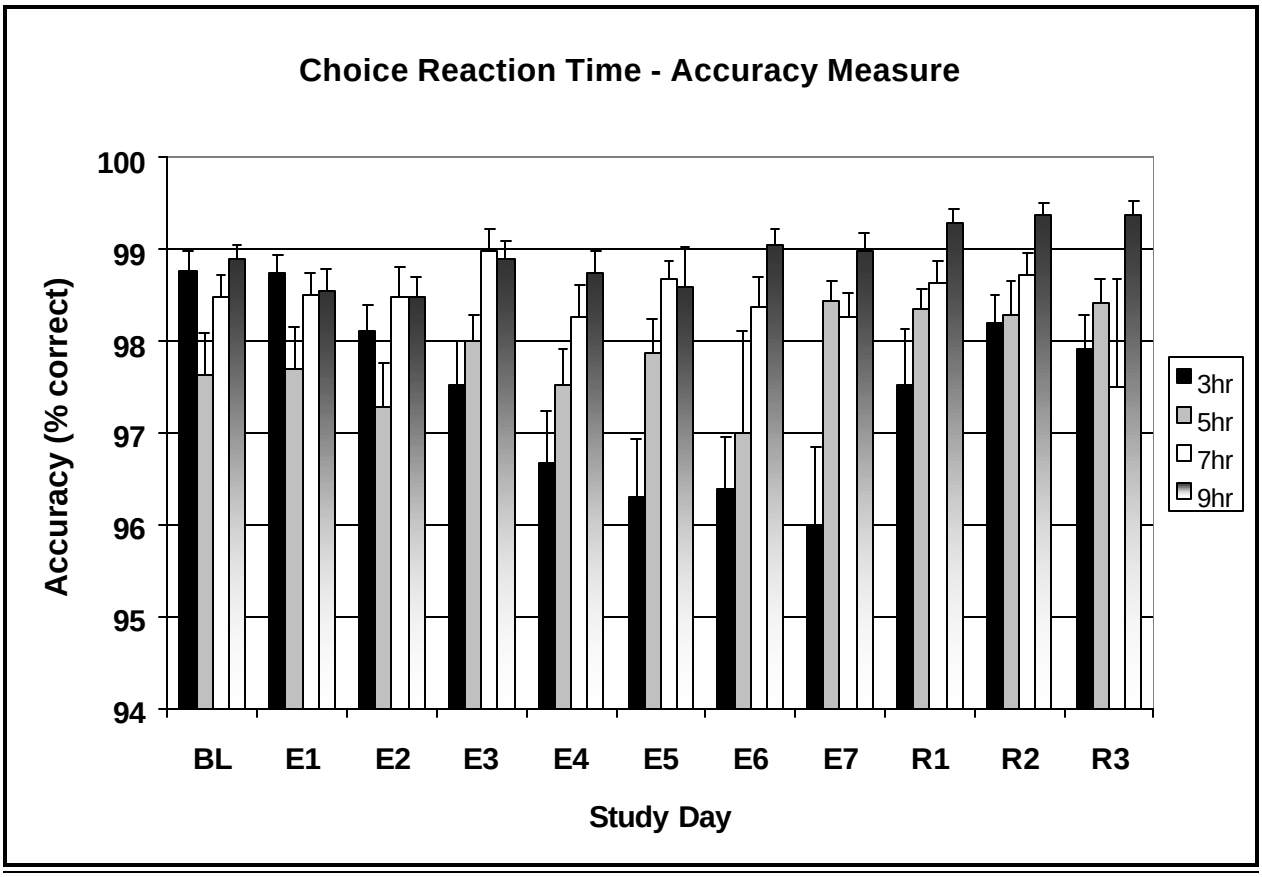

Figure 2-21. 10-choice reaction time accuracy across study days as a function of sleep group.

Speed. Speed for this task was not significantly different among sleep groups or time of day. However, highly significant differences were found for day ($F_{10,620} = 30.56$, $p < 0.0000$), Day x Sleep Group ($F_{30,620} = 3.68$, $p < 0.0000$), Time of Day x Sleep Group ($F_{9,186} = 2.52$, $p = 0.0106$), Day x Time of Day ($F_{30,1860} = 17.42$, $p < 0.0000$), and Day x Time of Day x Sleep Group ($F_{90,1860} = 1.95$, $p = 0.0002$). Tukey's means comparisons showed no significant differences between groups for Baseline, Experiment 1, Recovery 2, and Recovery 3 days, while the remaining days reflected mainly the 3-hour sleep-group differences with the other three groups. Tukey's means comparisons for group differences within times of day showed no significant difference among groups for the 0900 hours test time, but did show differences for the 9- and 7-hour sleep groups with the 3- and 5-hour sleep groups for the other three test times. **Figure 2-22** compares performance among the four sleep groups, as well as within group differences across the 11 days for this measure.

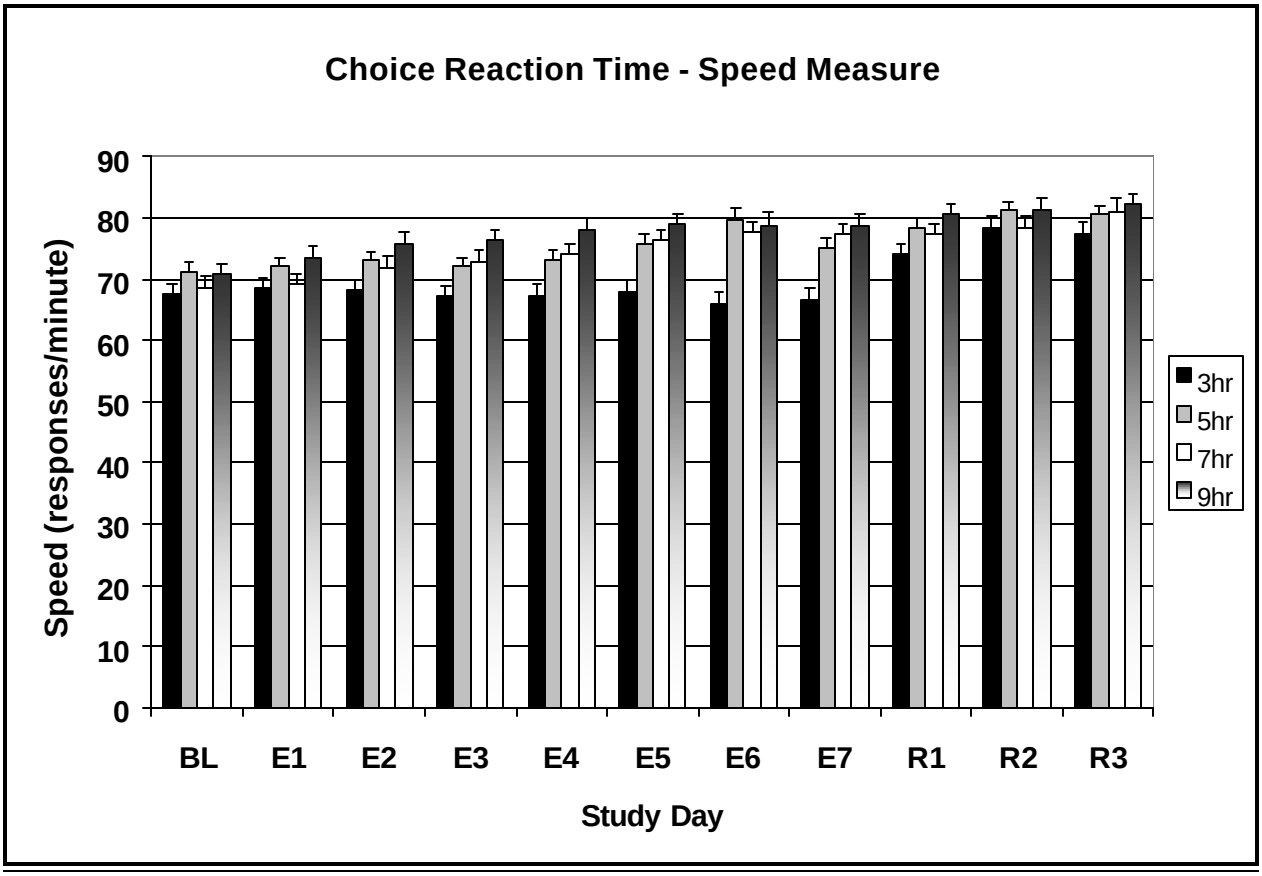

Figure 2-22. 10-choice reaction time speed across study days as a function of sleep group.

Throughput. As with 4-Choice Reaction Time, results of statistical analysis for this measure were similar to that for speed. There were no significant differences for either sleep group or time of day. However, significant differences were found for day ($F_{10,620} = 26.02$, $p < 0.0000$), Day x Sleep Group ($F_{30,620} = 4.01$, $p < 0.0000$), Day x Time of Day ($F_{30,1860} = 16.34$, $p < 0.0000$), Time of Day x Sleep Group interaction ($F_{9,186} = 2.53$, $p = 0.0103$), and Day x Time of Day x Sleep Group ($F_{90,1860} = 1.94$, $p < 0.0002$). Tukey's means comparisons for within days reflect the same statistical results as for the speed measure. Sleep-group differences for time of day show essentially the same daily significant differences among selective groups as for the speed measure, with the exception that at 0900 hours, the 5-hour sleep group was statistically different from the 3-hour sleep group. **Figure 2-23** compares performance among the four sleep groups, as well as within group differences across the 11 days for this measure.

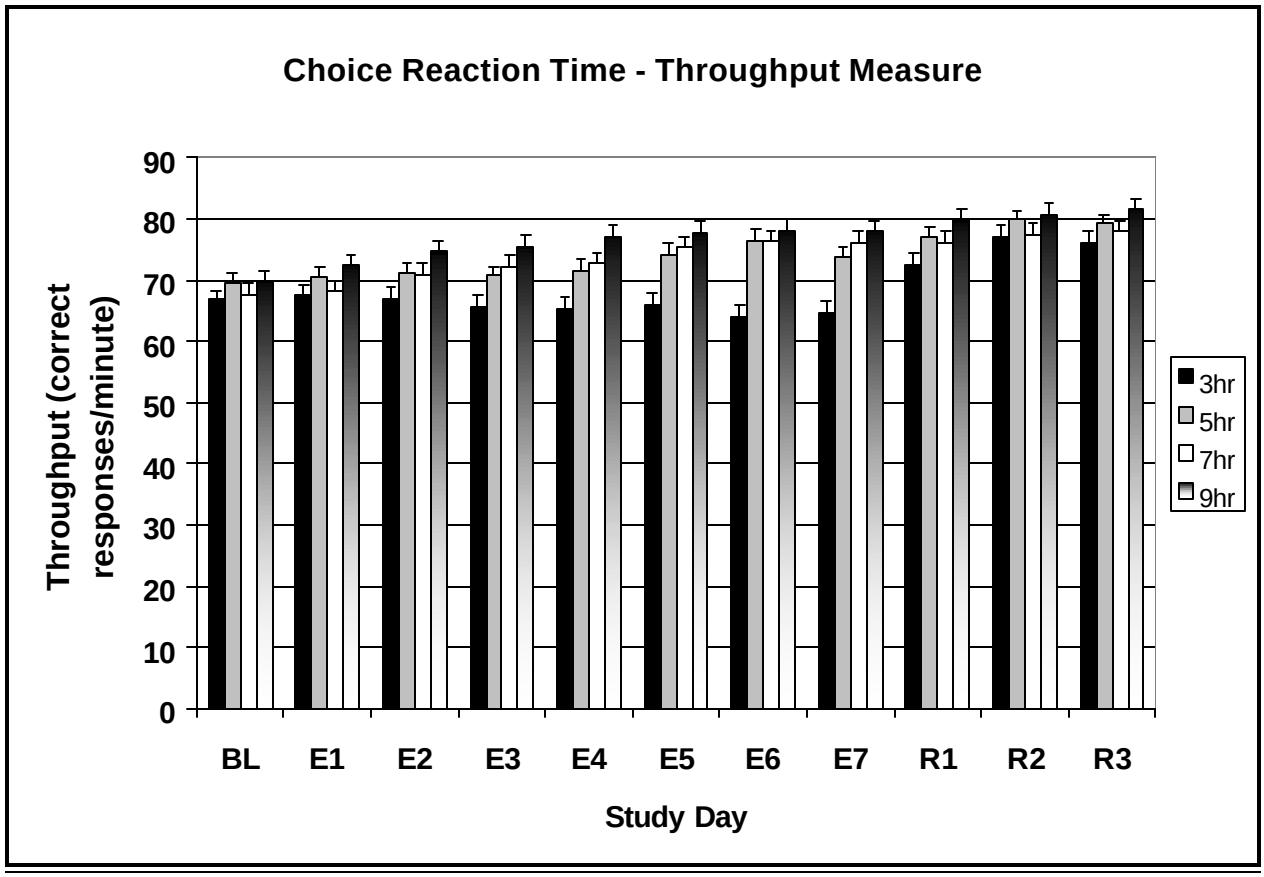

Figure 2-23. 10-choice reaction time throughput across study days as a function of sleep group.

Psychomotor Vigilance Task (PVT)

The Psychomotor Vigilance Task (PVT) was administered during the same test sessions but following the other performance tasks at 0930, 1230, 1530, and 2130 hours. Accuracy is not a meaningful measure on a forced one-choice (no choice) simple reaction time task, nor is throughput calculable. Two output measures were analyzed: mean speed (1/RT) and the number of RTs exceeding 0.5 s, sometimes called "lapses."

The results of the ANOVA are given in **Appendix 4**.

Speed. Speed for this task was significantly different among sleep groups ($F_{3,62} = 30.70$, $p < 0.0000$), between days ($F_{10,620} = 9.58$, $p < 0.0000$), Day x Sleep Group ($F_{30,620} = 4.25$, $p < .0000$), Day x Time of Day ($F_{30,1860} = 5.62$, $p < .0000$), and Day x Time of Day x Sleep Group ($F_{90,1860} = 3.04$, $p < .0000$). Time-of-day difference was not significant, nor was Time of Day x Sleep Group interaction. Tukey's means comparisons showed no significant differences among groups for the Baseline day, while the remaining days reflected the 9-hour sleep-group difference from the other three groups. Tukey's means comparisons for group differences within times of day show mainly the 9- and 7-hour sleep-group differences from the 3- and 5-hour sleep groups for all test times. **Figure 2-24** compares performance among the four sleep groups, as well as within group differences across the 11 days for this measure.

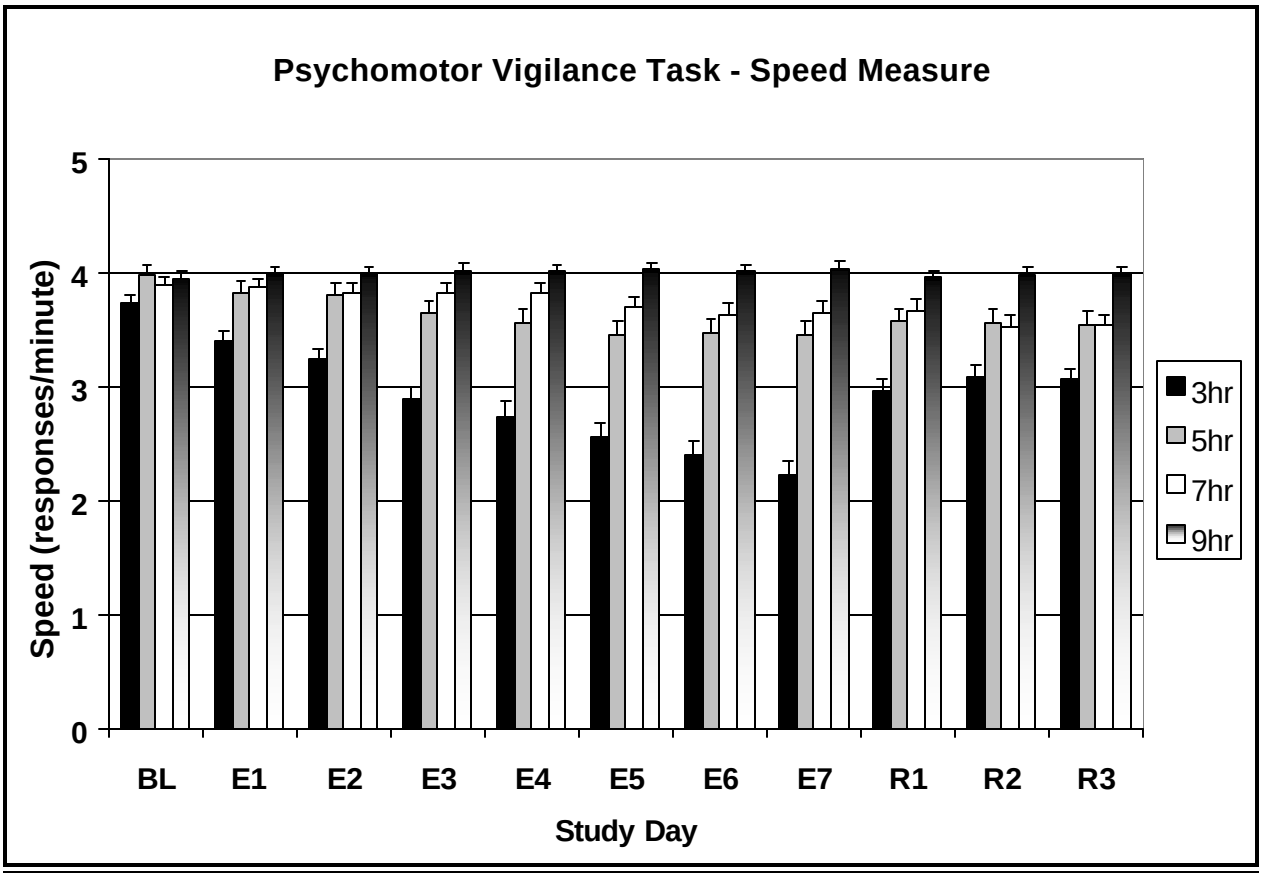

Figure 2-24. Mean speed (1/RT) on the psychomotor vigilance task (simple reaction time task) across study days by sleep group.

Lapses. Since number of lapses is not a normally distributed measure, transformation of these data was necessary to achieve a normal distribution; hence, 1 was added to each datum followed by log transformation. The Greenhouse-Geisser epsilon value of 0.9762 (with 1.0 the maximum value) and the fact that no corrections were made for the probability values in the repeated-measures ANOVA affirmed that the transform resulted in data having the necessary compound symmetry for repeated-measures analysis. The difference among sleep groups was highly significant ($F_{3,62} = 41.13$, $p < .0000$), as were day ($F_{10,620} = 8.13$, $p < 0.0000$), Day x Sleep Group ($F_{30,620} = 3.14$, $p = .0003$), Day x Time of Day ($F_{30,1860} = 4.99$, $p < .0000$), and Day x Time of Day x Sleep Group ($F_{3,2046} = 2.76$, $p < .0000$). Effects of time of day and Time of Day x Sleep Group were not significantly different. Tukey's means comparisons show no significant differences among groups for Baseline day only, while the remaining days reflect the 9- and 7-hour sleep-group difference from the other groups. Tukey's means comparisons for time-of-day

differences are identical to those for the Speed measure. **Figure 2-25** compares performance among the four sleep groups, as well as within-group differences, across the 11 days for this measure.

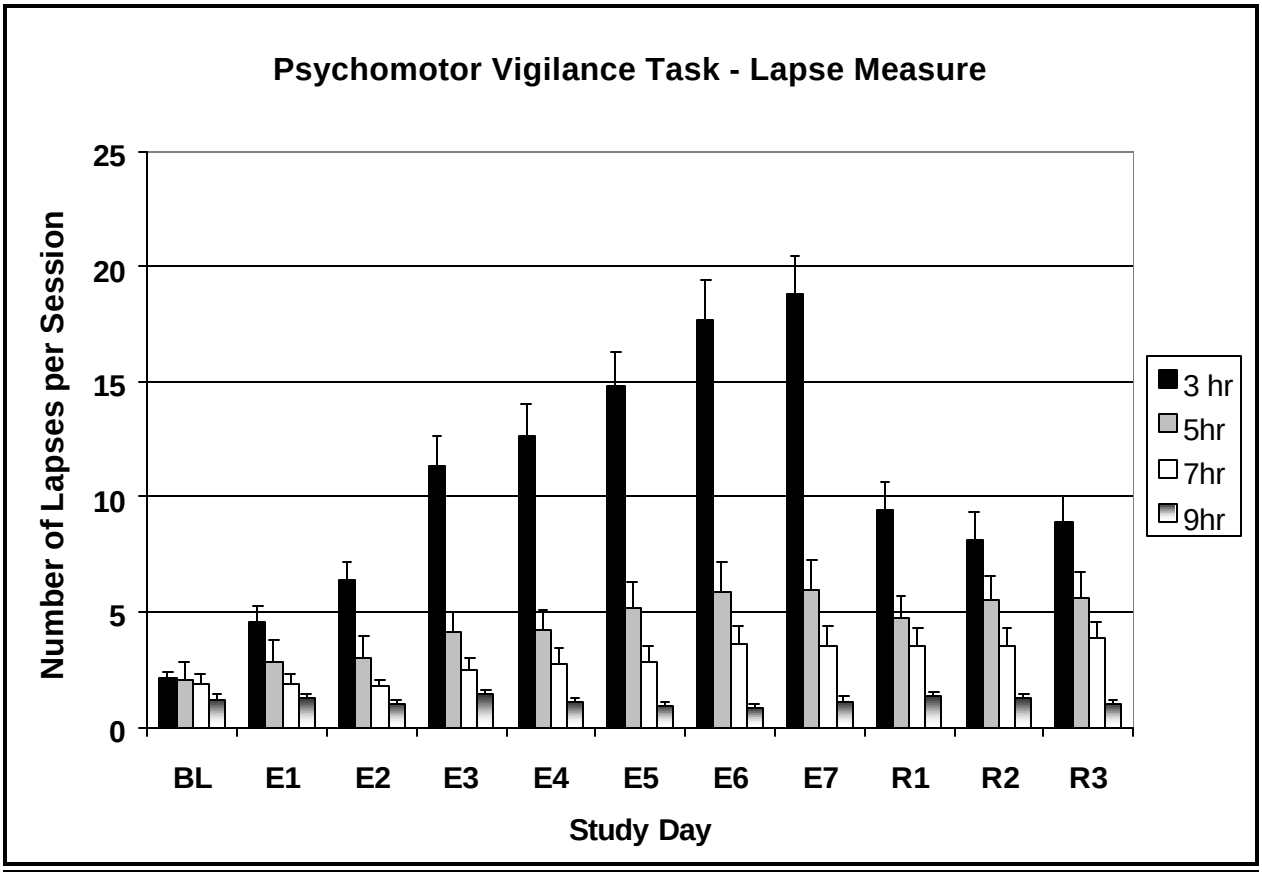

Figure 2-25. Mean number of response times greater than 0.5 s, on the psychomotor vigilance task across study days by sleep group.

Synthetic Work Task (SYNWORK)

The Synthetic Work Task generated only one output measure, a total (composite) score that was the weighted sum from the four different tasks within this test (see Methods). Because some of the scores generated were negative in value, the largest of the negative values was added to each datum. This total score and log and square-root transformations of the score were each

analyzed by repeated-measures ANOVA. Surprisingly, the total score showed the largest Greenhouse-Geisser epsilon (0.9384), followed by the square-root transform (0.9239), with the log transform the smallest (0.8984). Based on the Greenhouse-Geisser criterion, the statistical-analysis results from total score are presented here. The task was administered during the same test sessions but following the Serial Add/Subtract task at 0915, 1215, 1515, and 2115 hours each day during the study.

The results of the ANOVA are given in **Appendix 4**.

Total score. The score for this task was not significantly different among sleep groups nor for Time of Day x Sleep Group. Significant differences were found for all other effects and interactions as follows: day ($F_{10,620} = 20.60$, $p < 0.0000$), time of day ($F_{3,186} = 4.46$, $p = .0096$), Sleep Group x Day ($F_{30,620} = 5.28$, $p < 0.0000$), Day x Time of Day ($F_{30,1860} = 25.70$, $p < 0.0000$), Day x Time of Day x Sleep Group ($F_{90,1860} = 1.61$, $p = 0.0210$). Tukey's means comparisons showed no significant differences among groups for Experiment 2 and Recovery 3 days, while the remaining days reflect the 9-hour sleep-group differences from the other three groups. Tukey's means comparisons for group differences within times of day show mainly the 9-hour sleep-group differences from the other three sleep groups for all test times. **Figure 2-26** compares performance among the four sleep groups, as well as within group differences, across the 11 days for this measure.

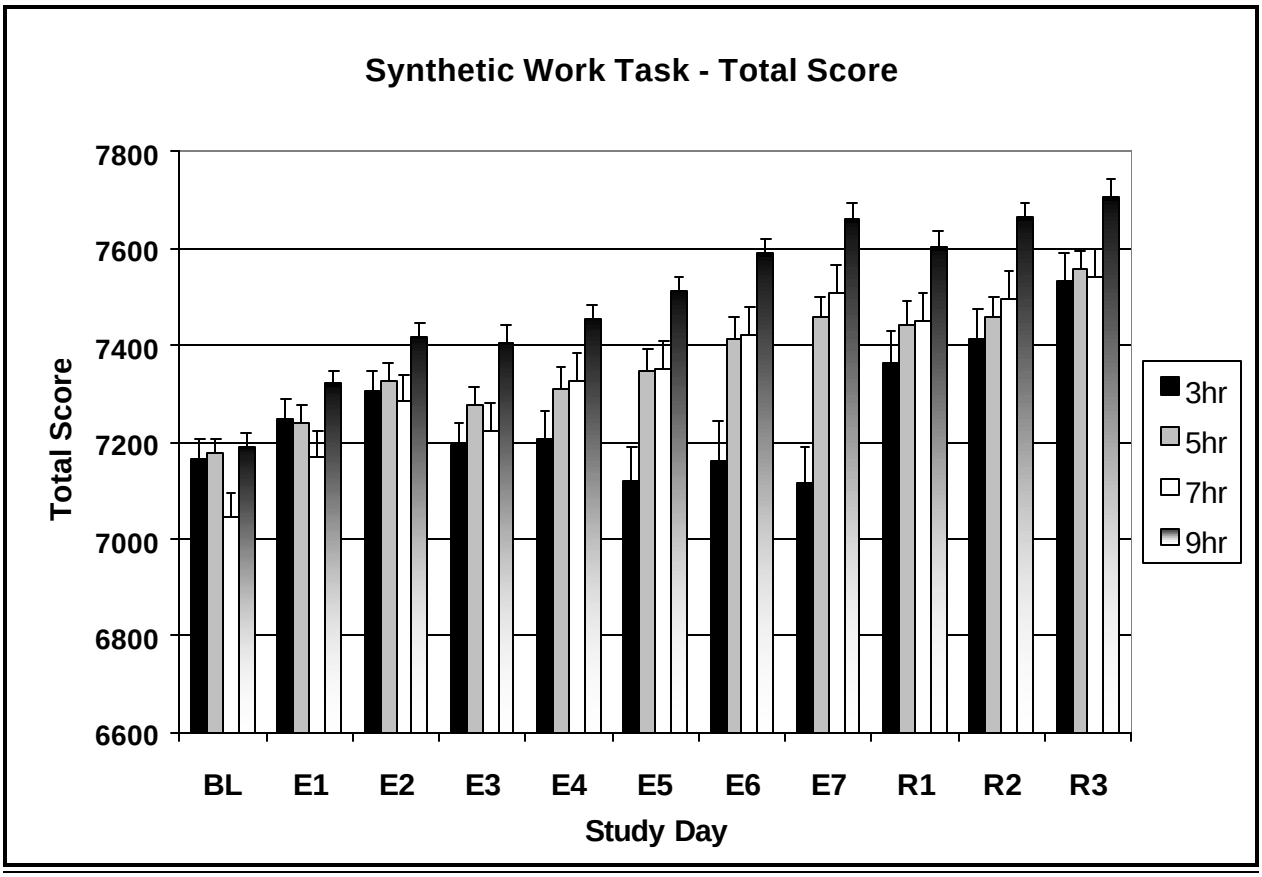

Figure 2-26. Synthetic work task (SYNWORK) total score across study days as a function of sleep group.

Driving Simulator (STISIM) Performance Measures

The simulator-driving task was the first performance task given each day and was administered at 0740, 1040, 1340, and 1940 hours. Each 45-minute driving session included seven data-sampling segments differing in lane numbers and speed limits, spaced throughout the scenario. The massive amount of data generated by this task and the number of possible combinations of segments, lane numbers, speed limits, measures, groups, days, and times precluded inclusion of all possible outcome measures and comparisons. Consequently, representative speed- and lane-tracking measures within or across posted speed limits were chosen for evaluation of the various group, day, and time-of-day effects using repeated-measures ANOVA. The results of the ANOVAs are given in **Appendix 4**. All significant results presented here are given as Greenhouse-Geisser adjusted values.

Mean Speed

Figure 2-27 shows mean driving speed averaged across the two 35-mi/h zones (56.3 km/h—data Segments 3 and 5) and across the five 55-mi/h zones (88.5-km/h—Segments 1, 2, 4, 6, 7). The 7- and 9-hour sleep groups remained near the posted speed limit throughout the study (with one exception at the end). The 3-hour sleep group gradually accelerated throughout the sleep-deprivation phase and continued into the recovery phase. This is especially evident in the 35-mi/h (56.3-km/h) zone, where this group's mean simulated speed eventually exceeded 50 mi/h (80.5-km/h). A similar but much smaller effect is also seen with the 5-hour sleep group in the 35-mi/h (88.5-km/h) zone.

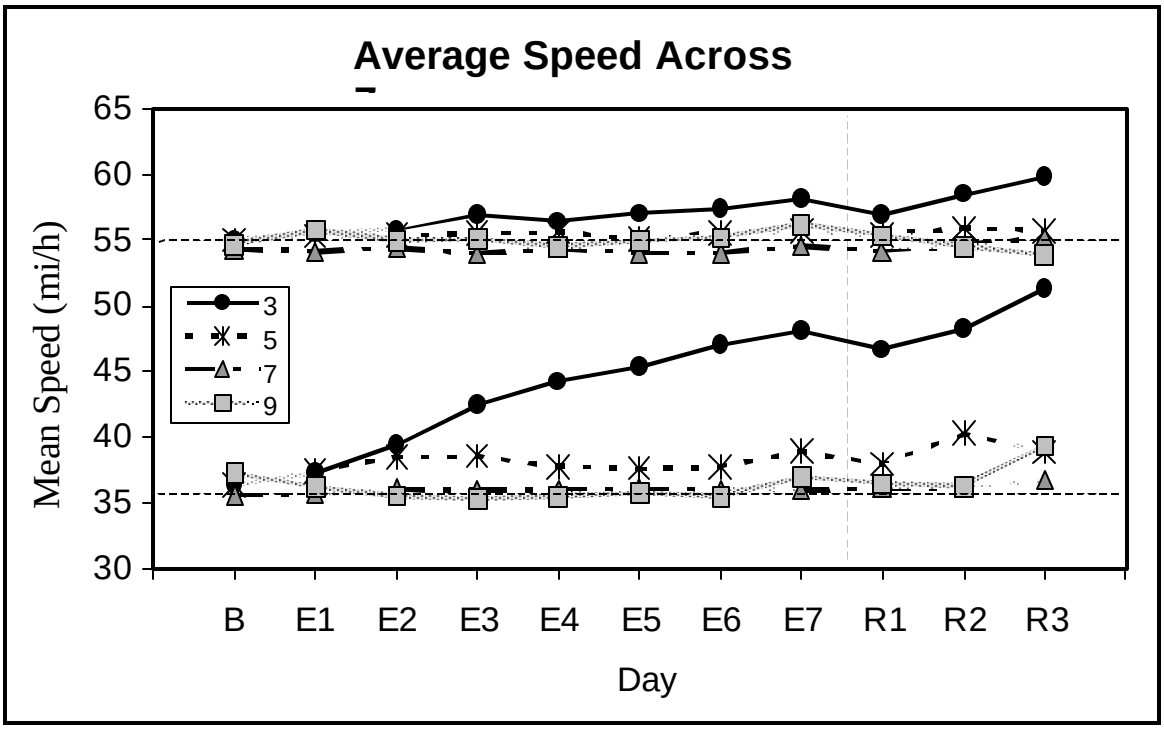

Figure 2-27. Simulator-driving mean speed averaged over all 55-mi/h (88.5-km/h) zones (top) and all 35-mi/h (56.3-km/h) zones (bottom), across study days by sleep group.

Speed at 55 mi/h (88.5 km/h). Mean speed across the five 55-mi/h zones was significantly different for all main effects: among sleep groups ($F_{3,62} = 9.87$, $p < 0.0000$), days ($F_{10,620} = 8.22$, $p < 0.0000$), and time of day ($F_{3,186} = 10.91$, $p < 0.0000$). Two-way interactions were significant only for Day x Sleep Group ($F_{30,620} = 3.10$, $p = 0.0002$). The three-way interaction of Sleep Group x Day x Time of Day was not significant.

Within sleep groups, significant differences among days were found for the 3-hour ($F_{10,748} = 8.50$, $p < 0.0000$), and 9-hour ($F_{10,660} = 2.61$, $p = 0.0041$) sleep groups; and for time of day in the 5-hour ($F_{3,660} = 5.21$, $p = 0.0015$) and 7-hour ($F_{3,660} = 4.11$, $p = 0.0066$) sleep groups. No significant interactions of Day x Time of Day were found for any of the four sleep groups.

Speed at 35 mi/h (56.3 km/h). Highly significant differences in speed were observed among sleep groups ($F_{3,62} = 19.11$, $p < 0.0000$), days ($F_{10,620} = 15.61$, $p < 0.0000$), and time of day ($F_{3,186} = 8.76$, $p = 0.0001$). As with the speed at 55 mi/h, two-way interactions were significant only for Day x Sleep Group ($F_{30,620} = 9.00$, $p < 0.0000$). The three-way interaction of Sleep Group x Day x Time of Day was not significant.

Significant differences among days were found in the 3-hour ($F_{10,748} = 20.74$, $p < 0.0000$), 5-hour ($F_{10,660} = 2.34$, $p = 0.0101$), and 9-hour ($F_{10,660} = 2.46$, $p = 0.0069$) sleep groups. Time-of-day effects were evident only in the 5-hour ($F_{3,660} = 3.15$, $p = 0.0245$) sleep group. As with driving speed at 55 mi/h, no significant interactions of Day x Time of Day were found for any of the four sleep groups.

Speed Variation

Figure 2-28 shows group standard deviations of speed (speed variability) averaged across all 55-mi/h (88.5-km/h) zones. Variability for the 5-, 7-, and 9-hour sleep groups remained relatively constant throughout the experimental and recovery phases. Variability for the 3-hour sleep group increased during sleep restriction and then quickly recovered.

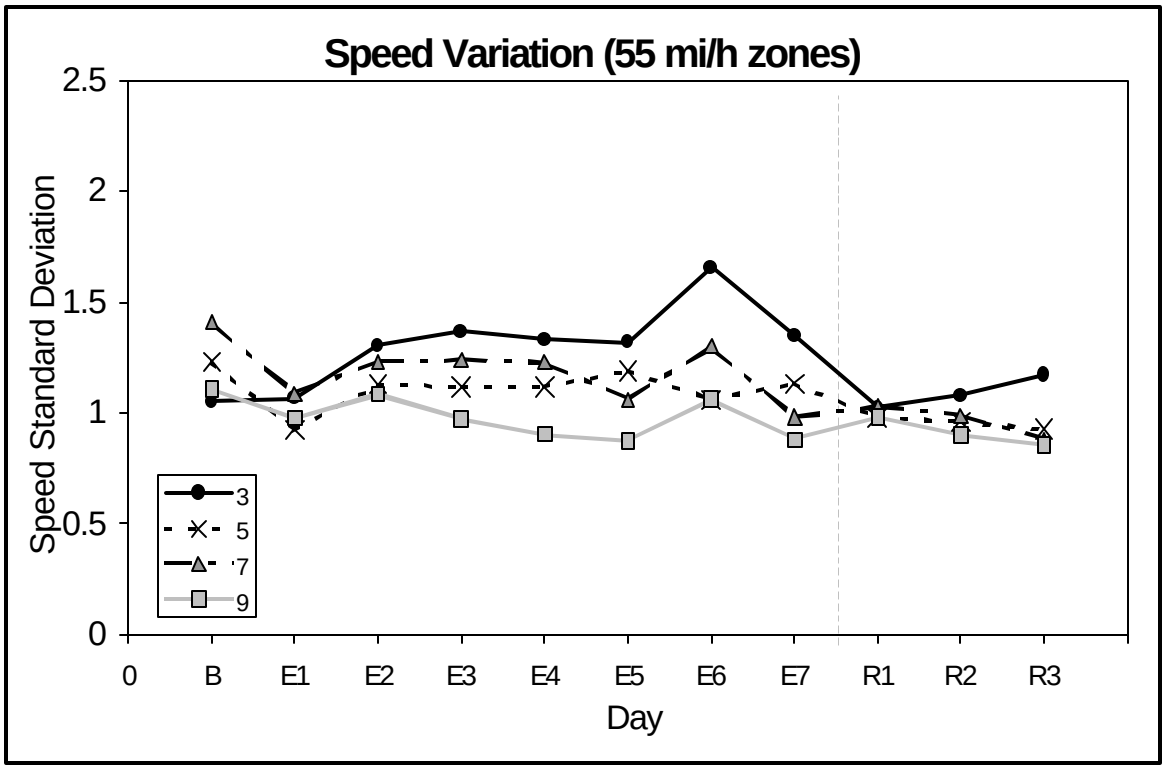

Figure 2-28. Standard deviation of speed averaged over all 55-mi/h (88.5-km/h) zones across study days by sleep group**.**

Figure 2-29 shows group standard deviations of speed (speed variability) averaged across the two 35-mi/h (56.3-km/h) zones. Variability for the 7- and 9-hour sleep groups was lower than variability in the 55-mi/h (88.5-km/h) zones and remained relatively unchanged throughout the experimental and recovery phases. Variability for the 3-hour sleep group increased considerably with continued sleep restriction and showed only partial recovery. The 5-hour sleep group was intermediate, evidencing dose dependency.

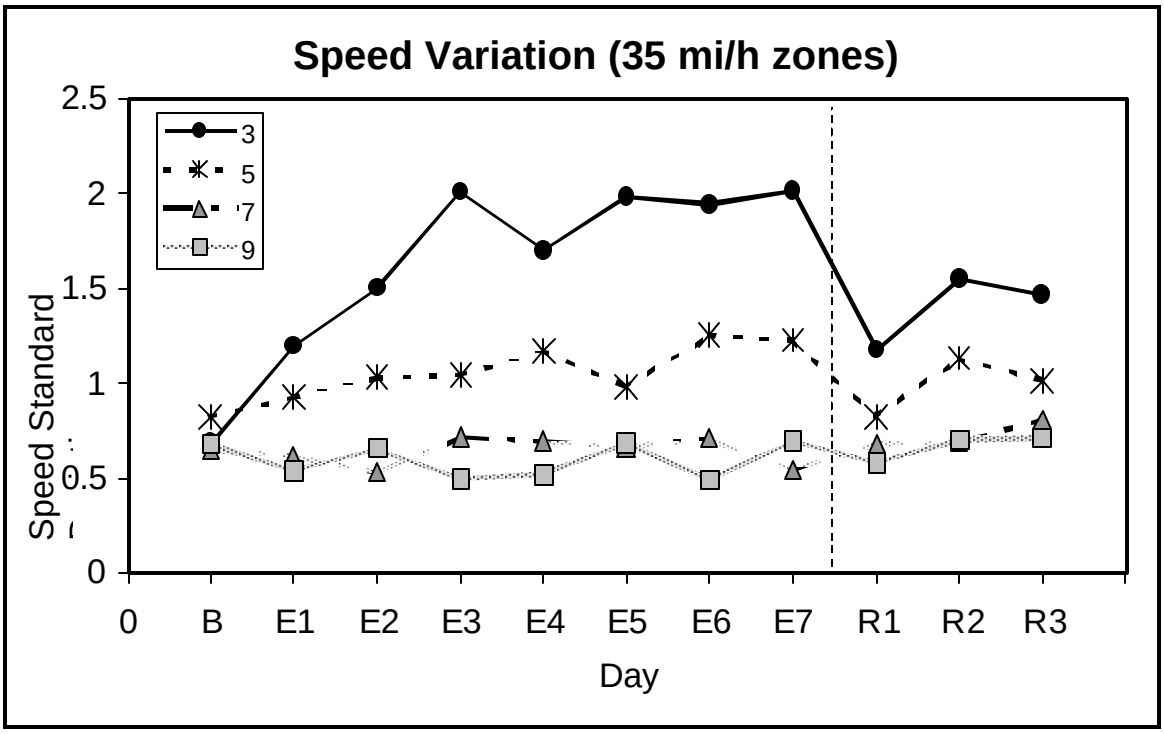

Figure 2-29. Standard deviation of speed averaged over all 35-mi/h (56.3-km/h) zones, across study days by sleep group.

Speed variation (the standard deviation of speed) for main effects was significantly different among sleep groups ($F_{3,62} = 3.74$, $p = 0.0155$), days ($F_{10,620} = 2.92$, $p = 0.0050$), and segments ($F_{6,372} = 57.14$, $p < 0.0000$), but not time of day. Significant two-way interactions were found for Day x Sleep Group ($F_{30,620} = 1.79$, $p = 0.0167$), Segment x Sleep Group ($F_{18,372} = 2.56$, $p = 0.0056$), Day x Segment ($F_{60,3720} = 2.33$, $p = 0.0007$), and Time of Day x Segment ($F_{18,1116} = 2.98$, $p = 0.0016$). No three- or four-way interactions were significant.

Within sleep groups, significant differences among days were found for the 3-hour ($F_{10,5236} = 5.09$, $p < 0.0000$) and 7-hour sleep groups ($F_{10,4620} = 1.92$, $p = 0.0363$); among times of day in the 5-hour ($F_{3,4620} = 3.26$, $p = 0.0204$), and in the 9-hour ($F_{3,4620} = 3.81$, $p = 0.0096$) sleep groups; and among segments in all sleep groups, 3-hour ($F_{6,5236} = 32.13$, $p < 0.0000$), 5-hour ($F_{6,5236} = 39.84$, $p < 0.0000$), 7-hour ($F_{6,5236} = 76.20$, $p < 0.0000$), and 9-hour ($F_{6,5236} = 67.03$, $p < 0.0000$). No significant interactions were found for the 3-hour sleep group, but significant effects were found for Day x Time of Day for the 9-hour sleep group ($F_{30,4620} = 1.53$, $p = 0.0315$), Time of Day x Segment for the 5-hour sleep group ($F_{18,4620} = 2.73$, $p = 0.0001$), Day x Segment for the 9-hour ($F_{60,4620} = 1.61$, $p = 0.0020$) and 7-hour ($F_{60,4620} = 1.68$, $p = 0.0008$) sleep groups, and Day x Time of Day x Segment for the 9-hour ($F_{180,4620} = 1.46$, $p = 0.0001$) and 7-hour ($F_{180,4620} = 1.35$, $p = 0.0015$) sleep groups.

Lane Tracking

Mean lane position. Group mean-lane position (also known as Lateral Placement) did not differ with speed zones, which are averaged together in **Figure 2-30**. Lane position was measured as the distance in feet from the center of the vehicle to the center of the current driving lane. Deviations to the right and left of center were denoted as positive and negative, respectively. All sleep groups drove approximately 1 foot to the left of lane center. This offset increased over days of sleep restriction to approximately 1.8 ft for the 3-hour group, which then showed immediate but incomplete recovery. A smaller increase was seen in the 5-hour sleep group. The 7- and 9-hour sleep groups remained unchanged throughout.

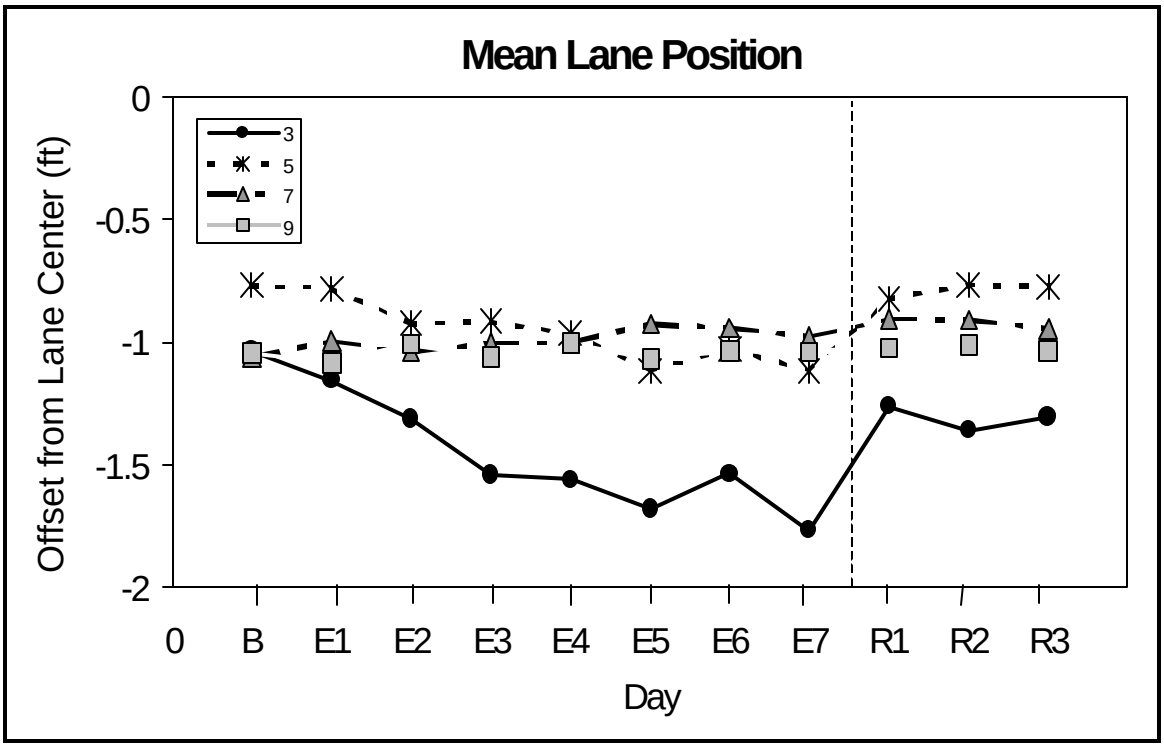

Figure 2-30. Mean lane position (in feet to the left of the lane center) averaged over all scenario segments, across study days by sleep group.

Mean lane position was not significantly different among sleep groups or time of day; however, there was significant difference among days ($F_{10,620} = 7.67$, $p < 0.0000$) and segments ($F_{6,372} = 57.61$, $p < 0.0000$). A significant two-way interaction was found only for Day x Sleep Group ($F_{30,620} = 3.73$, $p < 0.0000$). Again, no three- or four-way interactions were significant.

Within sleep groups, significant differences among days were found for the 3-hour ($F_{10,5236} = 22.07$, $p < 0.0000$) and 5-hour ($F_{10,4620} = 7.82$, $p < 0.0000$) sleep groups, among times of day only in the 3-hour sleep group ($F_{3,5236} = 3.05$, $p = 0.0274$), and among segments in all sleep groups: 3-hour ($F_{6,5236} = 52.92$, $p < 0.0000$), 5-hour ($F_{6,5236} = 46.01$, $p < 0.0000$), 7-hour ($F_{6,5236} = 25.76$, $p < 0.0000$), and 9-hour ($F_{6,5236} = 42.34$, $p < 0.0000$). No significant interactions were found within any of the sleep groups.

Lane-tracking variability. Lane-tracking variability is defined as the standard deviation of lane position (also known as lane deviation). **Figure 2-31** shows group standard deviations of lane position (lane deviation) averaged across speed zones. Variability exhibited clear dose dependency. The largest increase in variability was seen for the 3-hour sleep group, which also showed only partial recovery. Variability for the 9-hour sleep group actually decreased slightly with the extra hour in bed. The 5- and 7-hour sleep groups were intermediate.

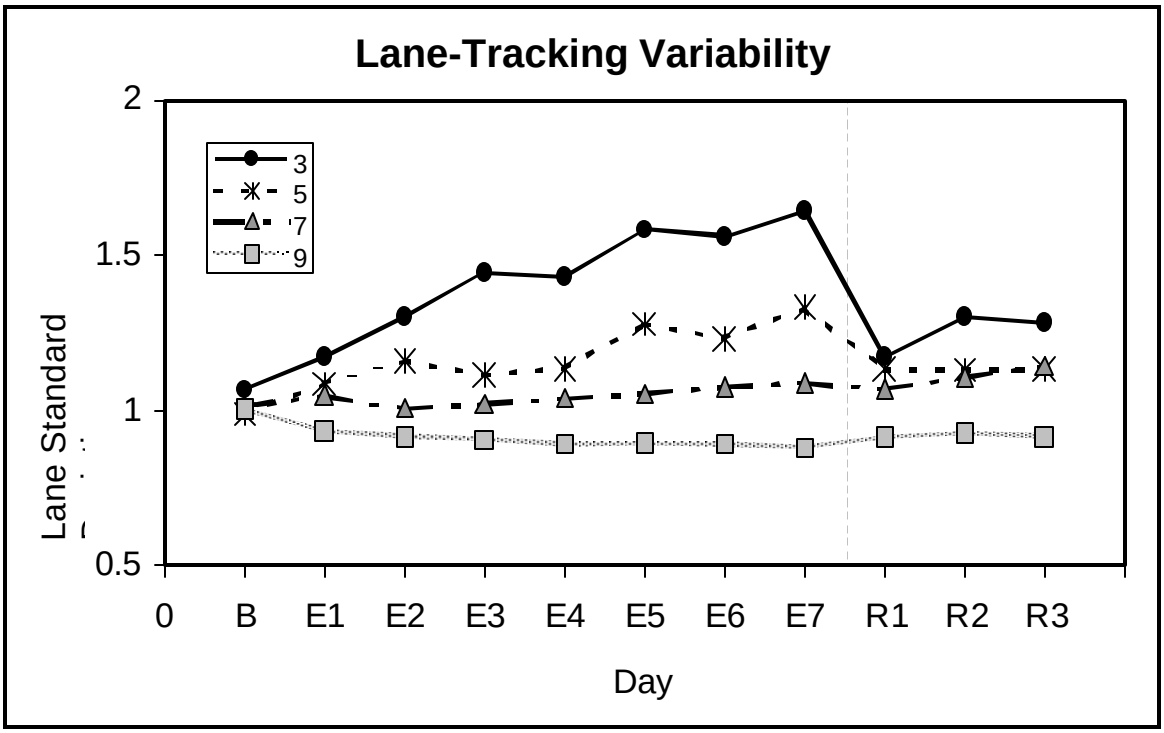

Figure 2-31. Standard deviation of lane position averaged over all scenario segments, across study days by sleep group.

Lane-tracking variability also showed time-on-task (segment order) effects. This is illustrated in **Figure 2-32** for the 3-hour sleep group. Note that beginning on the baseline day, variability was lower in the early segments of the scenario and higher in the later segments. The same ordering and approximate magnitudes were seen on Recovery Day 1. During sleep restriction, variability increased in all segments but did so differentially, suggesting a Day x Time-on-Task (segment) interaction.

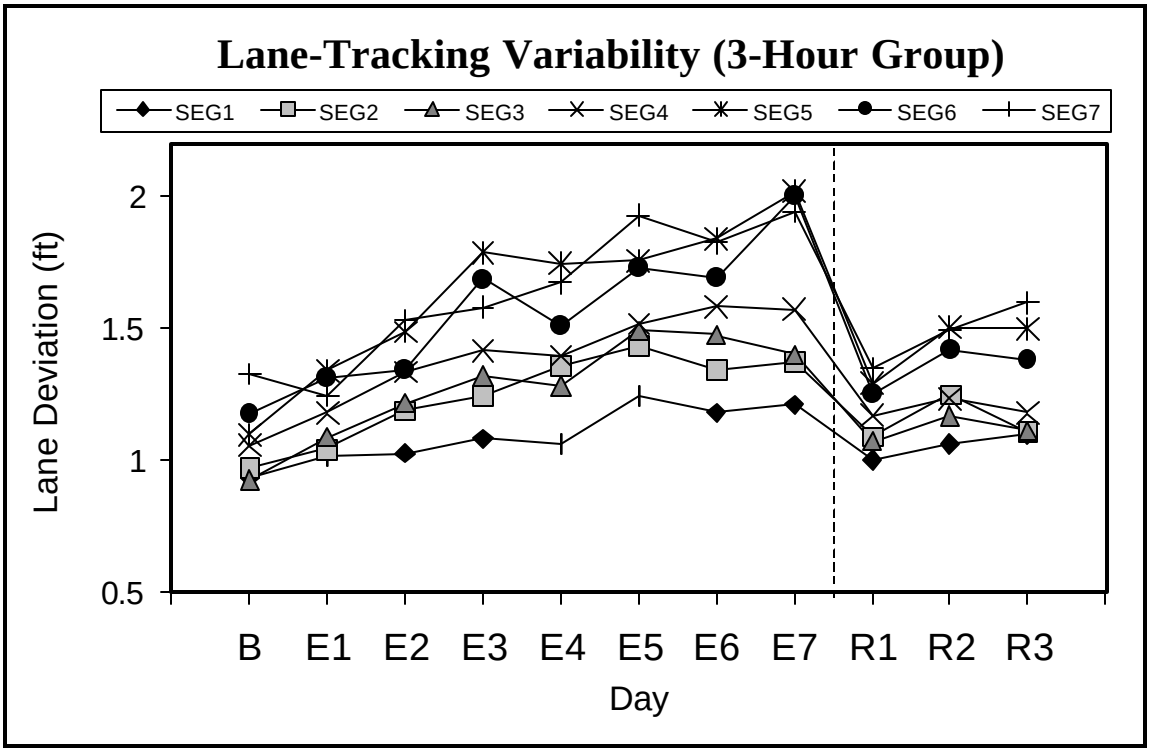

Figure 2-32. Standard deviation of lane position for Scenario Segments 1 through 7, across study days, for the 3-hour sleep group.

All main effects for the lane-position-variability measure showed highly significant differences: among sleep groups ($F_{3,62} = 3.74$, $p = 0.0012$), days ($F_{10,620} = 10.44$, $p < 0.0000$), times of day ($F_{3,186} = 7.96$, $p = 0.0005$), and segments ($F_{6,372} = 57.14$, $p < 0.0000$). All two-way interactions except for Time of Day x Sleep Group were significant and included Day x Sleep Group ($F_{30,620} = 6.57$, $p < 0.0000$), Segment x Sleep Group ($F_{18,372} = 4.08$, $p = 0.0005$), Day x Time of Day ($F_{30,1860} = 1.93$, $p = 0.0337$), Day x Segment ($F_{60,3720} = 1.68$, $p = 0.0441$), and Time

of Day x Segment ($F_{18,1116} = 2.92$, $p = 0.0014$). As with the other two variability measures just discussed, no three- or four-way interactions were found to be significant.

Significant main effects of day ($F_{10,4620} = 32.89$, $p < 0.0000$) and segment ($F_{5,4620} = 59.01$, $p < 0.0000$) were evident in the 3-hour sleep group. The Day x Time of Day interaction effect was also significant ($F_{30,5236} = 2.08$, $p = 0.0005$). Significant differences among days were found in the 5-hour sleep group ($F_{10,4620} = 12.91$, $p < 0.0000$), the 7-hour sleep group ($F_{10,4620} = 3.96$, $p < 0.0000$), and the 9-hour sleep group ($F_{10,4620} = 3.93$, $p < 0.0000$); and among times of day in the 5-hour sleep group ($F_{3,4620} = 7.11$, $p = 0.0001$), the 7-hour sleep group ($F_{3,4620} = 14.89$, $p < 0.0000$), and the 9-hour sleep group ($F_{3,4620} = 32.03$, $p < 0.0000$); among segments in the 5-hour sleep group ($F_{6,4620} = 50.56$, $p < 0.0000$), 7-hour sleep group ($F_{6,5236} = 57.72$, $p < 0.0000$), and 9-hour sleep group ($F_{6,5236} = 41.54$, $p < 0.0000$). No significant interactions were found for either the 5- or 7-hour sleep groups. However, for the 9-hour group, Time of Day x Segment was significant ($F_{18,4620} = 1.99$, $p < 0.0078$).

Accidents

Figure 2-33 shows daily mean accidents per 45-minute driving simulation. These include both off-road accidents and on-road collisions. Accident rates for the 9-hour sleep group approached but did not quite reach zero. The 9-hour sleep group continued at a low accident rate, while the other groups' rates increased in a dose-dependent fashion. The increase for the 3-hour sleep group was much larger than for the other groups, reaching a peak on the fifth experimental day and then declining.

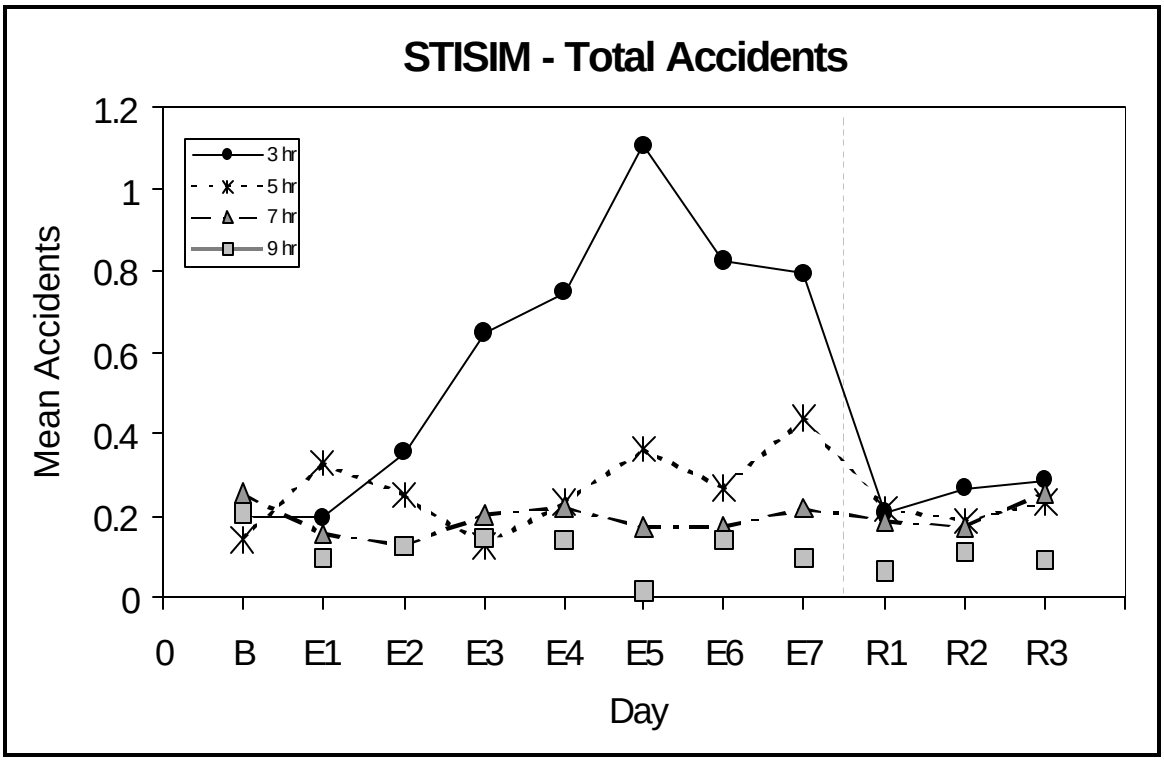

Figure 2-33. Mean number of accidents per 45-minute simulation, across study days by sleep group.

The number of accidents is a metric similar to that of number of lapses in the PVT, having many zero values and not normally distributed. Hence, log transformation after addition of one to each datum was performed prior to statistical analysis. The Greenhouse-Geisser epsilon value of 0.9704 from the repeated-measures analysis confirmed appropriateness of the transformation. The difference among sleep groups was significant ($F_{3,61} = 6.75$, $p = .0005$). Significant differences for days ($F_{10,610} = 5.18$, $p < 0.0000$), and Sleep Group x Day ($F_{30,610} = 2.20$, $p = .0021$) were also found. The time-of-day effect was not significant, but Time of Day x Sleep Group ($F_{9,183} = 2.09$, $p = .0373$) and Day x Time of Day x Sleep Group ($F_{90,1830} = 1.38$, $p = .0490$) interactions were significant. Tukey's means comparisons show no significant differences among groups for Baseline day, Experiment 2, and all three recovery days, while the remaining days reflect the 3-hour sleep-group differences from the other groups. Tukey's means comparisons for time-of-day differences show significant differences between the 3-hour sleep group and the other groups at every time period.

Ocular Measures – FIT

The FIT generated two measures, pupil diameter and saccadic velocity, deemed pertinent in determining probable performance impairment as a consequence of oculomotor changes. The test times common to all four sleep groups were: 0735, 1030, 1330, 1630, 1930, and 2145 hours; the measures from these time periods were used in the standard repeated measures ANOVA, as in all of the previous tasks. Results for all FIT analyses are shown in **Appendix 4**.

Pupil Diameter

To eliminate confounding statistical significance of group differences, each datum of pupil diameter was normalized with the individual's baseline value corresponding to the same time of day. This resulted in a set of ratios in which all baseline values for each group were equal to one, and all other values were ratios of the baseline values. These ratios were then analyzed in the usual manner. No significant differences were found in any main effects or interactions in the overall repeated-measures ANOVA. Tukey's means comparisons for groups within days showed no significant differences among groups for all days except Experiment 2 and Experiment 4 days. On those days, there were significant differences between the 5- and 3-hour sleep groups in Experiment 2, and between the 9- and 5-hour and 9- and 3-hour sleep groups in Experiment 4. Tukey's means comparisons for group differences within times of day show significant differences for all test times except at 1330 and were mainly differences of the 9- and 7-hour sleep groups from that of the 5- and 3-hour sleep groups. However, highly significant differences within groups were found for the 3-hour sleep group among days ($F_{10,990} = 3.58$, $p = .0001$) and times of day ($F_{5,990} = 3.22$, $p = .0069$). In addition, significant differences were obtained for time of day for the 5-hour sleep group ($F_{5,858} = 2.41$, $p = .0352$), the 7-hour sleep group ($F_{5,792} = 2.75$, $p = .0178$), and the 9-hour sleep group ($F_{5,857} = 2.74$, $p = .0184$). **Figure 2-34** compares performance among the four sleep groups, as well as within-group differences across the 11 days for this measure.

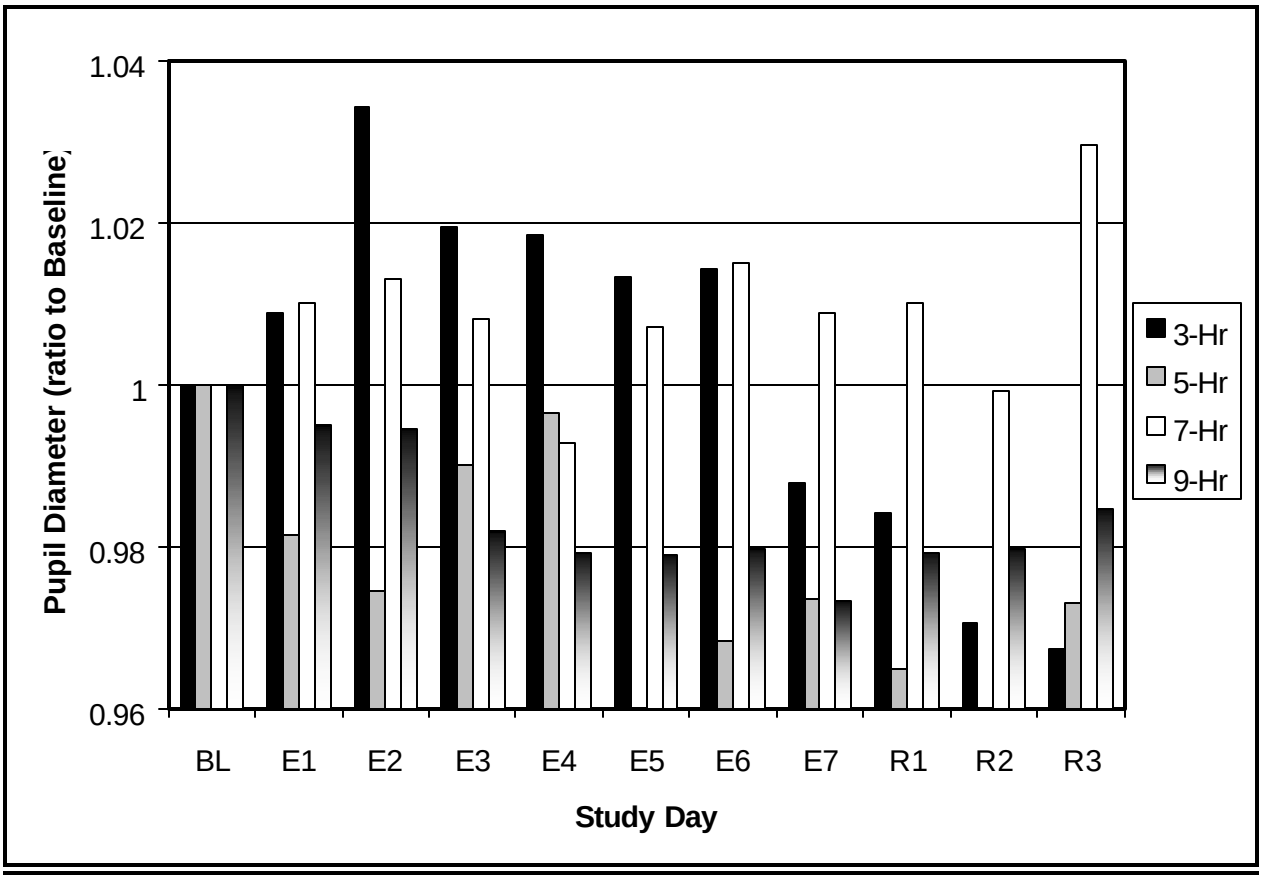

Figure 2-34. Oculomotor FIT pupil diameter across study days as a function of sleep group.

Saccadic Velocity

Although the sleep groups were not statistically different on baseline day, the range of values even within groups was sufficiently large so that saccadic velocity measures were also normalized against baseline. Results of the overall analysis show significance only among sleep groups ($F_{5,53} = 4.59$, $p = 0.0063$) and Day x Time of Day interaction ($F_{50,2653} = 1.81$, $p = 0.0233$), but no significant difference for day, Sleep Group x Day, time of day, Sleep Group x Time of Day, or Sleep Group x Day x Time of Day. Tukey's comparisons of day differences between groups indicated that no significant differences between groups were found for baseline, Experiment Days 3 and 4, or Recovery Days 1, 2, and 3. For Experiment Days 1, 2, 5, 6, and 7, significance was found mainly for differences of the 3-hour sleep group from the 7-hour sleep group. Comparisons of day differences within each group reflected only the 3-hour sleep group with significant difference ($F_{10,990} = 3.28$, $p = 0.0003$), in which baseline had greater saccadic velocity than Experiment 7. Comparison of time-of-day difference between groups showed no significant difference at 1930, while the other time periods reflect significant differences between the 3-hour sleep group versus the 7- and 9-hour sleep groups. Comparisons of time-of-day differences within groups show significant differences for the 7-hour sleep group ($F_{5,792} = 5.61$, $p = 0.0063$) and the 9-hour sleep group ($F_{5,857} = 5.12$, $p = 0.0001$). **Figure 2-35** compares performance among the four sleep groups, as well as within group differences across the 11 days for this measure.

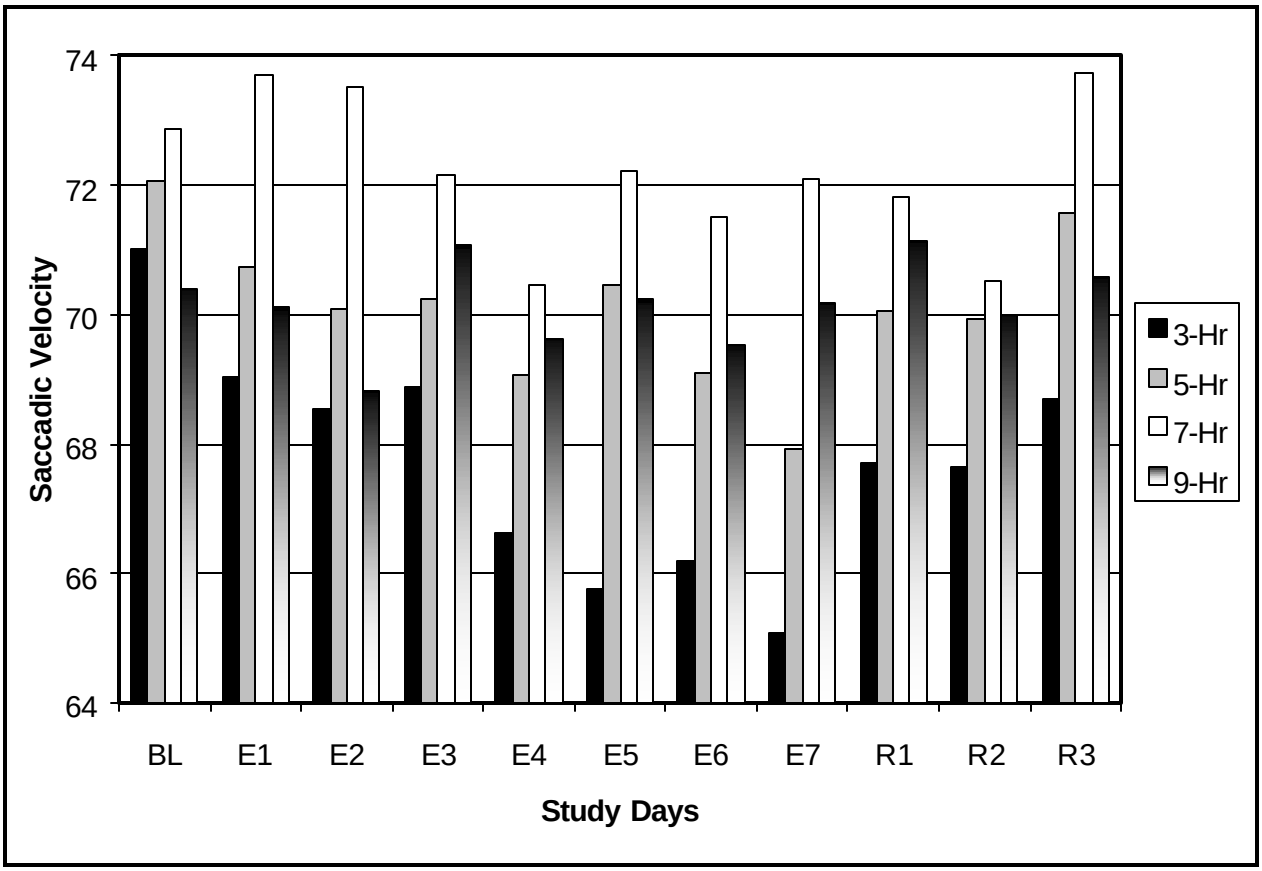

Figure 2-35. Oculomotor FIT saccadic velocity across study days as a function of sleep group.

Health Measures

Tympanic Temperature

Tympanic temperature was analyzed using a three-way mixed ANOVA with sleep group (3, 5, 7, or 9 hours/night), day (11 days; B_1- R_3), and time of day (five levels—0715, 1025, 1320, 1625, and 1920 hours) as factors. Note that tympanic temperature was evaluated only for purposes of monitoring health status—the relatively infrequent sampling interval (five measures per day, all during daytime hours) and the relative variability in the tympanic recording device itself (in contrast to core body temperature as measured by a temperature pill or rectal probe) preclude the use of tympanic temperature as an index of circadian phase.

Figure 2-36 illustrates mean tympanic temperature separately for each sleep group as a function of day and time of day. Consistently across days and groups, peak tympanic temperature occurred in the early evening at 1920 hours (last measurement of the day). Also consistently across days and groups (with the exception of the 5-hour sleep group on E5), the trough in tympanic temperature occurred at 0715 hours (first measurement of the day). However, tympanic temperature did not monotonically increase across the day—for some groups and days, a secondary trough in tympanic temperature occurred at 1625 hours (time of day main effect, $p < .05$).

Across days, highest tympanic temperature (collapsed across groups and time of day) occurred on day E2, while lowest temperature occurred on E5 (day main effect, $p < .05$).

Differences in tympanic temperature among groups (collapsed across day and time of day) were small (0.2 degrees) and not significant (group main effect, $p > .05$).

For the 3-hour sleep group, tympanic temperature amplitude (difference from peak to trough) appeared to decrease across E4, E5, and E6. In contrast, for the 9-hour sleep group, tympanic temperature amplitude appeared to increase slightly. For both of these groups, mean daily tympanic temperature (collapsed across time of day) appeared to remain relatively constant. In contrast, mean daily body temperature for the 5-hour and 7-hour sleep groups appeared to decrease across the latter portion of the experimental phase. This decrease appeared to be due to a decrease in the trough of temperature (at 0715 hours) rather than a decrease in the

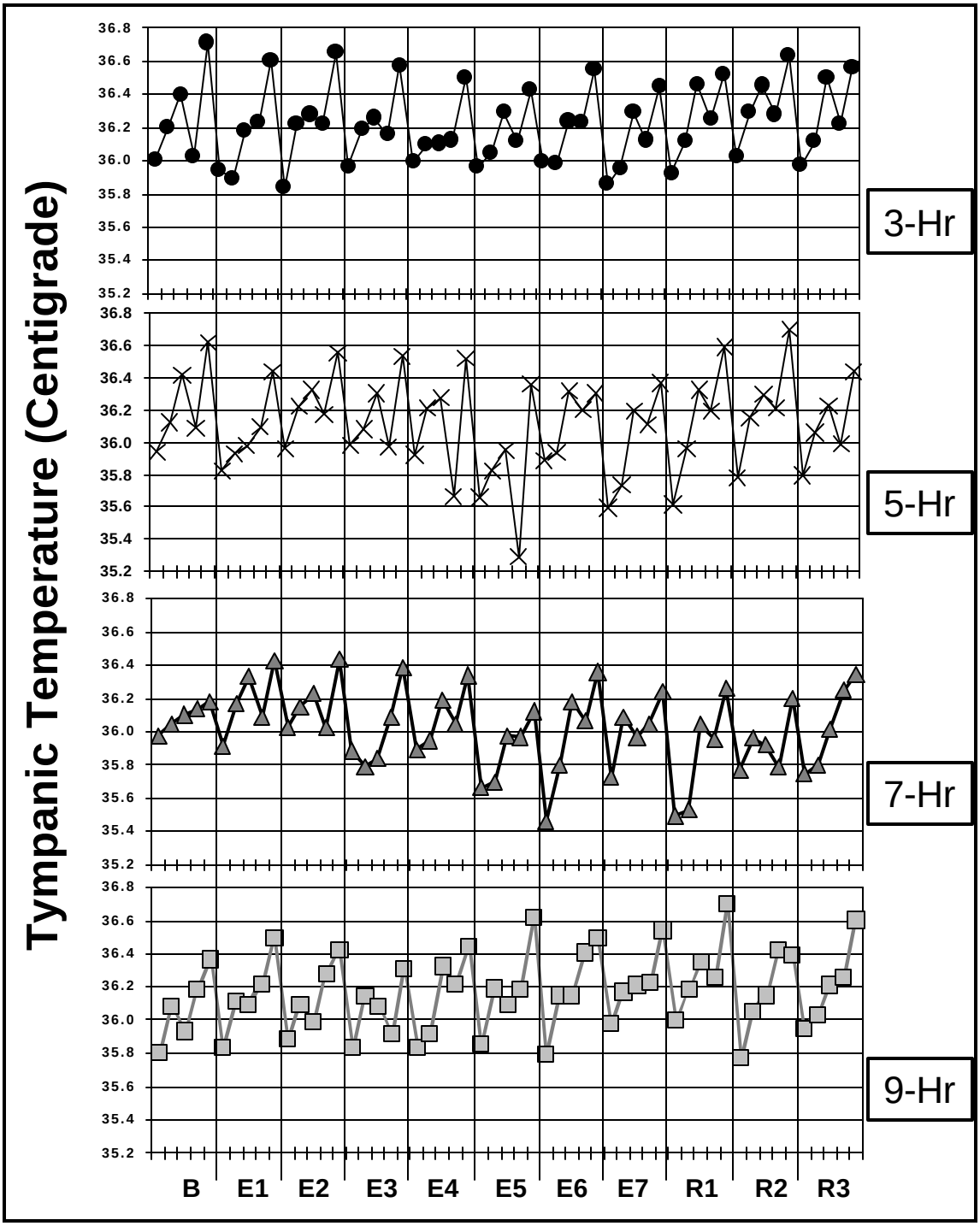

Figure 2-36. Mean tympanic temperature (centigrade) by day and time of day, separately as a function of sleep group.

peak (1920 hours) for both groups. These observations were confirmed by significant interactions for Sleep Group x Day, Sleep Group x Time of Day, Day x Time of Day, and Sleep Group x Day x Time of Day (all *p*s < .05).

Results of these analyses are summarized in **Appendix 4.**

Heart Rate

Heart rate (HR) in beats per minute (BPM) was analyzed using a three-way mixed Analysis of Variance (ANOVA) with sleep group (3, 5, 7, or 9 hours/night), day (11 days; B_1-R_3), and time of day (five levels—0715, 1025, 1320, 1625, and 1920 hours) as factors.

Overall highest HR (collapsed across day and time of day) was seen in the 3-hour sleep group (mean BPM = 79.74) and 7-hour sleep group (mean BPM = 78.64), while lowest HR was seen in the 9-hour sleep group (mean BPM = 70.46) and 5-hour sleep group (mean BPM=75.48; group main effect, $p < .05$).

Across study days (collapsed across sleep group and time of day), highest HRs occurred across the last four days (E7 through R3; mean BPM = 77.51, 77.18, 77.02, and 77.11, respectively) while the lowest HR was observed on day E2 (mean BPM = 74.93; day main effect, $p < .05$).

Within days (collapsed across day and sleep group), the highest HR occurred at 1930 hours (mean BPM = 79.87), whereas the lowest HR occurred at 1630 hours (mean BPM = 72.60; time-of-day main effect, $p < .05$). Also, HR varied as a function of day and time of day (collapsed across group; Day x Time of Day interaction, $p < .05$)

The variation in HR both within and across study days differed marginally as a function of groups (Sleep Group x Time of Day, Sleep Group x Day x Time of Day, $p = .05$). For example, the greatest variation in HR within a day occurred in the 9-hour sleep group on Day E3. However, the Sleep Group x Day interaction was not significant ($p > .05$).

Results of these analyses are summarized in **Appendix 4.**

Blood Pressure – Systolic

Systolic blood pressure (SBP) was analyzed using a three-way mixed Analysis of Variance (ANOVA) with sleep group (3, 5, 7, or 9 hours/night), day (11 days; B_1- R_3), and time of day (five levels—0715, 1025, 1320, 1625, and 1920 hours) as factors.

Table 2-11 lists mean systolic blood pressures by day (collapsed across group and time of day) and by time of day (collapsed across group and day). SBP did not differ among sleep groups, nor did sleep group interact with day or time of day (group main effect, $p > .05$; interactions with group, ps > .05). The highest SBP was found on day E4, while the lowest SBP occurred on Day R2 (Day main effect, $p < .05$; Tukey HSD, $p < .05$). With respect to time of day, the highest SBP occurred at 1320, while the lowest SBP occurred at 0715 (time-of-day main effect, $p < .05$; Tukey HSD, $p < .05$). No other effects were significant (ps > .05). Results of the above analyses are summarized in **Appendix 4.**

Table 2-11. Mean (standard error) systolic blood pressure (mm/Hg) by day and time of day.

By day:	Systolic BP
B1	126.0091 (0.802)
E1	126.9545 (0.733)
E2	126.0045 (0.731)
E3	126.0636 (0.735)
E4	128.1455 (0.812)
E5	127.9636 (0.768)
E6	127.0022 (0.795)
E7	126.5093 (0.731)
R1	125.3998 (0.759)
R2	124.4364 (0.745)
R3	125.1818 (0.802)
Tukey HSD:	**2.77**

By time of day:	Systolic BP
0715	124.0930 (0.518)
1025	126.5455 (0.536)
1320	128.9697 (0.514)
1625	125.4989 (0.498)
1920	126.5799 (0.503)
Tukey HSD:	**1.59**

Blood Pressure – Diastolic

Diastolic blood pressure (DBP) was analyzed using a three-way mixed Analysis of Variance (ANOVA) with sleep group (3, 5, 7, or 9 hours/night), day (11 days; B_1- R_3), and time of day (five levels—0715, 1025, 1320, 1625, and 1920 hours) as factors.

Table 2-12 lists mean DBP by time of day (collapsed across sleep group and day).

Table 2-12. Mean (standard error) diastolic blood pressure (mm/Hg) by time of day.

Time of Day	Diastolic BP
0715	75.2148
1025	72.6479
1320	73.7796
1625	74.0730
1920	73.7383
Tukey HSD:	**0.97**

Diastolic pressure did not vary as a function of sleep group or day, nor did these factors interact (main effects and interactions, *p*s > .05). Diastolic pressure varied across the day (time-of-day main effect, $p < .05$)—the highest DBP values occurred at 0715 hours, and the lowest DBP occurred at 1025 hours. DBP values at 1320, 1625, and 1920 were intermediate between 0715 and 1025 hours and similar among each other.

Results of the above analyses are summarized in **Appendix 4.**

D. DISCUSSION

VARIATIONS IN NOCTURNAL SLEEP TIME AND NEXT-DAY PERFORMANCE

Cognitive Tasks—Effects of Sleep Restriction and Recovery

As hypothesized, all of the cognitive tasks (Serial Addition/Subtraction, 10-Choice RT, and 4-Choice RT) were sensitive to differential sleep restriction. For the most part, these effects were dose-dependent—the greatest declines in performance were seen in the 3-hour sleep group, with less effect in the 5- and 7-hour sleep groups, respectively. Virtually no negative effects on performance were seen in the 9-hour sleep group.

Sleep restriction effects were consistent across tasks for speed and throughput measures. Accuracy was also affected by sleep restriction for all tasks except 10-Choice RT. Performance in the 3-hour sleep group typically declined below baseline within 2 to 3 days of sleep restriction. Performance in the 5-hour sleep group was consistently lower than performance in the 7- and 9-hour sleep groups—however, the pattern of change across experimental days in the 5-hour sleep group was not consistent. In some instances performance declined and then leveled off, while in other instances performance in the 5-hour sleep group simply showed a reduced rate of improvement compared to the 7- and 9-hour sleep groups (see upcoming discussion on learning effects). In general, performance for the 3- and 5-hour sleep groups was below that of the 7- and 9-hour sleep groups. Performance in the 7- and 9-hour sleep groups improved throughout the study and was often indistinguishable. In some instances, the 7-hour sleep group performed better (albeit nonsignificantly better) than the 9-hour sleep group. The exception to this observation was seen with 4-Choice RT—in this task, performance in the 7-hour sleep group decreased across experimental days compared to the 9-hour sleep group.

Thus, restricting sleep resulted in dose-dependent performance impairment. However, the degree to which sleep restriction impaired performance was, to some extent, task-specific. This would be expected based on the cognitive load imposed by a given task and the extent to which performance of a given task tends to unmask physiological sleepiness (see Horne, 1988 for reviews; and Carskadon and Dement, 1982).

In addition, the degree to which sleep restriction impaired performance was measure-specific. Across tasks, speed and throughput were consistently affected. Although reaction time

(speed) appears on the surface to be a highly practiced motor task, it should be noted that speed measures in this study were dependent on decision-making. For example, in the Serial Addition/Subtraction task, response speed reflected working memory and arithmetic processing. Accuracy was also affected by sleep restriction, albeit less consistently than speed. This finding is consistent with many other studies in which it has been shown that during sleep deprivation, subjects tend to sacrifice speed to maintain accuracy (e.g., Williams and Lubin, 1967; Thorne et al., 1983). In other words, sleep deprivation/restriction appears to slow the speed with which a decision is made—whether the ability to make the decision is also directly impaired is less clear. Region-specific changes in brain metabolism during sleep deprivation (Thomas et al., 1998) suggest that decrements of both mechanisms may contribute to sleep-deprivation-induced performance impairment.

Other mechanisms putatively affecting performance during sleep restriction include decreased motivation and attention lapses. Because "motivation" is a hypothetical construct, no definitive measure of motivation exists—however, it is reasonable to postulate that there may be an interaction between motivation and sleep deprivation effects. In contrast, attention lapses correspond to a directly measurable phenomenon (failure to respond within a given time period), and their contribution to performance decrements during sleep restriction are discussed in some detail below.

The effects of recovery sleep were variable—in some instances, performance recovered to baseline levels across the 3 days of recovery sleep (8 hours per night, all sleep groups), while in other instances it did not. Interestingly, when performance did recover, it was generally not complete after the first 8-hour recovery sleep period. Rather, recovery to baseline or near-baseline levels of performance often required a second or third night of recovery sleep. This observation clearly indicates that, following chronic sleep restriction, 8 hours in bed (which resulted in approximately 6.5 hours of sleep) is insufficient for restoration of performance on tasks requiring higher-order cognitive processing. In addition, in the 3-hour sleep group, three 8-hour recovery sleep periods were sometimes insufficient to restore performance to baseline levels (depending on the task). This suggests that *full* recovery from severe, extended sleep restriction may require more than 3 nights of normal-duration sleep. The extent to which a single period of unrestricted recovery sleep (i.e., following sleep deprivation/restriction) restores performance is a focus of a currently ongoing laboratory study.

Psychomotor Vigilance—Effects of Sleep Restriction and Recovery

Response speed on the Psychomotor Vigilance Task (PVT) showed orderly dose-dependent sleep deprivation effects: the 9-hour sleep group maintained baseline levels of speed across the experimental phase while the 7-, 5-, and 3-hour sleep groups declined. Greatest impairments in speed across the experimental phase were seen in the 3-hour sleep group.

During the recovery phase, the 5- and 7-hour sleep groups showed minimal or no recovery, remaining consistently below the 9-hour sleep group and below their own baseline levels. The 3-hour sleep group showed some recovery on the first day and more on the subsequent days but also remained well below their own baseline and below the performance levels of the other groups.

Unlike the tasks described earlier (e.g., Serial Addition/Subtraction), the cognitive load required by the PVT was minimal. However, as noted in Chapter 1, sleep loss exerts two main effects. First, it directly impairs cognitive performance (as evidenced by sleep restriction effects on serial addition/subtraction, for example). Second, sleep loss increases the likelihood of falling asleep under mental or physically nonstimulating ("boring") conditions, particularly when there is a substantial delay between relevant events. As noted in Chapter 1, Wilkinson (1965) showed that relatively uninteresting, complex, long-duration (30 minutes or longer) tasks are especially affected by sleep loss. Wilkinson (1965) specifically constructed his auditory vigilance tasks to capture these aspects—and numerous studies since then have confirmed that vigilance tasks are particularly sensitive to sleep loss.

Oculomotor (FIT) Measures—Effects of Sleep Restriction and Recovery

Saccadic velocity slowed significantly with 3 and 5 hours of nightly sleep, with significance reached early and maintained through the recovery period. Pupil diameter showed significant changes early in the 3-hour sleep group, but high variability may have prevented significant changes toward the end of the experimental period.

Saccadic velocity, which showed the most change, is the oculomotor measure

with the largest voluntary and cerebral component in that controls are present in the frontal and parietal regions. In the FIT saccadic velocity tests, movement initiation, gaze direction, and focal point are voluntarily determined, with only speed of movement under involuntary control. Constriction latency, initial pupil diameter, and amplitude of constriction are all mostly under involuntary control, with the voluntary feature being the attempt to focus on a given point. Constriction latency is an involuntary response time test, and increasing constriction latencies possibly reflect slowing of the afferent and/or efferent signals through the neuronal circuits due to decreased neuronal metabolic activity. Initial pupil diameter is a balance between parasympathetic and sympathetic pupillomotor control in response to a given amount of ambient light, and the diameter is maintained in a small physiologic range. The high variability towards the end of the experimental period after early, significant changes could represent the increasing instability in the sympathetic and parasympathetic control systems after early dominance of the sympathetic control system. The ambient light remains constant in the FIT testing scenarios and cannot be a cause of the variability. The lack of any significant findings in the amplitude of pupil constriction could be a result of factors intrinsic and extrinsic to the pupil. The pupil has an anatomically-limited range of responses determined by its intrinsic properties. The parasympathetic pupil constriction system may be maximally responding to the supramaximal stimulation (flash of bright white light). The result is that the anatomic limitations of the pupil become the limiting factor, and diffuse neuronal dysfunction does not change the end result.

Saccadic velocity was the oculomotor measure most sensitive to restricted sleep. This may be due to the relatively large voluntary component of saccadic velocity as compared with other pupilomotor measures such as constriction latency, initial pupil diameter, and amplitude of constriction. That is, it is possible that the observed changes in saccadic velocity during sleep restriction reflected (a) a sleep loss-mediated decrement in motivation to perform the task, (b) a subsequently reduced level of effort and attention directed toward performance of the task, and (c) any other changes in neuronal activity and processing speed that might impact the underlying physiological capacity to perform the task. Further research is needed to specify and quantify the extent to which volitional versus non-volitional processes determine saccadic velocity following sleep loss.

Health Measures

These results do not support the notion that physiological measures can serve as indices of subtle changes in cognitive performance capacity following sleep loss. This is not surprising since these measures largely reflect involuntary behaviors and processes. To date, there is only limited evidence that sleep restriction, or sleep deprivation, affects physiological systems under involuntary control. In fact, none of the physiological health measures evaluated in this study (heart rate, respiration, and blood pressure) were sensitive to sleep restriction. These results also are consistent with the view that sleep deprivation mainly impairs higher-order cognitive performance.

RELATIONSHIP BETWEEN NOCTURNAL SLEEP AND OBJECTIVE AND SUBJECTIVE ALERTNESS

The effects of sleep restriction on daytime sleep latency were less consistent than effects seen on performance measures. First, although sleep latency decreased (indicating increased sleepiness) across the first few days of the sleep restriction period in both the 3- and 5-hour sleep groups, sleep latency appeared to increase slightly in both groups toward the end of the experimental phase. Sleep latency remained relatively consistent across the experimental phase in the 7-hour sleep group but actually increased slightly in the 9-hour sleep group. This pattern corresponds to changes in nocturnal sleep times in both of these groups. For the 7-hour sleep group, nocturnal recuperative sleep time decreased slightly during the experimental phase (as would be expected based on less available time in bed), while for the 9-hour sleep group, nocturnal recuperative sleep time increased slightly. Likewise, following the first night of recovery sleep, sleep latency decreased (indicating reduced alertness) in the 9-hour sleep group and corresponded with slightly decreased nocturnal sleep time on the first recovery night. These results suggest that the SLT (Sleep Latency Test), although not without problems (see upcoming discussion), is relatively sensitive to changes in prior sleep amounts.

During the recovery phase, sleep latency did not increase substantially in the 3-hour sleep group. This finding suggests (as indicated earlier) that recovery sleep, if restricted to 8 hours, may be insufficient to restore performance and alertness after severe, chronic sleep restriction (i.e., 3 hours of sleep per night for 7 consecutive nights).

The decline of sleep latencies in the 3- and 5-hour sleep groups across the first 2 experimental days was comparable. This may have been due to "floor effects." That is, although the 3-hour sleep group may have been sleepier than the 5-hour sleep group, the SLT may not have been sensitive enough to detect the difference because mean sleep latencies for both groups approached the lower limits of possible sleep latencies.

NOCTURNAL SLEEP TIME—SIMULATED DRIVING

The majority of driving-performance measures showed dose-dependent and/or cumulative sleep restriction effects. These included total accidents and the standard deviations for speed and lane position. In some cases, only the 3-hour sleep group reached statistical significance, with the 5-hour sleep group showing similar but non-significant trends and the 7- and 9-hour sleep groups remaining unchanged.

Mean driving speed (within 55- and 35-mi/h zones—88.5- and 56.3-km/h, respectively) was affected by sleep restriction. However, effects were significant only for the 3-hour sleep group, in which driving speed *increased* across the experimental phase. It is not known whether this effect would generalize to the real world or is, to some extent, an artifact of the STISIM simulator. The simulation was reported as quite boring and aversive. Thus, there was some incentive to speed, as this shortened the duration of each run. However, if this effect generalizes to real-world driving, it suggests that sleepy drivers may increase driving speed in an attempt to reach their destination (perhaps with the goal of obtaining sleep or some other intervention sooner). However, driving speed in the 3-hour sleep group increased across the 3 recovery days as well, suggesting possible learning, motivational, or other effects independent of sleepiness per se.

Speed variability (standard deviation) was also affected by sleep restriction in a dose-dependent fashion, with the largest effects being in the 35-mi/h (56.3-km/h) zones and for the 3-hour sleep group. Standard deviations tended to covary with the mean speed itself, as one might reasonably expect. The rapid recovery in the 55-mi/h (88.5-km/h) zones but limited recovery by the 3-hour sleep group in the 35-mi/h (56.3-km/h) zones may be at least partly due to the continued higher *mean* speed maintained by this group in these zones.

Mean lane position showed an initial bias or offset of about 1 foot to the left of lane center, closer to the center of the road. This bias increased for the 5-hour sleep group and particularly for the 3-hour sleep group as sleep restriction continued but remained unchanged for the 7- and 9-hour sleep groups. The 3-hour sleep group again showed incomplete recovery. This drift toward the center of the road, combined with increased variability, might be expected to increase the probability of collisions with oncoming traffic if generalized to the real world.

Lane-tracking variability (standard deviation of lane position) showed clear dose-dependent effects, cumulative day effects, and relatively rapid though not necessarily complete recovery. Tracking variability also showed a time-on-task effect over the 45-minute drive, even though this would normally be considered a very short haul. This fatigue-like time-on-task effect was amplified by sleep restriction. Both effects could be expected to increase the probability of accidents, so the interaction effect is noteworthy.

Number of accidents (crashes) also was affected by sleep restriction and, like speed, was significant only for the 3-hour sleep group. By far, the majority of accidents involved running off the road. On-road collisions were approximately 10 times less frequent than off-road accidents but did occur and also increased with sleep restriction. Accident rates returned to near-baseline levels after 1 night of recovery sleep. Crashes are discussed in greater detail in the next section.

Most of the standard deviation measures showed immediate recovery, often followed by a delayed rebound, the cause of which is unclear.

RELATIONSHIP BETWEEN SIMULATED DRIVING PERFORMANCE AND MICROSLEEP—DO MICROSLEEP EVENTS ACCOUNT FOR DRIVER CRASHES? THE WALTER REED LAPSE HYPOTHESIS REVISITED

The cause of performance decrements during sleep deprivation/restriction has been the subject of ongoing debate. As reviewed in Chapter 1, Williams et al. (1959) and Lubin (1967) hypothesized that *all* sleep-loss-induced performance deficits may be the result of "lapses" in performance, perhaps due to involuntary brief sleep intrusions or microsleeps (defined earlier on p. 2-10). This hypothesis was tested directly in this study—i.e., the authors determined whether

accidents were preceded by Rechtschaffen and Kales (1968)-defined sleep and/or microsleep events.

The majority of simulator-driving accidents that occurred in this study (more than 93 percent) were not immediately preceded (i.e., within 2 s) by Rechtschaffen and Kales (1968)-defined sleep nor by microsleep events. Even though the 3-hour sleep group (sustaining the greatest amount of sleep loss) displayed the highest number of crashes, in this group only 14 percent of accidents were closely associated with microsleep events. This means that a microsleep event was detected within 2 s prior to the crash (within 10 s prior to a crash, only 22 percent of accidents were associated with microsleeps). Using the 2-s criterion (or even the 10-s criterion), it can be concluded that most of the simulator-driving accidents were not caused by the drivers falling asleep behind the wheel.

These results are in agreement with a previous analysis of microsleep events and simulator-driving accidents during 64 hours of total sleep deprivation (Welsh et al., 1998; Peters et al., 1998), also showing a low rate of temporal concordance between accidents and falling asleep behind the wheel. Likewise, Gillberg and Akerstedt (1998) recently reported that less than half of missed targets on a vigilance task were accounted for by electrophysiologically defined microsleep events, even after 24 hours awake. Such findings suggest that while brief sleep episodes may cause some driving accidents (performance lapses), other sleep deprivation-induced behavioral impairments must account for the bulk of driving (and perhaps other operational) accidents. The results of a brain imaging study (Thomas et al., 1998) assessing the effects of 24 to 72 hours of sleep deprivation on brain activity and cognitive performance suggest the nature of those behavioral decrements. In that study, regions associated with attention and visual peripheral awareness (prefrontal lobes and inferior parietal lobules—Mesulam, 1985), were deactivated to the greatest extent during sleep deprivation. On the other hand, areas associated with sleep onset and sleep [e.g., basal forebrain, hypothalamus, and pons (Steriade and McCarley, 1990] were affected to a lesser extent.

An additional analysis was performed to determine if there were systematic differences in microsleep events during simulator driving as a function of degree of sleep restriction. In general, there were no significant differences between the sleep groups with respect to relative number, relative maximum duration, or total relative amount of microsleep events. This finding may seem surprising given the amount of sleep deprivation incurred by the 3-hour sleep group.

As previously described in the Methods section (Objective Alertness—Microsleep), the microsleep analysis for the STISIM 1340 hours data set had a lower inter-rater reliability than what is typically used for Rechtschaffen and Kales (1968)-defined sleep, resulting in an underscoring of microsleep events. As previously mentioned, there are no established inter-rater reliability standards for microsleep scoring. To control for systematic scoring differences between microsleep analysts, the authors assigned equivalent numbers of PSG records from each sleep group to each analyst and used relative, not absolute, measures. Still, the effect that low inter-rater reliability may have had on the present results cannot be completely discounted. However, analyses from another study do corroborate these findings. In the authors' total sleep deprivation/simulator-driving performance study (Thomas et al., 1995), regarding PSG records for the afternoon time point at which STISM driving performance was assessed following total sleep deprivation out to 64 hours, the authors did *not* find a significant difference in microsleep events for each day of total sleep deprivation compared with rested baseline (unpublished data). In that study, rather than using multiple scorers (necessitated by the size of the current data set), one experienced analyst scored all of the afternoon PSG/STISIM simulator-driving records. In a comparison analysis in which the HYSIM (High Fidelity Driving Simulator, Turner-Fairbank Highway Research Center, McLean, Virginia) was used, however, a total sleep deprivation, dose-dependent increase in the number of microsleeps *was* found during the afternoon 45-minute HYSIM drive (Welsh et al., 1998). The reason for the differences in results for microsleeps between the two simulators during total sleep deprivation in that study is unclear but may have been due to the relatively higher realism of the HYSIM. Also, novelty effects may have played a part since the HYSIM was driven only four times (plus a training drive) during the study rather than multiple times each day, as in the case of the STISIM, which may have unmasked drowsiness during the comparable baseline, rested driving test.

This overall finding that sleep restriction did not result in a relative increase in microsleep events indicates that, although cumulative sleep restriction (at least in the amounts evaluated in this study) does not result in greater polysomnographically defined sleep events, accidents still increase. One practical implication of this finding is that alertness monitoring devices relying solely on polysomnographically defined sleep events will not necessarily predict impending accidents. Other methods that rely on the frequency components of the EEG signal (rather than

visual scoring) may be better predictors of accidents. This issue is currently undergoing laboratory evaluation (Sing et al., 1998).

LEARNING/PRACTICE EFFECTS

In this study, performance on virtually all of the cognitive tasks improved throughout all phases of the study for the 9-hour sleep group (and usually for the 7-hour sleep group, as well). Improvement was greatest for throughput and response speed but was also evident for accuracy on most tasks. This systematic improvement indicates that the pre-baseline training period was not of sufficient duration to attain asymptotic performance (i.e., learning was still occurring during the three study phases). Performance improvement was expected in the training phase of the study but was *not* expected thereafter. Previous studies conducted by the Walter Reed laboratory and by other WRAIR PAB users indicate that 10 practice sessions are typically sufficient to reach or closely approach asymptotic performance levels. In this study, the subjects received a total of 12 practice sessions prior to baseline. The most likely explanations for the learning-rate disparity between subjects in this study versus previous studies are: 1) differences in the subject population between this study and previous studies; 2) the presence of similar learning effects that were masked by more potent independent variables in previous studies (e.g., total sleep deprivation, drugs, work load, heat stress, hypoxia, etc.); or 3) some combination of both.

Regarding differences in subject population, **Figure 2-37** shows that the non-sleep-deprived subjects in this study (the 9-hour sleep group) required more than 50 sessions to approach the same response speed obtained by previous subjects in 10 sessions. Throughput required considerably more than 50 sessions, accuracy noticeably less.

For most previous studies conducted in this laboratory, the subjects have been college students in their late teens or early twenties currently enrolled in school. The population sampled in this study consisted of older subjects (24 to 62, mean 38 years), and it can be presumed that many of them had been out of school for a considerable time. It is well known that reaction times increase with age. This would explain a lower asymptote for speed but would not explain a slower learning rate per se. Neither is it likely to be due to unfamiliarity with a computer or a keyboard since the tasks included here did not require computer knowledge or typing skills. One

possibility is that the observed differences were due to novelty and recency effects, possibly combined with age effects. College students are trained and experienced in quickly acquiring novel skills. They could be relatively "test savvy," having recently mastered what are called "learning to learn" skills—skills that may dissipate with disuse and the passage of time.

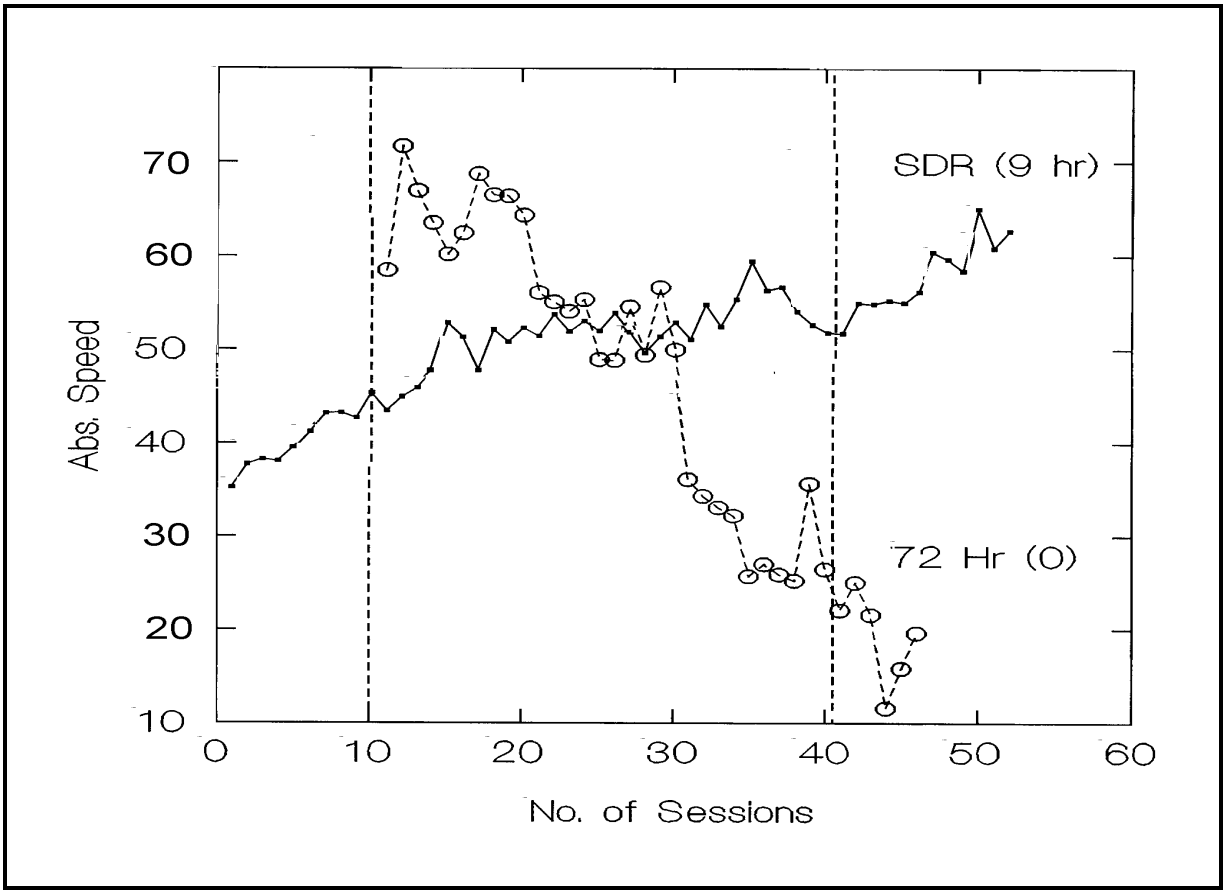

Figure 2-37. Absolute speed on Serial Addition/Subtraction versus number of test sessions. Open circles are for a group of young students beginning 72 hours of total sleep deprivation after 10 previous practice sessions. Solid line is for the SDR 9-hour sleep group.

Also, it is possible that these subjects were generally sleepier than the college-age subjects of previous studies—and that the apparent learning effect actually reflects a gradual dissipation of sleepiness in those subjects who obtained normal or extra-normal sleep during the experimental phase of the study. This possibility is consistent with the authors' finding that the SLT revealed that approximately one-third of this study's subject sample was "pathologically sleepy" on the baseline day.

Regardless of the specific mechanism, however, it is apparent that the subject population from which this study sample was drawn differs in some relevant aspect from the college student population from which subject samples typically have been drawn for previous studies. The immediate consequence of not achieving asymptotic performance prior to the experimental phase of this study was that the data from the Serial Add/Subtract test (used in previous iterations of the Sleep Performance Model [SPM]) could not be used for fitting parameter values to the SPM. This is because the SPM does not currently include functions or parameters for different learning rates (i.e., parameter estimation requires initial stable-state performance).

Learning Effects—Implications for Modeling

The consequence of the just-discussed learning effect is that data from cognitive tasks showing extended learning are not appropriate for fitting parameter values to the SPM. The SPM does not currently include functions or parameters to account for different learning rates, and it depends on parameter estimation from initial (baseline) stable-state performance.

Unlike the cognitive tasks described earlier, learning/practice effects were negligible in the PVT, and effective asymptotic performance was attained by the baseline day. The absence of learning effects means that response-speed data from this task can be used for estimating parameters for the SPM (see Chapter 3).

3. THE SLEEP/PERFORMANCE MODEL[1]

A. BACKGROUND: A CRITICAL REVIEW OF SLEEP/ALERTNESS MODELS—INPUT FACTORS, PREDICTION OUTPUT, AND LIMITATIONS

There are several models that describe the cyclical nature of sleep and wakefulness, and many models of sleep architecture dynamics (for reviews of models of sleep regulation, see Borbely & Achermann, 1992; and Beersma, 1998). Also, there are some models describing the relationship between sleep, circadian rhythm and *alertness*. However, with the exception of the Walter Reed Sleep/Performance Model (SPM), there are currently no existing models constructed for the express purpose of quantifying the relationship between sleep, circadian rhythm, and subsequent performance. Although alertness and performance are distinct concepts and therefore do not co-vary perfectly, those models that allow alertness prediction are relevant to this discussion, since alertness can impact performance. Models of this type most notably include the Moore-Ede Model, Dawson's Work-Related Fatigue (WRF) Model, and the Three Factor Model, which are briefly reviewed next.

THE MOORE-EDE MODEL

Moore-Ede and Mitchell (Method for predicting alertness and bio-compatibility of work schedule of an individual. U.S. Patent #5,433,223, awarded 18 July 1995) describe a method for predicting the likely alertness level of an individual at a specific point in time based upon an unspecified mathematical computation involving a variety of factors (referred to as "real-world" factors) known to impact alertness. The individual's Baseline Alertness Curve (BAC) is first determined based on five inputs—age, home time zone, work shift or sleep schedule to which the individual is currently acclimatized, circadian tendency of the individual (morningness/eveningness tendency), and the presence of any underlying

[1] In this chapter, the Walter Reed Sleep Performance Model (SPM) is presented in a series of increasingly sophisticated sections that progress from the conceptual underpinnings of the model, through the mathematical formulation of the model, to a technical discussion of the various methods used to derive weights for the model parameters. Thus, an attempt has been made to present this material in a manner that engages the widest possible range of readers—in terms of both technical background and interest—but that is also exhaustively complete. A reasonable understanding of the SPM does not, however, depend on a thorough reading of all of the sections of this chapter—and each reader is encouraged to focus on those sections of greatest interest to him or her.

circadian or sleep-related pathology. This BAC is determined prior to consideration of physiological status of the individual (e.g., sleep debt) or the presence of transient external (environmental) variables that may also impact alertness measures (i.e., it serves as the individual's characteristic baseline). Next, this BAC is impacted by "alertness modifying" stimuli, including: level of sleep debt, light exposure, nutritional/chemical intake, environmental sound, and exposure to fragrances (aromas)—resulting in a "Modified BAC." Thus, the model's intended purpose is prediction of an individual's alertness level, based on relatively stable personal characteristics, (e.g., age), extant physiological status (e.g., sleep debt and circadian phase), and transient external factors (e.g., environmental sound level).

Major impediments to actual implementation of the Moore-Ede model include the considerable number of input variables that must be determined and entered (very few of which are easily measured in the operational environment) and the nonquantitative nature of the model in its current form. Even if it were possible to measure each relevant variable, the effects (both singly and especially in combination) on the outcome measures of alertness are not well delineated. Therefore, the model serves primarily as a list of variables known to impact alertness measures, with inclusion of all relevant input variables, regardless of the extent to which they impact alertness in a quantitative sense and without specifying the nature of possible interactions between these input variables. For example, Moore-Ede's model allows input related to fragrance exposure without specifying a method for quantifying this variable and without specifying in a quantitative manner its expected effect on alertness. [Although it has been shown that certain fragrances possess "alertness-enhancing" properties (Badia et al., 1990), these effects are inconsistent and negligible compared to the robust effects of, for example, the individual's sleep/wake history and time of day—and it is likely that the alertness-enhancing effects of fragrances would be evident only under a restricted range of sleepiness levels, and then only in the relative absence of other, more powerful alertness-enhancing stimuli (e.g., loud noise)].

THE WORK-RELATED FATIGUE (WRF) MODEL

This model, first described by Fletcher and Dawson (1997), predicts "work-related fatigue" as a function of number of hours on duty. In this model, a simplifying assumption is made—i.e., that length of on-duty time correlates positively with time awake. To implement the

method, the user inputs a real or hypothetical on-duty/off-duty (work/rest) schedule. Output from the model is a score that indicates "work-related fatigue" level.

There are two potential shortcomings of this model. First, although the dependent variable in this model, "work-related fatigue," has been shown to correlate with some aspects of actual performance, it is not a direct index of performance. Rather, like predicted "alertness" in the Moore-Ede model discussed earlier, work-related fatigue is presumed to be an intervening variable that impacts performance capacity. Second, the WRF model as it is currently constituted uses only duty hours as the input variable. Thus, subsequent sleep duration is predicted to be a function of duty hours. Therefore, the reliability and validity of WRF model-generated predictions of fatigue are critically dependent on both the accuracy and the stability of the presumed relationship between on-duty time and subsequent sleep duration as well as the accuracy of the proposed mathematical relationship between sleep duration and subsequent fatigue measures. In this respect, the WRF model can be thought of as two conjoined models: one in which sleep duration is estimated (or implied) from duty hours and the other in which fatigue level is subsequently estimated as a function of that previously estimated (or presumed) sleep duration. Therefore, in the WRF model, the potential for error is compounded by the fact that the input variable (duty hours) is two logical steps removed from the outcome variable (predicted fatigue).

The potential difficulties associated with predicting (or presuming) sleep duration based on prior duty hours are apparent. Although the sleep durations of workers on especially long shifts might be expected to be negatively affected, there is still a possibility of significant inter-individual differences in subsequent sleep duration. Inter-individual differences in sleep duration may be magnified in workers completing relatively short shifts, since exigencies in their personal lives may result in restricted sleep (e.g., nighttime child-care requirements) or they may, for example, simply choose to restrict sleep duration to engage in recreational activities. Also, potential implementation of the model in the operational environment is impeded to some extent by the requirement that the user input on-duty/off-duty information (although systems using automated detection of on- and off-duty times can be easily envisioned for some occupations).

THE THREE-PROCESS MODEL OF ALERTNESS/PERFORMANCE

Of particular relevance to this discussion is the Three Process Model of Alertness/Performance (TPM) because this model has been used to predict performance (on a 30-minute vigilance task), as well as alertness (as operationally defined by measures of EEG theta and alpha power density, sleep latency, and subjective scales).

Factors (or processes, as Akerstedt and Folkard, 1997, refers to them) determining both alertness and performance include Process S, an exponential function that reflects the sleep homeostat (or extent to which the need for sleep has been satisfied). Process S is elevated immediately upon awakening from an adequate period of restorative sleep, initially declines rapidly, and levels off as it approaches a lower asymptote. At sleep onset, this factor is designated S^1 to indicate the reverse process (recovery during sleep) that occurs at an initially rapid rate and gradually levels off with continued sleep as an upper asymptote is approached. Although it is recognized that other factors such as motivation, stress, and environmental noise may affect the propensity to actually initiate sleep, they do not impact Process S, which reflects the underlying, physiologically based need for sleep (Beersma, 1998).

Process C is the circadian factor, a sinusoidal function with a peak (acrophase) in the early evening and the nadir in the early morning hours. Functionally, it has been suggested that Process C serves as an "opponent" to Process S, consolidating wakefulness during daytime hours (in diurnal animals such as humans) by counteracting the duration-of-wakefulness dependent decline in Factor S across the day. Similarly, Process C maintains and consolidates nocturnal sleep by counteracting the sleep-duration-dependent increase in S^1 across the night (Edgar et al., 1993; Dijk & Czeisler, 1995). Thus, in humans, for example, it is the interactive effects of Processes S and C that effectively determine the thresholds for both sleep onset at night and the awakening threshold on the following morning.

Process W is the third factor, and this is the amount of time spent awake—a factor that is included to account for the fact that the transition from sleep to wakefulness is not immediate, but characterized by a "sleep inertia" period of approximately 20 minutes (e.g., see Lubin et al., 1976), during which performance and alertness improve to normal wakefulness levels. In the current version of the TPM, the mathematical characterization of Process W is not yet well delineated—so this factor remains somewhat notional. But performance and alertness prediction

functions are essentially derived by summing the functions for Processes S, C, and W. Inputs for the TPM include only the times for retiring and arising.

The Three Process Model is clearly the model most similar in terms of function and input variables to the Walter Reed Sleep Performance Model (SPM). In both models, the factors accounting for most of the variance in performance are recognized to be the amount of prior sleep and the extant circadian phase (consistent with the relevant literature). In both models, too, sleep need is presumed to increase systematically as a function of "time since awakening"—although in the current SPM the need for sleep increases in a linear fashion, whereas a curvilinear relationship between sleep need and time awake is used in the TPM. Also, in both models, performance predictions are a function of the combined effects of extant sleep debt and circadian phase, although the prediction is based on an additive combination of these factors in the TPM, whereas in the SPM these factors are combined in a multiplicative manner.

As described in greater detail later, other differences between the two models include: (a) a double-cosine function in the SPM (rather than a single function as in the TPM) to describe not only the overall circadian rhythm effects but also the asymmetry in the waveform and the well-documented "dip" in performance that occurs in the afternoon; and (b) the inclusion in the SPM of a 5-minute functional delay before sleep-related restoration begins to accrue after each sleep onset. The latter was added to the SPM to reflect the reduced restorative value of Stage 1 sleep (the transition stage between wakefulness and deeper, more restorative sleep stages), which can constitute a significant portion of total sleep time when sleep is fragmented.

B. THE WALTER REED SLEEP/PERFORMANCE MODEL (SPM)

The SPM is a series of empirically derived mathematical relationships describing the continuous decrement of cognitive performance during wakefulness, restoration of cognitive performance during sleep, and cyclic variation in cognitive performance during the course of the day. Unlike previous modeling efforts, the Walter Reed SPM predicts performance rather than sleepiness, sleep onset, or other aspects of the sleep/wake cycle. Its development reflects the empirical goal of managing sleep to sustain performance.

INPUT TO THE SPM 1: SLEEP/WAKE HISTORY

The timing and duration of sleep and wakefulness periods over several cycles (i.e., several days) constitute an individual's sleep/wake history. In the SPM, four separate functions or equations are used to relate sleep/wake history to level of cognitive performance capacity. These include: (a) a wake function, (b) a sleep function, (c) a "delay of recuperation" function, and (d) a sleep inertia function. Each of these is described in the following sections.

Wake/Decrement Function

The wake/decrement function is a mathematical formula describing the rate at which cognitive performance capacity declines during continuous wakefulness. Previous iterations of this function were based on studies showing that: (a) cognitive performance is maintained at a steady state across days when individuals obtain 8 hours of sleep each night; (b) cognitive performance (defined as throughput—a product of speed and accuracy that constitutes a measure of useful work performed per unit time) declines by approximately 25 percent for every 24 hours of total sleep deprivation (Thorne et al., 1983); and (c) a single, daily 30-minute nap over 85 hours of sleep deprivation has substantial recuperative value, slowing the rate of performance decline from 25 percent to 17 percent per day (Belenky et al., 1996). Data from the Sleep Dose/Response study (see Chapter 2) were used to estimate the wake function during cumulative restricted sleep.

Sleep/Restoration Function

The sleep/restoration function is a mathematical formula describing the rate at which restoration of cognitive performance capacity accrues during sleep. In the SPM, this rate is determined by: (a) the individual's sleep debt at the time of sleep onset, and (b) the amount of time spent asleep. Thus, the rate at which recuperation occurs during sleep varies continually as a function of extant sleep debt—with recuperation at the beginning of the sleep period (when sleep debt is relatively high) occurring at a faster rate than at the end of the sleep period (when sleep debt is relatively low). [Previous studies suggest that recuperation accrues during sleep in a nonlinear manner (e.g., Lumley et al., 1986) with a high rate of recuperation during the first few hours of sleep that gradually wanes (approaches an asymptote) as the sleep period is

extended—until the benefit realized from additional sleep becomes negligible (Harrison & Horne, 1996)]. Of particular interest in this study was the extent to which adaptive increases in the rate of recuperation during sleep would compensate for reduced sleep durations over several consecutive nights.

Delay-of-Recuperation Function

The delay-of-recuperation function is a mathematical formula describing the time lag between deactivation of the wake/degradation function and activation of the sleep/restoration function at sleep onset. This function reflects the fact that the first few minutes of sleep are generally comprised of Stage 1 sleep (Hauri, 1982)—and, as discussed in Chapter 1, Stage 1 sleep probably has little or no recuperative value (also see Wesensten et al., 1999). Previous studies suggest that 4 to 11 minutes is the approximate length of time required to return to recuperative sleep (Stage 2 or deeper) following a nighttime awakening (e.g., Balkin et al., 1988). If several hours of sleep are obtained without interruption, then these delays make only a small difference in overall restoration of cognitive performance capacity during sleep. However, as sleep is interrupted more frequently, the delays in recuperation begin to significantly impact total recuperative sleep time—consistent with the literature on the effects of sleep disruption on subsequent performance and alertness (e.g., Bonnet, 1985).

By preventing immediate accumulation of cognitive performance capacity at the beginning of a sleep period or following awakenings from sleep, the delay of recuperation function adjusts (and thereby improves the precision of) the cognitive performance capacity estimation. At present, this delay is set at 5 minutes following each arousal or awakening. However, it is likely that the function will, in the future, be modified in such a way that the delay will be mediated by extant sleep debt and/or time of night.

Sleep Inertia Function

The sleep inertia function is a mathematical formula that describes the gradual (over approximately 20 minutes) restoration of normal performance and alertness levels that occurs upon awakening from sleep. It is therefore a function that describes performance for a relatively restricted period of time each day. It is based on both performance (for a review of sleep inertia

effects, see Dinges et al., 1981) and positron emission tomography data (Balkin et al., 1998) showing that those brain regions known to mediate cognitive performance are relatively deactivated immediately upon awakening from sleep. At present, the sleep inertia function is not implemented in the SPM. However, data from a recently completed study in the Walter Reed laboratory will be used to determine the shape of the sleep inertia function. It is anticipated that this function will be added within the year.

INPUT 2: TIME OF DAY (CIRCADIAN PHASE)

Time of day also serves as input to the SPM and reflects the influence of circadian and ultradian rhythms on performance. The time-of-day function is based on empirical data showing that, under constant routine and/or total sleep deprivation conditions (i.e., with sleep/wake history controlled), cognitive performance oscillates between approximately 5 and 20 percent peak to peak over a 24-hour period. Although there is typically a lag of an hour or more, alertness and performance tend to track the core body temperature rhythm with a nadir in the early morning hours, and increase across the day (except for a dip in the afternoon), and a peak in the evening hours, prior to sleep onset (see Monk, 1987; Johnson, 1982).

INPUT 3: COMBINING CIRCADIAN AND SLEEP/WAKE INPUTS TO PREDICT COGNITIVE PERFORMANCE CAPACITY

The overall process of calculating predicted cognitive performance is straightforward. Time-of-day information (Input 2) modulates (in a multiplicative manner) the cognitive performance capacity, which is a function of extant sleep debt (derived from Input 1: sleep/wake history)—resulting in the final predicted performance values.

In the SPM, the preferred numerical representation of cognitive capacity has a value ranging from zero to 100—with 100 representing the maximum cognitive performance capacity possible with extended (infinite) sleep. However, predicted cognitive *performance* can meaningfully exceed 100 under special circumstances due to time-of-day modulation (Input 2) of current cognitive performance capacity (generated from Input 1). For example, in the unlikely event that an extended sleep period (i.e., resulting in near-100 percent restoration of cognitive performance capacity) terminated at the circadian acrophase (i.e., the highest point of the

circadian rhythm), super-optimal cognitive performance (i.e., greater than 100 percent) would be predicted by the SPM (after sleep inertia effects had dissipated). Although this scenario is theoretically possible, it is unlikely since there would be a strong, natural tendency to awaken during the ascending phase of the circadian temperature rhythm long before the acrophase had been reached.

CURRENT WRAIR SLEEP/PERFORMANCE MODEL (SPM)

In the current version of the model, Predicted Performance (P) at a given time t is equal to the Current Cognitive Capacity (C), multiplied by a diurnal Modulating function (M) having both a circadian (24-hour) and an ultradian (12-hour) component. That is, $P = C * M$. Current cognitive capacity (C) is the result of recent sleep history and is determined by both a waking decrement function and a sleep recovery function that operate in alternation. (Sleep inertia and delayed recovery functions are not included here).

Wakefulness is represented by a simple linear decay function. If the subject awoke at 100 percent of cognitive capacity and remained awake for a period of time t, cognitive capacity would equal $100 - c_1 * t$, where the coefficient c_1 is the waking decrement constant—one of the parameters estimated from the Sleep Dose/Response Study data described in Chapter 2. Similarly, if the subject awoke at 80 percent of maximum capacity and remained awake for a period of time w, cognitive capacity would equal $80 - c_1 * w$. In general $C_t = C_w - c_1 * w$, where t is the current time, C_w is the value of cognitive capacity upon awakening, and w is the period of time awake.

The sleep recovery function is an exponential growth function. If the subject went to sleep when cognitive capacity reached zero and remained asleep for a period of time t, cognitive capacity would equal $100 * (1 - e^{-c_2 * t})$, where the coefficient c_2 is the sleep recovery time constant (another parameter estimated from the Sleep Dose/Response Study data set). Computing the value of C after a particular starting value and elapsed time asleep is a two-step process involving a backward calculation that will not be described here.

The circadian phase modulator function is the sum of two cosine waves fluctuating about a mean value of 1. Four parameters (c_3 through c_6) determine the waves' amplitudes and phases in the equation:

$$M = 1 + c_3 * \cos((2\mathbf{p} / 24) * t + c_4) + c_5 * \cos((2\mathbf{p} / 12) * t + c_6)$$

where t = 0 corresponds to 0000 hours.

C. PARAMETER ESTIMATION: METHOD AND RESULTS

Parameter values for the Sleep Performance Model were estimated using normalized Response Speed on the Psychomotor Vigilance Task (PVT) as the performance metric. These normalized values were computed separately for each individual based on the mean of his or her performance across the four PVT administrations on the baseline day. Each individual's performance on subsequent tests and days was expressed as a proportion, or percentage, of this baseline mean. These values were then averaged for the corresponding experimental group when group data were the focus of interest. Normalized, rather than absolute, speed was used for generality—both to correct for large individual differences in response speed and because the Sleep Performance Model is itself a relative rather than absolute model.

Model parameters were estimated using two different subsets of the data and two different estimation techniques. The first data set used group daily means, and the second included all daily time points. The first estimation technique used iterative exhaustive search, and the second used particle swarm optimization (described next) applied to both group and individual data.

ITERATIVE PREDICTION OF DAILY MEANS

As indicated earlier, the first data set consisted of group daily means for each of the 7 experimental days of the study, based on the four daily administrations common to all four groups. The purpose of using daily means rather than individual time points was to estimate the two primary parameters c_1 and c_2 (the waking decrement constant and the recovery time-constant) in a manner that would minimize the influence of circadian rhythms. These two parameters determine the major variation in performance due to time awake and asleep and therefore constitute the most basic elements of the model.

The four circadian parameters in the SPM contribute much less to predicted variation ($\approx \pm 10$ percent) but their inclusion can influence the other parameter estimates significantly,

particularly if the estimation technique tacitly gives them equal weight and/or if the data to be fitted include a large amount of error variance. The daily time points (≈ 0900 to 2100 hours) span most of the trough-to-peak range of the circadian performance rhythm as estimated from previous studies and are approximately symmetrical about the line of zero crossing. Thus, averaging the performance data from these times would tend to cancel both circadian and random variation and to approximate the zero-crossing value. This was considered desirable since four to six determinations per day are only marginally adequate for estimating a 24-hour rhythm and are less adequate for identifying a 12-hour rhythm. If the two-parameter values derived by this method differed significantly from subsequent values estimated using the full data set and all six parameters, then this would indicate a problem. Similarly, if the two-parameter values derived separately for each of the four sleep groups differed markedly from one another, then this would also indicate a problem (for example, a curvilinear rather than linear decrement function). Thus, the rationale for using daily means was to get uncontaminated estimates of the two major parameters and to assess the basic adequacy and logic of the model itself. An additional advantage of this approach was that it reduced the size of the data set enough to make conventional iterative estimation techniques (exhaustive search) practical.

The initial "proof-of-concept" estimation technique employed a simple, straightforward program that used the polysomnographically-scored average sleep duration from each night and the equations of the model to predict the normalized performance on the next day for a single group. These predictions were then compared with the actual performance data, and an error score was accumulated across the 7 experimental days. This technique began with candidate values for each of the two constants, which were used to calculate an equilibrium-performance "starting value" based on the amount of sleep obtained the night before baseline. That is, it was assumed that the PSG-scored value was representative of 8 hours in bed per night and that a similar amount of sleep had occurred for enough nights prior to baseline for waking performance to attain its asymptotic equilibrium value. *Some* starting value must always be assumed with the model, and this was the most defensible. The model then calculated the predicted wake-up value, the bedtime value, and the 0900 to 2100 hours normalized, average values for the subsequent days, using the candidate parameters and the recorded sleep and wake times. Then it tallied an error score, as described previously. Next, one of the two parameters was held constant while the second was iteratively stepped in small increments throughout a range that

usually included a local error-score minimum. The first parameter was then incremented by a small amount, the second was returned to its initial value, and the entire procedure was repeated. Finally, the parameter pair producing the smallest total error score was taken as the best estimate of the decrement constant and the recovery time-constant for that group. For this data set, the PSG-scored average sleep durations excluded Stage 1 sleep since evidence suggests that Stage 1 sleep has little or no recuperative value (Wesensten et al., 1999).

This procedure yielded small error scores for performance decrement constants in the neighborhood of one half of a percent per hour awake (e.g., 0.4 – 0.6 percent per hour) and recovery time-constants approximately one-tenth that of the decrement constant. That is, the two constants were related by a nonlinear proportionality—a faster decrement rate could be compensated for by a more rapid recovery rate. Relatively large simultaneous changes in *both* parameters yielded comparable error scores, yet small changes in either *one* of the parameters yielded much larger error scores. The significance of this will be discussed more fully later. Partly because of this, slight differences in the computer program, the number of digits of precision, the starting value, the normalization procedure, the step size, or the order of calculations lead to slightly different "best" estimates. This phenomenon is not unusual and is familiar to those working with curve fitting and "estimation" (versus simple calculation)—the answer obtained depends on the assumptions and details of the techniques employed, much like the different answers obtained using least squares versus maximum likelihood estimates. The paired decrement and recovery constants giving the smallest sum of absolute and squared errors with this data set were 0.55 and .059, respectively, for the 3-hour group, but a nearly identical error score was obtained with pair values of 0.45 and .041. Nevertheless, as illustrated in **Figure 3-1**, parameter values derived for any one group generated good visual fits to the data for the other three groups—an encouraging first finding.

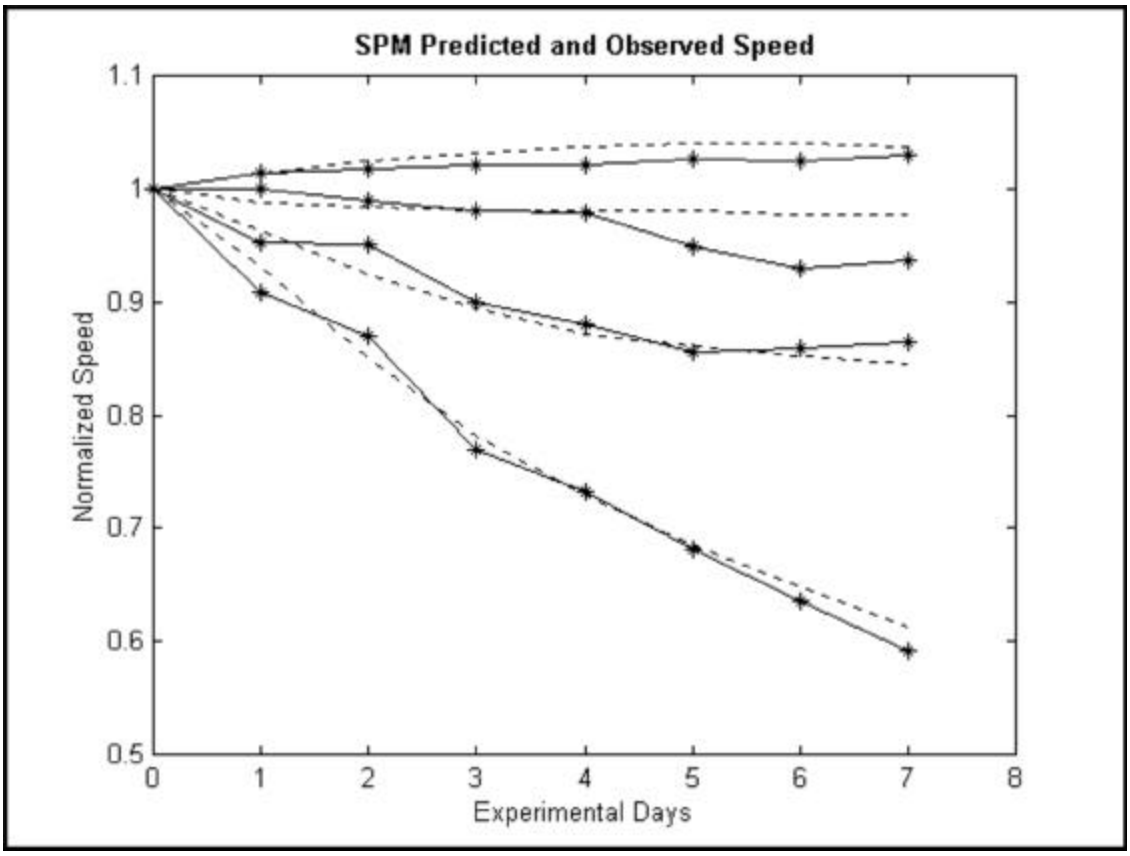

Figure 3-1. Initial fit of predicted values (dashed lines) to group daily means (solid lines) using parameter values derived from the 3-hour group's data using a simple iterative search technique (decrement constant 0.55 percent per hour, recovery constant 0.06).

As a cross–check, the same data set was then processed by a more elaborate second computer program independently written in a different language with consequent internal differences, using smaller step size increments, and designed to estimate parameters for either single groups or all groups combined. This program yielded decrement and recovery constant estimates of 0.425 and 0.0374 for the 3-hour group. When optimized across all four sleep groups, the parameter pair yielding the smallest overall error score was 0.476 and 0.0477, again showing proportionality, within the same general range. Therefore, the second computer program was produced as a means of double-checking the results generated by the first program and did, in fact, confirm the results generated by the first program.

PARTICLE SWARM PREDICTION OF DAILY MEANS

The same data set that was just described was also processed using a random particle swarm method (described next) instead of exhaustive search by iteration. This procedure yielded decrement and recovery values of 0.4204 and 0.0366 for the 3-hour group. When optimized across all four sleep groups, the parameter pair yielding the smallest overall errors score was 0.4766 and 0.0477, essentially identical to the above. The predicted speeds obtained using these pairs of constants are shown with the observed speeds in **Figure 3-2** (Panels a and b).

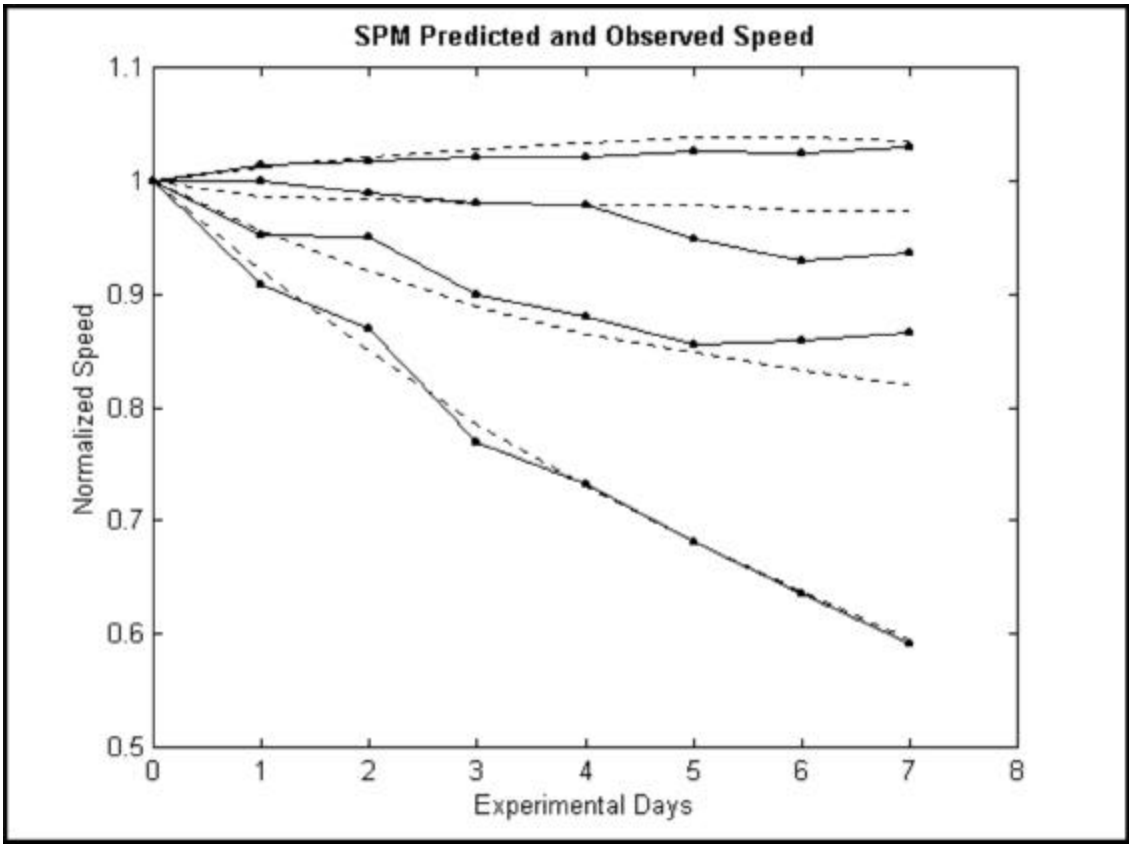

Figure 3-2 (a). Initial fit of predicted values (dashed lines) to group daily means (solid lines) using parameter values derived from the 3-hour group's data using particle swarm optimization (decrement constant 0.4204 percent per hour, recovery constant 0.0366).

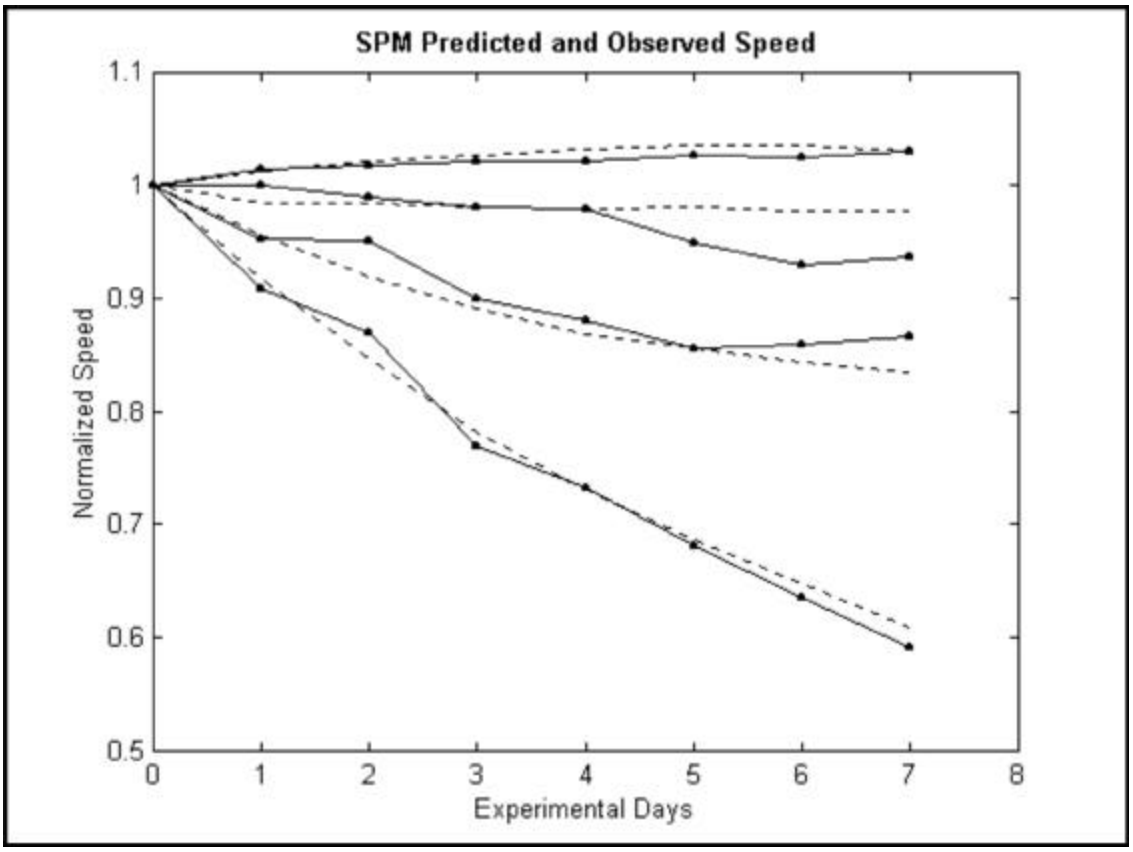

Figure 3-2 (b). Initial fit of predicted values (dashed lines) to group daily means (solid lines) using parameter values derived from all four groups' data using particle swarm optimization (decrement constant 0.4766 percent per hour, recovery constant 0.0477).

Particle Swarm Prediction of Daily Time Points (Circadian Effects)

To estimate all six SPM parameters, the complete group mean data set was used. The performance data set included the four PVT administrations per day for the baseline and recovery days (following 8 hours in bed) and the four to six administrations per day for the experimental days (during which one of four sleep/wake schedules was applied). The times of test administrations are listed in Chapter 2.

The sleep data set consisted of the mean amount of sleep actually obtained by each sleep group on each night. Unlike the data set used with the iterative prediction technique (in which Stage 1 sleep was excluded from total sleep time), the summed durations of Sleep Stages 1–4 and REM [using the Rechtschaffen and Kales (1968) sleep scoring criteria] were used. This was

because, contrary to expectations, it was found that inclusion of Stage 1 sleep reduced the model's error (albeit slightly).

Parameter values were estimated by minimizing the root-mean-square difference between observed and predicted normalized response speeds on the PVT using Particle Swarm Optimization (PSO), as described by Kennedy and Eberhart, 1995. This technique is one of several within the field of computational intelligence and is particularly efficient at converging within a reasonable time on a solution to multivariate problems involving large data sets that would be difficult or impractical to process by more conventional techniques. Each computation used 20 particles and 1,000 iterations. PSO yielded a minimum root-mean-square error of 15.96 percent with the following parameter values:

Table 3-1. Particle swarm optimization parameter values.

Parameter	Name	Value	Unit
c1	Decrement	-0.42	percent per hour
c2	Recovery	0.0437	hour $^{-1}$
c3	24-hour Amplitude	6.97	percent
c4	24-hour Phase	0.4780	radians
c5	12-hour Amplitude	5.33	percent
c6	12-hour Phase	-0.0637	radians

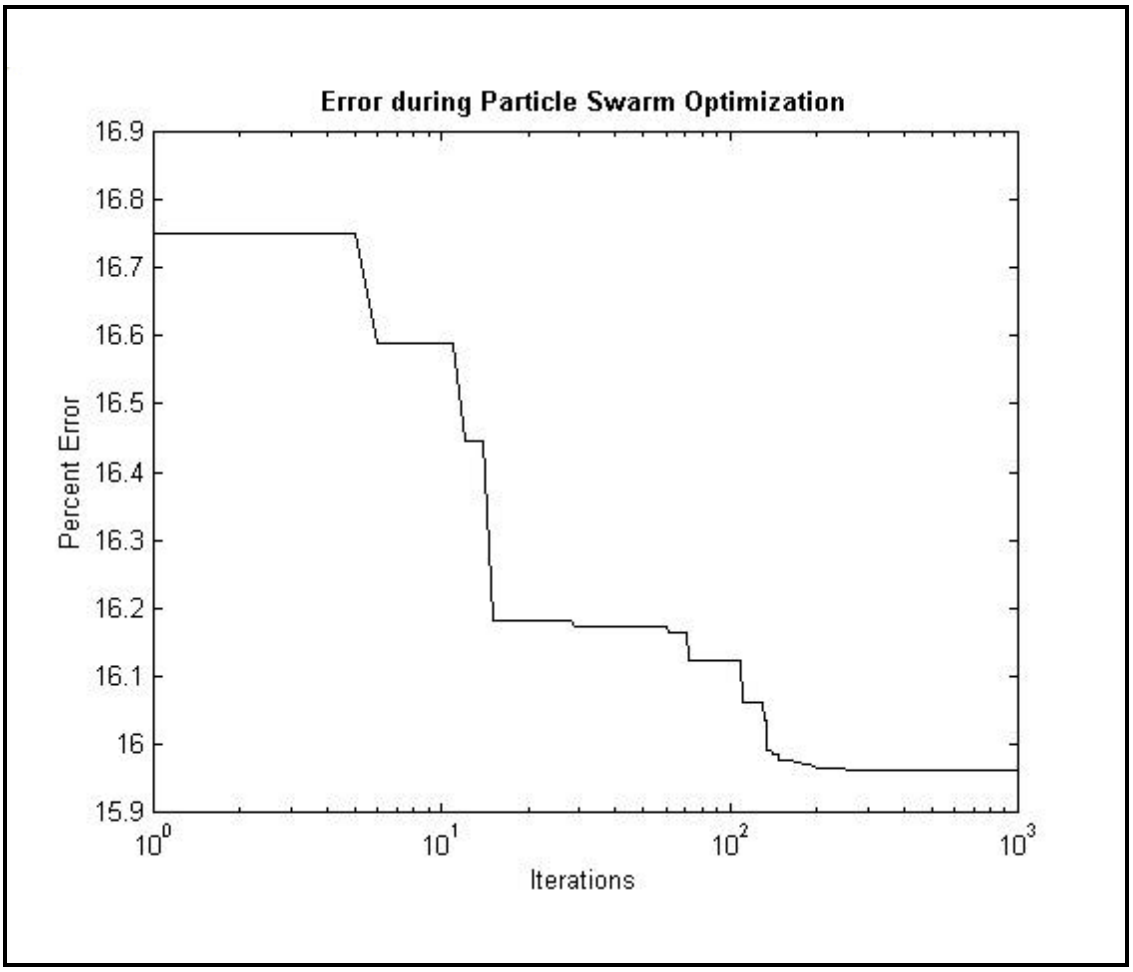

Figure 3-3. Convergence of the prediction error during Particle Swarm Optimization.

Particle Swarm Prediction of Individual Performance

The same PSO procedure was also applied to 65 subjects separately using their individual performance values and their obtained amounts of sleep on the preceding night. The results were inconsistent—yielding both high and low error scores and parameter values that varied by two and three orders of magnitude. In some cases, the time-series plots fitted individual data quite well and, in others, not well at all. The source or causes of the large individual differences is unknown.

D. DISCUSSION

The model and derived parameter values fit the group daily mean data quite well and the group time-of-day data relatively well. The underlying assumptions and equations of the model are deemed reasonable and adequate.

Two different data sets and two different parameter estimation techniques yielded roughly similar values for the waking decrement constant and the sleep-recovery constant when applied to the group data. Different pairs of constants gave similar error scores, but in each case the two were proportionally related—a faster decrement rate could be compensated for by a more rapid recovery rate. Although one pair of values always gave the smallest total error score with a given data set and estimation technique, the differences may be considered minor in light of the variability in the data themselves and the sensitivity to small differences in the estimation procedures. The proportionality seen between the two constants warrants further comment. If plotted in three dimensions (i.e., error scores plotted against these two constants), the resulting figure would resemble a valley with steep slopes and a relatively flat floor or "river bed" running along the diagonal. This riverbed would have a deepest point and rise gently on either side. Due to large individual variability, it is expected that a different group of subjects, or the *same* group run a second time, would give a different deepest point and a different "best" pair of constants. Thus, the estimated values of the decrement and recovery constants derived in this study should be considered workable approximations.

Similarly, the time-of-day modulator parameters should be considered approximations, especially since the study upon which these parameter estimates were based was not optimally designed for assessing 24- and 12-hour rhythms (nor would it have been practical to do so within the constraints of the study). Not only were there relatively few determinations per day, but also they were unequally spaced and differed in number across the sleep groups. The estimates for the four modulator parameters differed from those found in earlier studies, yielding a combined overall modulation of ±11 percent. This is comparable to the ±10 percent value seen previously for throughput under the Serial Addition/Subtraction task but larger than the ±7 to 8 percent seen for speed. Furthermore, the combination of amplitude and phase values generated an exaggerated post-prandial dip—larger than seen in the authors' previous studies or the literature. Finally, the combined phase values were later than typically seen in previous studies. The nadir

was around 0700 hours (versus 0200 to 0600 hours), the postprandial dip around 1700 hours (versus 1300 to 1500 hours), and the evening peak around midnight (versus 2000 to 2200 hours). It is likely that the four modulator parameters are approximate, due to the limited number of daily time points available for their estimation and the variability in the data. It should also be pointed out that different values for the circadian modulator parameters would result in different best estimates for the decrement and recovery constants.

The estimated decrement constant (≈0.5 percent per hour) is roughly half that estimated in previous studies in the Walter Reed laboratory for Serial Add/Subtract throughput. Furthermore, the throughput value could be even higher than first estimated if learning effects were present but concealed by the large total sleep deprivation effects. It is quite possible that the smaller decrement constant found here is appropriate for simple reaction times (i.e., the PVT) and that larger decrement rates would occur for tasks involving a higher cognitive load. Such a hypothesis is intuitively reasonable but would reduce the generality of the model. This hypothesis cannot be confirmed or disconfirmed with the present data.

To a limited extent, it may be possible to quantify the precision of the model using the current data set. If the amount of computational time required to find the parameter set that yields the best fit to a data set can be reduced, then repeated resampling of the data can be used to compute confidence intervals for each parameter. However, the accuracy of the intervals depends on the extent to which the sample reflects the population being modeled. Considering the relatively small sample size, the confidence intervals, like the parameters, would be approximate.

It may also be possible to model the distribution of performance for a given sleep/wake schedule, rather than a single (mean) predicted performance. Assuming that the distribution of performance is normal, its standard deviation could be estimated as a function of its mean. Just as it may be possible to optimize parameters to fit the mean performance of different individuals, it may also be possible characterize individual differences in the standard deviation of the performance distribution. If so, it may be possible to account for the differences in the quality of the model's fit to different individuals [see the discussion of Subjects 518 and 544 (pages 3-23 to 3-25)].

The extent to which the SPM may be population-specific is not clear. Large differences (two and three orders of magnitude) between individuals within this selected population make

this a distinct possibility. There is also the suggestion that the subject sample tested in this study differed markedly from the subject samples of previous studies conducted by the Division of Neuropsychiatry at the Walter Reed Army Institute of Research, since these subjects failed to reach asymptotic performance on the serial add/subtract test after 3 days of practice. Subjects in this study were drawn from a population of professional drivers aged 21 to 65. Most previous studies conducted at the Walter Reed Army Institute of Research recruited college students as subjects—a potentially more homogeneous population with respect to several factors that could affect serial addition/subtraction performance, including age, education, adaptability to novelty, and familiarity with manipulating negative numbers.

Many of these uncertainties could be clarified by a total sleep deprivation experiment using both the PVT and a number of PAB tasks, where the pre-deprivation learning/practice phase was continued long enough for the cognitive tasks to stabilize at their asymptotic levels. Past experience suggests that this would be hastened by using young college students as subjects. This would answer the question of whether the decrement and recovery constants generalize across both simple and complex tasks. In addition, a total sleep deprivation study, unlike this sleep restriction study, would provide a direct measure of the waking-decrement constant that is independent of the sleep-recovery-constant estimation. Because of the proportional relationship between the decrement and recovery constants, this would facilitate the process of determining which of many effectively equivalent "pairs of constants" is optimal.

UTILITY OF SPM FOR PREDICTION OF INDIVIDUAL VERSUS GROUP PERFORMANCE

The extent to which actual performance data from individuals matched (or "fit") the SPM-generated performance predictions varied from very well to very poorly. The reasons for this variability are unknown, and further study is required before the model can confidently be applied to the prediction of individuals' performance.

Figure 3-4 (Panels a-d) shows the mean observed performance for each sleep group co-plotted with SPM-predicted performance. Mean nightly sleep totals (i.e., TST rather than group time in bed) served as input to the model, and all SPM predictions were based on the study-derived parameters described above.

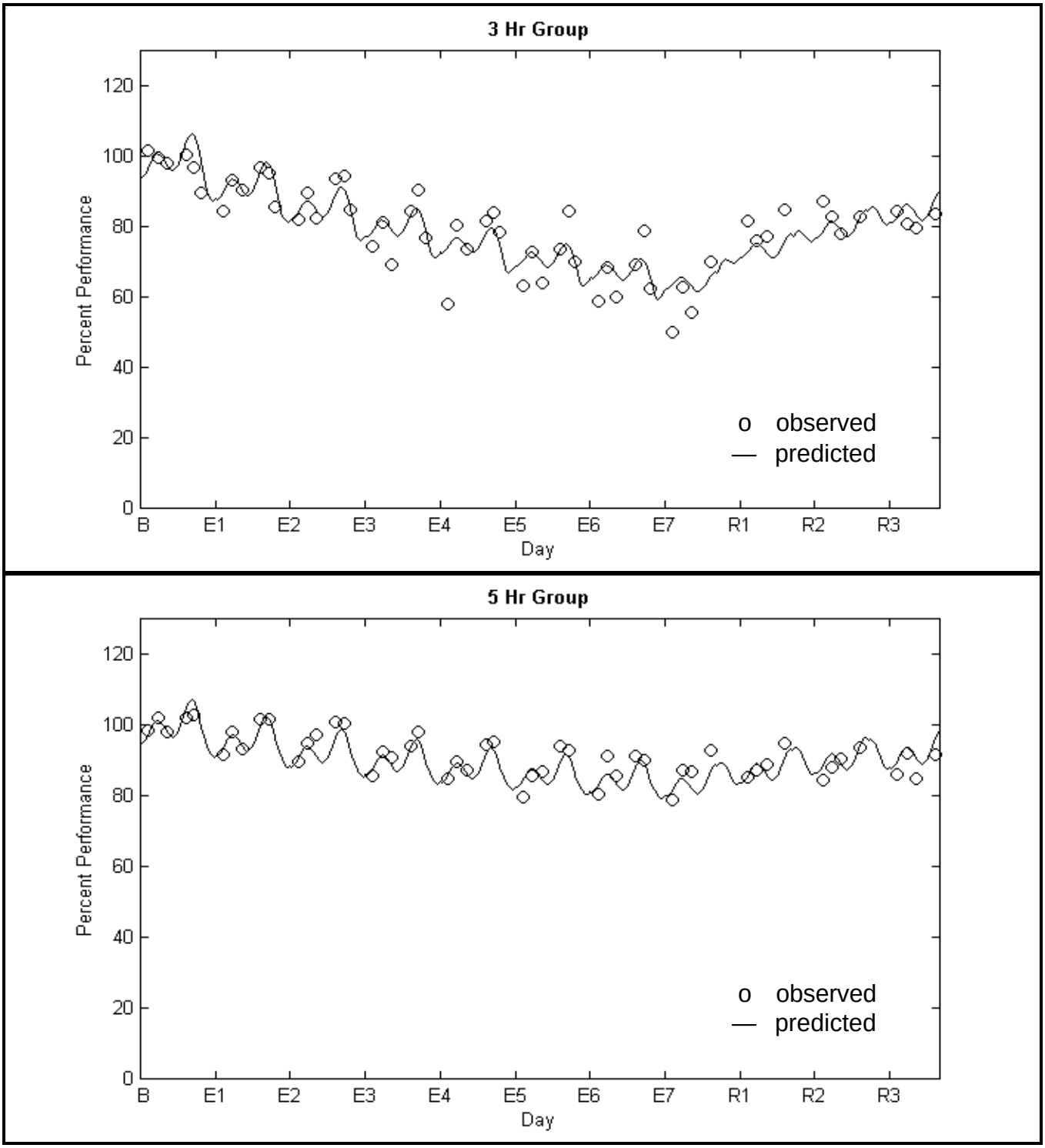

Figure 3-4 (a and b). Observed and predicted performance for 3-hour and 5-hour sleep groups.

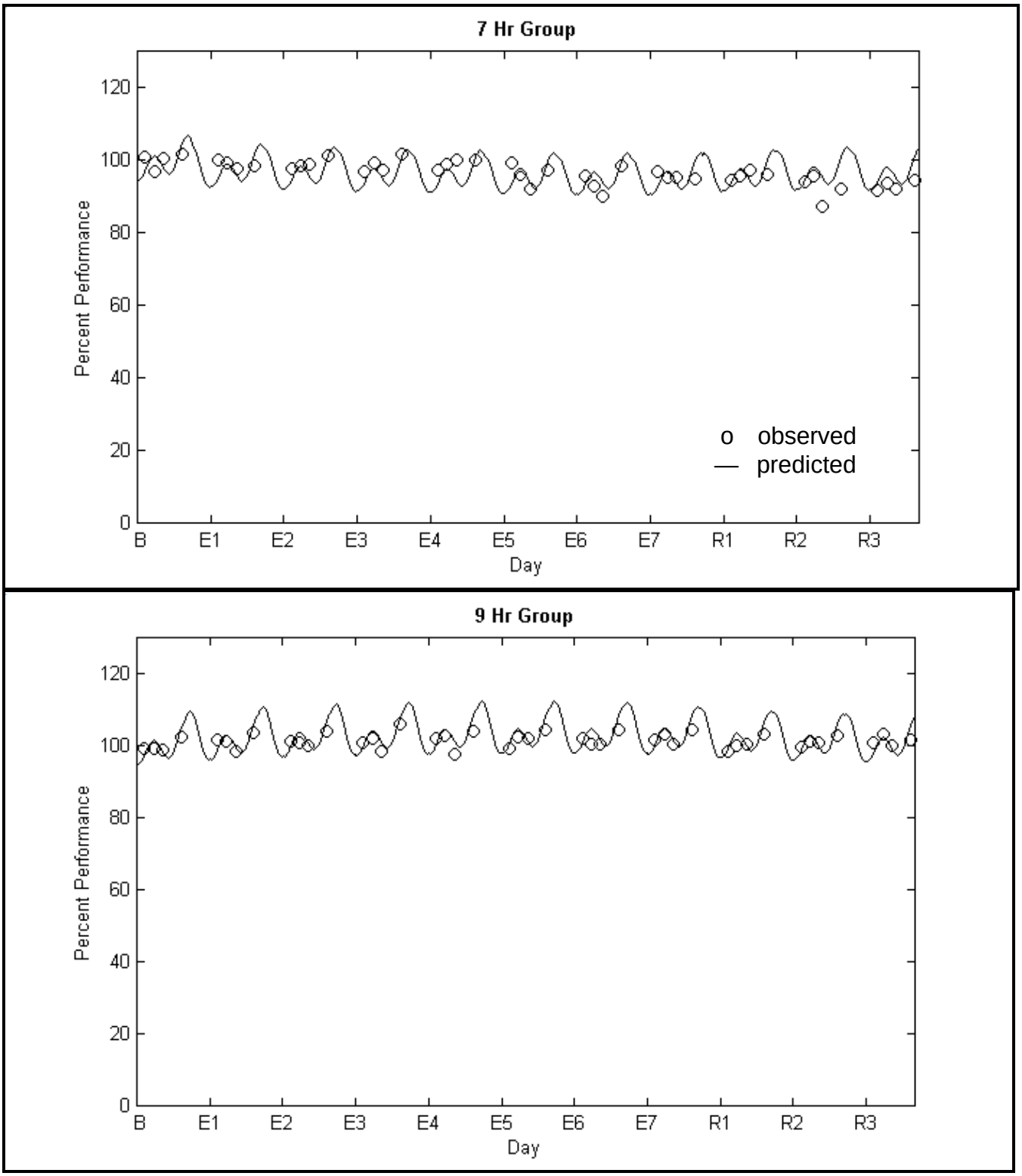

Figure 3-4 (c and d). Observed and predicted performance for 7-hour and 9-hour sleep groups.

Figure 3-5 shows the percentage of subjects at various error levels. The error for most subjects is between 2.5 and 17.5 percent. The highest error was 43.62 percent for Subject 544, who was a member of the 5-hour sleep group. By contrast, the lowest error in the 5-hour sleep group was 5.29 percent for Subject 518. **Figure 3-6** (Panels a and b) shows the predicted versus observed performance for these two subjects.

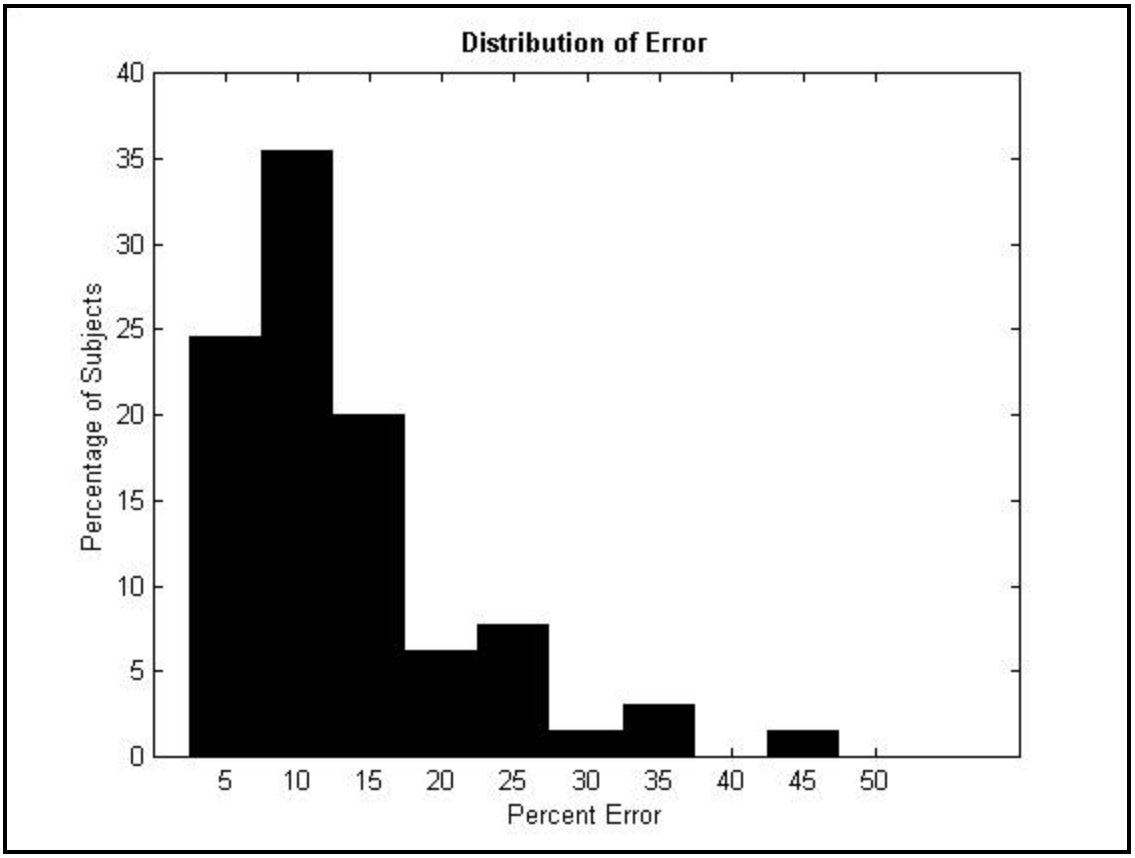

Figure 3-5. Percentage of subjects with various levels of error. The height of each bar represents the percentage of subjects with a percent error in each 5 percent error bin.

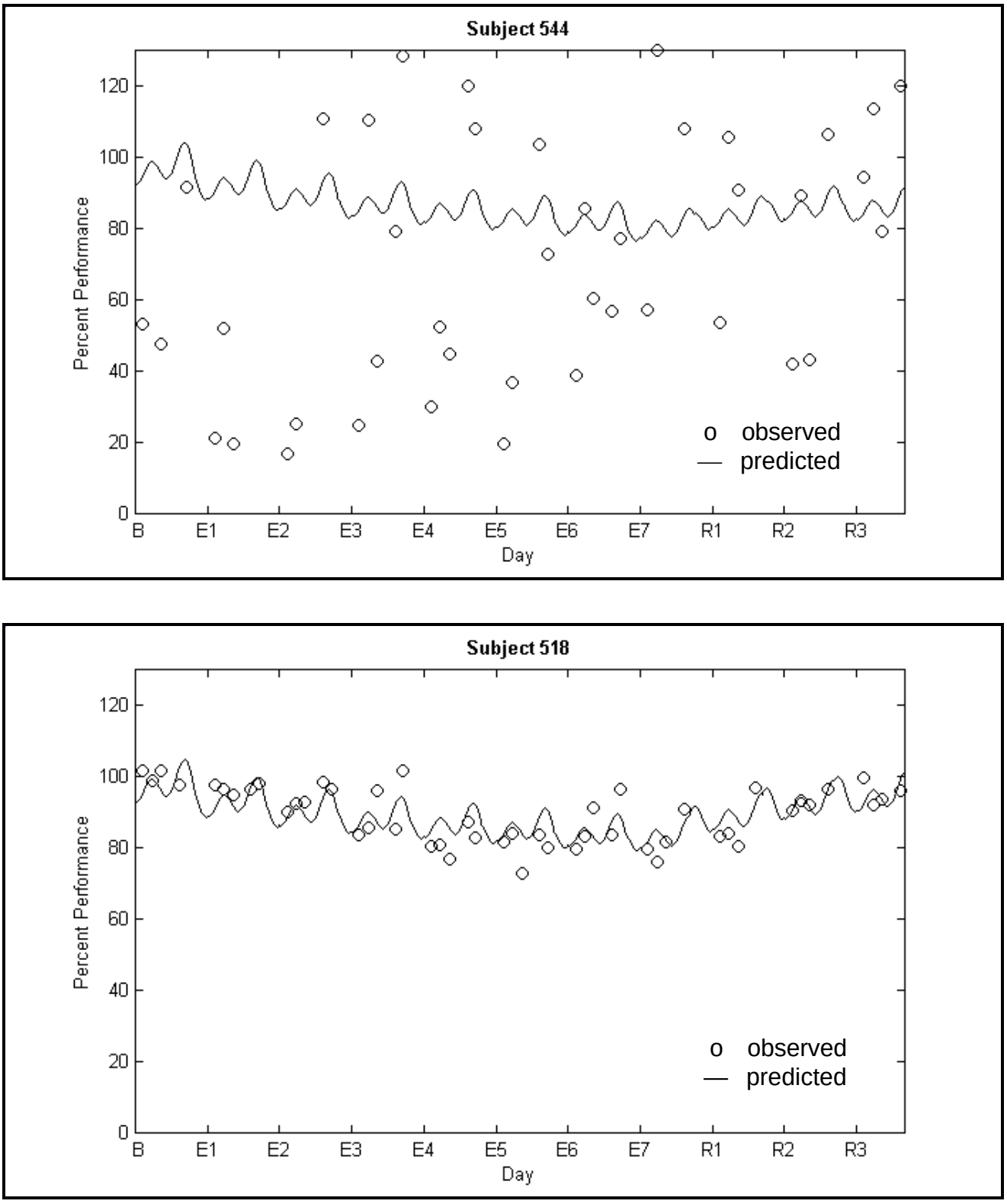

Figure 3-6 (a and b). Observed and predicted performance for subjects whose data were predicted by the model very well (Subject 518) versus very poorly (Subject 544).

Thus, SPM parameters obtained with both Particle Swarm Optimization and Iterative Search prediction methods were comparable and produced SPM parameters that predict group–mean data reasonably well—although the global root-mean-square error of 15.96 percent is somewhat high due to individual differences between subjects. All of the relevant individual characteristics that impact performance significantly could not be determined in this study, but likely candidates include age, education level, and motivation levels. The data from Subjects 544 and 518 shown in **Figure 3-6** illustrate the most extreme examples from the present study of good and poor fit to the SPM predictions—and suggest that a single set of SPM parameter values may not be adequate for prediction of the performance of all individuals. Based on these findings, it is anticipated that accurate prediction of individual performance with the SPM will require individual parameter-optimization routines.

4. FIELD STUDY: ACTIGRAPHIC ASSESSMENT OF CMV DRIVERS OVER 20 CONSECUTIVE DAYS

A. OVERVIEW AND STUDY OBJECTIVES

As reviewed in Chapter 1, insufficient sleep impairs cognitive performance and alertness. Driving, in particular, may be sensitive to insufficient sleep—specifically, the sustained vigilance required during driving parallels laboratory tasks that are impaired by both partial and total sleep deprivation. It is unknown, however, how much sleep commercial motor vehicle (CMV) drivers are obtaining, *or are able to obtain*, per day as determined objectively and in the field, both on- and off-duty. This study addressed these two issues by using actigraphy to objectively record sleep and wakefulness in 50 CMV drivers (25 short-haul, 25 long-haul) continuously for 20 consecutive days. This study served as a demonstration of the utility and limitations of actigraphy for quantifying sleep in the field.

In this study, actigraphy was used to quantify the sleep time of 50 CMV drivers continuously (24 hours per day) over 20 consecutive days, in their normal on-duty and off-duty environments. The actigraph is the size of a large wristwatch and records arm movements. These movements are scored for determination of sleep and wake periods. Important for subject compliance, the actigraph is self-contained and unobtrusive and does not interfere with drivers' normal on-duty and off-duty routines.

For long-haul drivers, the record-of-duty status (RODS) includes a category for indicating sleep taken while away from home, on the road (i.e., the "Sleeper Berth" category). Short-haul drivers generally do not fill out a RODS and generally are able to return home each day to sleep. Even if short-haul drivers usually do not exceed 12 on-duty hours, they may nevertheless obtain some sleep during their work shifts. Continuous recording by actigraphy made it possible to objectively determine how much sleep is obtained across all duty statuses in long-haul and short-haul drivers, independent of driver self-reports (RODS).

B. METHODS

SUBJECTS

Subjects were 50 drivers (men and women), aged 21 to 65, holding a valid Commercial Driver License (CDL). Twenty-five of the drivers maintained driving schedules that enabled them to return home at the end of most work periods to sleep and thus were categorized as "short-haul" drivers. The other 25 drivers maintained schedules that did not always allow them to return home at the end of work periods to sleep. These drivers were categorized as "long-haul." Drivers were recruited from advertisements posted at truck stops and by word of mouth. They were initially screened via a comprehensive medical questionnaire for current serious physical or mental health problems. They were also screened via comprehensive questionnaire for current or past sleep problems, including narcolepsy, sleep apnea, nocturnal myoclonus, or disorders of the sleep/wake cycle. Drivers with a serious current medical illness (as judged by an on-staff physician) or with a current or past history of diagnosed sleep disorder were excluded from participation. They were also questioned about current and past drug use but were not excluded based on that information unless drug use implied presence of a disorder that was exclusionary (e.g., the use of stimulants to control narcolepsy). Drivers were allowed to use their normal amounts of tobacco and caffeine during the study. Copies of all questionnaires used for screening are included in **Appendix 5**.

MATERIALS

Actigraphy

Movement activity was recorded using the Walter Reed wrist actigraph. A review of actigraphy and its reliability/validity for quantifying sleep is provided in **Appendix 6**.

Questionnaires

Drivers were given sleep logs to fill out on each of the 20 consecutive study days. Sleep logs were used to gather subjective information on sleep times; sleep latency; arousals during

sleep; alertness upon awakening; napping (number and duration); and self-reported caffeine, alcohol, and drug use. A copy of the sleep log is included in **Appendix 5**.

Driver's Record of Duty Status (RODS)

Initially, long-haul drivers were asked to provide copies of their RODS corresponding to study dates, and short-haul drivers were asked to keep track of their on-duty and off-duty times across the 20 days of the study. Because of noncompliance in the short-haul group (mainly attributed to drivers forgetting to keep track of duty times), all drivers were then given record-of-duty status (RODS) sheets to fill out on each of the 20 consecutive study days. The RODS used in this study was comparable to those normally used by drivers as part of Department of Transportation requirements. A copy of the RODS is provided in **Appendix 5**.

PROCEDURE

Professional drivers holding a valid CDL were recruited via flyers placed at truck stops and other driver-relevant posts. Some volunteers were recruited from another driving study conducted by WRAIR at the Johns Hopkins General Clinical Research Center Bayview, located in Baltimore, Maryland (Sleep Dose/Response Study, described in Chapter 2). Potential volunteers were contacted by telephone, at which time a full description of the study was read to them, including information on pay. After hearing the study description, drivers who wished to continue were then asked a series of general health questions (Telephone Screen Checklist—**Appendix 5**). Only those drivers with a current serious illness (as judged on a case-by-case basis by the attending physician) were excluded from participation. No other restrictions (e.g., caffeine or nicotine use) were considered exclusionary for purposes of this study.

Once cleared for participation, drivers received an information packet (either in person or by mail) that contained the following: (a) consent form with a description of all procedures, study proscriptions, possible risks, and information on pay; (b) Department of the Army Volunteer Registry Data Sheet (required by the Army Surgeon General); (c) Walter Reed Army Institute of Research Preliminary Sleep Questionnaire; (d) Report of Medical History form; (e) Daily Sleep Log; (f) Driver's Record of Duty Status (RODS); (g) Actigraph Instructions sheet;

and (h) the actigraph itself. Copies of these forms are provided in **Appendix 5**. Drivers were contacted by telephone to verify that they received the packet. Prior to the 20-day study, drivers read, signed, and returned the informed-consent form. A technician verified that each driver possessed a valid CDL by visual inspection of each driver's license.

The study started during daylight hours, at the convenience of the individual driver. The actigraph was programmed to begin data collection some time prior to the driver's first main sleep period of Day 1 so that the first main sleep period was recorded. For most drivers, the actigraph was programmed to begin data collection either at 1200 or 1800 hours. An attempt was made to begin actigraph data collection during off-duty time, but on several occasions this was not possible. In those instances, the actigraph began data collection during on-duty time. The actigraph never began data collection in the middle of a sleep period, as verified by post hoc examination of the actigraphs and Daily Sleep Logs. Once actigraph data collection began, it continued uninterrupted for 20 consecutive days. Drivers were instructed to begin filling out the Daily Sleep Log and RODS after they awakened from the first main sleep period of Day 1. At the end of the 20-day study, drivers returned the actigraph and all forms. They were paid $300 for completion of the study.

DATA PROCESSING AND ANALYSIS

Data from each actigraph were downloaded to a personal computer and scored for any and all sleep periods, regardless of duration or timing. Sleep and wake periods were identified by visual inspection of the actigraph records by a senior staff member with extensive experience in visual scoring of actigraphy records. For the purpose of this study, a day was defined as a 24-hour period beginning and ending at noon.

For the first set of analyses, each 24-hour period was broken down by RODS category, based on the driver's corresponding entry on the RODS. Sleep bouts were then associated with the driver's corresponding RODS entry (all duty status times were identified from the driver's completed RODS).

Sleep associated with any and all periods within the 24-hour period marked by the driver as "off duty" comprised the first category. This was regardless of length of that off-duty period, not simply the longest consecutive off-duty period—to have excluded any off-duty period, no

matter how short, might have meant missing sleep bouts as well. If the RODS indicated more than one off-duty period within a given 24-hour period, then each off-duty period was examined for sleep. For example, if a 24-hour period contained two off-duty periods (as indicated on the RODS), then all sleep from both of the off-duty periods was summed to obtain total off-duty sleep for that 24-hour period. Note that if sleep off-duty was taken in the sleeper berth but the driver indicated "off-duty" on the RODS, then the sleep also was included as "off-duty."

A second category contained sleep during all other times of the day. This category included periods marked by drivers (on the RODS) as sleeper berth (accounting for the bulk of sleep found within this category). This category also contained within-shift sleep—that is, sleep identified during periods marked by the driver as "on-duty, not driving." Finally, in the event that the RODS was either incorrectly filled out or simply imprecise (see below, Actigraph versus RODS), this category also contained actigraphically recorded sleep periods identified during periods marked by the driver as "on-duty, driving." The three duty statuses were combined since it was deemed that they were most likely to reflect sleep away from home for both short-haul and long-haul drivers. It is noted that sleep occurring during off-duty hours for long-haul drivers may still be sleep taken away from home—for example, if, as noted sleep was taken in the sleeper berth but marked as "off duty." However, it was felt that using consistent categorizations for both long- and short-haul drivers would be preferable.

Because CMV operators should be driving during time they marked as "on-duty, driving" in the RODS, this duty status would not be expected to contain any sleep—nonetheless, any time marked by the driver as "on-duty, driving" was examined for sleep (as noted earlier). This was done to ensure that the entire 24-hour period was examined for sleep, not just those duty status periods when sleep would likely occur. Sleep during a period marked as "on-duty, driving" would likely reflect an imprecision with the RODS, since drivers are only required to record duty status in the RODS to the nearest 15 minutes. It is also possible (although probably less likely) that the RODS might be incorrectly marked as "on-duty, driving" when the actual duty status was something else.

In short, each 24-hour actigraph recording period was examined for sleep in its entirety—no portions of the 24-hour period were excluded from examination for sleep bouts, regardless of RODS-indicated duty status type or length, or the likelihood that sleep would or would not occur.

In the second set of analyses, total sleep within each 24-hour period (summed across all duty statuses) was calculated and described.

Data were processed and illustrated separately for long-haul and short-haul drivers.

C. RESULTS

DRIVER DEMOGRAPHICS

The number of subjects and their age range in each category were as follows: (a) long-haul: 24 men, age range 26 to 56 (mean = 40); one woman, age 55; and (b) short-haul: 25 men, age range 23 to 65 (mean = 36); there were no women in the short-haul driver category.

STUDY COMPLIANCE

In general, compliance with study procedures was good among both long-haul and short-haul drivers. Inspection of the actigraphy records in conjunction with the Daily Sleep Log verified that most drivers wore the actigraph continuously as instructed and removed it only during designated times (e.g., while bathing or showering). In addition, forms (Daily Sleep Log, RODS) were completed on a daily basis as requested. The actigraph and other forms were returned at the end of the study.

Out of a possible 1,000 days (24-hour periods) of data (20 24-hour periods x 50 drivers), usable actigraph data were obtained for 802 24-hour periods total (80.2 percent)—376 24-hour periods (75.2 percent) for long-haul drivers and 426 24-hour periods (83.6 percent) for short-haul drivers. However, of the total 802 24-hour periods, 35 actigraph 24-hour periods were unusable due to missing RODS information (those 24-hour periods could not accurately be divided into time off-duty and time other than off-duty). This resulted in 767 24-hour periods total (76.7 percent)—370 24-hour periods (74 percent) for long-haul drivers and 397 24-hour periods (79.4 percent) for short-haul drivers. These 767 24-hour periods were used for all subsequent analyses. A section further detailing reasons for unusable data is found at the end of the Results section.

The first goal of this study was to objectively and unobtrusively quantify the amount of time that drivers spend sleeping each day. These results are described in the two following sections (Off-Duty Time Spent Sleeping; Sleep During Other Times of Day). The first section describes time spent sleeping during periods designated by the driver (from the RODS) as "off-duty."

OFF-DUTY TIME SPENT SLEEPING

This section describes time spent sleeping during periods designated by the driver (from the RODS) as "off-duty." As noted earlier, within each 24-hour period, *all* sections marked by the driver as "off-duty" in the RODS were examined for sleep, regardless of off-duty duration. Thus, in the figures that follow, off-duty sleep per 24 hours reflects the sum of all off-duty sleep within that 24-hour period. Information concerning the specific timing, duration, and number of sleep bouts per 24-hour period is provided in "Timing of Daily Sleep Bouts."

Short-Haul Drivers

Figure 4-1 depicts off-duty time that short-haul drivers spent sleeping as a function of hours off-duty. Amount of off-duty sleep increased as hours off-duty increased. The correlation between hours off-duty and hours of sleep during this time was 0.42 ($p < .01$). The associated equation was Off-duty sleep = (0.1853*Hours off-duty) + 4.2493.

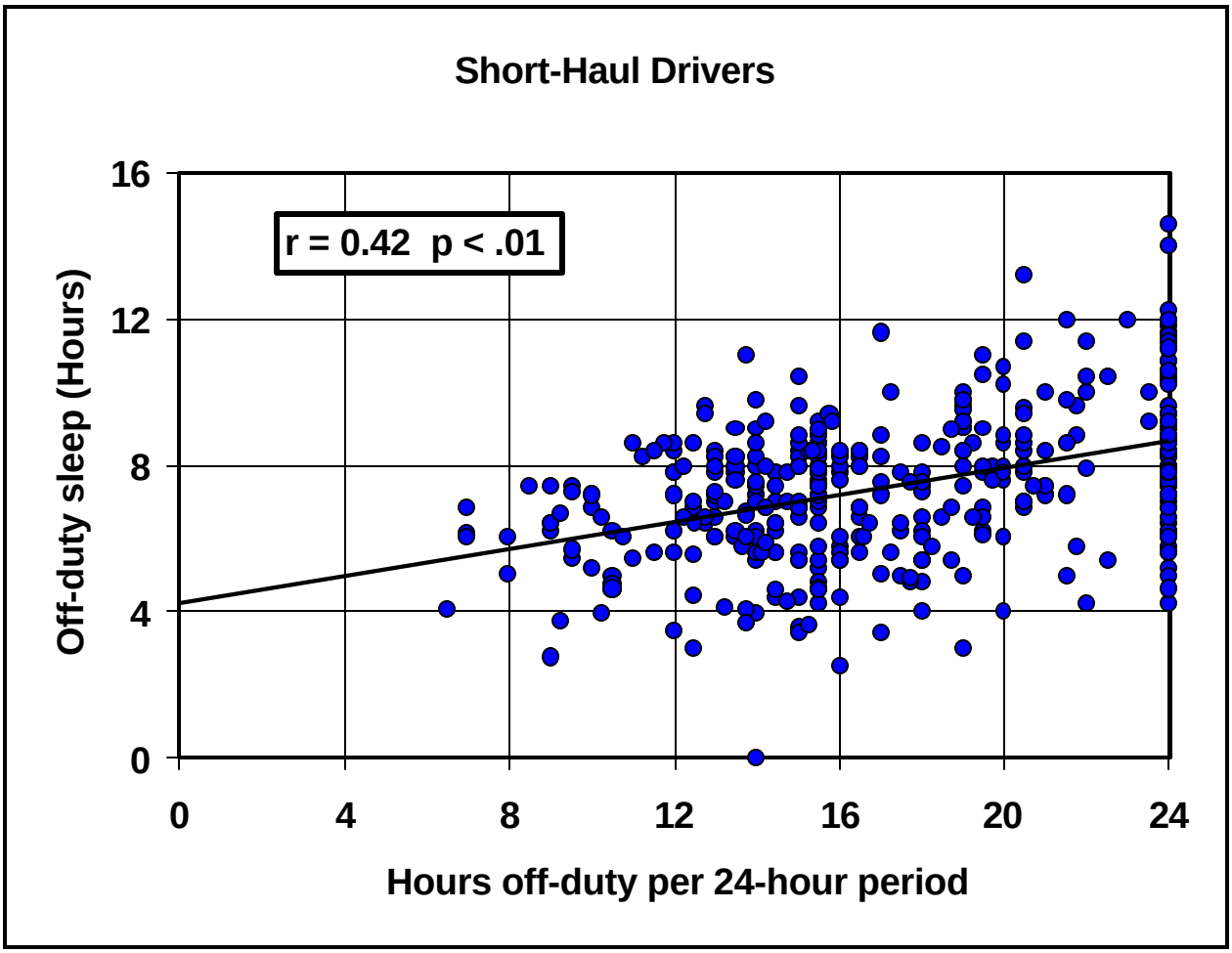

Figure 4-1. Off-duty time spent sleeping as a function of hours off-duty per 24-hour period, short-haul drivers.

Figures 4-2 and **4-3** expand on the data depicted in Figure 4-1 but are illustrated as frequency distributions. Figure 4-2 shows the frequency distribution of off-duty durations, and Figure 4-3 shows the frequency distribution of off-duty sleep durations. As seen in Figure 4-2, the most frequent off-duty duration was 24 hours. The latter indicates off-duty 24-hour periods. In those 24-hour periods, short-haul drivers obtained 4 to 15 hours of sleep per 24-hour period (also indicated in Figure 4-1). That is, no driver went without sleep for a full 24-hour off-duty period. Figure 4-2 also shows that off-duty durations of 14 to 16 hours accounted for the next most frequent off-duty duration; as shown in Figure 4-1, drivers obtained 3 to 11 hours of sleep over that length of off-duty time.

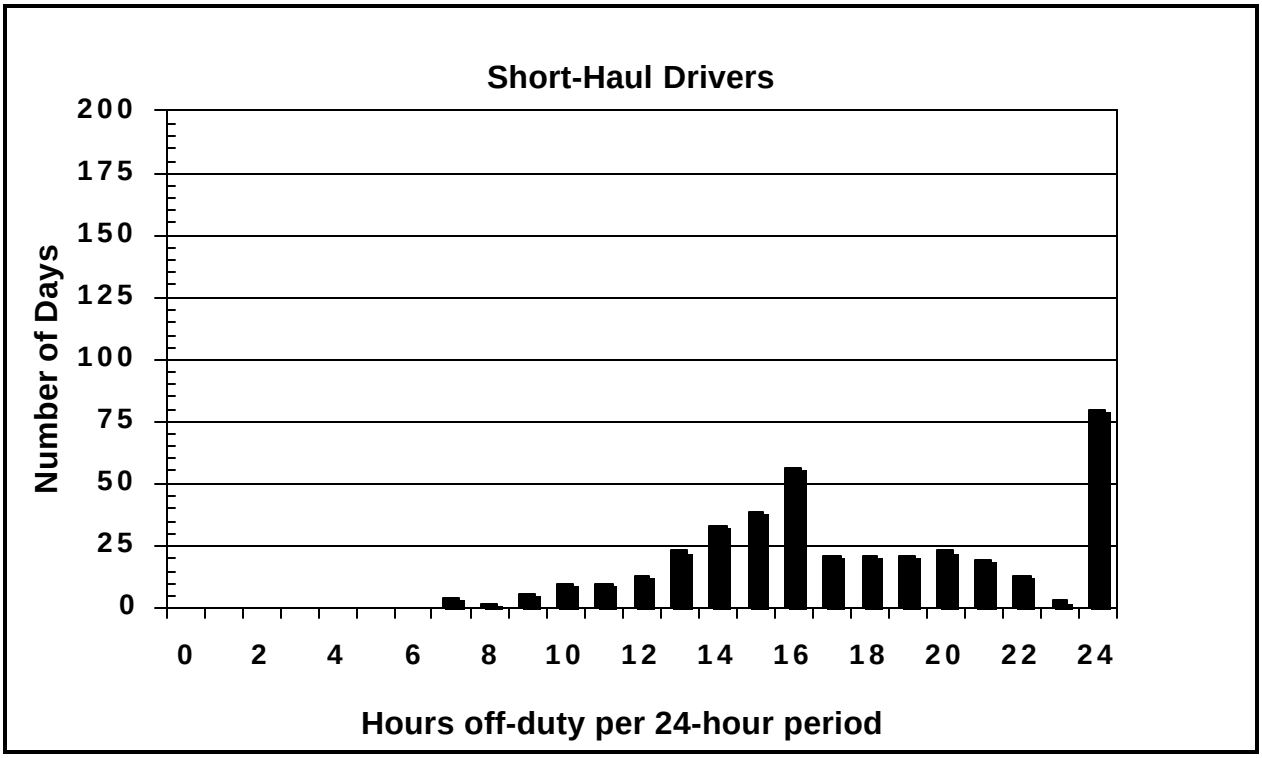

Figure 4-2. Frequency distribution of off-duty durations per 24-hour period, short-haul drivers.

Finally, Figure 4-3 shows the frequency of different off-duty sleep durations per 24-hour period for short-haul drivers. These sleep durations reflect total sleep per 24-hour period. In most 24-hour periods, short-haul drivers obtained 6 to 9 hours of sleep. More than 89 percent of the off-duty sleep durations per 24-hour period were 6 hours or longer.

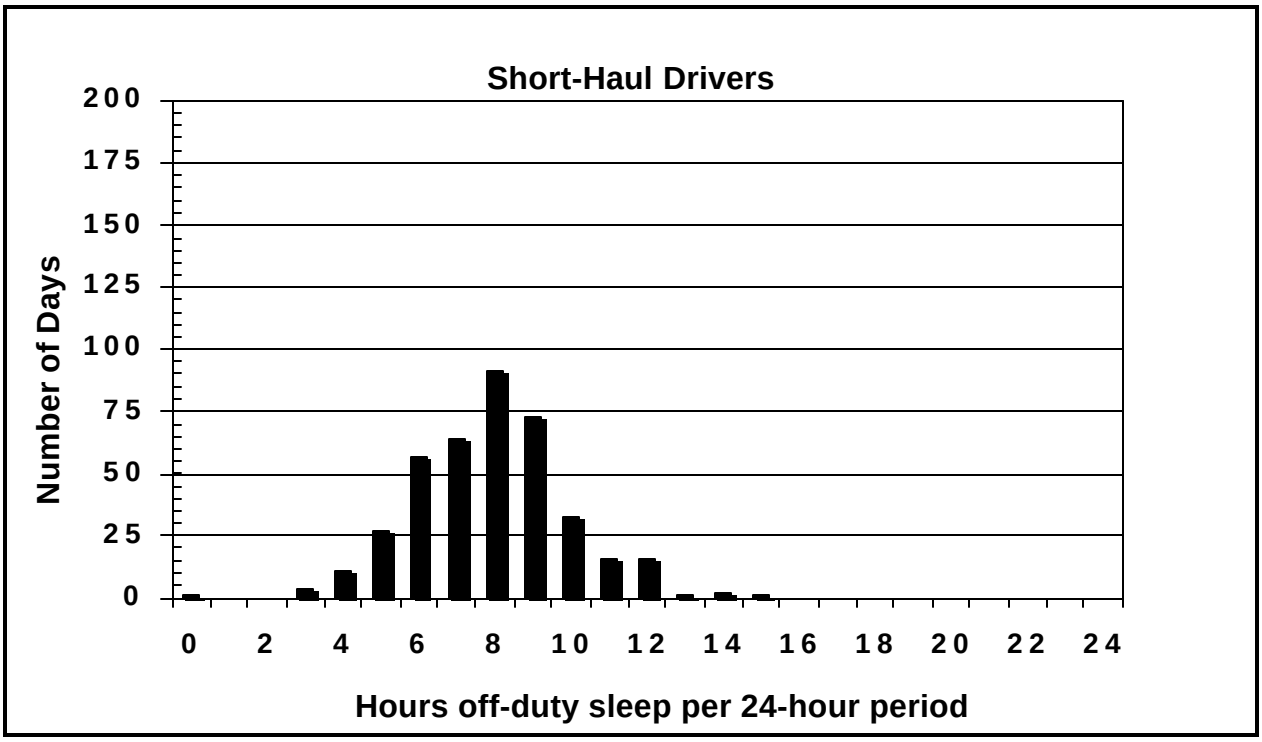

Figure 4-3. Frequency distribution of off-duty sleep durations per 24-hour period, short-haul drivers.

Long-Haul Drivers

Figure 4-4 depicts off-duty time spent sleeping as a function of hours off-duty for long-haul drivers. Off-duty sleep duration increased as hours off-duty increased. The correlation between hours off-duty and off-duty sleep time was 0.82 (p <.01). The associated equation was Off-duty sleep = (0.4146*Hours off-duty) – 1.2916.

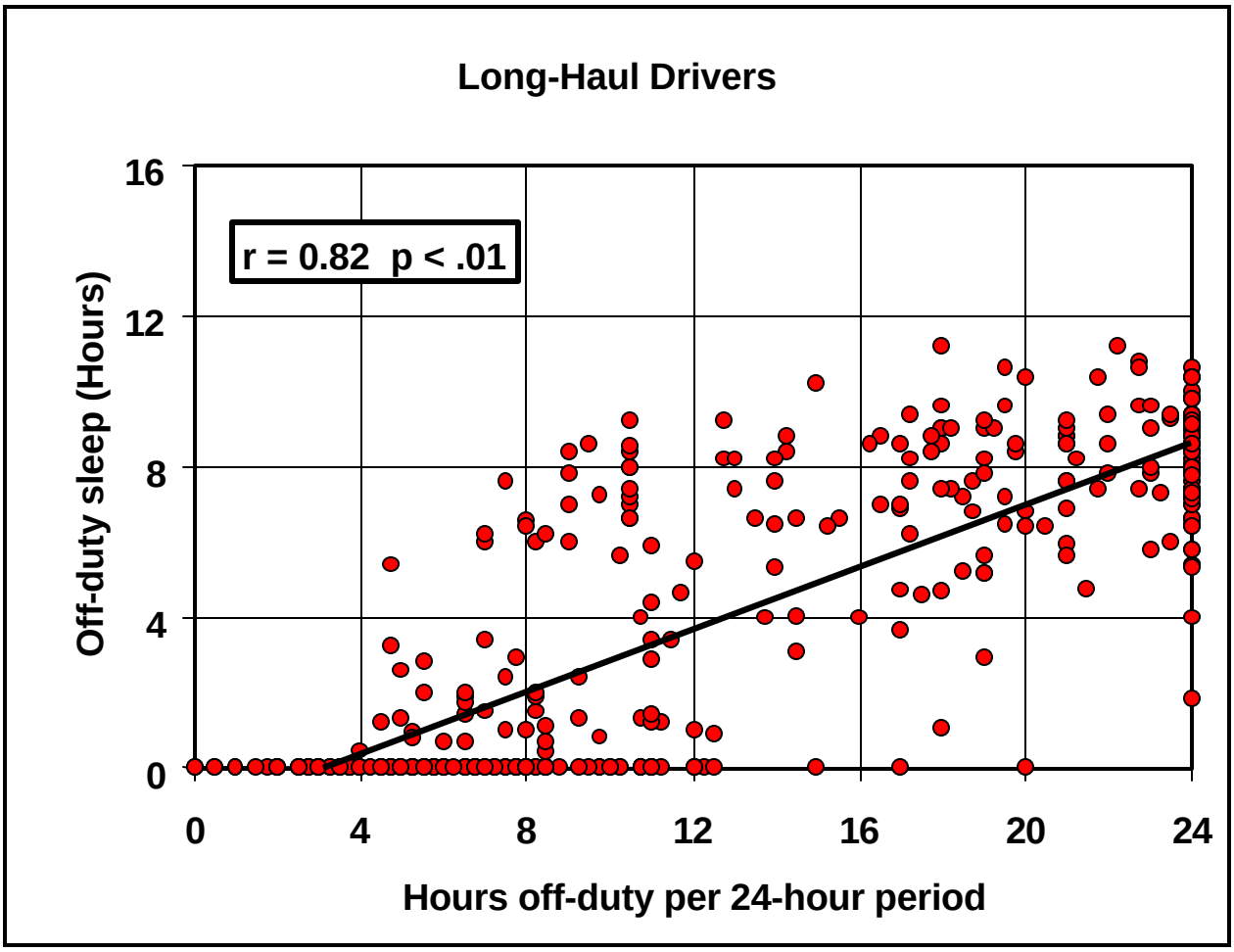

Figure 4-4. Off-duty time spent sleeping as a function of hours off-duty per 24-hour period, long-haul drivers.

Data from Figure 4-4 are plotted in **Figures 4-5** and **4-6** as frequency distributions. Figure 4-5 shows off-duty durations; Figure 4-6 shows off-duty sleep durations. As shown in

Figure 4-5, the single most frequent off-duty duration was 24 hours, indicating an off-duty day. On off-duty days, long-haul drivers obtained 2 to 11 hours of sleep per 24-hour period (see Figure 4-4); as was the case for short-haul drivers, no long-haul driver went without sleep for a full 24-hour off-duty period. However, as shown in Figure 4-4, many instances of no sleep occurred during off-duty durations of 0 to 20 hours, and Figure 4-6 shows that the most frequent length of off-duty sleep, in fact, was zero hours (no sleep). Finally, Figure 4-5 shows that, other than full 24-hour periods off (24 hours off-duty), frequencies were rather evenly dispersed among remaining off-duty durations (0 to 23 hours).

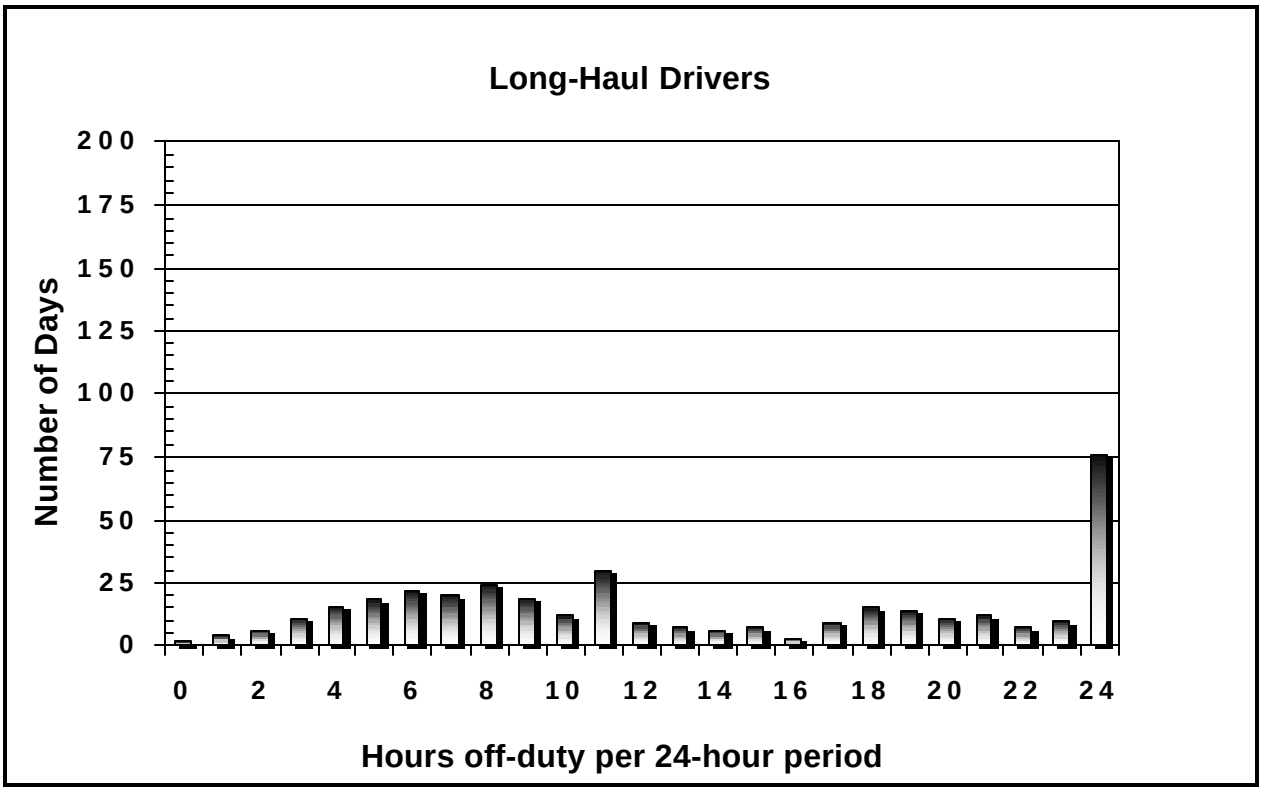

Figure 4-5. Frequency distribution of off-duty durations per 24-hour period, long-haul drivers.

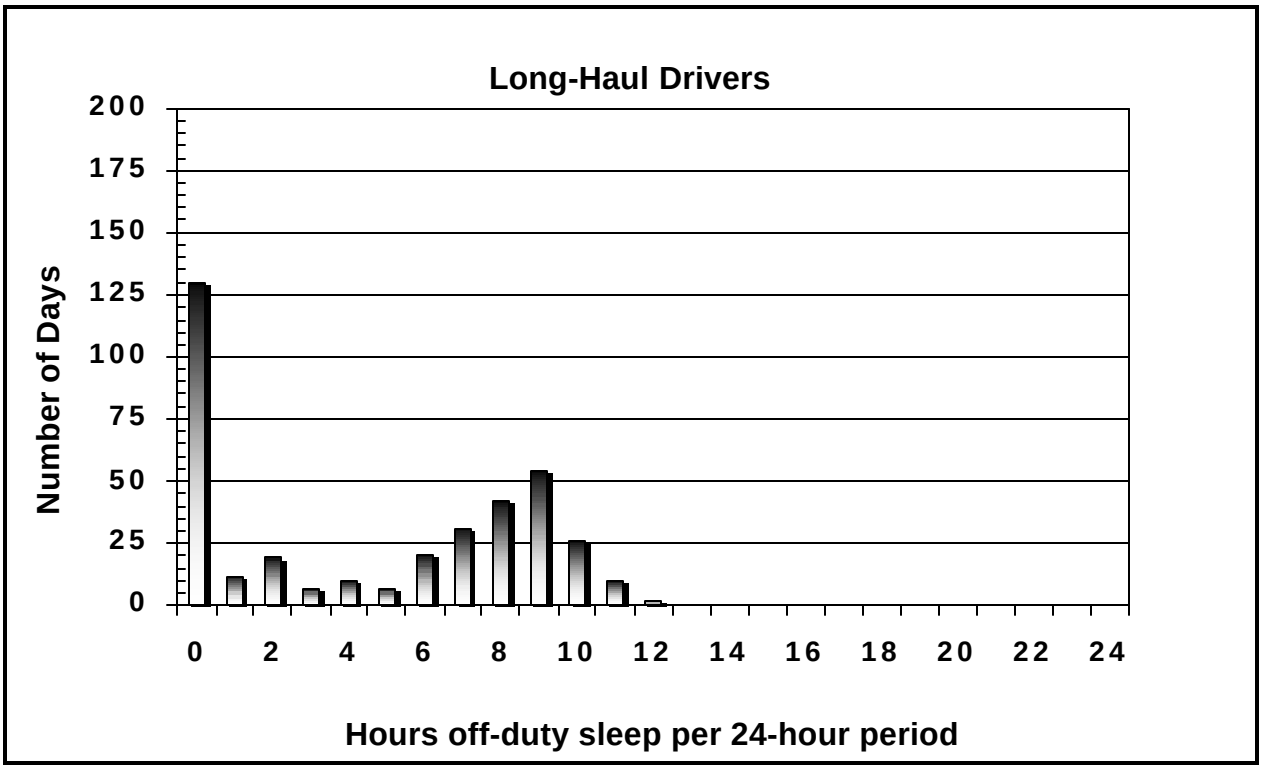

Figure 4-6. Frequency distribution of off-duty sleep durations per 24-hour period (includes sleeper-berth time), long-haul drivers.

Short-Haul versus Long-Haul Drivers

Figure 4-7 shows the average daily off-duty sleep duration for short-haul versus long-haul drivers. Short-haul drivers obtained an average of 7.46 hours of sleep daily during off-duty periods, while long-haul drivers obtained 4.32 hours of sleep off-duty.

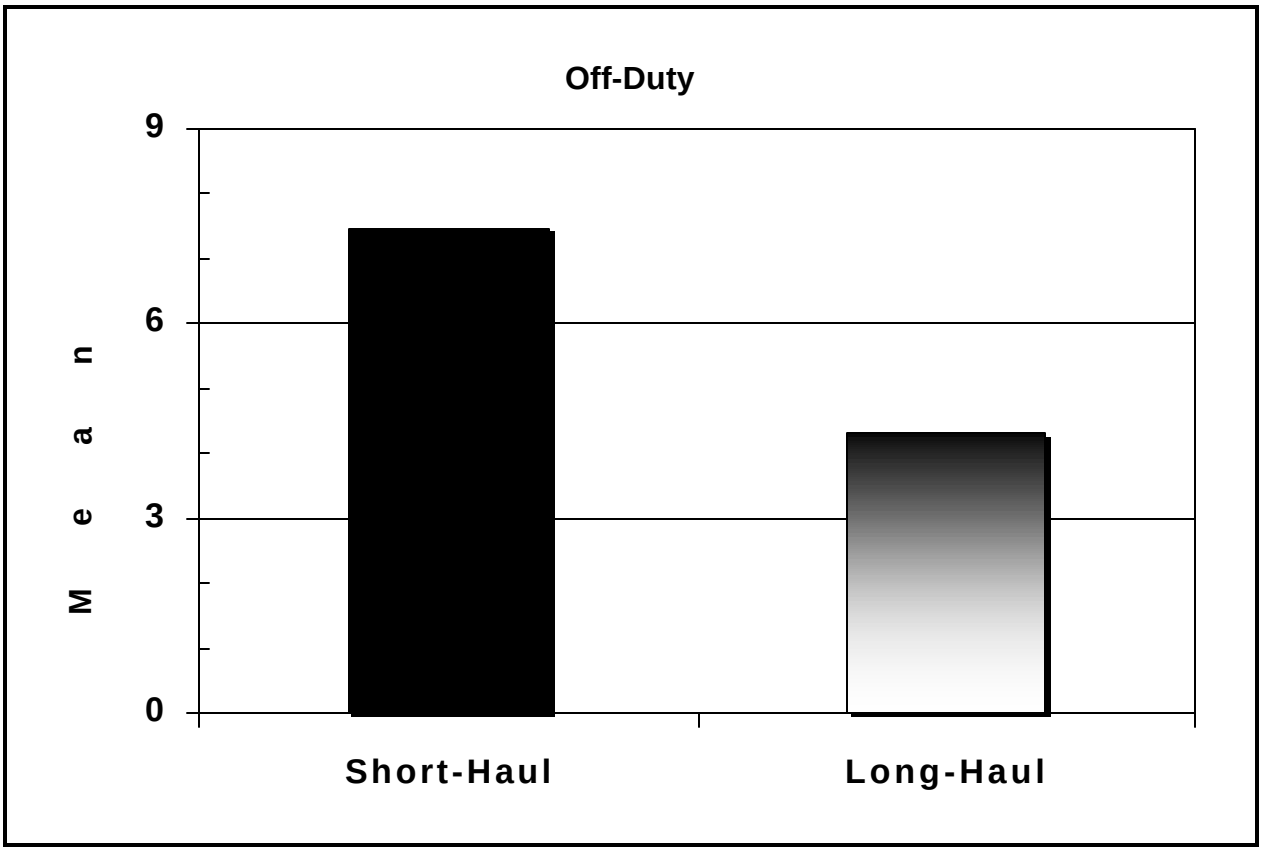

Figure 4-7. Mean daily sleep per 24-hour period obtained off-duty, short-haul versus long-haul drivers.

SLEEP DURING OTHER TIMES OF THE DAY ("TYPE B" TIME)

As noted earlier, since actigraph data were collected continuously throughout the day, the amount of time spent sleeping across all duty status categories (i.e., total sleep per 24 hours) could be determined. Sleep during time marked as off-duty in the RODS was described earlier. Also of interest was the amount of time spent sleeping during times other than off-duty. The

question was whether and to what extent this sleep contributed to total daily sleep time. In particular, since long-haul drivers can log "sleeper berth" time, it was of interest to determine how much sleep they were obtaining that was likely to have occurred away from home. As noted, the category "other times of the day" includes anything outside of time indicated by the driver as "off-duty." For long-haul drivers, this would mainly consist of sleeper berth time. For both long-haul and short-haul drivers, other periods of within-shift sleep were examined (i.e., time spent sleeping associated with RODS periods marked as "on-duty, not driving"). Finally, as noted in the Methods section, periods marked in the RODS as "on-duty, driving" also were examined for sleep periods (long- and short-haul drivers)—although, clearly, drivers would not be asleep while driving, it is possible that, due to imprecision with the RODS itself, sleep may have overlapped with RODS periods marked as "on-duty driving." In the upcoming results, these "other times of the day" are referred to as Type B time.

Within each 24-hour period, *all* sections marked by the driver as "sleeper berth," "on duty, not driving," and/or "on duty, driving" in the RODS were examined for sleep, regardless of duration. Thus, in the figures below, sleep per 24 hours reflects the sum of all sleep within that 24-hour period for sleeper berth and other within-shift periods. Information concerning the specific timing, duration, and number of sleep bouts per 24-hour period is provided in "Timing of Daily Sleep Bouts."

Short-Haul Drivers

Short-haul drivers did not use the RODS sleeper-berth category. Thus, for these drivers, Type B time (within-shift sleep) consisted of all periods other than those marked as "off-duty." **Figure 4-8** shows Type B time spent sleeping as a function of total Type B time. Amount of Type B time spent sleeping increased only slightly as Type B hours increased. The correlation between total available Type B hours and Type B hours spent sleeping was 0.30 (p <.01). The associated equation was Type B Sleep = (0.0432*Type B Time) – 0.0865. Most periods contained no sleep.

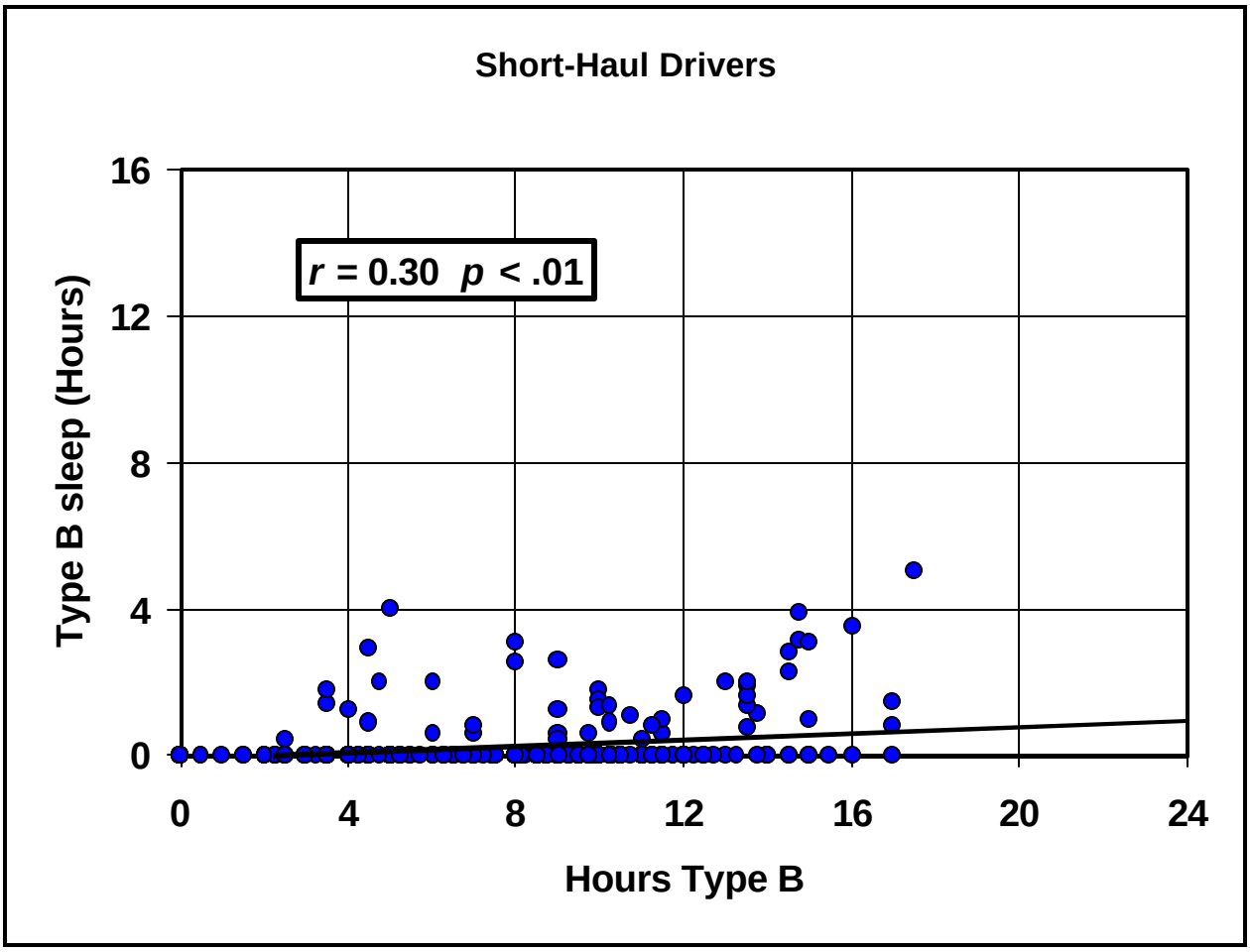

Figure 4-8. Type B times spent sleeping per 24-hour period as a function of Type B hours, short-haul drivers.

This observation is also evident from **Figure 4-9**, which shows the frequency distribution of Type B sleep durations. Three-hundred fifty of the 397 short-haul-driver 24-hour periods (88 percent) contained sleep during Type B time. However, Figure 4-9 also shows that several episodes of short-duration (less than 4 hours) bouts of sleep during Type B time were apparent. Figure 4-9 shows that sleep occurred most frequently with Type B periods exceeding 8 hours.

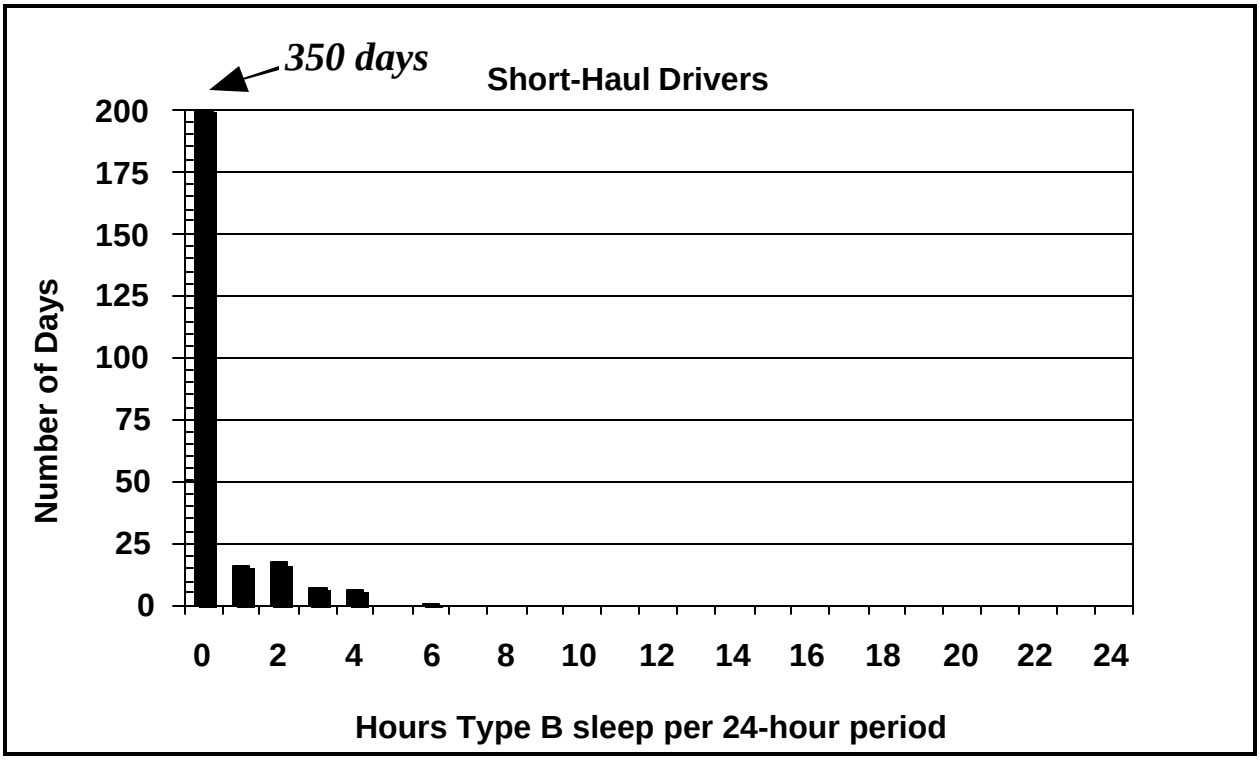

Figure 4-9. Frequency distribution of Type B sleep durations per 24-hour period, short-haul drivers.

Figure 4-10 shows the frequency of distribution of Type B durations. Excluding 24-hour periods off-duty (indicated by zero hours of Type B), most Type B duty periods for short-haul drivers were 9 hours long.

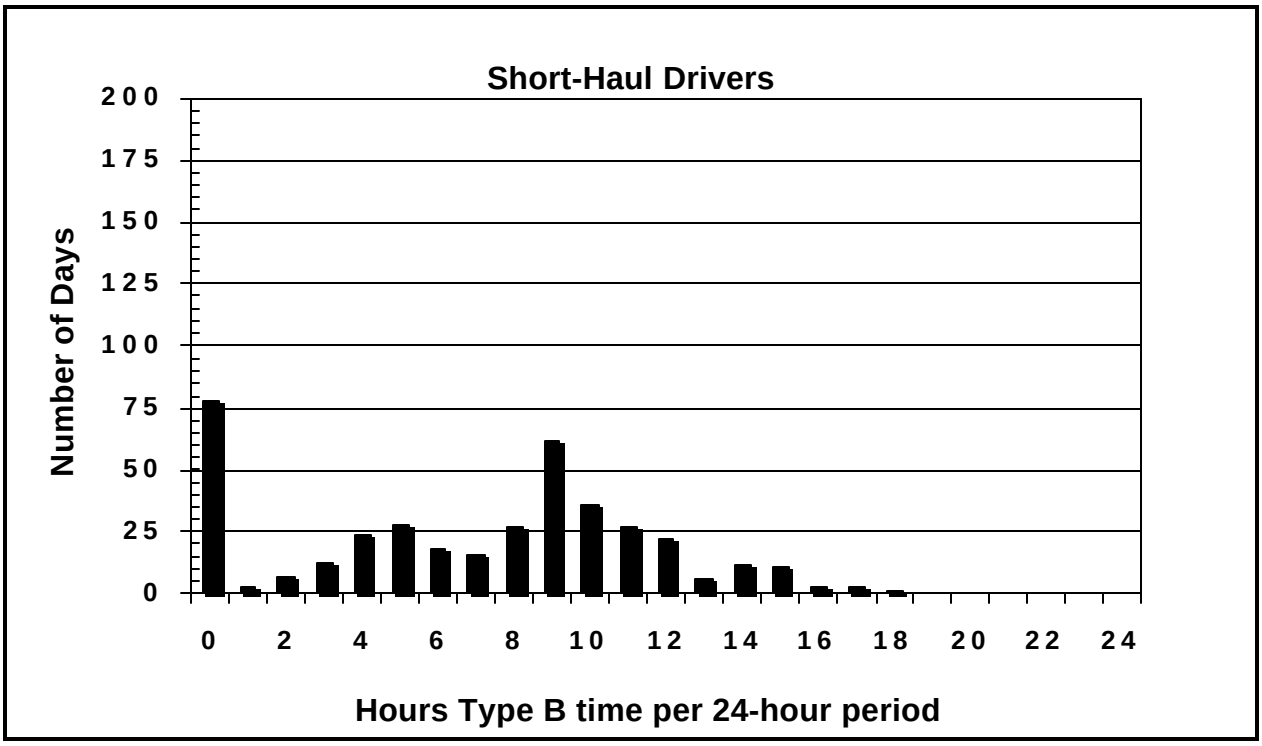

Figure 4-10. Frequency distribution of Type B durations per 24-hour period, short-haul drivers, excluding 24-hour periods off-duty.

Long-Haul Drivers

Long-haul drivers did use the RODS sleeper berth category. For these drivers, Type B time consisted mainly of sleeper-berth time. Again, however, since the Type B category was intended to capture all periods *other than* off-duty, for long-haul drivers (as for short-haul), Type B also reflected other sources of within-shift sleep. Note also that any sleep within a single, long sleeper-berth period would be included in Type B sleep time, while any sleep within a single, long off-duty period (out of shift) would have been included in the off-duty sleep times reported earlier. **Figure 4-11** depicts Type B time spent sleeping as a function of Type B hours for long-haul drivers. It shows that amount of sleep increased as Type B hours increased. The correlation between Type B time and sleep during Type B was 0.42 ($p < .01$). The associated equation was Type B Sleep = (0.3436*Hours of Type B Time) – 0.6066. As with short-haul drivers, many Type B periods contained no sleep. In addition, the longest Type B period without sleep was 20 hours, and this occurred in only one instance. Otherwise, Type B periods of 20 hours or greater contained at least 2 hours of sleep.

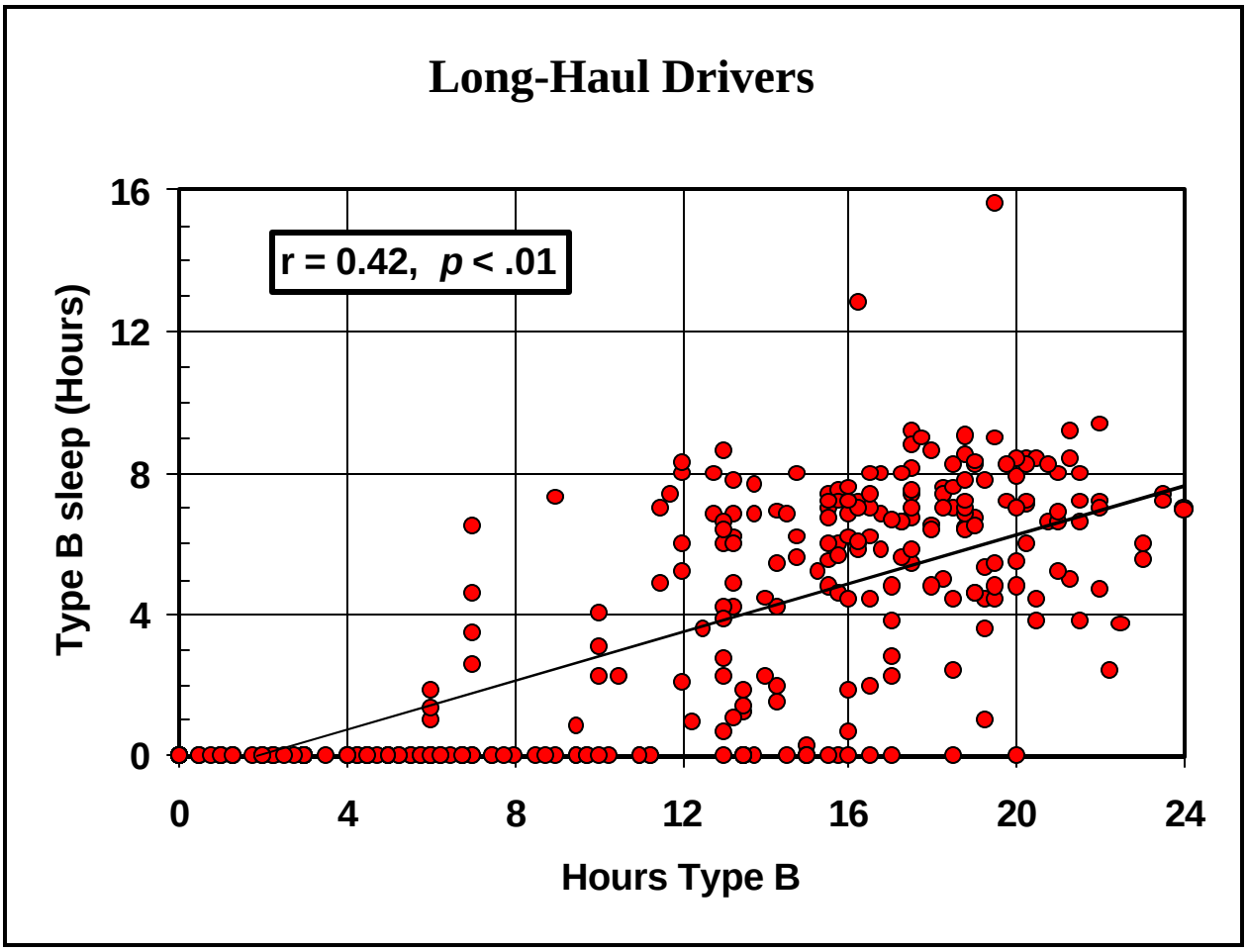

Figure 4-11. Type B time spent sleeping per 24-hour period as a function of Type B hours, long-haul drivers.

Figure 4-12 shows the frequency distribution of sleep durations during Type B periods; many periods did not contain sleep. For those that did contain sleep, durations of 5 to 9 hours were most common.

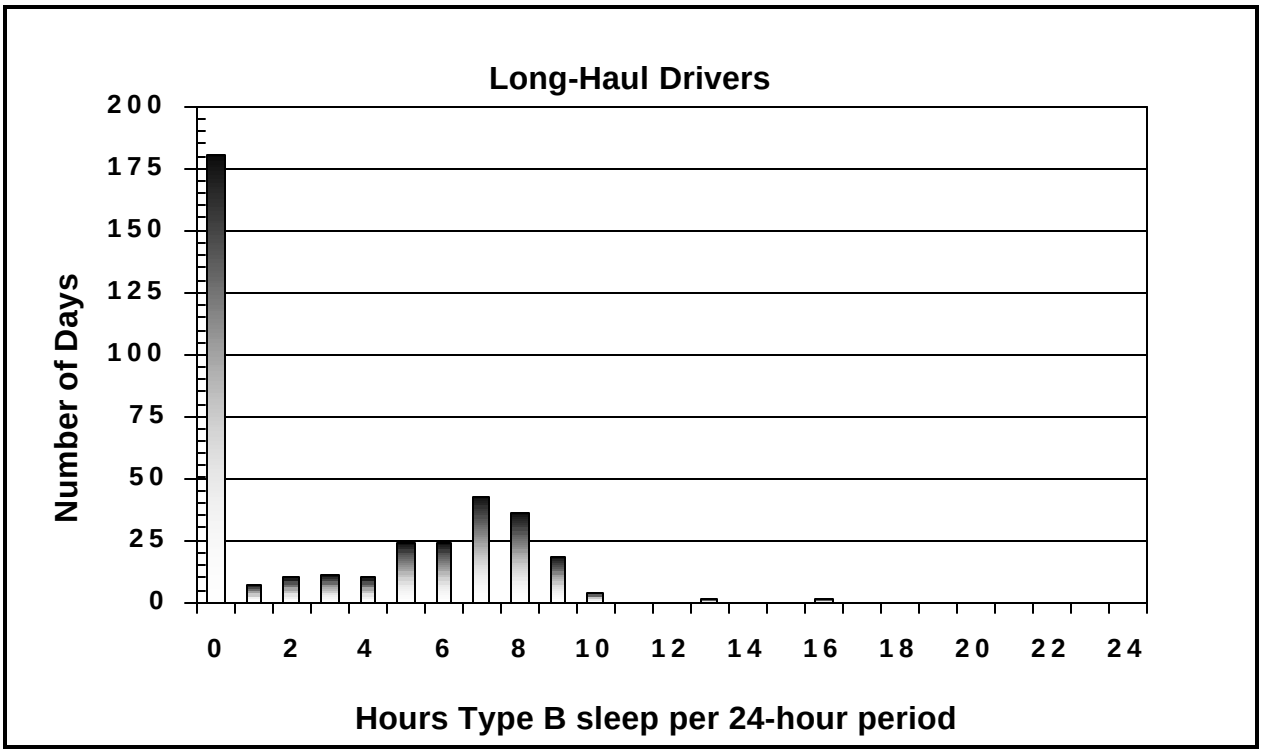

Figure 4-12. Frequency distribution of Type B sleep durations per 24-hour period, long-haul drivers.

Figure 4-13 shows the frequency distribution of Type B durations in long-haul drivers. Other than 24-hour periods off (zero hours of Type B time), frequencies were fairly evenly dispersed among remaining Type B time durations (0 to 23 hours).

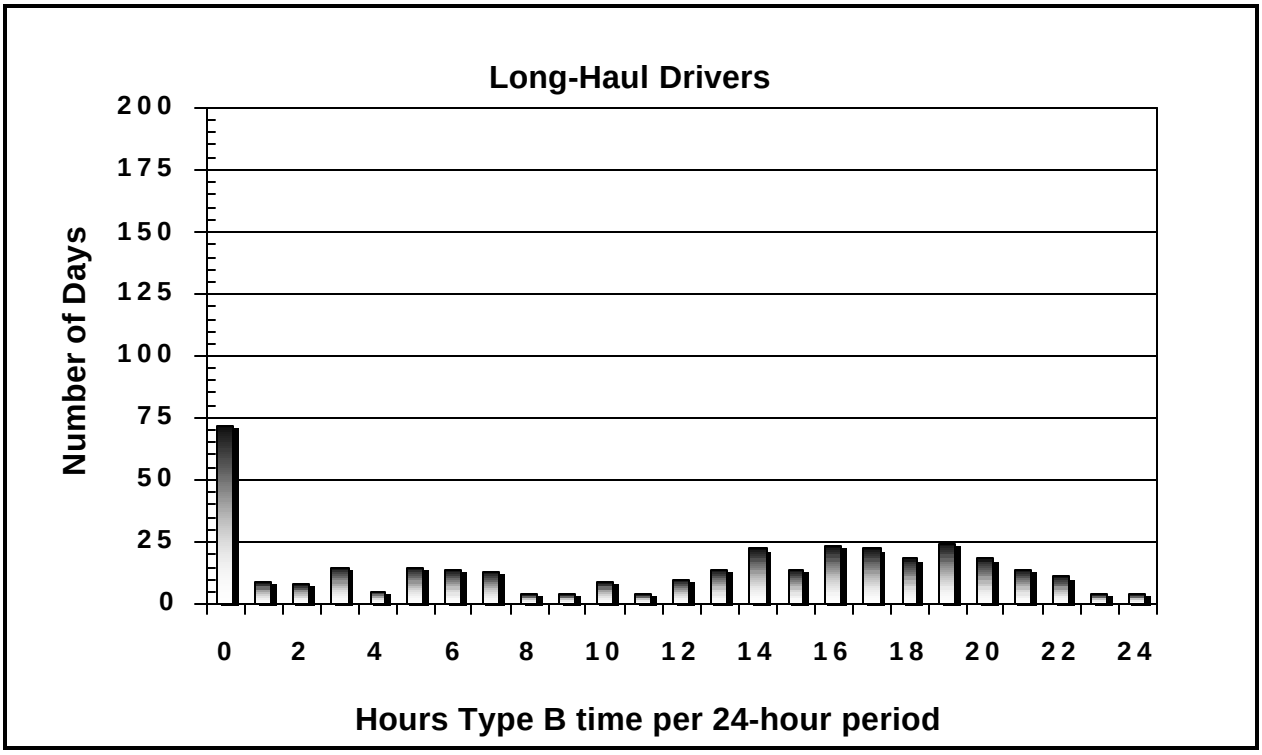

Figure 4-13. Frequency distribution of Type B durations per 24-hour period, long-haul drivers.

Short-Haul versus Long-Haul Drivers

Figure 4-14 shows the average daily Type B sleep duration for short-haul versus long-haul drivers. Short-haul drivers obtained an average of 0.2 hours (12 minutes) of sleep per 24-hour period associated with Type B time (within-shift sleep). Long-haul drivers obtained 2.99 hours of sleep during Type B periods (sleeper berth and other sources of within-shift sleep).

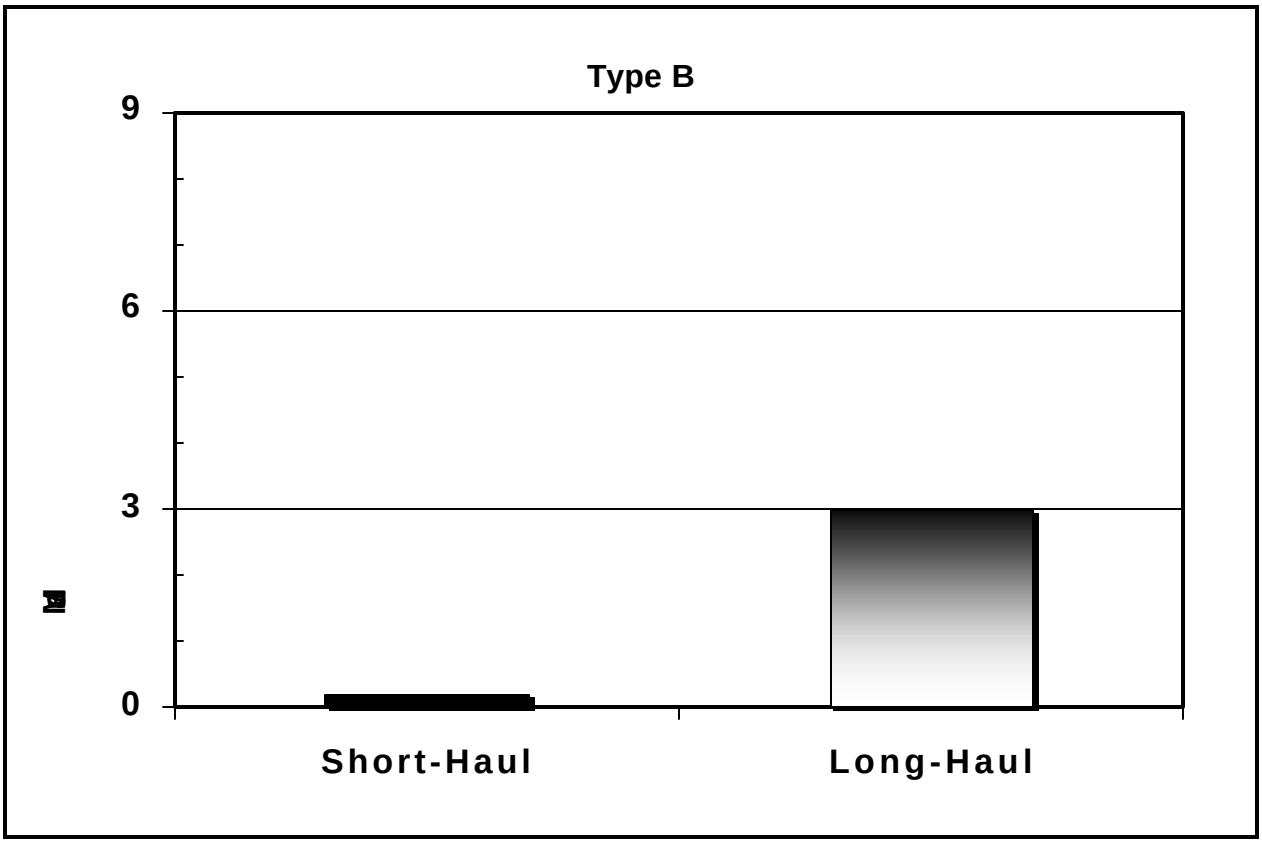

Figure 4-14. Mean sleep obtained during Type B time per 24-hour period, short-haul versus long-haul drivers.

LIMITATIONS OF DRIVER'S RECORD OF DUTY STATUS (RODS)

In many instances, assumed wake times as implied by "On-duty, driving" categories in the RODS coincided with actigraphically recorded sleep. For example, an actigraphically identified sleep period recorded as "Off-duty" in the RODS continued into time recorded as "On-duty, driving." Likewise, actigraphically identified sleep periods started during "On-duty, driving" times and continued into sleeper berth or off-duty time. These inconsistencies are highlighted by the data points indicated by arrows in Figure 4-4, in which actigraphically recorded sleep time exceeded the presumed available period (as taken from the RODS). Several examples are further amplified in **Figure 4-15**, which shows a daily actigraph record, underscored by the duty statuses as taken from that driver's RODS. For the most part, inconsistencies between the actigraph and RODS were relatively small (60 minutes or less), suggesting that drivers roughly estimated duty-status times to the nearest hour or half-hour in the RODS. However, in other instances the inconsistencies were much larger (several hours). This suggests that the RODS (or any subjective measure of sleep/wake time or on-/off-duty time) may be unreliable for accurately gauging wake and sleep times because it is less precise than, for example, an actigraph—further indicating that portions of the actigraph record scanned for sleep should not be restricted to times that the driver indicates are potential sleep periods.

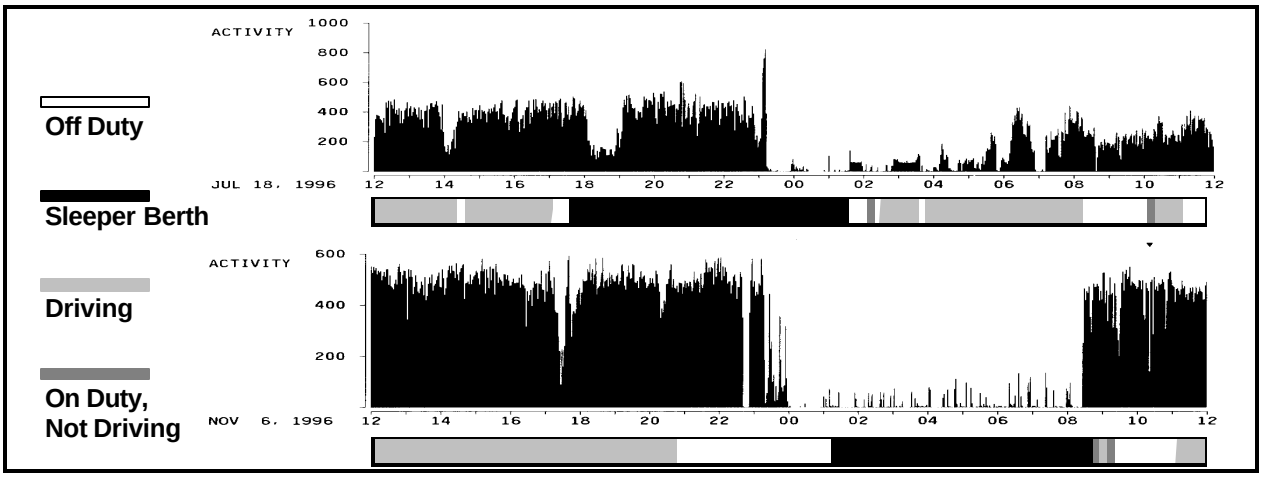

Figure 4-15. Sample actigraph records with corresponding Driver's Record of Duty Status (RODS): inconsistency between actigraph and RODS.

Based on these observations, a further descriptive analysis was conducted on actigraphically recorded sleep and wake times. In this analysis, sleep times were summed across off-duty and Type B periods to yield total sleep per 24 hours, without regard to driver-identified on-duty, driving; on-duty, not driving; sleeper-berth; or off-duty periods.

TOTAL SLEEP PER 24 HOURS

Short-Haul Drivers

Figure 4-16 shows the frequency distribution of daily total sleep times (summed across sleep periods identified actigraphically within off-duty; on-duty, driving; and on-duty, not driving times recorded by the driver in the RODS—that is, summed across each entire 24-hour period) among short-haul drivers. Most 24-hour periods consisted of 6 or more hours of sleep per 24-hour period. More than 92 percent of daily total sleep times were 6 hours or longer. A comparison of Figure 4-16 with Figure 4-1 (off-duty sleep, short-haul) suggests that the bulk of daily sleep in short-haul drivers occurred outside of the work shift.

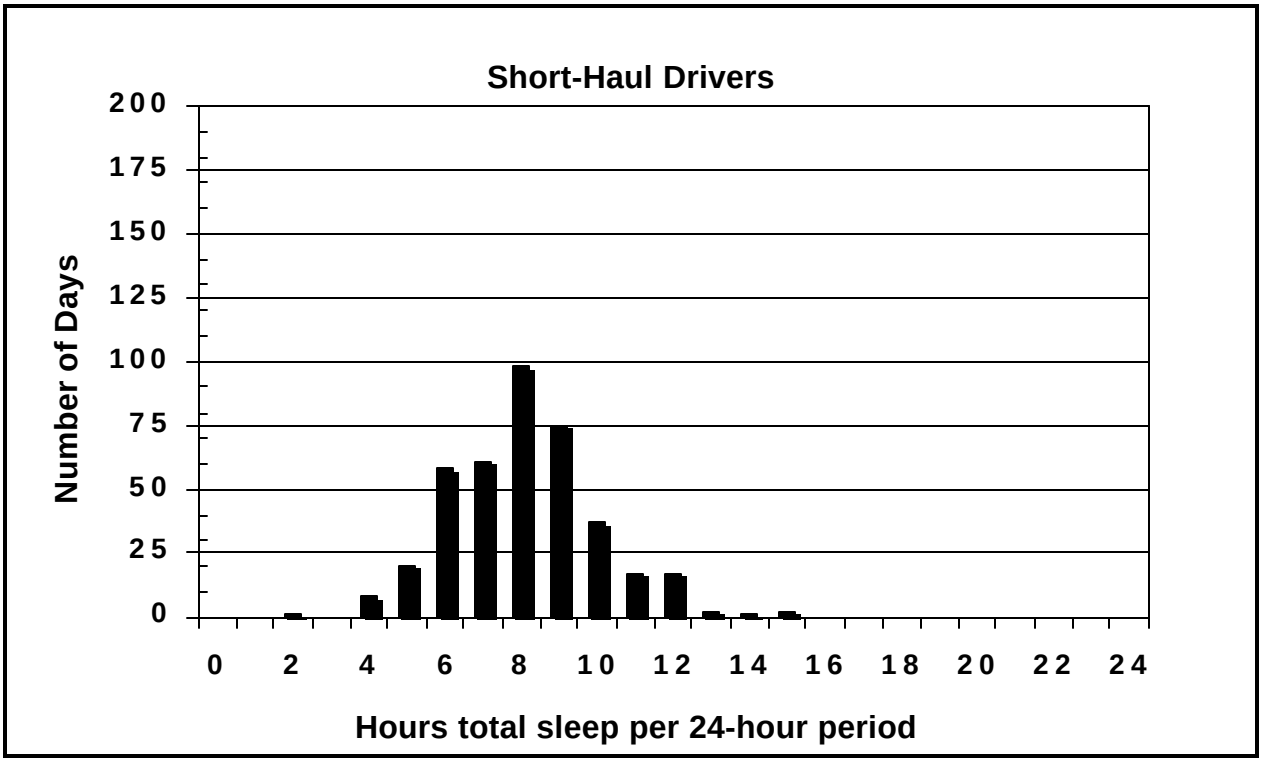

Figure 4-16. Frequency distribution of total sleep times per 24-hour period (summed across all possible duty statuses), short-haul drivers.

Long-Haul Drivers

Figure 4-17 shows the frequency distribution of daily total sleep times (summed across sleep periods identified actigraphically within off-duty; on-duty, driving; on-duty, not driving; and sleeper-berth times from the RODS—i.e., summed across the entire 24-hour period) among long-haul drivers. Most 24-hour periods consisted of 6 or more hours of sleep per 24-hour period, similar to short-haul drivers. More than 88 percent of daily total sleep times were 6 hours or longer. However, a comparison of Figure 4-17 (total sleep) with Figure 4-6 (off-duty sleep) and Figure 4-12 (B sleep) suggests that only slightly greater than 50 percent of daily total sleep times for long-haul drivers occurred outside of the work shift.

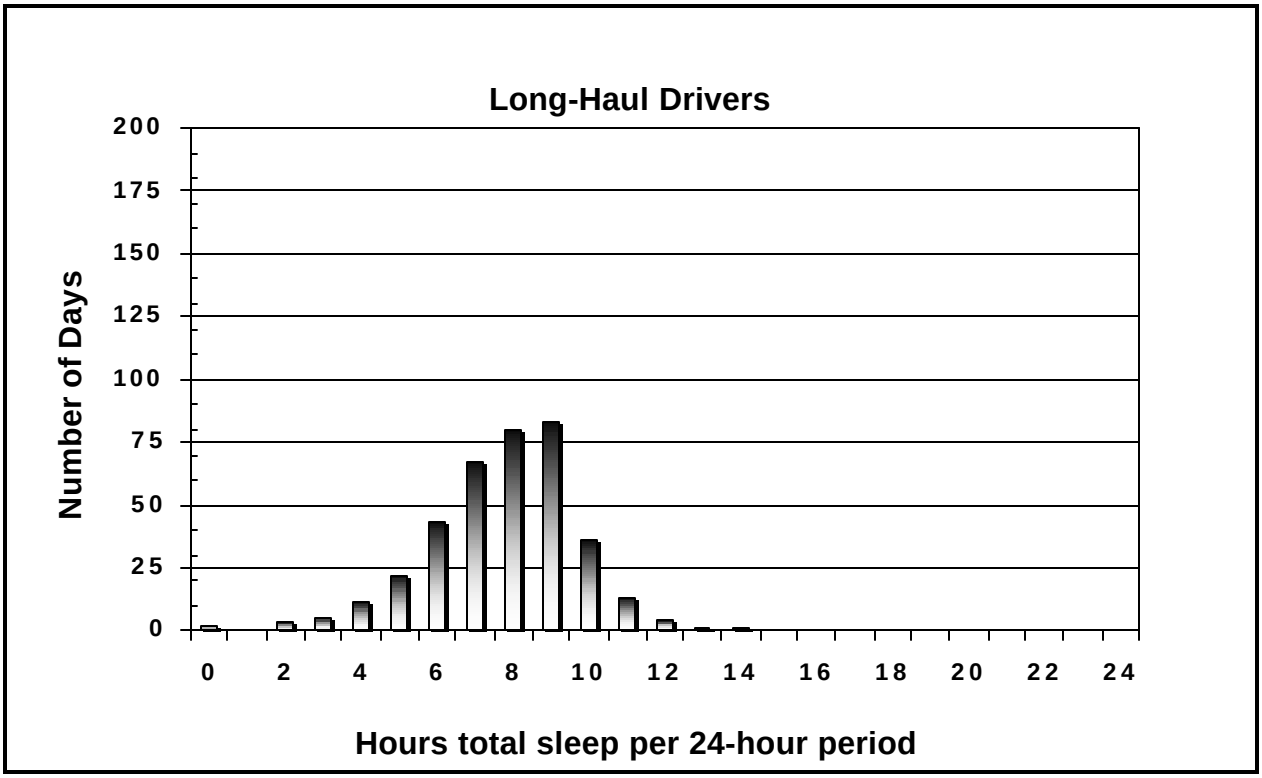

Figure 4-17. Frequency distribution of total sleep times per 24-hour period (summed across all possible duty statuses), long-haul drivers.

Short-Haul versus Long-Haul Drivers

Figure 4-18 shows the average daily total sleep duration (summed across all possible duty statuses) for short- versus long-haul drivers. Short-haul and long-haul drivers obtained comparable amounts of daily total sleep (7.66 and 7.31 hours, respectively). The proportions of off-duty versus Type B time sleep contributing to the average daily total also are indicated. Unlike total sleep, the proportions of off-duty and Type B time sleep differed substantially between short- and long-haul drivers. Short-haul drivers obtained only a small proportion (3 percent) of daily total sleep during Type B time (within shift), with the bulk of daily total sleep (97 percent) obtained during time marked as off-duty in the RODS (outside of shift). In contrast, long-haul drivers obtained 44 percent of daily total sleep during Type B time (within shift), with the other 56 percent during time marked as off-duty in the RODS (outside of shift).

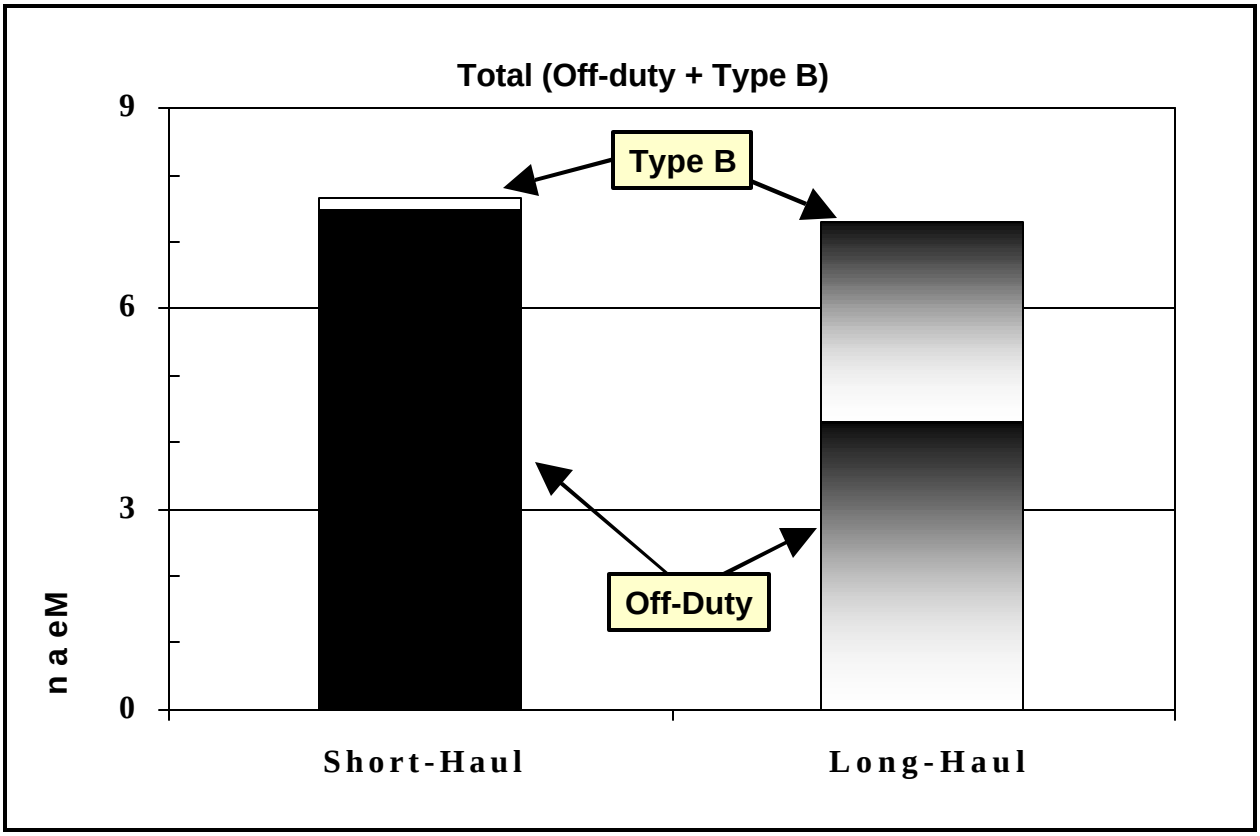

Figure 4-18. Mean total sleep off-duty and during Type B time per 24-hour period, short-haul versus long-haul drivers.

Figure 4-19 presents cumulative plots of daily total sleep (sum of all possible duty statuses) for short-haul and long-haul drivers. Plots are depicted as the percent of cases accounting for "X" or less hours of sleep. Figure 4-19 shows that the frequencies of obtaining 4 to 12 hours of sleep daily (middle range of total sleep durations) were comparable for short- and long-haul drivers. Similarly, median daily total sleep amounts were 7.8 and 7.4 hours for short-haul and long-haul drivers, respectively.

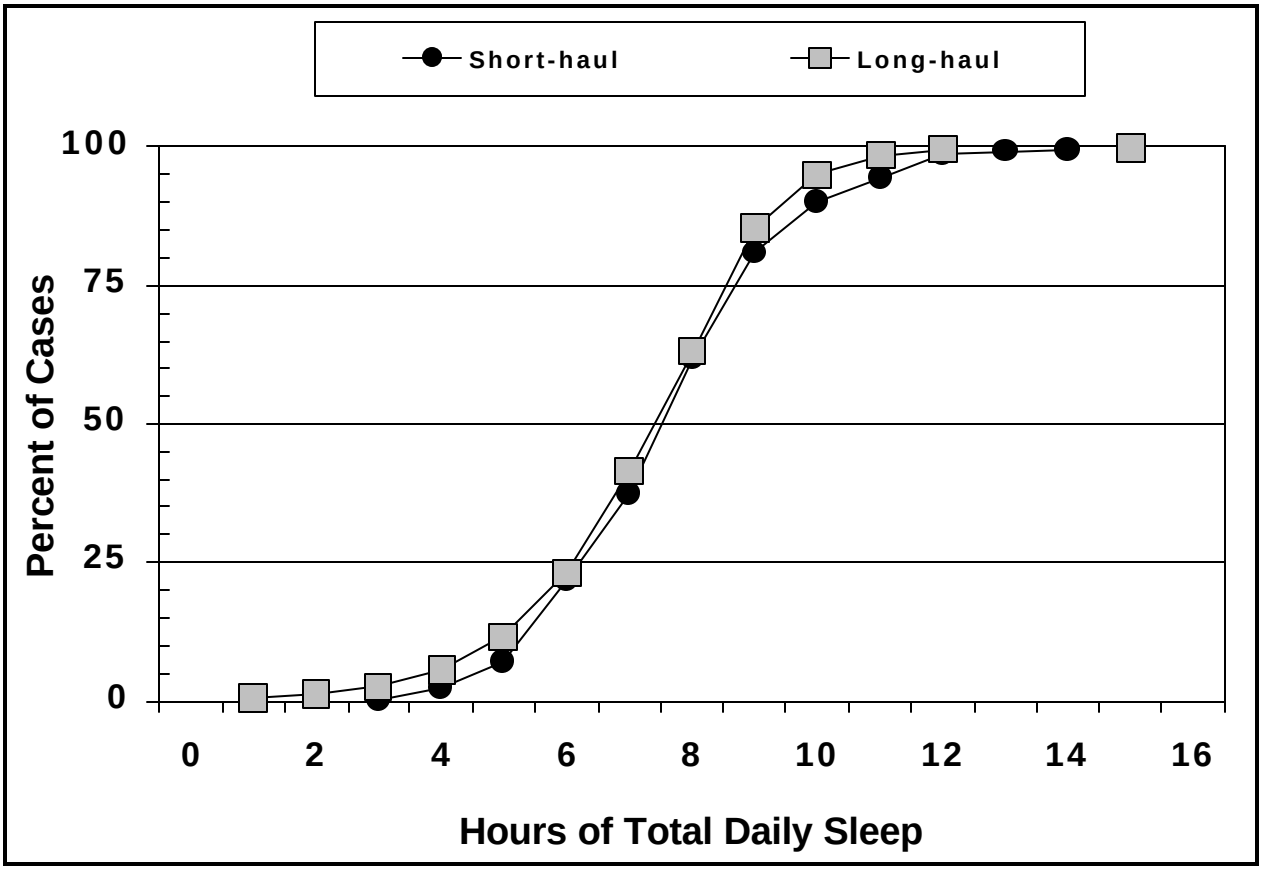

Figure 4-19. Cumulative percentage distribution of total sleep durations per 24-hour period for short-haul and long-haul drivers.

TIMING OF DAILY SLEEP BOUTS

The results that were just presented focused on daily sleep amounts (off-duty, during Type B time, and total daily sleep) for short-haul and long-haul drivers. Daily total sleep can be accumulated as a single sleep bout or as several sleep bouts across the 24-hour recording period. Of particular interest was whether the length of a sleep period or sleep bout is systematically related to the time of day at which the sleep bout is initiated. This section addresses the timing, length, and number of daily sleep periods. As noted in Methods, actigraphs were programmed to begin recording at 1200 hours each day (rather than 0000 hours), in an attempt to capture entirely the first sleep bout of the day. It was assumed that the first (and presumably longest) sleep bout was likely to begin during evening hours.

Short-Haul Drivers

Figure 4-20 shows sleep-bout duration for the first actigraphically identified sleep bout of each 24-hour period as a function of sleep-bout onset time for short-haul drivers. As anticipated, the bulk of first daily sleep bouts were initiated between 2000 and 0200 hours. Further, sleep bouts initiated at these times lasted longer than sleep bouts initiated at other times of day—sleep-bout durations clustered between 6 and 10 hours in duration. Several of the sleep bouts initiated between 2000 and 0200 hours lasted longer than 12 hours. No sleep bouts were initiated between 0800 and 1159 hours. Of those sleep bouts initiated in the afternoon hours (1200 to 1759 hours), most were less than 4 hours in duration. However, three bouts initiated between these hours lasted more than 8 hours each.

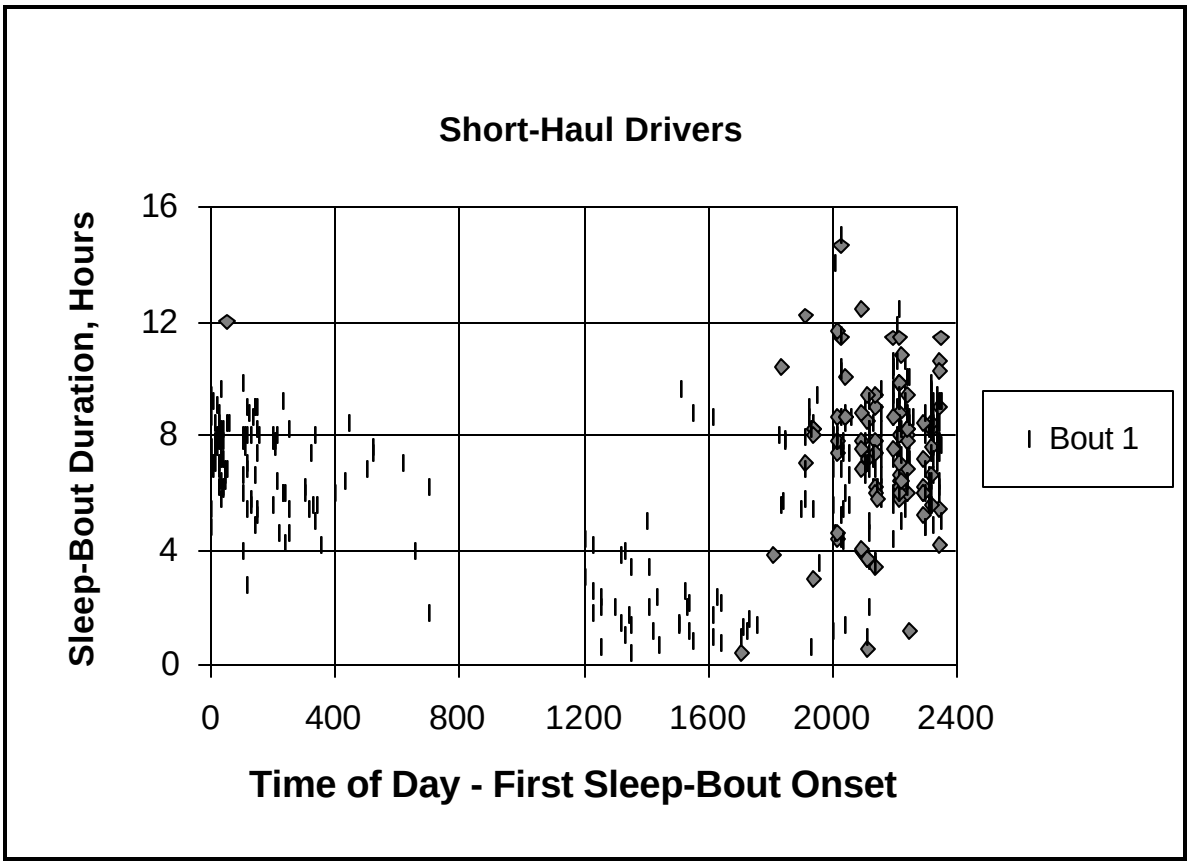

Figure 4-20. Sleep-bout duration for the first actigraphically identified sleep bout of each 24-hour period as a function of time of day of sleep-bout onset, short-haul drivers.

Figure 4-21 illustrates data from Figure 4-20 as a frequency distribution of first sleep bouts as a function of time of day of sleep-bout onset (short-haul drivers). Note that each time of day represents the frequency of all sleep bouts within a 2-hour bin starting at that time of day (e.g., 2200 hours reflects the frequency distribution 2200 to 2359 hours; 0000 hours reflects the frequency distribution 0000 to 0159 hours, etc.). As noted, the first sleep bout of each 24-hour period was most frequently initiated within the 2200 to 2359 hours time frame, followed by 2000 to 2159 hours and 0000 to 0159 hours. Also as noted earlier, (Figure 4-20), no sleep bouts were initiated between 0800 and 1159 hours.

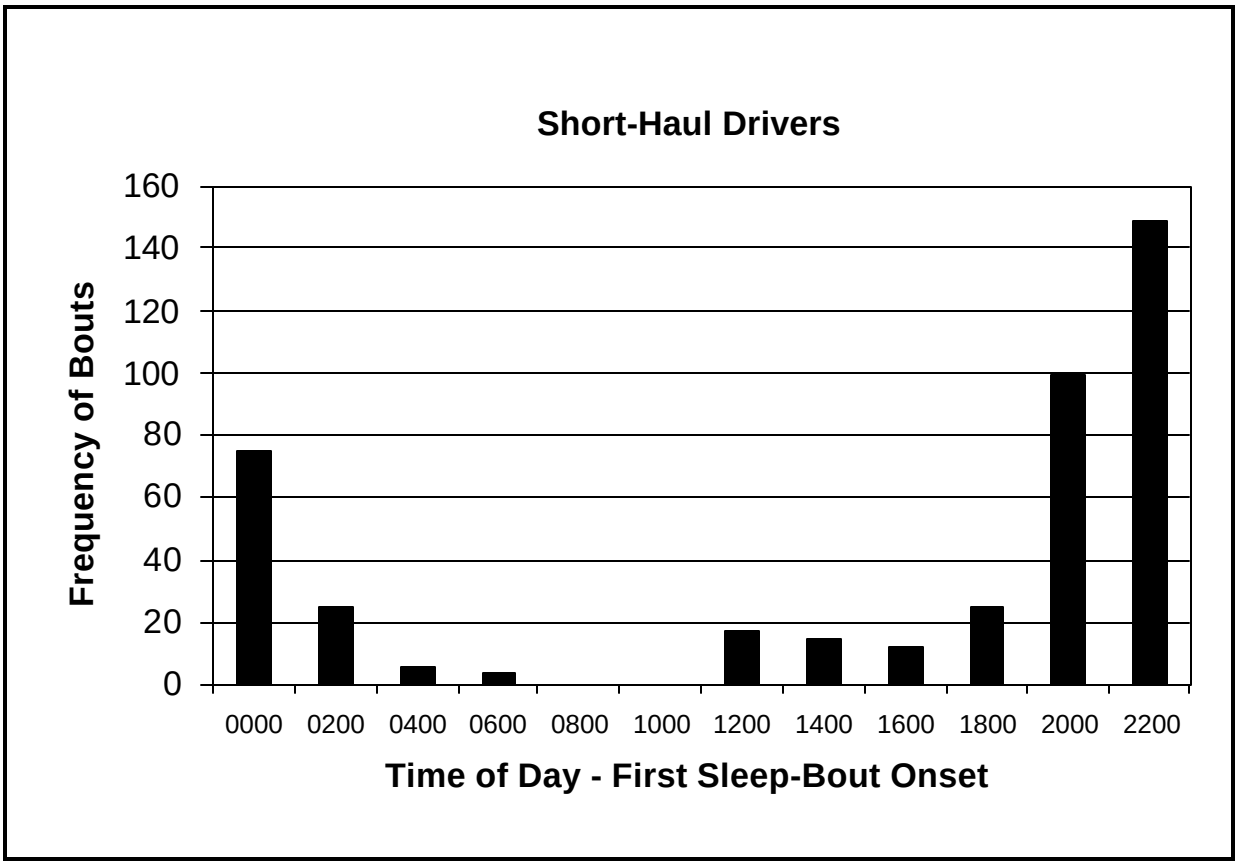

Figure 4-21. Frequency of first sleep bouts per 24-hour period as a function of onset time, short-haul drivers. Each clock time reflects the frequency of all sleep bouts within a 2-hour bin starting at that time of day.

Some 24-hour periods contained more than one sleep bout. **Figure 4-22** shows sleep-bout duration for actigraphically identified sleep bouts within each 24-hour period that occurred subsequent to the first sleep bout, as a function of sleep-bout onset time. Note that no more than five sleep bouts in a single 24-hour period were found—and only one 24-hour period contained five separate sleep bouts. In general, few 24-hour periods contained more than two bouts. Like the first sleep bout, subsequent sleep bouts occurred most frequently during evening hours (the 4-hour period between 2000 and 2359 hours). However, unlike the first sleep bout, a number of subsequent sleep bouts were initiated between 0800 and 1159 hours. In general, these subsequent sleep bouts were of less than 8 hours' duration and most frequently were within the range of 1 to 3 hours' duration.

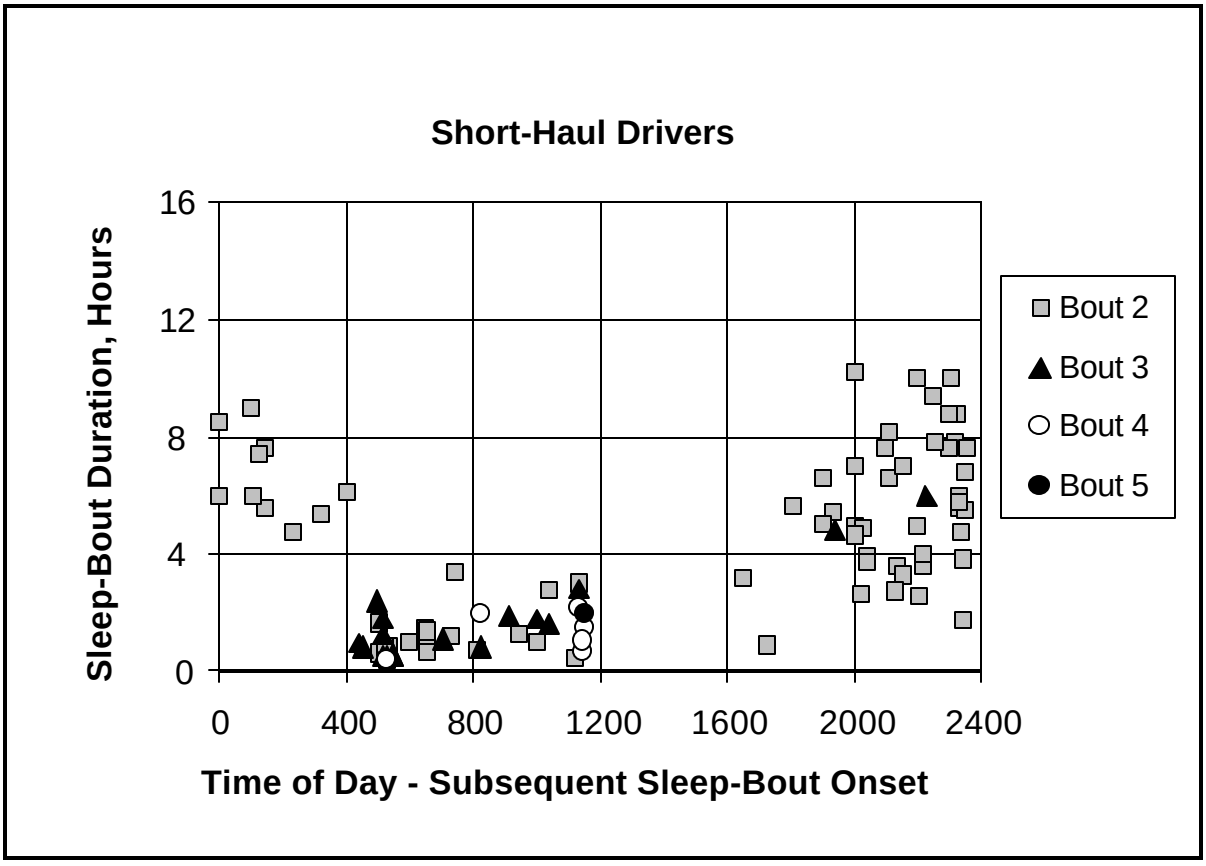

Figure 4-22. Sleep-bout duration for subsequent actigraphically identified sleep bouts of each 24-hour period as a function of time of day of sleep-bout onset, short-haul drivers.

Figure 4-23 illustrates data from Figure 4-22 as a frequency distribution of subsequent sleep bouts as a function of time of day of sleep-bout onset (short-haul drivers). As noted earlier, most subsequent sleep bouts were the second and final sleep bout identified within a given 24-hour period—third, fourth, and fifth sleep bouts were uncommon. The frequencies of subsequent sleep bouts were slightly more evenly distributed throughout the 24-hour period than was the first sleep bout. However, like the first sleep bout, subsequent sleep bouts were most frequently initiated within a 4-hour window between 2000 and 2359 hours. Some subsequent sleep bouts also were initiated between 0400 and 0559 hours. As noted earlier and shown in Figure 4-22, no subsequent sleep bouts were initiated between 1200 and 1559 hours.

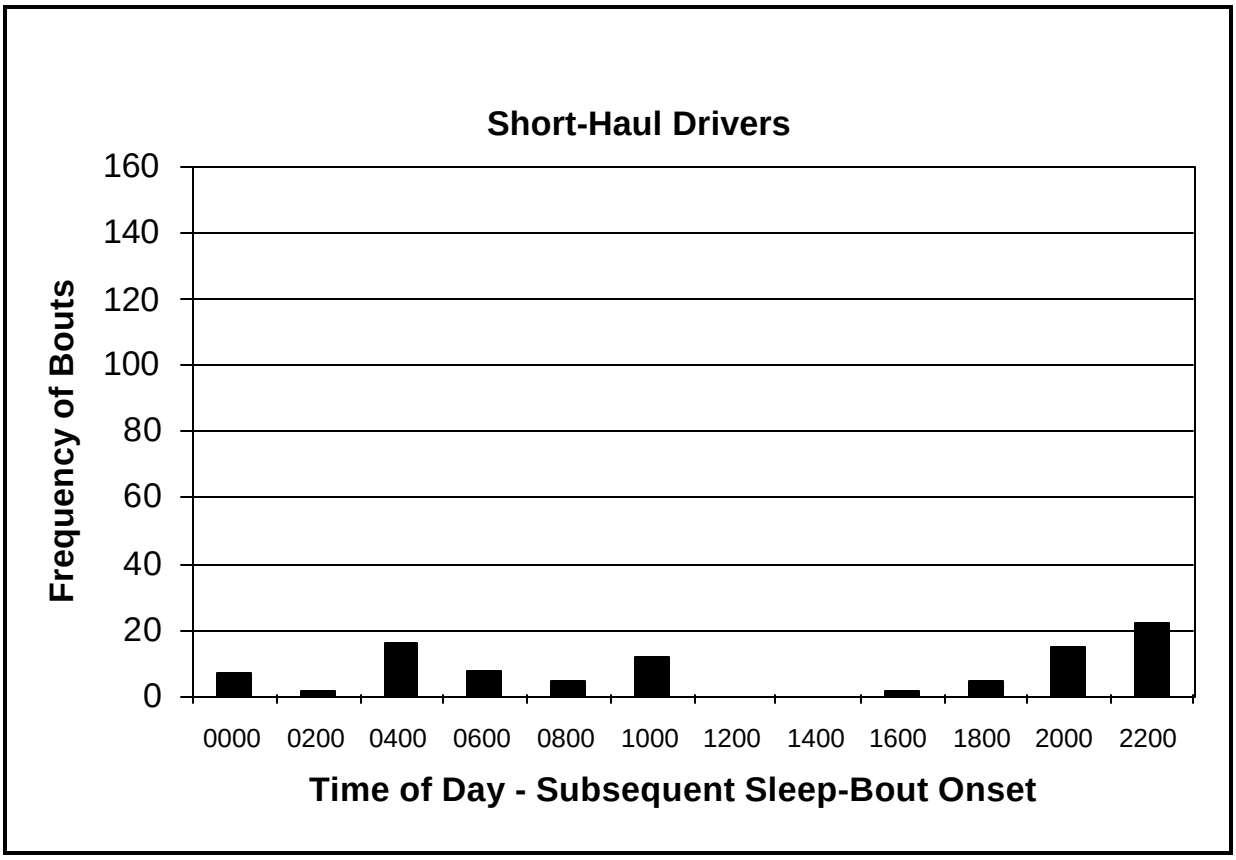

Figure 4-23. Frequency of subsequent sleep bouts per 24-hour period as a function of onset time, short-haul drivers. Each clock time reflects the frequency of all sleep bouts within a 2-hour bin starting at that time of day.

Long-Haul Drivers

Figure 4-24 illustrates sleep-bout durations for the first actigraphically identified sleep bout within each 24-hour period as a function of sleep-bout onset time for long-haul drivers. Similar to the short-haul drivers, the majority of long-haul drivers' first sleep bouts were initiated between 2200 and 0359 hours. Also, the duration of long-haul drivers' first sleep bouts clustered between 6 and 10 hours in duration. However, for long-haul drivers, no sleep bout exceeded 12 hours in duration. Moreover, sleep bouts exceeding 10 hours in duration were uncommon. No first sleep bouts were initiated between 0500 and 1159 hours. Some sleep bouts were initiated in the early- and late-afternoon hours (1200 to 1959 hours)—and, unlike short-haul drivers, almost half of the first sleep bouts initiated during this time frame were *longer* than 4 hours in duration.

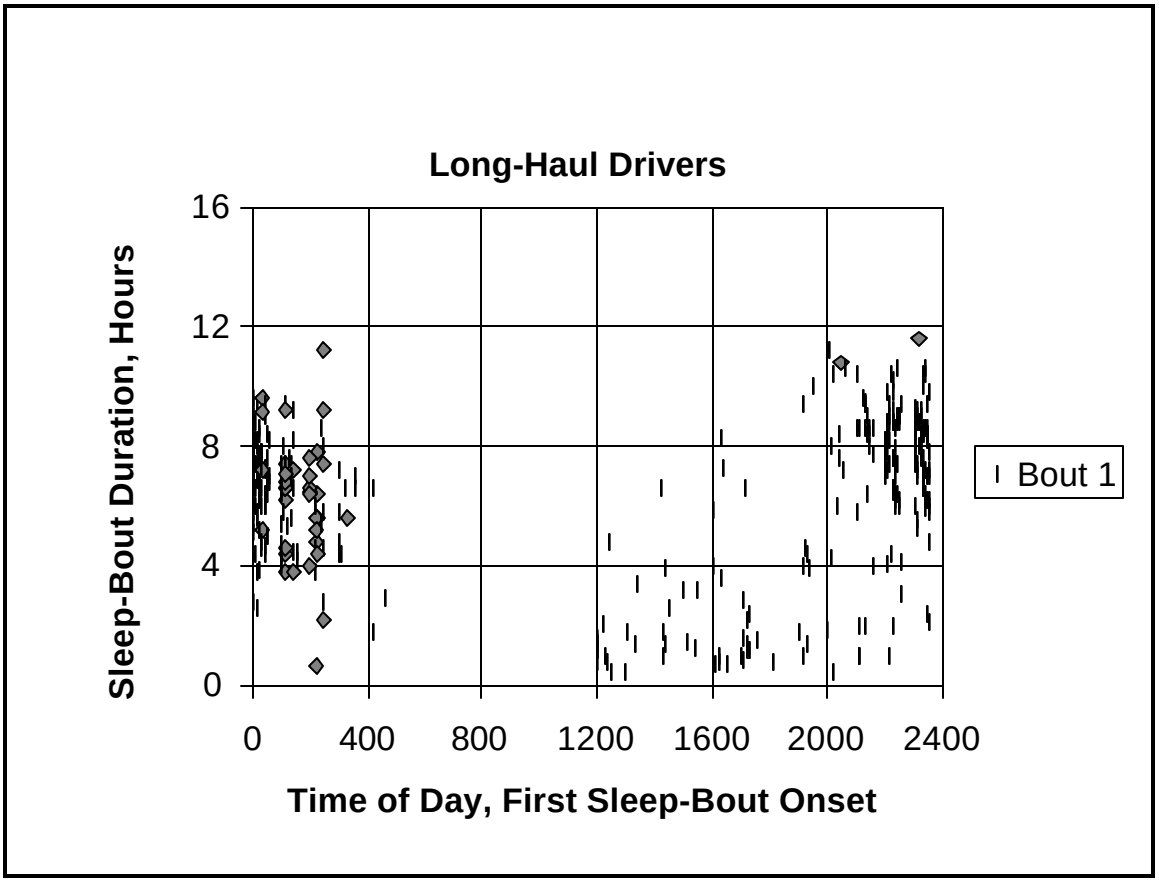

Figure 4-24. Sleep-bout duration for the first actigraphically identified sleep bout of each 24-hour period as a function of time of day of sleep-bout onset, long-haul drivers.

Figure 4-25 illustrates data from Figure 4-24 as a frequency distribution of first sleep bout as a function of time of day of sleep-bout onset (long-haul drivers). Again, the bulk of first daily sleep bouts for long-haul drivers was initiated between 2200 and 0159 hours. No first sleep bouts were initiated between 0600 and 1159 hours.

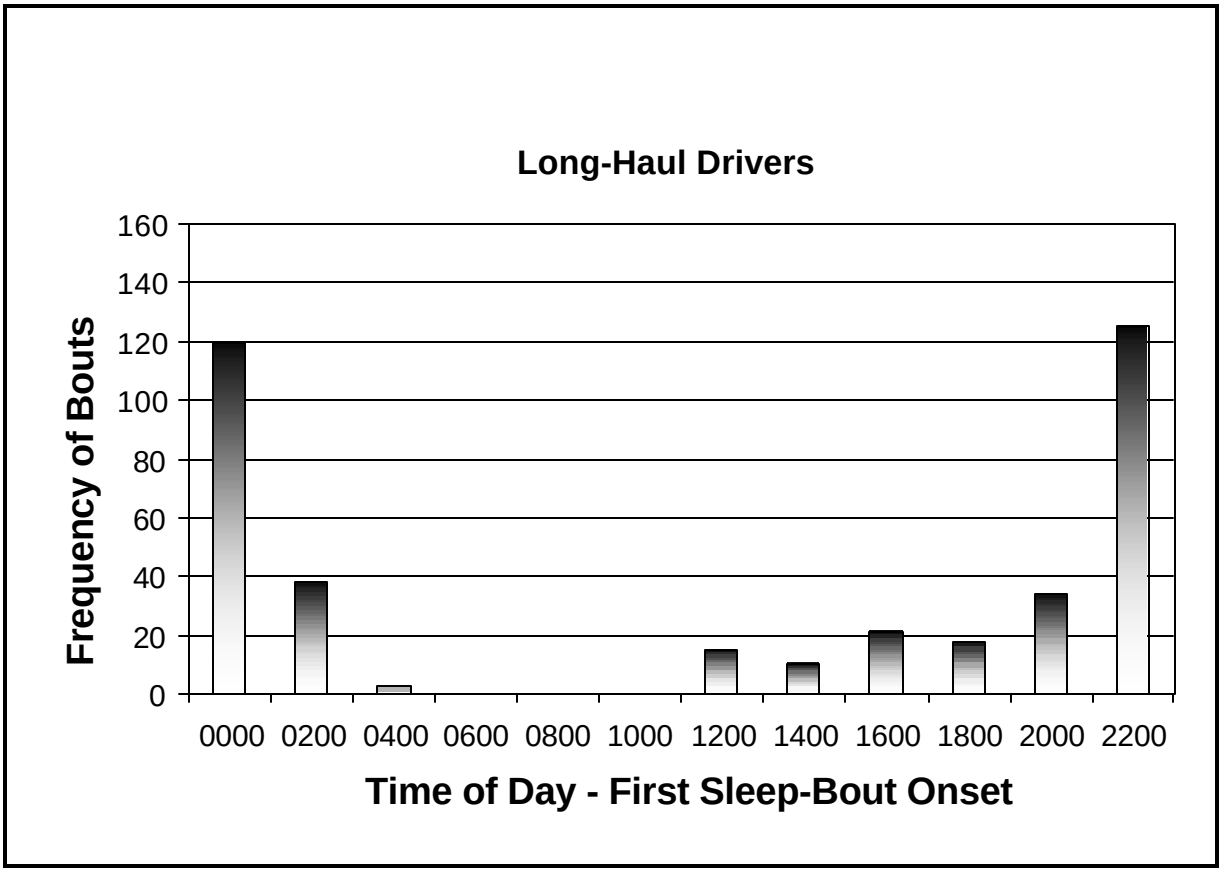

Figure 4-25. Frequency of first sleep bouts per 24-hour period as a function of onset time, long-haul drivers. Each clock time reflects the frequency of all sleep bouts within a 2-hour bin starting at that time of day.

As was the case for short-haul drivers, for long-haul drivers some 24-hour periods contained more than one sleep bout. **Figure 4-26** illustrates sleep-bout durations for subsequent actigraphically identified sleep bouts within each 24-hour period as a function of sleep-bout onset time for long-haul drivers. Subsequent sleep bouts in long-haul drivers ranged in duration from less than 1 hour to 9 hours. The shorter-duration subsequent sleep bouts mainly occurred during the morning hours (0400 to 1159 hours), whereas longer-duration subsequent sleep bouts occurred during evening hours (2000 to 0159 hours). More than two sleep bouts per 24-hour period were uncommon (N=9), and only one 24-hour period contained four sleep bouts. No subsequent sleep bouts were initiated between 1600 and 1959 hours.

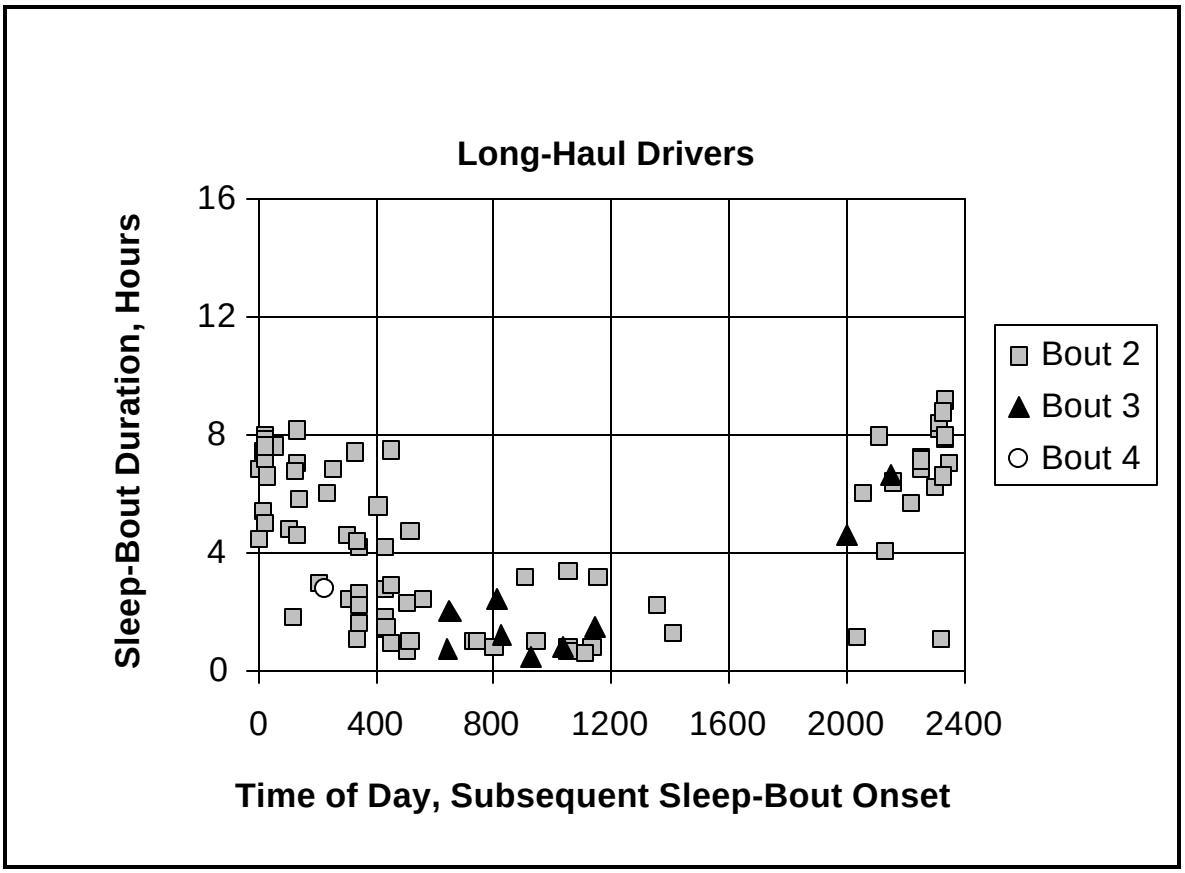

Figure 4-26. Sleep-bout duration for subsequent actigraphically identified sleep bouts of each 24-hour period as a function of time of day of sleep-bout onset, long-haul drivers.

Figure 4-27 illustrates data from Figure 4-26 as a frequency distribution of subsequent sleep bouts as a function of time of day of sleep-bout onset (long-haul drivers). Similar to short-haul drivers, long-haul drivers' subsequent sleep bouts appeared to be more evenly distributed across the 24-hour period than were the first sleep bouts. However, the late-evening to early-morning hours (2200 to 0359 hours) did account for most subsequent sleep bouts. No sleep bouts occurred between 1200 and 1959 hours.

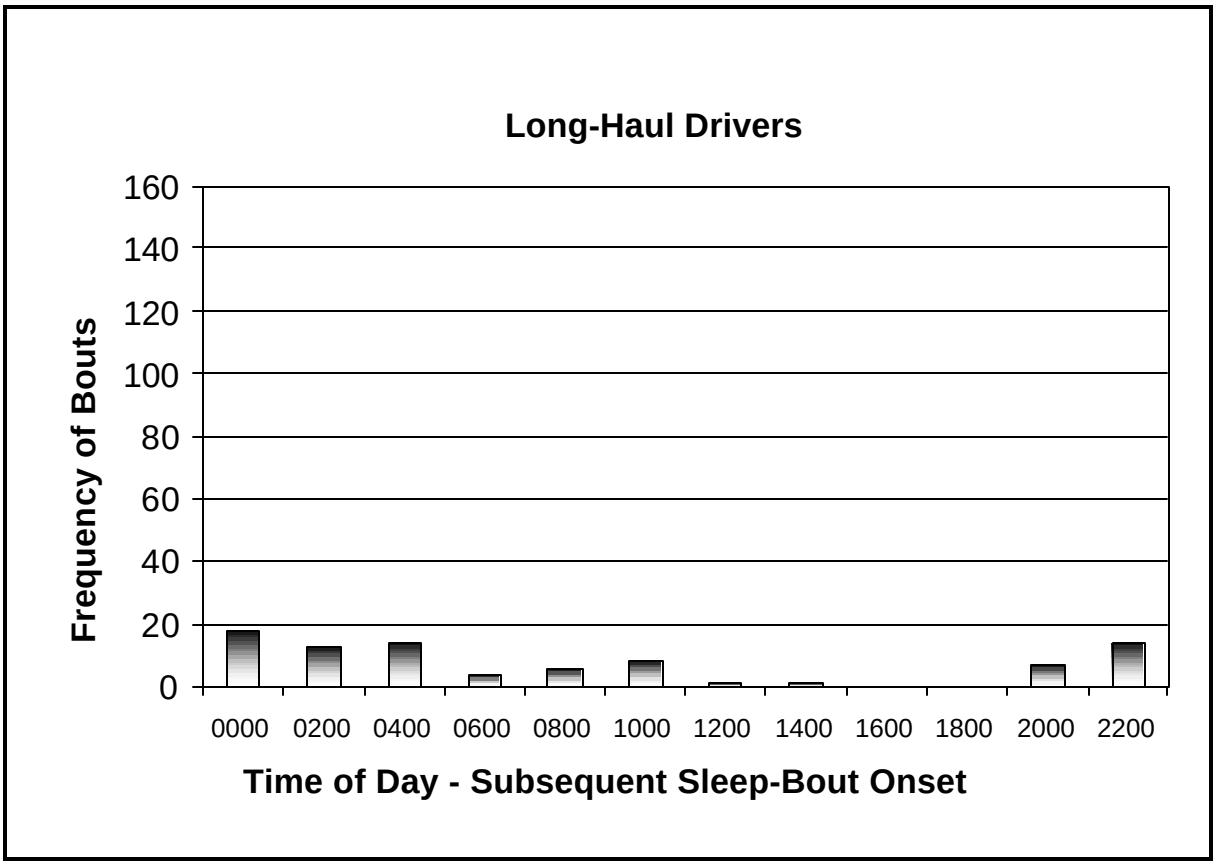

Figure 4-27. Frequency of subsequent sleep bouts per 24-hour period as a function of onset time, long-haul drivers. Each clock time reflects the frequency of all sleep bouts within a 2-hour bin starting at that time of day.

Short-Haul versus Long-Haul Drivers

Figure 4-28 illustrates frequency of first sleep bouts as a function of time of day of sleep-bout onset for short- versus long-haul drivers. Short-haul drivers initiated first sleep bouts earlier in the evening of each 24-hour period than did long-haul drivers. The frequencies of first sleep-bout onsets were higher for short-haul drivers than for long-haul drivers during the 4-hour interval between 2000 and 2359 hours. Long-haul drivers initiated their first sleep bouts more frequently during the 4-hour interval between 0000 and 0359 hours. Sleep bouts were very infrequent for both short- and long-haul drivers during the 4-hour interval between 0400 and 0759 hours. Neither short-haul nor long-haul drivers initiated any first sleep bouts during the 4-hour interval of 0800 to 1159 hours.

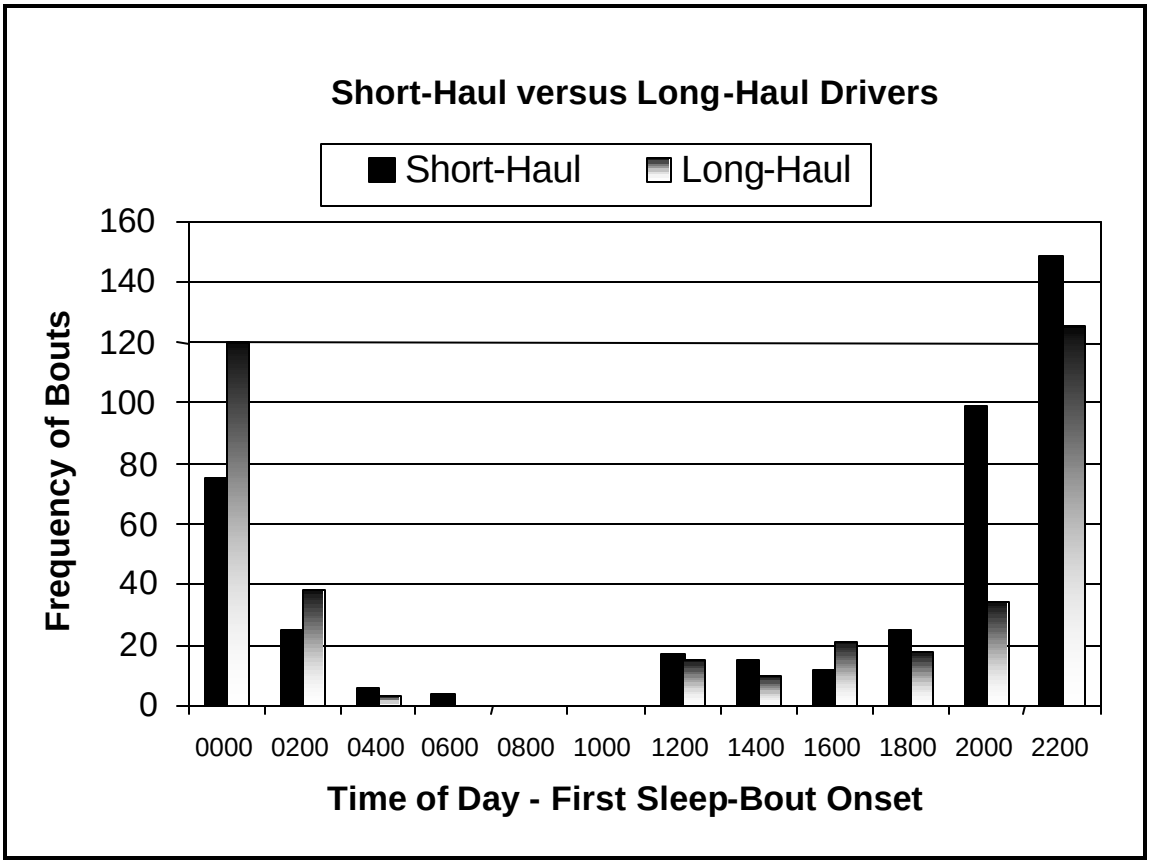

Figure 4-28. Frequency of first sleep bouts per 24-hour period as a function of onset time, short-haul versus long-haul drivers.

Figure 4-29 illustrates frequency of subsequent sleep bouts as a function of time of day of sleep-bout onset for short- versus long-haul drivers. Again, note that more than two sleep bouts per 24-hour period were uncommon for both short- and long-haul drivers (i.e., a second daily sleep bout accounts for the bulk of "subsequent" sleep bouts for both short- and long-haul drivers). Subsequent sleep bouts were initiated *more* frequently by short-haul versus long-haul drivers during the 4-hour interval between 2000 and 2359 hours. Subsequent sleep bouts were initiated *less* frequently by short-haul versus long-haul drivers during the 4-hour interval of 0000 to 0359 hours. Thus, as was the case for the first sleep bout per 24-hour period, short-haul drivers initiated subsequent sleep bouts earlier in the evening of each 24-hour period than did long-haul drivers. Subsequent sleep bouts occurred very infrequently in the early- to late-afternoon hours (1200 to 1759 hours) for short-haul drivers, and no subsequent sleep bouts occurred among long-haul drivers during these hours.

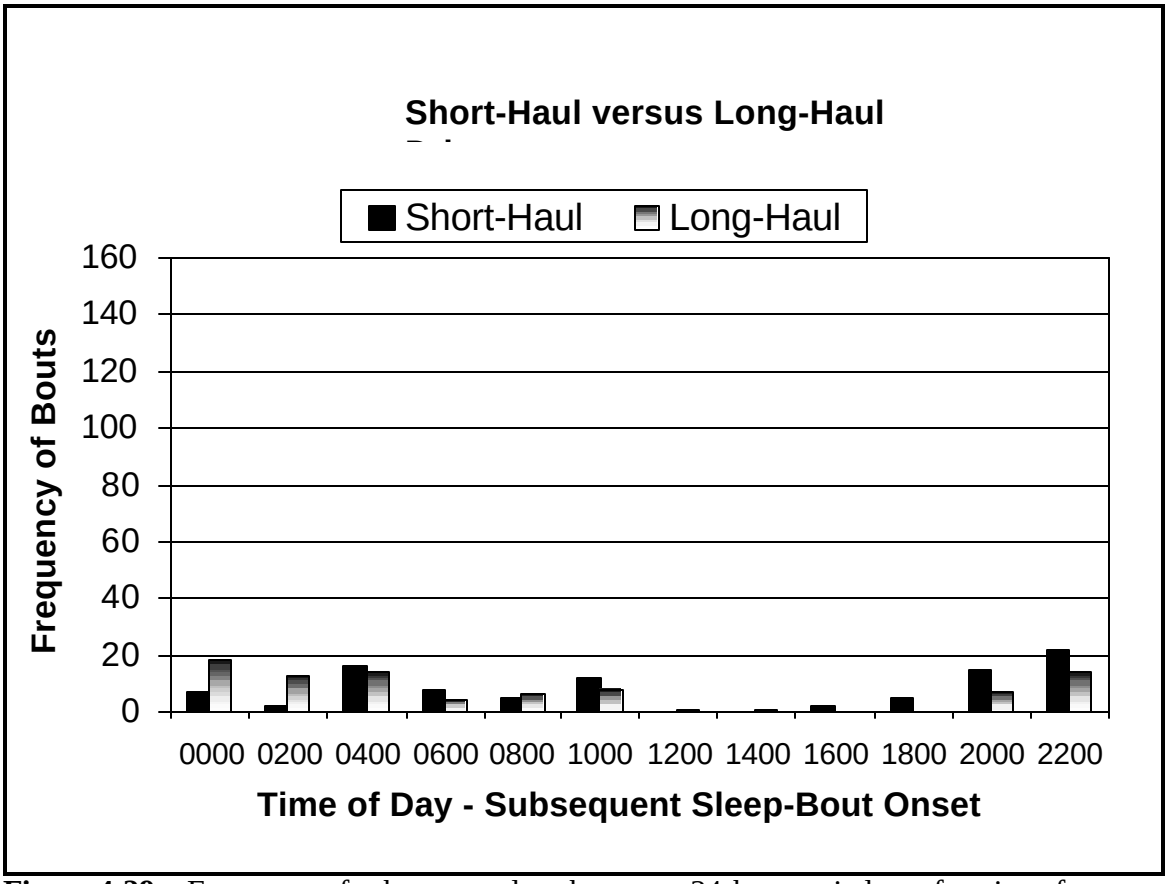

Figure 4-29. Frequency of subsequent sleep bouts per 24-hour period as a function of onset time, short-haul versus long-haul drivers.

VARIABILITY IN TOTAL DAILY SLEEP AMOUNTS

The previous analyses indicate that, in general, both short-haul and long-haul drivers (a) obtain 6 or more hours of sleep per 24-hour period, regardless of duty status; (b) may divide sleep per 24 hours into two bouts; and (c) generally initiate their first (and longest) sleep bout between 2000 and 0159 hours. However, whether sleep amounts vary across days is critical: variable sleep durations across days will result in variable performance across days. The next set of analyses was conducted to determine the degree of variability in driver sleep durations across days (24-hour periods). For the following analyses, total sleep time for each available day (24-hour period) was calculated by summing across all possible duty statuses. Next, measures of variability as well as average sleep per 24-hour period were calculated. As noted, the term "day" is used to mean the 24-hour recording period from 1200 to 1200 hours (noon to noon—see Methods).

Table 4-1 and **Table 4-2** list each driver's mean total sleep per 24-hour period averaged across all available participation days, standard deviation, minimum sleep per 24-hour period, maximum sleep per 24-hour period, and number of available days (see the next section of this chapter, titled "Missing Data," for a discussion of factors contributing to missing data). Data for short-haul drivers are listed in Table 4-1; long-haul driver data are listed in Table 4-2. For both tables, data are rank-ordered by standard deviation, with the highest standard deviations at the top of the tables. Although average total sleep per 24-hour period for most drivers appeared to be adequate (i.e., greater than 6 hours), the variability in sleep times (as indicated by standard deviations) across 24-hour periods also was high for some drivers.

Table 4-1. Mean daily (per 24-hour period) total sleep time (averaged across all available participation days) for each short-haul driver. Data are in descending order by standard deviation (column 3). Data are illustrated in Figure 4-30.

DRIVER	MEAN TST	STD DEV	MIN	MAX	DAYS
H7076	8.39	3.08	4.40	14.60	19*
W9751	7.81	2.70	3.40	12.00	16
K8543	7.89	2.22	5.20	15.00	17
R8669	8.05	2.17	4.60	11.20	11
R3934	7.22	2.11	4.00	11.17	19
J0746	7.21	2.01	3.40	11.63	19
G3081	7.37	1.91	1.80	9.80	18
D9777	7.02	1.81	4.80	10.80	17
G5420	8.62	1.78	5.60	12.20	19
G6754	7.85	1.78	5.20	11.40	12
A0669	8.46	1.77	4.20	12.00	18
L6201	6.89	1.66	4.20	10.60	13
C2979	7.79	1.59	5.50	12.37	19*
G1260	7.96	1.58	6.00	12.00	18
Z3826	5.29	1.57	3.45	9.18	17
L8026	7.16	1.53	4.00	10.00	18
S1462	6.39	1.32	4.60	8.80	15
T9080	8.61	1.29	6.20	11.50	18
W2984	6.85	1.29	5.60	9.80	13
H1146	8.02	1.26	5.40	9.60	13
T5452	8.50	1.13	6.80	11.40	17*
H5975	8.57	1.10	6.80	11.40	19
M7744	7.15	1.03	5.60	9.40	18
K9006	8.70	0.97	8.00	10.80	8
W4579	8.23	0.88	6.80	9.20	6

*Drivers' sleep/wake data used for modeling

Table 4-2. Mean daily (per 24-hour period) total sleep time (averaged across all available participation days) for each long-haul driver. Data are in descending order by standard deviation (column 3). Data are illustrated in Figure 4-31.

DRIVER	MEAN TST	STD DEV	MIN	MAX	DAYS (#)
D1949	7.48	5.23	1.82	16.82	6
M3265	7.00	2.73	0.00	10.93	14
M2058	7.94	2.63	1.70	11.60	16
B6828	6.98	2.57	3.80	12.80	17*
D2392	6.95	2.48	0.00	11.20	17
C8814	5.82	2.23	2.85	9.82	17
C0995	7.88	2.01	3.73	10.40	14
S4985	6.17	1.98	2.40	9.20	18
T7039	7.10	1.97	2.00	9.60	18
S3946	6.98	1.88	2.20	9.80	18
M8181	7.44	1.86	4.20	10.80	19
S4565	7.62	1.82	3.80	11.00	20
C2229	6.50	1.67	3.87	8.97	17
Z2911	7.53	1.61	4.40	10.40	20*
C9596	7.91	1.37	4.80	11.20	18
N9719	7.86	1.21	5.80	10.60	13
O7609	7.70	1.32	4.40	9.60	19
J9730	7.53	1.17	4.60	9.40	19
J5832	6.61	1.04	4.80	9.00	20
K4658	8.29	0.91	6.60	9.40	20
K9113	8.40	0.91	6.60	10.00	20*
P7627	7.33	0.46	6.95	8.00	4
P3544	7.55	0.44	7.00	8.00	4
B3899	5.03	0.40	4.75	5.32	2
P9919	Data not used - Co-Driver				0

*Drivers' sleep/wake data used for modeling

For the following analyses, all drivers with less than 15 days of data were disregarded. Fifteen days corresponds to 75 percent of total data (it was reasoned that less than 15 days of data could artificially inflate the standard deviation). Three drivers from each category (long-haul, short-haul) were selected for illustration. These three drivers showed high, medium, and low day-to-day variabilities in total sleep time. They are indicated in the tables by asterisks. Their daily total sleep times (summed across all possible duty statuses) are shown in **Figure 4-30** (short-haul) and **Figure 4-31** (long-haul). For both figures, each subject's average daily sleep time and standard deviation are also shown (as from tables). Missing 24-hour periods are indicated by a gray box for short-haul drivers and a black box for long-haul drivers.

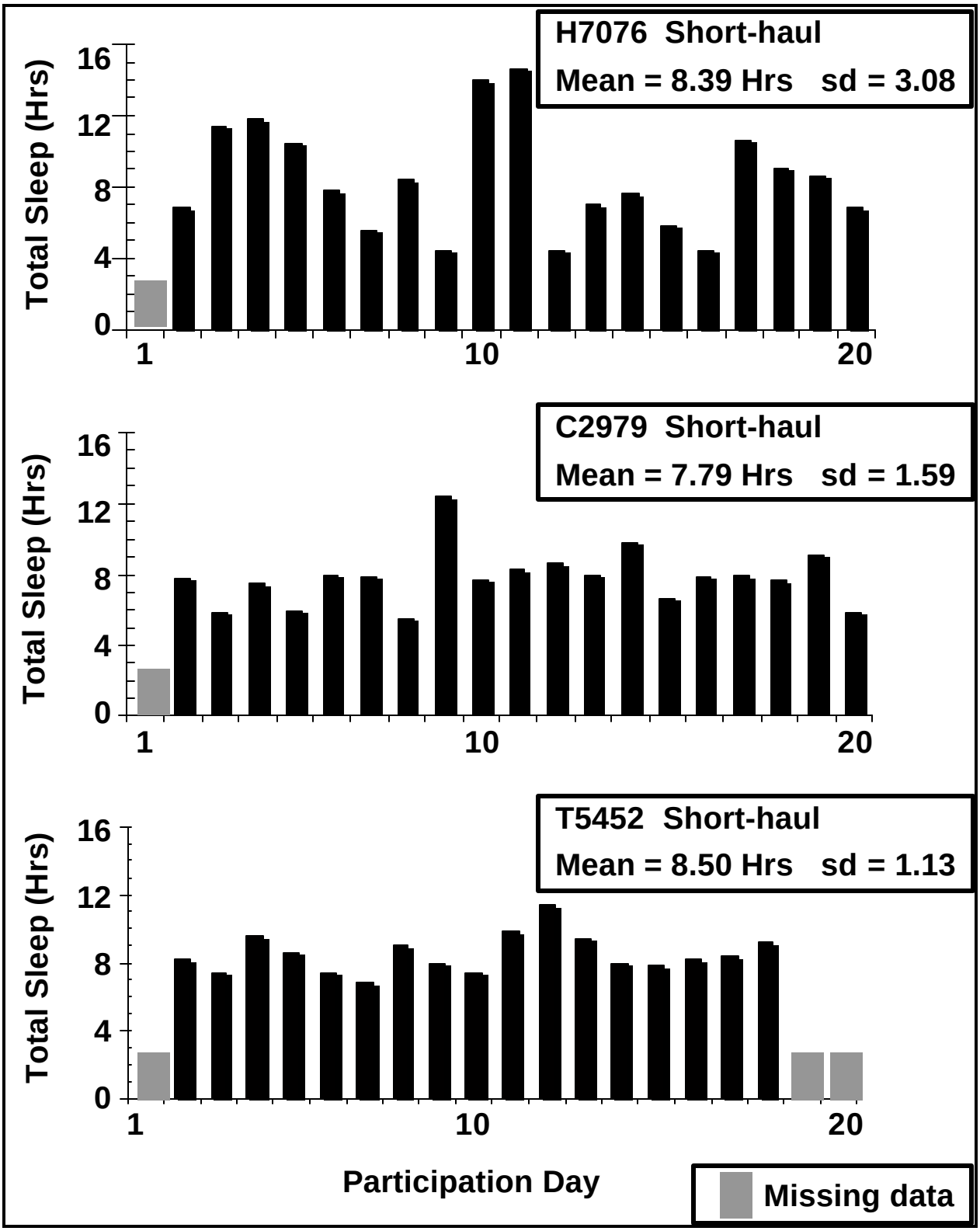

Figure 4-30. Daily total sleep time per each 24-hour period across all 20 study days for three short-haul drivers (drivers with high/medium/low variability in daily total sleep times).

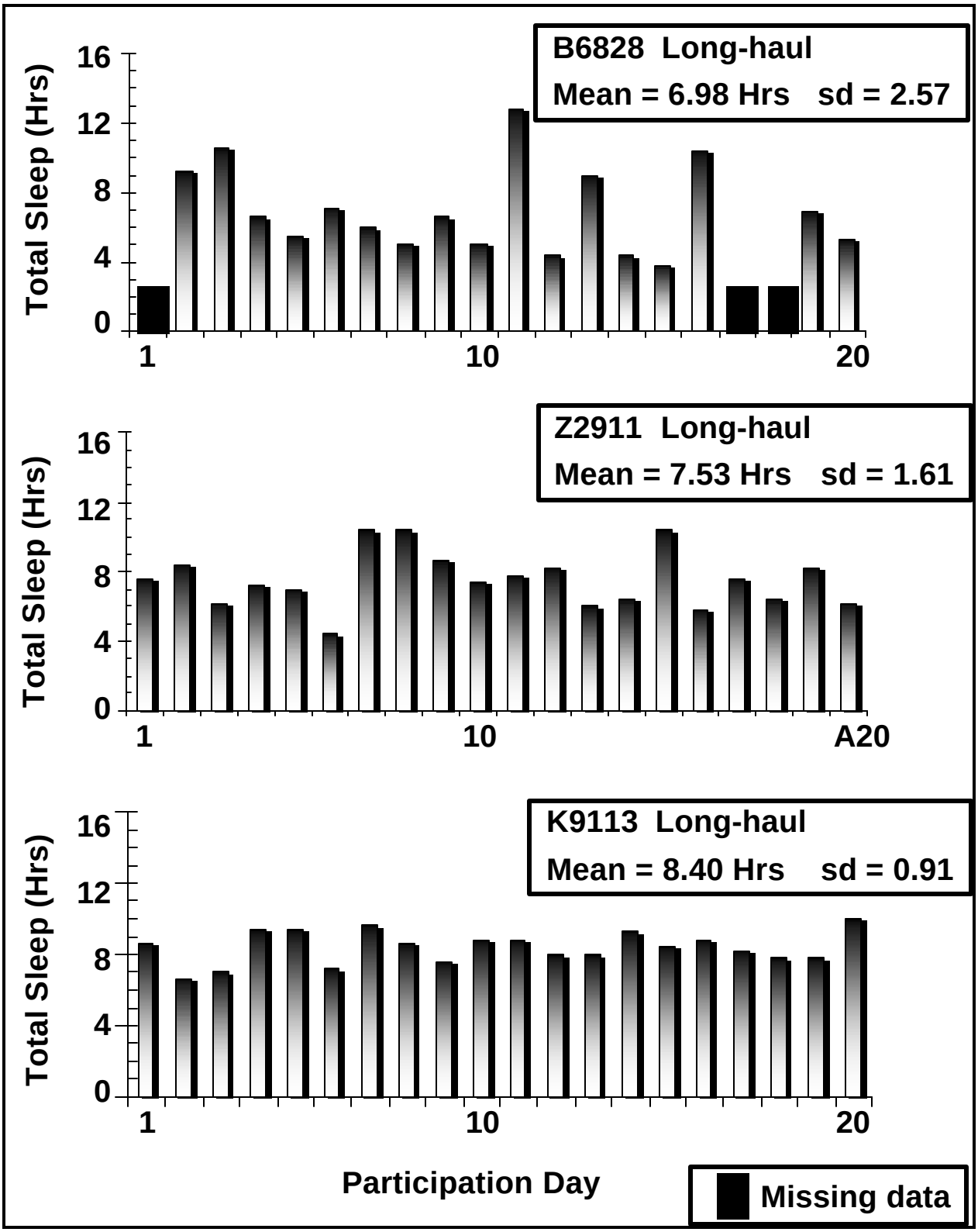

Figure 4-31. Daily total sleep time per each 24-hour period across all 20 study days for three long-haul drivers (drivers with high/medium/low variability in daily total sleep times).

Daily sleep times varied substantially across days for some long-haul and short-haul drivers. For both long- and short-haul drivers, sleep times varied by up to 11.2 hours across the 20 study days. A pattern of decreasing sleep time across 24-hour periods, followed by a "rebound" night of more than 8 hours of sleep, was evident among both long- and short-haul drivers. Drivers with little variation in daily sleep times are also shown in Figures 4-30 and 4-31; their daily sleep times varied by less than 5 hours. Furthermore, daily total sleep was nearly uniformly 6 to 8 hours per night.

The results indicate that some drivers obtained approximately the same number of hours of sleep daily, while other drivers obtained widely variable amounts of daily sleep. Later, the impact of daily sleep times on predicted performance is determined.

MISSING DATA

Some actigraphy data were unusable due to the following reasons: (a) the actigraphy signal suggested that the driver removed the actigraph for some portion (greater than 1 hour) of that day, but the missing data could not be assigned reliably as wake time (e.g., the driver gave no indication of why the actigraph was removed, nor could the missing data be attributed to shower time, etc.); (b) actigraph equipment problems resulted in a lost day (e.g., actigraph batteries failed and the actigraph stopped collecting data); and (c) actigraph data were uninterpretable due to noise (see next paragraph). The majority of missing or incorrect RODS data came from the short-haul driver group (as noted, short-haul drivers do not typically fill out RODS). In those instances, actigraphy data could not be divided reliably among on-duty, driving; on-duty, not driving; or off-duty time and thus were not included in data analyses.

For short-haul drivers, the number of inconsistencies/errors can be summarized as follows: (1) 29 driver days (recall that 1 day = one 24-hour period) contained RODS inconsistencies; (2) 67 driver days contained actigraph errors; and (3) 17 driver days contained both RODS inconsistencies and actigraph errors. For long-haul drivers, inconsistencies/errors can be summarized as follows: (1) 6 driver days contained RODS inconsistencies; (2a) 32 days contained actigraph errors; (2b) 108 days contained actigraph errors due to sleeper-berth noise (co-driver days); (3a) 7 days contained both RODS inconsistencies and actigraph errors; and (3b) 1 day contained both RODS inconsistencies and actigraph (co-driver) errors.

For six of the long-haul drivers, some 24-hour periods of actigraph data during sleep periods were uninterpretable. Inspection of the driver logs, actigraphy signals, and self-reports indicated that these six drivers were part of a two-driver (co-driver) team. Thus, the majority of these drivers' sleep periods took place in the truck sleeper berth while the co-driver operated the vehicle. Truck movement interfered with the actigraph signal and thus precluded the use of these data for determination of sleep times. Refinements to the actigraph (which will eliminate this problem) are discussed briefly below.

D. DISCUSSION

The objectives of this study were to quantify, using the actigraph, the sleep of long-haul and short-haul drivers in real-world commercial trucking operations. Because the CMV driver volunteers in this study wore an actigraph 24 hours per day and kept sleep/wake logs and Record of Duty Status (RODS) forms, it was possible to quantify for each subject total daily sleep broken down into daily sleep taken off-duty (outside of work shift) versus daily sleep during other times of the day (Type B time—within-shift sleep) over the 20 days of the study.

Average total daily sleep, including both off-duty and Type B sleep, for short-haul drivers was 7.66 hours ± 0.1 standard error of the mean (SEM). Average total daily sleep, including both off-duty and Type B sleep, for long-haul drivers was 7.31 hours ± 0.1 SEM. These means are in the range found to sustain cognitive performance in the Phase II Sleep Dose-Response Study (7.93 hours—see Chapter 2), and thus, on average, would appear to be adequate to sustain performance across successive work/rest cycles. The separate contributions of off-duty and Type B time sleep to total daily sleep are discussed next.

OFF-DUTY AND TYPE B TIME SLEEP FOR SHORT-HAUL DRIVERS

For short-haul drivers, length of off-duty sleep periods was normally distributed around a mean of 7.46 hours of sleep within each 24-hour period. This suggests that, on average, short-haul drivers obtained daily amounts of sleep off-duty that were of sufficient daily duration (i.e., close to the 7.93 hours reported in Chapter 2) to sustain performance. The bulk of off-duty sleep periods for short-haul drivers fell within a range of 6 to 9 hours, suggesting that off-duty sleep

likely comprises the bulk of daily sleep for short-haul drivers. In fact, off-duty sleep comprises nearly all of these drivers' daily total sleep. Likewise, the amount of off-duty time spent sleeping was moderately and positively correlated with number of hours off-duty. These results suggest that, on average, short-haul drivers obtain adequate amounts of sleep during off-duty hours and that the number of off-duty hours can be used as a first approximation for estimating amount of short-haul drivers' total daily sleep.

Short-haul drivers do not have a duty status record corresponding to the long-haul drivers' "sleeper berth" designation. Nevertheless, short-haul drivers may be obtaining some within-shift sleep. Of considerable interest were the actigraph findings that some sleep was obtained by short-haul drivers during their work shifts (clock-in to clock-out). For the most part, these were short sleep bouts of 1 to 2 hours in duration (i.e., naps). Surprisingly, there was no apparent relationship between these naps and the duration of Type B periods. Naps were evenly distributed across the range of Type B periods. For example, even a Type B period of only 2 hours contained a short nap. The longest sleep bout obtained by a short-haul driver associated with Type B time (as logged by the driver in the RODS) was 6 hours in duration. Perhaps not surprisingly, this sleep occurred during a 17-hour Type B period. The results suggest that short-haul drivers occasionally nap within the work shift—for example, while they wait for the vehicle to be loaded or unloaded. In some cases, these naps may represent compensatory sleep following a night of reduced sleep. Although these naps contributed only slightly to the total daily sleep amounts of short-haul drivers, their presence may be informative since they suggest inadequate nighttime sleep durations and/or other problems with nighttime sleep (e.g., sleep disorder). Importantly, such naps would not have been detected (1) if the drivers had worn the actigraph only during off-duty time; or (2) if only actigraph periods corresponding to off-duty time been examined for sleep episodes. Alternatively, some of the sleep taken during apparent work shifts may have been an artifact of the accuracy with which drivers entered information into the RODS (as mentioned earlier—"Limitation of the RODS").

OFF-DUTY AND TYPE B TIME SLEEP FOR LONG-HAUL DRIVERS

For long-haul drivers, off-duty sleep amounts were distributed around a mean of 4.32 hours of sleep per 24-hour period. The distribution of off-duty sleep times was skewed—some

off-duty periods consisted of only short bouts of sleep (1 to 5 hours), and a substantial number of off-duty periods contained no sleep. The off-duty periods containing no sleep were generally 12 hours or less, suggesting that these periods were of insufficient length to allow long-haul drivers an opportunity to obtain sleep. It is possible that other factors such as errands, family matters, etc., took precedence over sleep during these short, off-duty periods. Long-haul drivers' off-duty-period length was positively correlated with the amount of sleep obtained during that period. On average, long-haul drivers' off-duty sleep was at the lower limits of sustaining normal levels of performance, and sleep amounts displayed more variability. These findings suggest that, for long-haul drivers, off-duty time may substantially underestimate daily sleep times. This was suggested earlier by the absence of any sleep in many of the long-haul drivers' off-duty periods. No sleep during off-duty periods implies that long-haul drivers are either chronically and severely sleep deprived or that they are obtaining a large portion of their daily sleep during other periods of the work day.

The amount of time that long-haul drivers spend sleeping during periods other than off-duty [that is, either during sleeper-berth time or other within-shift times (and consequently its contribution to total daily sleep)], as well as its relation to length of the duty period, was previously unknown. Again, in these analyses, it was assumed that sleep during periods other than off-duty would likely reflect sleep taken away from home. These results showed that Type-B-time sleep contributed substantially to total daily sleep times for long-haul drivers. Almost half (44 percent) of long-haul drivers' total daily sleep was obtained during Type B time. Accordingly, the frequency distribution for sleep during Type B time closely approximated that for off-duty sleep. As was the case for sleep periods associated with off-duty time (as indicated in the RODS), sleep associated with Type B time included a substantial number of short sleep bouts of 1 to 4 hours in duration. Many Type B periods contained no sleep. The longest Type B period without sleep was 20 hours, but this occurred in only one instance. Otherwise, all other Type B periods of 20 hours or greater for long-haul drivers contained at least 2 hours of sleep. Therefore, drivers are not working one or more 24-hour periods continuously without sleeping. In fact, when Type B sleep is subtracted from total Type B time (leaving only time spent awake during Type B time), long-haul drivers never exceeded 20 hours of continuous wakefulness during Type B time. Although 20 hours of continuous wakefulness would exceed predicted "safe" performance capacity, these results suggest that drivers attempt to take necessary steps to

combat sleepiness during excessive hours awake, and they do so by taking naps. Finally, length of the Type B periods was moderately and positively correlated with duration of Type-B-time sleep for long-haul drivers, with longer Type B periods associated with more sleep. This suggests that the number of hours of Type B time has some value for predicting number of hours of Type B sleep for long-haul drivers. Daily total sleep times would be significantly underestimated among long-haul drivers if only off-duty sleep were considered without including sleeper-berth and other within-shift periods.

Type B sleep contributed significantly to total daily sleep accumulations among long-haul drivers, and the distribution of sleep lengths was similar to the distribution seen for sleep during off-duty time (i.e., a relatively flat distribution, in comparison to short-haul drivers, for which most sleep bouts were of 7 to 9 hours in duration). Thus, the most accurate description of daily sleep amounts (and therefore enhanced precision in predicting performance effects) results when sleep obtained across all duty statuses (i.e., 24 hours per day) is included. Although short-haul drivers obtained relatively little sleep during their work shifts, the length of these sleep bouts suggested that napping is a strategy that is also used by short-haul drivers, perhaps to compensate for a prior night of inadequate sleep.

As noted above, average *total* daily sleep (summed across all duty statuses within a day) for short- and long-haul drivers was in the normal range and would appear to be adequate to sustain performance across successive work/rest cycles. Although these averages suggest that short-haul and long-haul drivers tended to obtain adequate total amounts of sleep (on average, more than 7 hours per 24-hour period for both groups), of concern was the variability in daily total sleep across days, discussed next.

TIME OF DAY AND FREQUENCY/DURATION OF SLEEP BOUTS

As just noted, drivers may accumulate their daily total sleep as a single sleep bout or as several sleep bouts across the 24-hour recording period. Of particular interest was whether the length of a sleep period or sleep bout was systematically related to the time of day at which the sleep bout was initiated. Also of interest was whether there appeared to be "preferred" (either by choice or due to scheduling conflicts) times of day when sleep was most frequently initiated, and in contrast, whether there appeared to be times of day when sleep was never initiated.

Sleep-period length did appear to be systematically related to the time of day at which the sleep bout was initiated among both short- and long-haul drivers. For both groups, the longest sleep bouts (both the first sleep bout and subsequent sleep bouts within each 24-hour period) were generally initiated between 2000 and 0159 hours. Sleep bouts initiated during these times tended to be 6 to 10 hours in duration. These results suggest that nocturnal sleep generally accounts for the bulk of sleep obtained for both short- and long-haul drivers. It may also suggest that these times are optimal for initiating and maintaining sleep—either as a result of work schedules, or as a result of circadian influences on sleep initiation and maintenance.

The data also appear to suggest that, in general, both short- and long-haul drivers are maintaining diurnal schedules. Further evidence of this may be the finding that neither short- nor long-haul drivers initiated their first sleep bout of the 24-hour period between the hours of 0800 and 1159 hours. This may have been due to (1) a relative lack of sleep debt at this time (as a result of nocturnal sleep), (2) work shift conflicts—i.e., that most drivers are on-duty during this time of day, or (3) a combination of these. In contrast, however, was the observation that, among long-haul drivers, some first sleep bouts were initiated in the early- and late-afternoon hours (1200 to 1959 hours)—and unlike short-haul drivers, almost half of their sleep bouts were *longer* than 4 hours in duration. Finally, short-haul drivers tended to initiate their longest sleep periods (during evening hours) approximately 2 hours earlier than long-haul drivers. The reason for this is unclear but may relate to scheduling differences between short- and long-haul drivers.

For both short- and long-haul drivers, a single sleep bout accounted for the majority of daily sleep obtained. Second sleep bouts were sometimes observed, but more than two daily sleep bouts were extremely uncommon. Like the first sleep bout, the second sleep bout tended to occur during evening hours (2000 to 2359). However, unlike the first sleep bout, subsequent relatively short sleep bouts (1 to 3 hours in duration) were observed between 0800 and 1159 hours. These subsequent sleep bouts may reflect a second, compensatory sleep following a night of restricted sleep. Surprisingly, subsequent sleep bouts occurred very infrequently in the early- to late-afternoon hours (1200 to 1759 hours) among short-haul drivers, and no *subsequent* sleep bouts occurred among long-haul drivers during these hours (although, again, sometimes long-haul drivers' first sleep bout of the 24-hour period was initiated at this time). The fact that few sleep bouts were initiated in the early- to late-afternoon hours seems surprising since this time of day coincides with a daily drop in alertness (i.e., the "post-lunch dip"). Again, however, it is

likely that a lack of sleep periods during this time is a result of scheduling—drivers, particularly short-haul, may be on-duty and driving during these time periods.

VARIABILITY IN TOTAL DAILY SLEEP ACROSS DAYS—IMPACT ON PREDICTED PERFORMANCE

Results for total sleep times per 24 hours (both long- and short-haul drivers) suggested that, on average, drivers obtain daily amounts of sleep that are adequate for sustaining performance within normal limits throughout the waking hours. However, further analyses of these data indicated that total sleep times were not consistent across 24-hour periods for many drivers. In one example, a driver's total daily sleep time varied by more than 11 hours. This amount exceeds the optimal nightly sleep quantity (8 hours) and resulted when a night of inadequate sleep (4 hours) was followed by two "rebound" nights of 14 and 15 hours, respectively. Excessive variability in total daily sleep amounts was not restricted to one particular category of driver but was evident in individuals from both short- and long-haul driver groups.

Fluctuations in total daily sleep would be expected to cause corresponding fluctuations in predicted performance. Thus, performance predictions were obtained for the three short-haul and three long-haul drivers whose actigraphically recorded sleep/wake data are illustrated in Figures 4-30 and 4-31. Their sleep/wake data served as input to the Sleep Performance Model (SPM). These sleep/wake data were initially modeled for performance predictions using the original version of the SPM referred to as "SPM-96." SPM-96 was developed based on studies of performance on a serial addition/subtraction task (described in Chapter 2, Methods) in young, healthy males undergoing total and near-total sleep deprivation. The data were then modeled a second time using a refined SPM. The SPM was refined based on Psychomotor Vigilance Task (PVT) performance in licensed commercial motor vehicle (CMV) operators participating in the Phase II Sleep Dose-Response study. See Chapter 2 for a description of the Phase II laboratory study. See Chapter 3 for a description of the methodology used to derive refined parameters for the SPM.

The drivers selected from each category (short-haul, long-haul) represented three levels of variability in daily sleep amounts (high, medium, low), relative to the other drivers studied in

that category—their daily sleep amounts were presented in Figures 4-30 and 4-31. Results of modeling using the refined SPM (see Chapter 3), are illustrated, along with timing and length of actigraphically identified sleep periods. Each "day" starts and ends at 1200 hours (noon), as indicated by dashed vertical lines. Solid vertical lines indicate 0000 hours (midnight).

For modeling purposes only, it was assumed that all drivers obtained 8 hours of sleep (2200 to 0600 hours) the night prior to the first day of actual actigraphically recorded sleep/wake data. It was also assumed that drivers remained awake from 0600 until commencement of actigraph data collection at 1200 hours. In effect, these assumptions served as "baseline" input to the model. Thus, for some drivers, predicted performance will decline across the first several days as predicted performance is adjusted to individual daily sleep amounts of less than 8 hours.

For each figure, the predicted performance output from the refined SPM is described. A description of SPM refinement methodology is described in Chapter 3. For each figure, solid black bars indicate actigraphically recorded sleep (note that the height of those bars was arbitrarily set at 65 percent so that sleep periods would be visible, but height is unrelated to the y-axis; y-axis values pertain only to refined SPM predicted performance shown as a continuous solid black line). Width of the solid black bars indicates length of sleep.

It is important to note that the output of the SPM consists of a numerical predicted performance index—a number reflecting predicted, relative performance on a specific cognitive task: the Psychomotor Vigilance Task (PVT, described on page 2-13). The PVT was selected for modeling because there was no evidence of learning (i.e., performance doesn't improve as a function of practice). Also, compared to the various other measures used in this study, it was found to be especially sensitive to the effects of sleep loss. Although the SPM output can and should be considered a reflection of changes in relative, general performance capacity, the implications of the specific predicted performance index values for other tasks (such as CMV driving) are not yet known. Specificity for other tasks such as driving will be achieved through either (1) correlation of the current SPM index with specific driving measures in field and laboratory studies; or (2) optimizing the SPM parameters directly using specific driving measures, so that the output of the model becomes a "driving performance index."

Predicted performance for the short-haul driver whose daily total sleep amounts were highly variable (standard deviation = 3.08) is illustrated in **Figure 4-32**. This driver obtained an average of 8.39 hours of sleep per 24-hour period. However, for driver H7076, the effects of variable daily sleep amounts is apparent. For example, restricted sleep resulted in predicted performance impairments on Day 2. The effects of restricted daily sleep become even more apparent on Days 5, 6, 7, and 8, then again across Days 14, 15, and 16—across these days, as sleep debt accumulated, predicted performance (refined SPM) failed to fully recover each night. This resulted in lower predicted performance upon awakening the next day. More than 8 hours of sleep were obtained on Days 9 and 10, resulting in corresponding improvements in predicted performance. However, 2 days was not enough to restore predicted performance entirely. Also of significance is the time of day at which the drops in predicted performance occurred. For short-haul driver H7076, predicted performance drops occurred during daytime hours. On Days 9 through 10 and 16 through 17, this predicted performance drop encompassed nearly the entire day. Assuming a day shift, this means poor predicted performance during working hours.

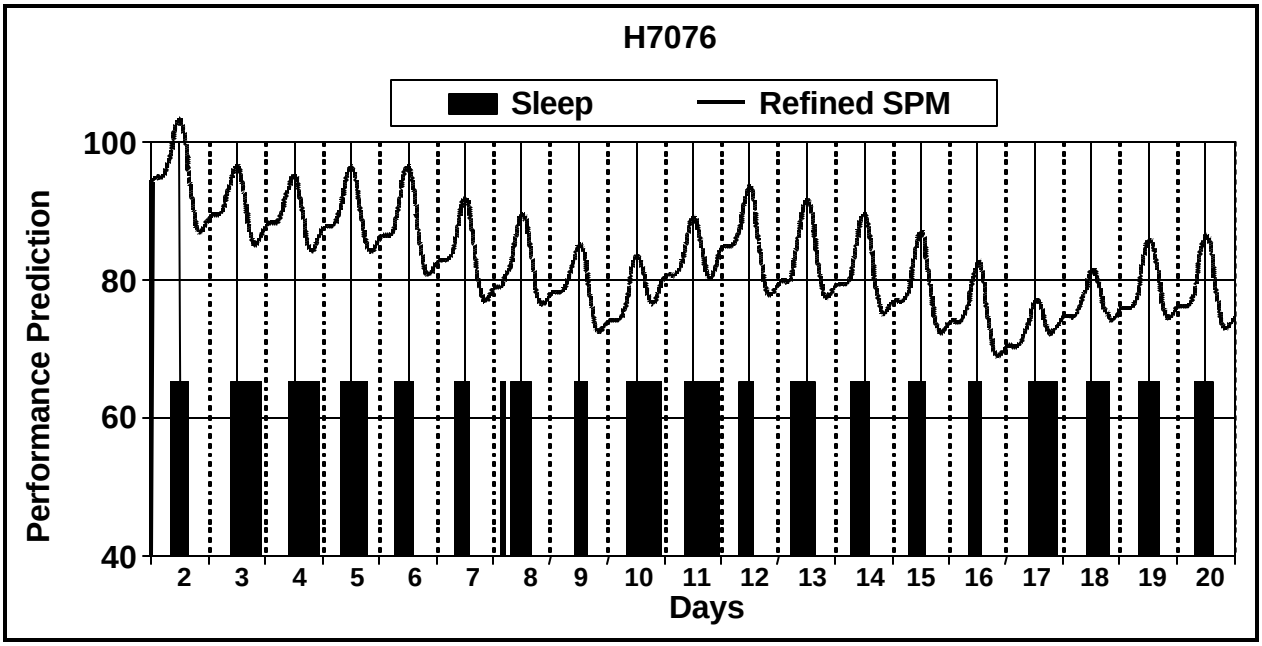

Figure 4-32. SPM predicted performance based on actigraphically recorded sleep per 24-hour period for short-haul driver H7076 (ranked high on daily variability in total sleep time relative to the other short-haul drivers studied). Actigraphically recorded sleep is indicated by black bars (height is arbitrary; width = length of sleep bout). Solid vertical lines indicate 0000 hours (midnight).

For long-haul driver B6828 with high daily variability in sleep amounts (Figure 4-33), the effect of this variability in daily sleep amounts on predicted performance can be seen. This driver obtained an average of 6.98 hours of sleep per 24-hour period. The effects of restricted sleep are apparent—across Days 4 through 11, restricted daily sleep amounts resulted in steadily decreasing predicted performance. On Days 8 and 9, it appears that the driver divided daily sleep into two bouts—on Day 8, this consisted of one short nocturnal sleep bout followed by a second, morning sleep bout. Either due to work schedule or possibly circadian effects, this latter sleep bout was of relatively short duration—and thus, only a small amount of recuperation of predicted performance was derived. Even relatively long (for this driver) daily sleep amounts (e.g., Days 3 and 11) were inadequate to restore predicted performance.

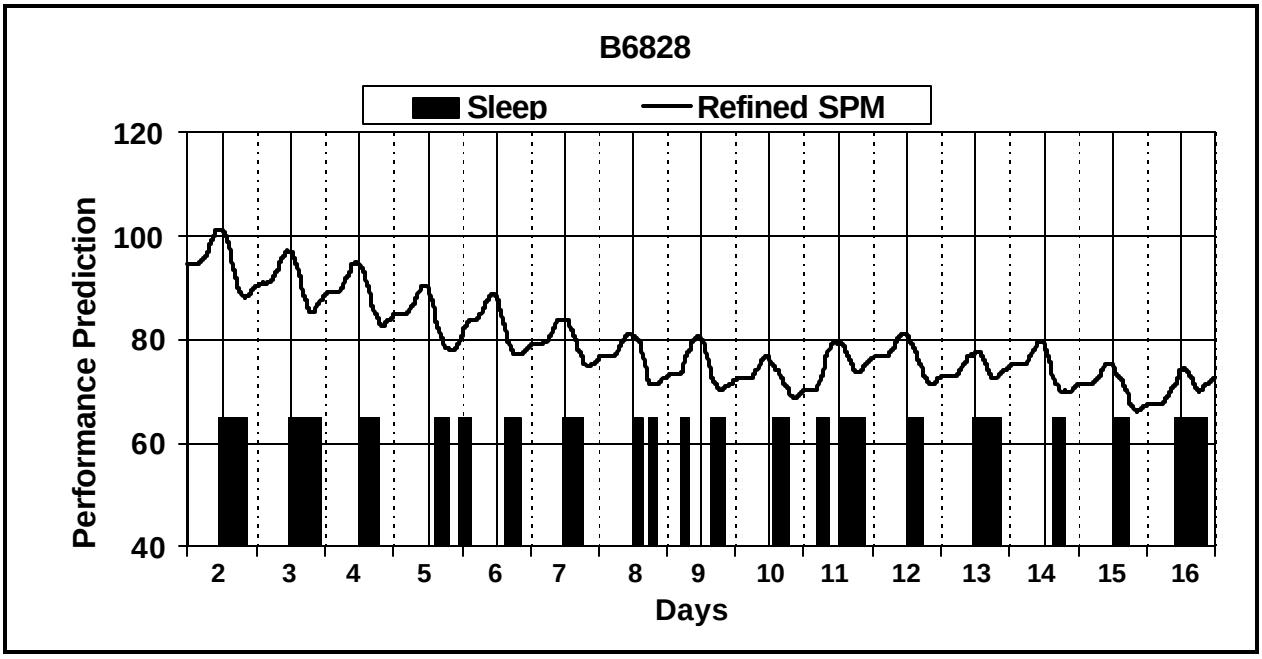

Figure 4-33. SPM predicted performance based on actigraphically recorded sleep per 24-hour period for long-haul driver B6828 (ranked high on daily variability in total sleep time relative to the other long-haul drivers studied). Actigraphically recorded sleep is indicated by black bars (height is arbitrary; width = length of sleep bout). Solid vertical lines indicate 0000 hours (midnight).

Predicted performance for the long-haul driver ranked as having medium daily variability (Z2911) is illustrated in **Figure 4-34**. Note that the day-to-day variability in predicted performance is less than was the case for H7076 or B6828. However, overall average daily predicted performance is relatively low. This is the result of the driver having obtained slightly less than the amount shown to sustain performance in the Phase II study (7.53 versus 7.93 hours—see Chapter 2). However, the driver did tend to initiate sleep at approximately the same time each night (0000 hours), and it appears that daily total sleep was consolidated into a single nightly bout. Thus, predicted performance variability within a day was relatively low (i.e., no predicted performance increases as a result of daytime sleeps).

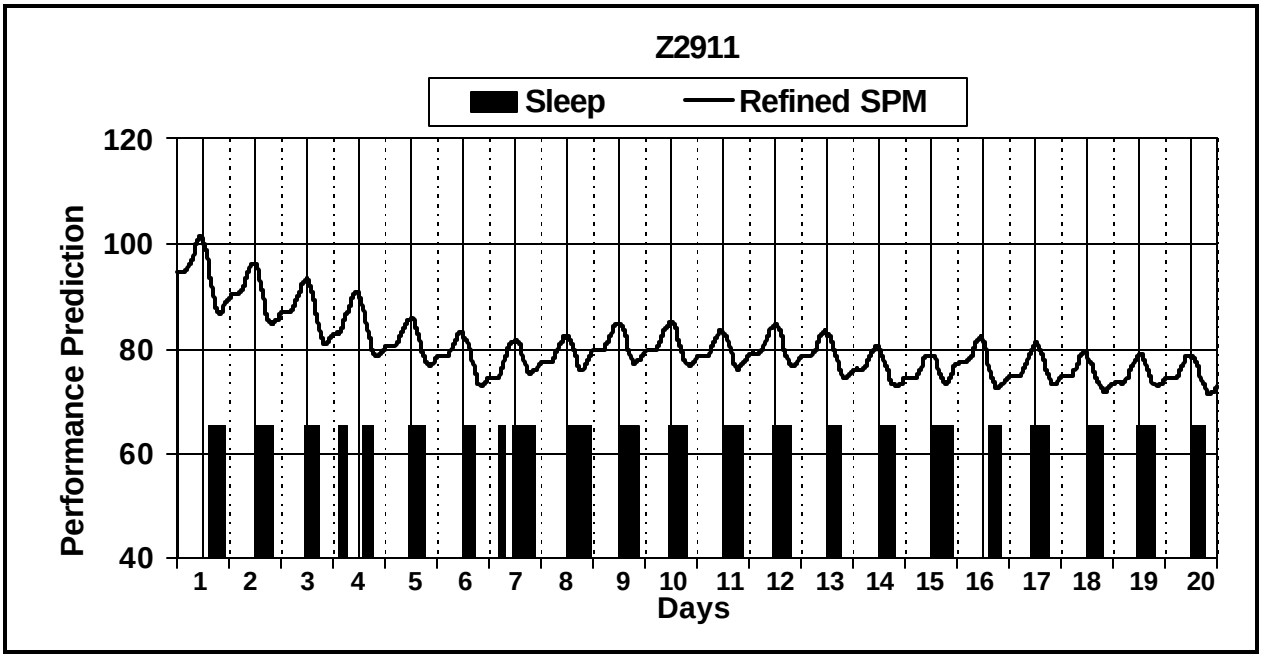

Figure 4-34. SPM predicted performance based on actigraphically recorded sleep per 24-hour period for long-haul driver Z2911 (ranked medium on daily variability in total sleep time relative to the other long-haul drivers studied). Actigraphically recorded sleep is indicated by black bars (height is arbitrary; width = length of sleep bout). Solid vertical lines indicate 0000 hours (midnight).

Predicted performance for the short-haul driver who was ranked as having medium daily variability (C2979) is illustrated in **Figure 4-35**. C2979 obtained similar average amounts of daily sleep (7.79 hours) and displayed similar variability to Z2911 (standard deviations of 1.59 for C2979 and 1.61 for Z2911, respectively). However, in stark contrast to Z2911, C2979 divided daily total sleep amounts into several bouts, which were initiated at varying times of day. This resulted in overall greater peak-to-trough differences in daily predicted performance for C2979. This is due to the effects of C2979's daytime sleeps on predicted performance—that is, daytime sleep reversed the overall daily decrement in predicted performance. This is indicated most clearly by the effect on predicted performance of the afternoon bouts of sleep obtained on Days 10 and 14.

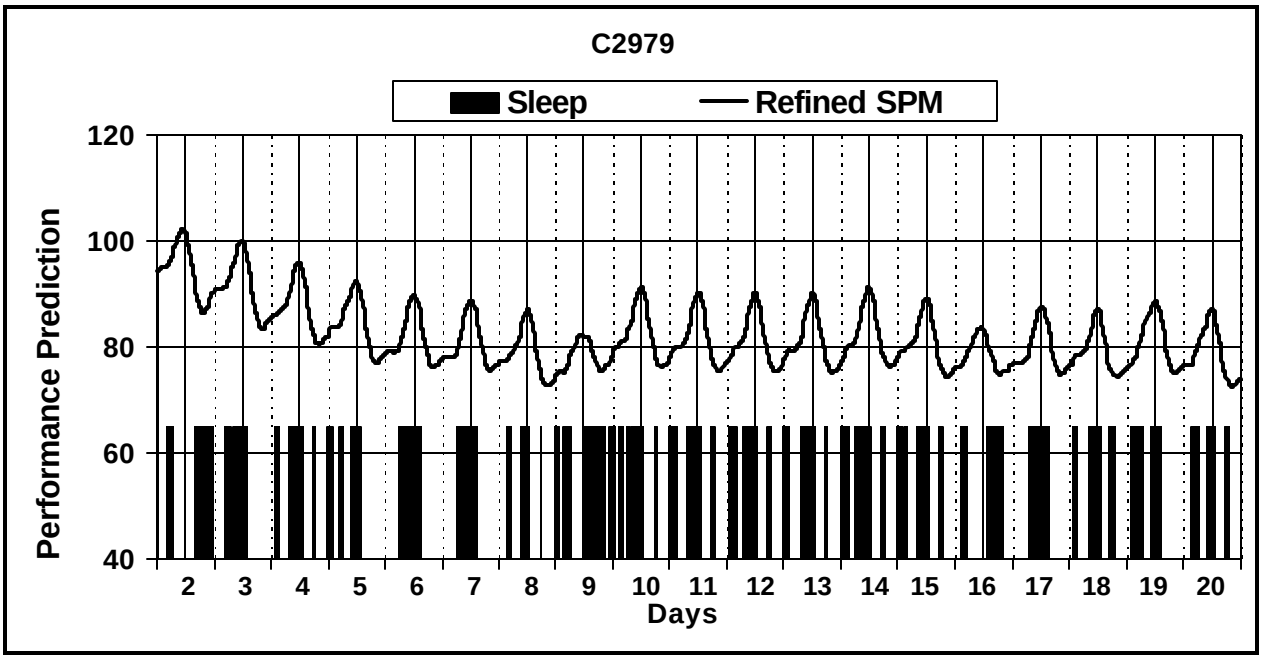

Figure 4-35. SPM predicted performance based on actigraphically recorded sleep per 24-hour period for short-haul driver C2979 (ranked medium on daily variability in total sleep time relative to the other short-haul drivers studied). Actigraphically recorded sleep is indicated by black bars (height is arbitrary; width = length of sleep bout). Solid vertical lines indicate 0000 hours (midnight).

Predicted performance for the short-haul driver who displayed the lowest daily variability in total sleep amounts (T5452) is illustrated in **Figure 4-36**. On average, T5452 initiated and terminated sleep at roughly the same times every day. T5452 obtained, on average, 8.50 hours of sleep per 24-hour period. Slight variations in daily total sleep had a relatively small impact on predicted performance. With the exception of Days 7 through 11, this driver maintained relatively high levels of predicted performance compared with the drivers described earlier.

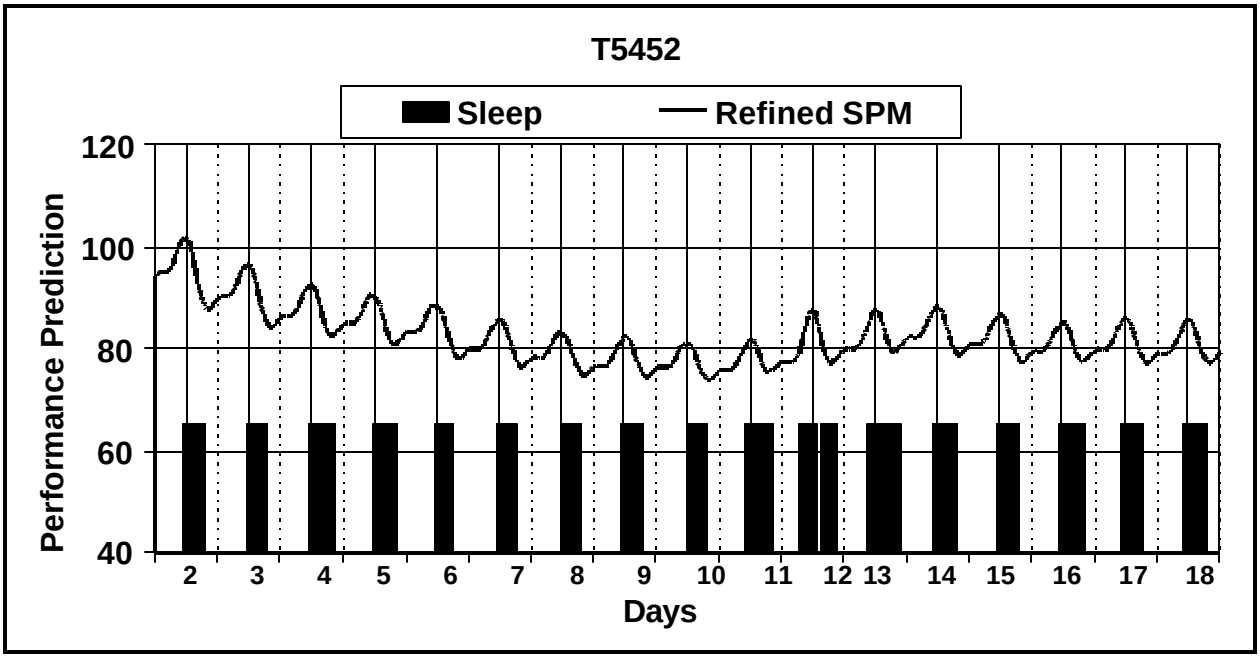

Figure 4-36. SPM predicted performance based on actigraphically recorded sleep per 24-hour period for short-haul driver T5452 (ranked low on daily variability in total sleep time relative to the other short-haul drivers studied). Actigraphically recorded sleep is indicated by black bars (height is arbitrary; width = length of sleep bout). Solid vertical lines indicate 0000 hours (midnight).

Predicted performance for long-haul driver K9113 (ranked low on daily sleep amount variability) is illustrated in Figure 4-37. K9113 obtained an average of 8.40 hours of sleep per 24-hour period. Day-to-day variability in predicted performance was even lower for K9113 than for T5452. The restorative value of short afternoon sleep bouts also can be seen on Days 7 and 8.

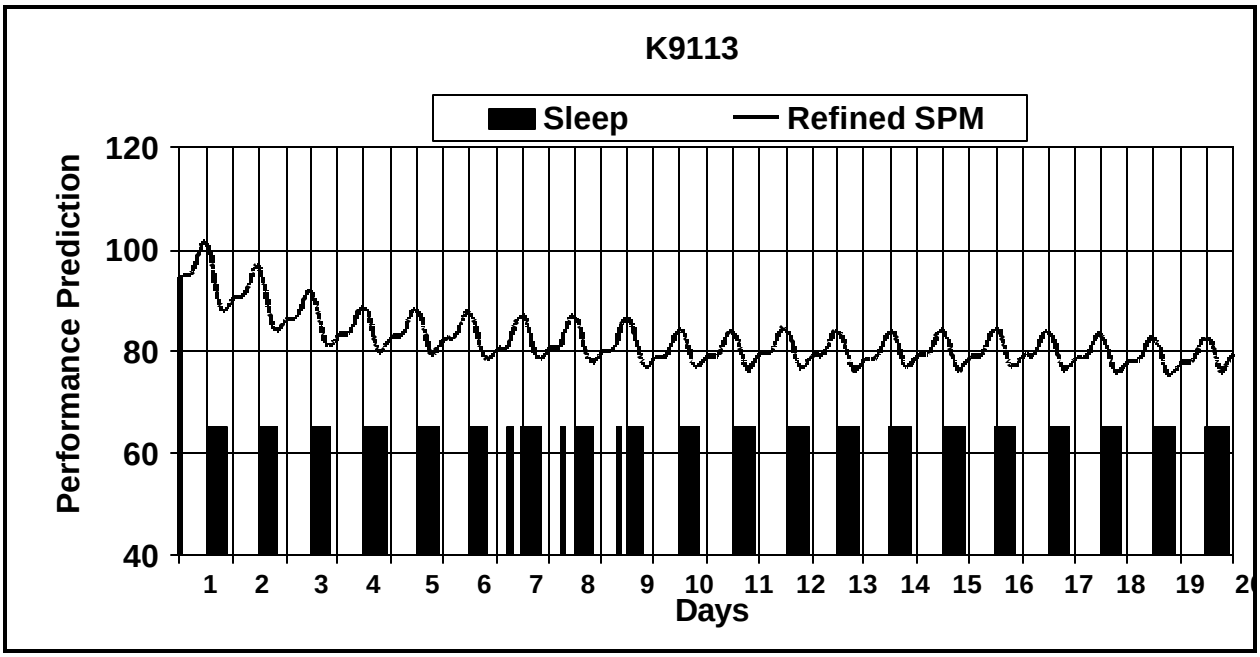

Figure 4-37. SPM predicted performance based on actigraphically recorded sleep per 24-hour period for long-haul driver K9113 (ranked low on daily variability in total sleep time relative to the other long-haul drivers studied). Actigraphically recorded sleep is indicated by black bars (height is arbitrary; width = length of sleep bout). Solid vertical lines indicate 0000 hours (midnight).

In short, SPM predictions based on actual sleep/wake data of drivers in this study suggest that drivers who maintain consistent sleep amounts/patterns will maintain daily predicted performance levels with less day-to-day variability. Drivers who obtain their sleep in a single, nightly bout may display less *within-day* variability, but this may not necessarily be preferable—large gains in predicted performance can be made via short sleep bouts taken during daytime hours. Drivers whose sleep schedules are less consistent will have greater day-to-day variability in predicted performance. For these latter drivers in particular, an output indicating the effects of their sleep patterns might be particularly advantageous.

MISSING DATA—ACTIGRAPHY

Further refinement of the actigraph is under way. In a step toward refining the actigraph, Precision Control Design, Inc. (PCD – partners with WRAIR in the development of the wrist actigraph) recently devised a method for reliably distinguishing true actigraph-wearer-initiated arm movements from environmental movements (e.g., vibrations caused by being in a moving vehicle). This will, for the first time, allow reliable measurements of total sleep times from individuals who are in the sleeper berth of moving vehicles (a cause of lost data in this study). Instances when the user removes the actigraph can now be automatically detected and "time off the wrist" quantified. The next version of the actigraph will also include a light sensor. This sensor will be used to calculate the acrophase of the wearer's circadian rhythm of temperature/performance—an issue relevant to the Sleep Performance Model described in Chapter 3 of this report.

STUDY LIMITATIONS

Limitations of the Driver's Record of Duty Status (RODS)

As noted in the Results section, there were many instances in which actigraphically identified sleep periods occurred during RODS-identified times when sleep would not be expected to occur (e.g., on-duty driving). Most of these inconsistencies were small (less than 30

minutes). However, among short-haul drivers, short sleep periods (1 to 2 hours in duration) occurred during Type B time, indicating that short naps were taken, mainly during long (greater than 9 hours) Type B periods interspersed among the work shifts. This suggests that drivers are generally sensitive to their own sleepiness and are taking appropriate countermeasures (e.g., naps) to combat excessive sleepiness when it occurs. In other instances, actigraphically recorded sleep periods that started during off-duty time (as recorded in the RODS) extended well into on-duty time, even into on-duty time logged as driving time. This does not imply that drivers do not make a good-faith attempt to fill out driver logs—it may be that immediate on-the-job requirements preclude detailed attention to the RODS. In short, these data indicate that driver logs alone (or any subjective measure of sleep time and wake time) may be inaccurate/imprecise for a variety of reasons. Second, the data indicate that, to accurately quantify all sleep occurring across the entire day (which it could be argued is the most relevant factor), the entire 24-hour period must be considered rather than a predetermined portion of the record. For either of these reasons, the actigraph should provide a preferable alternative since it unnobtrusively provides a continuous, objective measure of daily sleep amounts and timing across several consecutive days or weeks.

Limitations of the Conventional Actigraph (Used in the Field Study)

As noted in the Results section, some driver data were excluded from analyses due to artifact (environmental interference) in the actigraph signal. Many of these actigraph records were from drivers who were sleeping in the truck sleeper berth while another driver operated the vehicle, raising the possibility that the source of this interference was movement of the vehicle itself. To date, studies that would establish the reliability and validity of wrist actigraphy for distiguishing sleep from wakefulness in a moving vehicle (i.e., concurrent actigraphic and polysomnographic measurements in a moving vehicle) have not been performed. Therefore, these results highlight a significant caveat to the interpretation of actigraphic measurements—as currently configured, the reliability of the actigraph is unknown in situations in which environmental noise is potentially within the same frequency range as wrist movements. As noted, refinements of the actigraph are under way that include new, enhanced methods for

distinguishing true wrist movements from environmentally generated movements. A further discussion of actigraphy is provided in **Appendix 6**.

Potential Source of Error 1—Crossing Time Zones

Two potential sources of error were uncovered during this study. The first concerned time zones. Some drivers' company work sites were in a time zone different from the time zone in which the driver resided. Rules regarding the time zone to which the actigraph should be set must be generated. These rules should be implemented consistently across drivers and days. Refinement of the actigraph embodies an ambient light sensor that can be used to determine a driver's light-exposure history. The light-history information, in turn, will be used as another input to the SPM to more accurately calculate the driver's circadian phase, regardless of time zone. This information will be especially important for improving SPM predictions for individuals working non-day or alternating shifts.

Potential Source of Error 2—Shifts To and From Daylight Savings Time

Another potential source of error concerns the shifts to and from Daylight Savings Time (DST). In this study, several drivers participated during shifts to or from DST. These shifts were reflected in the RODS by the driver advancing or delaying time recorded by 1 hour; however, the shifts were not reflected in the actigraph, which remained on the same time schedule. These times had to be identified and the actigraph data adjusted to match the RODS (note, however, that this was not the source of the errors illustrated in Figure 4-15). Future refinements to the actigraph can include a mechanism to allow the driver to update the actigraph to the new time when and where necessary.

E. SUMMARY—FIELD STUDY

Results of the Field study are summarized as follows:

1. On average, both short-haul and long-haul drivers obtained daily amounts of sleep that are within the normal limits for sustaining alertness.
2. Short-haul drivers obtained the bulk of their daily sleep during off-duty periods, with only short sleep bouts occurring during the work shift.
3. Long-haul drivers obtained nearly half of their daily total sleep interspersed between duty periods.
4. Sleep amounts varied substantially from day to day (up to 11 hours) among some long-haul and short-haul drivers. Other drivers maintained more consistent sleep/wake schedules.
5. Actigraphy was useful and well accepted for recording driver sleep across all duty-status categories.
6. Inconsistencies were found between actigraphically determined sleep/wake periods and available sleep/wake periods as defined by the RODS.

F. CONCLUSIONS—FIELD STUDY

The goal of the field study was to quantify the amount of time that short- and long-haul drivers spend sleeping under their current work/rest schedules.

Actigraphy provided a suitable means of measuring sleep/wake time of drivers. Importantly, the actigraph is unobtrusive, thus making it possible to record drivers continuously through on-duty and off-duty cycles.

Results indicate that, under present FMCSA regulations, drivers tend to self-regulate their daily sleep so that they obtain, on average, adequate amounts of sleep. The results also suggest that current FMCSA rules that stipulate off-duty time may need revision for several reasons: first, the finding that shorter off-duty periods coincided with less sleep suggests that the current minimum 8 hours off-duty is inadequate for recovery sleep. Drivers would need to sleep the

entire 8 hours off-duty to obtain optimum recovery. Second, the current regulations pertaining to off-duty time may have less direct benefit for long-haul drivers who split their sleep periods. These findings point toward regulations that stipulate a performance standard, as highlighted elsewhere in this report.

Some of the variability in drivers' daily sleep may be neither physiological nor behavioral (voluntary) in the usual sense but is likely due to route variations and the location of suitable rest stops. Thus, some variability is beyond control by regulations. However, some general guidelines for drivers may be indicated. For example, there should be no stigma associated with sleeping while on-duty, not driving. It might even be explicitly suggested that drivers take advantage of opportunities for napping, such as during loading/unloading times.

G. RECOMMENDATIONS—FIELD STUDY

Several general guidelines for revision of FMCSA regulations also are indicated.

First, based on the known performance-impairing effects of temporal desynchronization, the authors recommend a change from regulations allowing for anything different from a 24-hour day. For example, the 23-hour day (15/8 on/off-duty) currently allowed under FMCSA regulations would have cumulative, deleterious effects on performance. Likewise, a day that is longer than 24 hours will negatively impact performance.

Second, drivers likely use a substantial portion of their off-duty time to attend to personal business. Time off-duty must be of sufficient duration to allow drivers to accomplish these tasks and to obtain sufficient sleep. This may be particularly important for long-haul drivers, who often did not sleep at all during off-duty periods.

Future directions should include a more detailed investigation of those factors that prevent drivers from obtaining enough sleep. Although anecdotal evidence from this study suggested several possibilities (e.g., errands, family demands), future studies must address this question directly.

Finally, as already highlighted, the authors recommend further effort toward removing the stigma associated with sleeping while on-duty but not driving—for example, brief naps during loading or unloading time. Ultimately, a mechanism that rewards drivers for

implementing safe practices (such as obtaining sufficient daily sleep) will likely be most effective in this regard.

H. SUBTASK: INTERVIEW OF CMV PERSONNEL

Amount of Time Professional Drivers Spend Sleeping

The field study included an optional activity to interview no more than nine individuals regarding their opinion on the percentage of off-duty time a CMV drive spends sleeping. The results of this activity are summarized in **Appendix 7**.

5. GENERAL RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

This project was a two-part effort. First, a field study was performed to determine the relative amounts of actigraphically determined sleep obtained by long- and short-haul drivers over a 3-week period (see Chapter 4). Also, the relationship between sleep duration and performance was determined in a laboratory study in which time in bed (TIB) was 3, 5, 7, or 9 hours over 7 consecutive days (see Chapter 2). The latter study (i.e., the Sleep Dose/Response or SDR) was performed for the express purpose of *quantifying* the relative performance effects of inadequate sleep durations (i.e., resulting from the 3- and 5-hour TIB groups); a near-normal sleep duration (i.e., the 7-hour TIB group); and a mildly extended sleep duration (i.e., the 9-hour TIB group)—information needed for optimization of the parameters of the Walter Reed Sleep/Performance Model (SPM—see Chapter 3). The CMV drivers field study was required to provide objective information on the amount of sleep obtained by drivers operating under current U.S. hours of service (HOS) regulations. The SDR laboratory study was required to provide objective information on the effects of restricted sleep—which may occur under current HOS regulations—on performance. Taken together, results from both studies can contribute to the development of strategies to manage sleep and performance effectively in the operational environment.

A. FIELD STUDY: ACTIGRAPHIC ASSESSMENT OF CMV DRIVERS

In the CMV drivers field study (Chapter 4), it was found that both long- and short-haul drivers average approximately 7.5 hours of sleep per 24 hours, which is within normal limits for adults (e.g., Williams et al., 1974). However, the short-haul drivers tended to consolidate their daily sleep into a single, off-duty sleep period, whereas long-haul drivers obtained approximately half of their daily total sleep as daytime naps and/or during sleeper-berth time. This suggests that long-haul drivers may spend a significant portion of the work shift in a state of partial sleep deprivation—i.e., until the opportunity to obtain recovery sleep presents itself.

Although there was a clear relationship between number of off-duty hours and amount of time spent sleeping during those off-duty hours, the correlation was stronger for the short-haul than for the long-haul drivers. In both groups, however, there was no off-duty duration that

guaranteed an adequate sleep duration—one driver obtained no sleep during a 20-hour off-duty period. Likewise, large day-to-day variations in total sleep time were evident for drivers in both groups, with some individuals showing a pattern that suggests chronic partial sleep deprivation with intermittent bouts of extended recovery sleep.

The results of the CMV drivers field study suggest that rigorous work schedules can and do result in less-than-adequate daily sleep durations—which can, in turn, result in drivers operating with a significant sleep debt. However, less rigorous work schedules that provide the opportunity for adequate sleep during off-duty hours are not always used to maximum benefit. So, to the extent that improvement of driver alertness and performance (and thus safety) is the goal, efforts toward reducing CMV driver sleep debt should be addressed directly. Accordingly, in the SDR laboratory phase of this project, the focus was on quantification of the relationship between nighttime sleep duration and subsequent performance across 7 consecutive days.

B. LABORATORY STUDY: THE SLEEP DOSE/RESPONSE (SDR) STUDY

In the SDR laboratory study, it was found that the 3-, 5-, 7-, and 9-hour TIB (time in bed) groups averaged 2.87, 4.66, 6.28, and 7.93 hours of sleep, respectively, across the 7 experimental phase days and that group-related differences in subsequent daytime performance were evident for a variety of measures. Performance on the serial addition/subtraction test (a component of the Walter Reed Performance Assessment Battery [PAB]) was of particular interest because this was the measure upon which previous versions of the SPM (Sleep Performance Model) had been based. The plan, therefore, was to optimize the model parameters using data from the serial addition/subtraction test. This strategy would have allowed comparisons between the new SDR study-results-modified SPM and previous versions of the SPM.

However, contrary to expectations based on prior studies at the Walter Reed Army Institute of Research, asymptotic performance levels were not achieved on the serial addition/subtraction task prior to initiation of the experimental phase of the study. This occurred despite 3 days of training. In fact, continued "learning effects" were evident across the entire experiment for this task as well as for other measures, such as the 10-choice reaction time task (also see Chapter 2, **Figure 2-33**). From a modeling standpoint, this presented a problem because the extent to which between-group differences on performance were due to differential

sleep debt could not be separated from the common or between-group differences in learning. Any attempt to subtract the effects of learning would have required that highly speculative assumptions be made regarding the nature of possible sleep-loss-induced performance and learning effects and their possible interactions. This process would have reduced the overall specificity and validity of the model.

Therefore, it was decided that another measure would be chosen for the modeling effort—a measure less prone to potentially confounding learning effects. Because of their relevance to driving performance, several STISIM (Systems Technology, Inc., Simulator)-generated performance measures were considered. However, other aspects of the STISIM-generated data sets made them less than ideal for modeling. For example, "off-road accidents" and "crashes" were considered, but they occurred so infrequently and probabilistically (even in the 3-hour TIB group) that meaningful modeling of these data was precluded. (That is, these measures were too unstable to justify quantification). Likewise, measures related to speed and lane deviations were considered, but the interaction between sleep loss and "time on task" effects for these measures could not be handled by the SPM in its current form. (The STISIM results therefore suggest that "time on task" might profitably be added to the SPM as a variable that moderates performance).

Of the various performance measures available for modeling in the SDR study, the Psychomotor Vigilance Task (PVT) was deemed optimal for modeling since: (a) there were no apparent learning effects with this measure during the experimental phase of the study; (b) there was adequate separation in mean performance levels between the various groups (i.e., the measure was sensitive to the experimental manipulation); (c) although time-on-task effects might be evident during performance of the PVT (and account for some of its sensitivity to sleep loss), it is a short-duration task (10 minutes) for which time on task might be expected to account for a relatively small portion of the variance; and (d) the PVT has been previously validated with respect to sleep deprivation and performance test outcomes.

C. RATIONALE FOR MODELING PSYCHOMOTOR VIGILANCE TASK (PVT) PERFORMANCE IN THE WALTER REED SLEEP PERFORMANCE MODEL (SPM)

As indicated in Chapter 1, and demonstrated in the results listed in Chapter 2, performance measures vary in terms of their sensitivity to the effects of sleep loss. This may reflect, at least in part, the extent to which performance of each unique task is mediated by a unique combination of brain regions that are themselves differentially affected by sleep loss. The SPM predicts performance capacity based on the combined effects of circadian rhythm and sleep debt (with the latter value based on amount of sleep obtained over the past few days, time elapsed since the last sleep period, and the predicted recuperative value of the last sleep period as a function of its continuity).

There are therefore two approaches that can be taken when modeling the effects of sleep loss on performance. The first and most straightforward approach is to model the effects of sleep loss directly on the performance measure of interest—e.g., accident rate. This approach is desirable since validation of the model might be less problematic (although generalization to the operational environment would be an important issue to address if the model parameters were based on simulator data), and the model output would be easily and widely understood by the user community. However, if accident rates are too low to model directly (as in this study), then the next most desirable dependent variable to use in the model would be one that correlates well with accident rate—that is, the measure that best indicates an increased *likelihood* of accidents. Use of a measure like this is desirable since it can increase the predictive value of the model. Lane deviations may increase in a reliable and predictable manner with increasing levels of sleep debt, allowing identification of trends, which suggest impending performance failure well in advance of the actual failure (thus increasing the opportunity to implement effective countermeasures in a timely manner). From a regulatory standpoint, however, the issue becomes "*how much* lane deviation is indicative of *significantly* increased risk of accidents?" There is no clear-cut (or scientific) way to answer this question—ultimately, the level of risk (performance deterioration) deemed acceptable is a nonscientific judgment.

The second approach—and the approach that has been adopted by the Walter Reed Army Institute of Research in developing the SPM—is to identify and model the performance measure that is: (a) most sensitive; (b) has a relatively large dynamic range; and (c) is also practical for

field testing—regardless of the nature of the performance measure itself. Using the most sensitive measure available allows construction of a performance decrement scale that is maximally sensitive—although the relevance of the scale to performance measures of interest (e.g., the ability to acquire and accurately fire upon an appropriate military target) may not be immediately apparent to the users. Rather, it is anticipated that the meaningfulness of the performance decrement scale will either (a) emerge for the user as the model (integrated into the Sleep Watch) is used in the operational environment; or (b) studies will be conducted to determine the meaningfulness of the scale with respect to specific aspects of military, transportation, or other types of operationally relevant performance.

The logic behind the latter approach requires some explanation. In essence, choosing the most sensitive performance measure, modeling that measure, and constructing a performance scale based on that measure means that the chosen measure serves as a "probe" of general performance capacity—and that the validity of the model in the operational environment depends on the degree to which performance on the chosen measure correlates with performance on the specific tasks of interest in the operational environment. Thus, it would be expected that the model would better predict the ability of a tank commander to acquire a target or a driver to follow a map (cognitively loaded tasks requiring vigilance and judgment) than more physically loaded tasks such as carrying ammunition or unloading freight (tasks requiring muscular strength and endurance). Performance of the cognitively loaded tasks would be expected to be relatively sensitive to the effects of sleep loss [with, for example, a just-noticeable-difference (JND) in target acquisition or map-reading performance corresponding to, say, a three-point excursion on the PVT-based performance scale used in the model], whereas performance on the physically loaded tasks would be expected to be relatively insensitive [for example, a 45-point excursion on the scale might correspond to a JND in freight unloading performance]. In either case, however, the potential usefulness of the scale is dependent on its relatively greater sensitivity to sleep loss than upon the measure of interest[1].

[1] As an analogy, modeling the measure most sensitive to sleep loss is like choosing a yardstick that shows each millimeter rather than a yardstick that is accurate only to the nearest centimeter, inch, or foot. The yardstick that is accurate to the nearest millimeter will be useful and appropriate for measuring any lengths that could have been measured by the other, less precise yardsticks—but the opposite is not the case. If accuracy to the nearest 3 mm is needed, only the yardstick with the millimeter gradations would suffice.

Importantly, at the very least, the SPM will be useful for allowing commanders to compare the likely relative effectiveness of one soldier, squad, or unit versus another. Likewise, dispatchers will be able to use the SPM to determine the relative effectiveness of drivers and optimize driving schedules accordingly. The question of thresholds (i.e., what predicted performance value represents an "unacceptable" level of performance) is less relevant in this context since performance in the operational environment is driven by, for example, the battlefield, delivery schedule, or other operational exigencies. (That is, in the operational environment, the most relevant question to be answered will often be "which squad is best prepared to execute this critical mission?" or "which of the available drivers is best able to deliver this load safely?" rather than "is the squad's (or driver's) predicted performance at a level that indicates an acceptable likelihood of success?" This is because determination of the threshold separating "acceptable" from "unacceptable" performance capacity within a specific operational context represents, to some extent, an arbitrary judgment. It is likely that if a threshold specifying the boundary between acceptable and unacceptable SPM-predicted performance capacity is established (for example, for CMV drivers), this threshold will not emerge as a result of a laboratory study. Rather, it is likely to accrue from collective, real-world, operational experience with the SPM, which will provide the data needed to determine the relationship between the SPM performance capacity index scores and the likelihood of real accidents.

D. REFINEMENTS OF THE SPM

As indicated in Chapter 1, performance of a particular task—especially a task requiring vigilance and/or higher-order cognitive processing—is largely a function of sleep debt and circadian phase. However, performance can be affected by other variables, including environmental stimulation (which can either enhance performance by increasing general alertness level or decrement performance if it serves to distract from the task at hand) and/or fluctuations in motivation. The latter may explain the "end spurt" effects that were evident in, for example, the serial addition/subtraction results. In Chapter 2, **Figure 2-15**, it can be seen that serial addition/subtraction performance improved during the recovery sleep phase of the SDR study for all groups. This included the 9-hour TIB group, despite the fact that the recovery phase

actually entailed a reduction of TIB for this group (from 9 to 8 hours). The reasons for this improvement are not clear, although it is hypothesized to have been at least partly due to enhanced mood resulting from the knowledge that the experimental phase of the study had been completed and the last leg of this 14.5-day residential study had been initiated.

Thus, the performance prediction provided by the SPM can be considered to represent an average level of performance for a given level of sleep debt and time of day, but other variables will also impact actual performance. The SPM prediction helps define the level and range of performance capacity, but it is recognized that actual performance within the range implied by the SPM prediction depends on the presence/absence of other variables as well—and that the accuracy of the model will improve as these variables are identified and incorporated. (For example, as indicated, a subroutine describing the moderating effects of "time on task" on performance might profitably be added to the SPM, although this might be a very "task-specific" effect.)

E. IMPLICATIONS FOR PERFORMANCE IN THE OPERATIONAL ENVIRONMENT

The primary purpose of the SDR study was to quantify the effects on performance of four TIB durations over 7 consecutive nights—information needed to optimize the accuracy of the SPM. The study was successful in this respect, and it is anticipated that the SPM, as implemented in the Sleep Watch Actrigraph (SWA), will soon constitute a valuable tool for management of work schedules in the operational environment (i.e., improving both productivity and safety through optimization of sleep and alertness).

This study also produced results that have more direct implications for management of sleep and performance in the operational environment. First, it was found that optimal (i.e., similar to baseline) performance was generally maintained across the 7 experimental days in the 9-hour group. This was not surprising since TIB durations were actually increased 1 hour relative to the 8-hour TIB during the 3 baseline nights. And, as expected, it was generally found that mean group performance across the 7 experimental days varied (was decremented) as a function of reduced TIBs. However, of particular interest was the finding that performance in the 7-hour group was consistently reduced across the 7 experimental nights relative to the 9-hour group. The mean nightly total sleep time (TST) during the experimental phase for the 7-hour

group was 6.28 hours, and, for the 9-hour group, was 7.93 hours. The nightly means did not vary significantly across the 7 experimental nights. [Thus, the efficiency with which TIB was used for sleep was consistent across nights and comparable for both groups (89.7 percent and 88.1 percent of TIB were spent asleep in the 7-hour and 9-hour groups, respectively)]. This indicates that even a relatively minor reduction (approximately 1.5 hours) in total nighttime sleep results in measurable decrements in next-day performance. Importantly, it further suggests that these decrements are maintained for as long as the reduced TST is maintained, with no evidence of a meaningful, adaptive, compensatory increase in sleep efficiency (which, if it occurred, would be expected to at least partially offset the next-day performance deficits).

Another finding with implications for management of sleep and performance in the operational environment is that, even after 3 nights of recovery sleep (i.e., nights with 8 hours in bed) performance (e.g., number of lapses recorded on the PVT) improved but failed to return to baseline levels—especially in the 3-hour group. This suggests that 3 consecutive nights of 8 hours in bed are not sufficient to recover fully from chronic, severe sleep restriction. It is possible that recovery would have been complete within the 3-day recovery period if the participants had been permitted to extend their nightly recovery sleep durations beyond 8 hours per night. However, the finding indicates that recovery from *substantial* sleep debt probably requires extended recovery sleep—and that when recovery sleep is restricted to 8 hours (a sleep duration that is within normal limits for adults), the extra sleep debt is not fully retired, even after 3 nights. This suggests that the extant level of daytime alertness and performance capacity is a function not only of an individual's circadian rhythm, time since the last sleep period, and duration of the last sleep period, but it is also a function of his/her sleep history, extending back for at least several days.

Of both theoretical and practical interest to the trucking industry is that the nature of sleep-restriction-induced performance deficits was investigated during simulated driving. It was found that only a small percentage of "accidents" were closely associated with a visually identifiable, EEG-defined lapse in alertness. Most accidents occurred during what appeared to be normal, EEG-defined wakefulness. Furthermore, the finding that performance was decremented on a secondary task (i.e., responding to a signal that was randomly and infrequently presented in the visual periphery during the driving simulator task) is consistent with the hypothesis that sleepiness results in a narrowing of the focus of attention. If these

findings generalize to actual driving situations, one implication is that sleepiness-induced accidents will most often occur in the absence of overt, EEG-defined lapses in alertness. Therefore, on-line alertness monitoring that detect only signs of sleep onset may be of limited usefulness, compared, for example, to systems which employ embedded driving performance measures.

F. FUTURE DIRECTIONS: THE SLEEP WATCH ACTIGRAPH (SWA) AS A COMPONENT OF A COMPREHENSIVE SLEEP/PERFORMANCE MANAGEMENT SYSTEM

An effective sleep management system to optimize performance in the transportation industry might, at this point, include: (a) a device to measure sleep in the operational setting and predict in real time the effect of the individual's cumulative sleep/wake history on his/her present and future performance (e.g., the Sleep Watch Actigraph [SWA]); (b) an online, real-time alertness and performance monitor (e.g., the Percent Eye Closure Alertness Monitor [PERCLOS]); and (c) software that takes input from the SWA and the on-line monitor and generates dynamic, on-the-fly scheduling of work/rest cycles across multiple days, operators, loads, and routes.

Viewed as an item of logistic resupply (the biological analog of diesel fuel and preventive maintenance for trucks), sleep cannot be managed effectively to sustain performance unless it can be measured. To plan when (and how much) is needed for resupply, one must know how much is on hand and be able to estimate how long the current supply will last. In addition, continuous updates of current supplies and rate of consumption improve the accuracy of estimated needs.

The SWA (see **Figure 5-1)** can be thought of as a fuel-gauge-like device that provides information on the wearer's current level of sleep debt, current circadian rhythm phase, and (through the imbedded Sleep Performance Model) the resulting implication of this information for performance. It currently contains a central processing unit, random access memory, and an accelerometer. Every minute, the SWA records whether and how much movement activity has occurred. If acceleration of the wrist changes, the accelerometer generates a small electrical

Figure 5-1. The Sleep Watch Actigraph (SWA) showing fuel-gauge-type current performance capacity read-out.

current. If the electric current exceeds a certain threshold, it is recorded as a "1"—otherwise it is recorded as a "0." The "1" or "0" is stored in the device. In this way, activity is recorded in 1-minute intervals continuously over hours and days. Built into the SWA is a sleep-scoring algorithm that takes the minute-by-minute activity score and determines if the wearer is awake or asleep. Also built into the SWA is the Sleep Performance Model (SPM) (described in detail in Chapter 3). The SPM takes the output of the sleep-scoring algorithm (the wearer's sleep/wake history) and uses this information to predict changes in performance in real time. The SPM includes a charging function for recuperation during sleep (with a 5-minute "delay of recuperation" function that is implemented after each arousal or awakening, to account for the reduced recuperative value of fragmented sleep), a discharging function that represents a linear decline in performance while awake, and a circadian rhythm modulating function with the acrophase (highest point of the circadian rhythm) occurring at 2000 hours. The SWA device has a display that includes both an analog and digital "fuel gauge" that indicate the current SPM performance prediction. The analog gauge is an LED meter that is color-coded in green, yellow, and red. The digital gauge displays the wearer's performance prediction as a percent of 100. The SWA device also includes a light sensor. Light is the primary determinant of circadian rhythm acrophase (i.e., peak). The future SWA will include a function that will adjust the circadian rhythm for time-zone changes based on actual history of bright light exposure.

Currently, although the SPM keeps track of each individual wearer's sleep/wake history, it is "one size fits all" with respect to the effect of any given amount of sleep on subsequent

performance. In the future, through the use of embedded alertness and performance measures (e.g., PERCLOS), an individual wearer's SPM could be made to adjust itself in a manner that accurately predicts the effects of sleep/sleep loss for each individual's performance.

Optimal utility of the SPM will most likely be realized in the context of a program of sound education and safety-promoting operational practices and as a component of a comprehensive sleep/performance management system in which physiological data and operationally relevant performance data are monitored and integrated. The latter would allow: (a) performance data feedback to the SPM so that the model parameters could be optimized to the individual on an ongoing basis; and (b) better-informed decision making regarding the likelihood of impending performance failure or the need for countermeasures. For example, if an embedded performance measure such as "lane deviation" suggests ambiguous driving performance—not yet clearly impaired but perhaps heading in that direction—the SPM output (which is based on sleep debt and circadian phase) could provide the appropriate context for interpretation. If the driver obtained adequate sleep on the prior night and ambiguous performance is occurring during the expected circadian dip in afternoon performance, it might accurately be predicted that performance will recover to the unambiguously normal range over the next few hours without initiating countermeasures. However, if ambiguous performance is detected following a less-than-adequate night of sleep, and at a time of day when it would be expected that performance would continue to deteriorate due to the moderating effect of circadian rhythms, then the advisability of implementing countermeasures would be clear. For the trucking industry, an integrated sleep management system might also include the development of scheduling software to optimize individual driver performance, well being, and aggregate productivity across days, drivers, and loads.

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APPENDIX 1: PHASE II STUDY CRITERIA AND RECRUITMENT FORMS

GENERAL OVERVIEW

In the following sections, subject acceptance and disqualification criteria are given. In addition, screening tools used in this decision-making process are provided. Criteria as well as screening tools used are those used previously in sleep and sleep deprivation studies at Walter Reed Army Institute of Research. In particular, the screening tools were chosen to exclude individuals who may have psychiatric disorders (diagnosed or undiagnosed) that are known to affect sleep in any way.

SUBJECT ACCEPTANCE AND REJECTION CRITERIA

Diagnostic Criteria for Entry

Subjects were in good general health as determined by history, physical examination, and laboratory work. Subjects were HIV negative and hepatitis-B negative (acute state). Due to potential hormonal influences of pregnancy on sleep, performance, and mood in women, a serum pregnancy test performed upon arrival for the study must have been negative. Subjects were evaluated for history of physical disorder, including (but not restricted to): infectious disease, cardiovascular disease, hypertension, respiratory disease, asthma, renal disease, gastrointestinal disease, allergies and immunological dysfunction, hematological disorders, cancer, endocrine and metabolic disorders, dermatological disorders, adverse drug reactions, narrow-angle glaucoma, and prostate enlargement. Subjects were evaluated for a history of drug and alcohol abuse. Depending on the severity of past conditions and possible continuation into the present, subjects may have been excluded from the study at the discretion of the examining physician or physician's assistant. Subjects did not have a history of neurological disease or mental disorder, including anxiety disorder, panic disorder, depression, epilepsy, clinically significant head injury, or sleep disorder (narcolepsy, sleep apnea, nocturnal myoclonus,

and other disorders of the sleep/wake cycle). Subjects did not use nicotine in any form and were no more than moderate caffeine users (i.e., consume no more than an average of 300 – 400 mg caffeine per day—roughly equivalent to 3 to 4 cups of coffee a day). Subjects were medication-free (to include over-the-counter medications such as analgesics, cold/hay fever preparations, as well as prescription drugs) starting 48 hours prior to the study. An exception was that women were allowed to use oral or implanted birth-control medications. Subjects were asked to abstain from caffeine or alcohol use for 72 hours prior to the beginning of the study (verified by urine drug screening during study conduct). Subjects had visual acuity corrected to 20/40 or better and normal color vision.

Exclusion Criteria

Subjects were excluded if they had a history or current condition of any disorders listed above if considered exclusionary by the examining physician or physician's assistant. Also, subjects were excluded if they had a resting blood pressure greater than 140/90 (on two occasions); cardiac enlargement or heart murmur (other than functional murmur); clinically significant abnormal EKG; hepatomegaly; clinically significant abnormal urinalysis (as determined by the reviewing physician); clinically significant abnormal results on blood tests (as determined by the reviewing physician); corrected visual acuity worse than 20/40; presence of alcohol, nicotine, or drugs in the urine as determined by urine drug screen; abnormalities in renal or liver function; history of seizure disorder or any neurological disorder or damage; a history of in-patient psychiatric therapy, depression, anxiety, and/or panic disorder; current use of benzodiazepine compounds, major tranquilizers, or antidepressant drugs; caffeine use in excess of 400 mg per day on average; chronic sleep disorder; and reported use of any drug which, based on its known pharmacokinetic profile, would not have been cleared from the body within 48 hours prior to participation (determined on a case-by-case basis depending on type of drug and when used). Because one of the computerized cognitive tests required color vision, subjects who were color blind were excluded.

Driver Demographics Questionnaire

Name: _____ Date: _____

1. I drive a: _____ Conventional _____ Cabover _____ Single-Unit

   _____ Bus _____ Inner-city Motor Coach _____ Other

2. Sleeper berth equipped? _____ Yes _____ No _____ Not Applicable

3. Trailers hauled: Length _____ ft.

   Type: _____ Dry Van _____ Reefer _____ Tanker _____ Flatbed

   _____ Belly or End-dump _____ Autohauler

   Other: _____

4. Do you drive multiple-trailer combos? _____ Yes _____ No

   If yes: _____ 28 ft.
   _____ Other doubles
   _____ triples

5. Do you drive: _____ Alone _____ Team

6. Truck driving school graduate? _____ Yes _____ No

7. Straight truck experience? _____ Yes _____ No

8. Experience driving tractor/trailers: _____ Yes _____ No

9. Time with current carrier: _____ (years/months)

10. How many nights do you spend away from home per month? _____

11. How many hours of sleep do you usually get during off-duty hours? _____

Sleep Dose Response Study - PI Gregory Belenky, MD
GCRC-JHBMC In-Patient Registration Information

Date of Participation:_____

Patient Name: _____

Patient SSN: _____

Date of Birth: _____

Age: _____

Sex: _____

Race: _____

Marital Status: _____

Patient Address: _____
Street

_____
City State ZIP

Patient Phone Number: (_____)_____

Name of Emergency Contact: _____

Relation to Patient: _____

Contact Home Phone Number: (_____)_____

Mother's Full Maiden Name: _____

Father's Name: _____

Form C (Revised 6/96)

CLINICAL INVESTIGATION CONSENT FORM

The Johns Hopkins Medical Institutions
(The Johns Hopkins Hospital
The Johns Hopkins Bayview Medical Center, etc.)
Date: 17 October 1996 RPN NO: HBV95-10-19-01
Title of Research Project: Effects of Work/Sleep Schedules on Performance

Patient I.D. Plate

Explanation of Research Project to Subject:

Purpose Of Study: Your participation is requested in a study to determine the effects of various work/sleep schedules on performance, particularly driving performance. While the effects of total sleep loss (no sleep in each 24-hour day) have been studied extensively, the effect of partial sleep loss (less than the usual 8 hours of sleep per 24-hour day) on performance--particularly driving performance--has not been studied. This is needed to help determine safe schedules for commercial motor vehicle drivers and other personnel involved in potentially hazardous occupations.

Procedures: You stay in the research center (GCRC) at the Johns Hopkins Bayview Medical Center in Baltimore for 15 days/14 nights. The 15-day study consists of 3 phases. The first phase, beginning on the first study day, is the **normal sleep phase** consisting of 3 consecutive days during which 8 hours of sleep are obtained each night. The second phase is the **altered sleep schedule phase**, where 9, 7, 5, or 3 hours of sleep are obtained on each of the next 7 nights. There is an equal likelihood (i.e., a 1-in-4 chance) of being assigned to any one of the altered sleep conditions. The altered sleep condition that is used in each of the 15-day study sessions is predetermined; however, you will not be told the condition that will be used for the study session you choose until Day 1 of the study. The third phase is the **recovery sleep phase** consisting of 4 consecutive nights during which 8 hours of sleep is allowed. At the beginning of the study, electrodes are pasted on your scalp, face, and chest for recording brain waves (EEG), eye movements (EOG), muscle tension (EMG), and heart rate (EKG). These remain on for the entire study and are checked periodically to see if they need to be re-attached. Wires from the electrodes go to a Walkman-sized tape recorder that you keep on you while awake and beside you while asleep. You wear on your non-dominant wrist a watch-like activity recorder. When you are awake, you are mostly working on a 3 hour cycle. Each cycle includes measurement of vital signs (blood pressure, heart rate, and temperature), taking a vision and eyeblink test, and computer-based performance tests which involve mental arithmetic, short-term memory, attention, time perception, logical reasoning, and reaction time. Also included is a test where performance on 4 simultaneous tasks is measured; as well as performance on a computer-based driving simulator. Several questionnaires to gauge your mood, sleepiness, and other subjective feelings are also administered. Each day you take tests to determine how quickly you fall asleep. Daily you take a test with a partner to solve a problem. At times during the study you provide a urine sample to screen for alcohol, nicotine, caffeine, and other drugs. To learn if getting different amounts of sleep can affect immune function (the ability to protect oneself from infection), a skin test is performed. It is similar to the TB skin tests commonly used, but uses several different substances. Little prongs are pressed into the skin, and skin responses are read later. On the morning of the 15th day, electrodes are removed, you are asked to give us feedback about the study and your feelings about having participated, and then you are released.

Risks And Discomforts: No serious effects are expected from any of the altered sleep schedules, nor any other aspect of the study. In prior studies, volunteer subjects were deprived of sleep to the same or greater degree without serious or lasting effects. The 4 full nights of recovery sleep before you are released will result in complete recuperation from any sleep loss effects. Risks of the skin test are minor. It has been used in thousands of people without major side effects. A small reaction similar to a mosquito bite may appear a few minutes after application, but this usually disappears rapidly, leaving no scar tissue. However, highly sensitive people may get a small blister with minor pain and drainage. Ice or corticosteroids can be applied to relieve this reaction. A slight discoloration of the skin can sometimes last for several weeks, but usually disappears completely. Other discomforts in the study include itch and skin irritation from the electrodes and boredom from the sameness and repetition of the testing schedule. A staff member will be with you at all times except when you are in the bathroom. A staff member will be awake and nearby while you are sleeping. A physician will supervise any study-related medical procedures and will be on call throughout the study.

Benefits: Participation in this study will result in no direct benefit to you, but data collected in the study may ultimately impact upon public safety if it is used to generate changes in work/rest schedules that improve the alertness and performance of commercial motor vehicle operators. Volunteers are authorized by the United States Army for all necessary medical care for injury or disease which is the proximate result of their participation in this study.

Alternatives To Participation: You may or may not choose to participate in the study without consequence.

THIS CONSENT FORM CONTINUES ON THE NEXT PAGE

Date: 10/17/96
Title: Effects of Work/Sleep Schedules on Performance
PI : Jonelle E. Wright, PhD RPN NO: HBV95-10-19-01

If you sign this form, you are willing to join the research project described to you on the other side of this page. Your doctors, or the investigators, did explain the other kinds of treatment that are available to you and to others. You should ask the principal investigator listed below any questions you may have about this research study. You may ask him/her questions in the future if you do not understand something that is being done. The investigators (or doctors) will share with you any new findings that may develop while you are participating in this study.

The records from this research study will be kept confidential and will not be given to anyone who is not helping on this study, unless you agree to have the records given out. If the study uses a new drug or device that is under the jurisdiction of the Food and Drug Administration (FDA), the FDA government officials may look at the relevant part of your medical records as part of their job to review new drug and device studies.

If you want to talk to anyone about this research study because you think you have not been treated fairly, or think you have been hurt by joining the study, or you have any other questions about the study, you should call the principal investigator, Dr. Jonelle E. Wright, at (410)550-1850; or call the Office of the Joint Committee on Clinical Investigation at (410)955-3008 or call The Johns Hopkins Bayview Medical Center Institutional Review Board for Human Research at (410)550-1853. Either the investigator or the people in the Committee office or IRB office will answer your questions and/or help you to find medical care for an injury you feel you have suffered. The Johns Hopkins University, The Johns Hopkins Hospital, The Johns Hopkins Bayview Medical Center, Walter Reed Army Institute of Research, and the Federal Government do not have any program to provide compensation to you if you experience injury or other bad effects which are not the fault of the investigators.

You may withdraw from the research study at any time. Even if you do not want to join the study, or if you withdraw from it, you will still have the same quality of medical care available to you at The Johns Hopkins or The Johns Hopkins Bayview Medical Center.

If you agree to join this study, please sign your name below.

NOT VALID WITHOUT THE COMMITTEE OR IRB STAMP OF CERTIFICATION

VOID ONE YEAR FROM ABOVE DATE
RPN NO. HBV95-10-19-01
Form C (Revised 6/96)

Subject's signature Date

Signature of Parent or Guardian (when applicable) Date

Signature of Investigator or Approved Designee Date

Witness to Consent Procedures * Date

* Optional unless subject is illiterate, or unable to sign.

NOTE: Signed copies of this consent form **must** be a) retained on file by the Principal Investigator; b) deposited in the patient's medical record; and c) given to the patient.

VOLUNTEER REGISTRY DATA SHEET

THIS FORM IS AFFECTED BY THE PRIVACY ACT OF 1974

1. **AUTHORITY: 5 USC 301; 10 USC 1071-1090; 44 USC 3101; EO 9397**

2. **Principal and Routine Purposes: To document participation in research conducted or sponsored by the U.S. Army Medical Research and Materiel Command. Personal information will be used for identification and location of participants.**

3. **Mandatory or Voluntary Disclosure: The furnishing of the SSN is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide information may preclude your participation in the research study.**

PART A - INVESTIGATOR INFORMATION

(To Be Completed By Investigator)

PLEASE PRINT, USING INK OR BALLPOINT PEN

1. **Study Number:**_____ 2. **Protocol Title:**

3. **Contractor (Laboratory / Institute Conducting Study):**

4. **Study Period: From:** ____/____/____ **To:** ____/____/____
DD MM YY DD MM YY

5. **Principal / Other Investigator(s) Names(s):** 6. **Location / Laboratory**

1. _____ _____/_____
2. _____ _____/_____
3. _____ _____/_____

PART B - VOLUNTEER INFORMATION

(To Be Completed By Volunteer)

PLEASE PRINT, USING INK OR BALLPOINT PEN

7. **SSN:** _____/_____/_____ 8. **Name:** _____

9. **Sex: M**____**F**____ 10. **Date of Birth:** _____/_____/_____ 11: ***MOS/Job Series**_____ 12: **Rank/Grade** _____

13. **Permanent Home Address (Home of Record) or Study Location:**

_____ _____
(Street) **(P.O. Box / Apartment Number)**

_____ _____ _____
(City) **(Country)** **(State)** **(Zip Code)**

Permanent Home Phone Number: _____

14. * **Local Address (If Different From Permanent Address):**

_____ _____
(Street) **(P.O. Box / Apartment Number)**

_____ _____ _____
(City) **(Country)** **(State)** **(Zip Code)**

Local Phone Number: _____

15. * **Military Unit:** _____ **Zip Code:** _____

Organization: _____ **Post:** _____ **Duty Phone Number:** _____

USAMRDC Form 60-R Revised 1 Apr 88 (Supersedes previous editions)

PART C - ADDITIONAL INFORMATION

PART C-ADDITIONAL INFORMATION

(To Be Completed By Investigator)

PLEASE PRINT, USING INK OR BALLPOINT PEN

16. Location of Study:

17. Is Study Completed: Y___ N___

Did volunteer finish participation: Y___ N___ If YES, Date finished: ___/___/___ *(DA/MO/YR)*

If NO, Date withdrawn: ___/___/___ *(DA/MO/YR)* Reason withdrawn:

18. Did Any Serious or Unexpected Adverse Incident or Reaction Occur: Y___N___ If YES, Explain:

19.*Volunteer Followup: _____

Purpose: _____

Date: ___/___/___ *(DA/MO/YR)* Was contact made: Y___N___ If No action taken, explain:

20.*Hard Copy Records Retired: Place: _____ File NR: _____

21.*Product Information:

Product: _____

Manufacturer: _____

Lot NR: _____ Expiration Date: _____

NDA NR: _____ IND/IDE NR: _____

*Indicates that item may be left blank if information is unavailable or does not apply.
Entries must be made for all other items.

Revised 01/97
Previous versions obsolete

VOLUNTEER AGREEMENT AFFIDAVIT

For use of this form, see AR 70-25 or AR 40-38; the proponent agency is OTSG.

PRIVACY ACT OF 1974

Authority: 10 USC 3013, 44 USC 3101, and 10 USC 1071-1087

Principal Purpose: To document voluntary participation in the Clinical Investigation and Research Program. SSN and home address will be used for identification and locating purposes.

Routine Uses: The SSN and home address will be used for identification and locating purposes. Information derived from the study will be used to document the study; implementation of medical programs; adjudication of claims; and for the mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.

Disclosure: The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this investigational study.

PART A VOLUNTEER AFFIDAVIT

Volunteer Subjects in Approved Department of the Army Research Studies

Volunteers under the provisions of AR 40-38 and AR 70-25 are authorized all necessary medical care for injury or disease which is the proximate result of their participation in such studies.

I,_____, SSN _____, having full capacity to consent and having attained my _____ birthday, do hereby volunteer to participate in:

Effects of Work/Rest Schedules on Driver Performance
(Research study)

under the direction of: **Gregory L. Belenky, M.D., COL MC**
conducted at: **Dept. of Behavioral Biology, Division of Neuropsychiatry, Walter Reed Army Institute of Research, Washington, DC 20307-5100 phone: (301) ~~427-5521~~ 295-7826**
(Name of Institution)

The implications of my voluntary participation; duration and purpose of the research study; the methods and means by which it is to be conducted; and the inconveniences and hazards that may reasonably be expected have been explained to me by:

Gregory L. Belenky, M.D. or qualified representative

I have been given an opportunity to ask questions concerning this investigational study. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or study-related injury, I may contact:

at: **Command Judge Advocate, U.S. Army Medical Research and Materiel Command**
Fort Detrick, Frederick, MD 21702-5012 (301)619-2065; DSN 343-2065
(Name, Address and Phone number include Area Code)

I understand that I may at any time during the course of the study revoke my consent and withdraw from the study without further penalty or loss of benefits; however I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of the attending physician, such examinations are necessary for my health and well-being. My refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled.

SUBJECT INITIALS/DATE_____ **WITNESS INITIALS/DATE**_____

SUBSTITUTE DA FORM 5305-R, FOR THOSE VOLUNTEERING FOR THEMSELVES ONLY, FEB 92

EFFECTS OF WORK/REST SCHEDULES ON DRIVER PERFORMANCE

PART B TO BE COMPLETED BY INVESTIGATOR

INSTRUCTIONS FOR ELEMENTS OF INFORMED CONSENT: *(Provide a detailed explanation in accordance with Appendix C, AR 40-38 or AR 70-25.)*

You are asked to volunteer for a 15-day research study examining the effects of different amounts of sleep on performance. After you read the following description of what will happen, we will discuss the entire procedure. Ask questions about anything that is unclear. It is important that you understand that:

a. **Your participation is completely voluntary**, and that you may withdraw from the study at any time without penalty or loss of benefits to which you are otherwise entitled,
b. The results of this study may be of no direct benefit to you, but knowledge gained by your participation may help others.

Information on monetary compensation for this study is found further below, in the section entitled "PAYMENT."

PROCEDURE

You must be between 21 and 65 years of age to be considered for participation. You must hold a valid driver's license, and you must have normal vision corrected to 20/40 or better. You must have normal color vision. Also, we must ensure that you are in good health. You will fill out some forms to gather background information, and then you will have a physical examination. This includes tests on your urine and blood. A small sample of blood will be drawn today. The blood tests include a hepatitis B screen, and a test for HIV antibody (the AIDS virus). You must test negative for both hepatitis B and for HIV antibody. If abnormal results are found on any test, you will be contacted by a medical doctor who will discuss the test results with you. Every effort will be made to keep the results as confidential as possible, within the limits of the law.

You may not eat or drink anything with alcohol or caffeine starting 48 hours before you arrive for the study, or during the study. You may not take illegal drugs, over-the-counter drugs (for example, cold medicines), or prescription drugs within a certain time before the study, or during the study. This time will be different for each drug, so for your own safety, you must tell the person doing your physical exam today what drugs you have taken within the last month, whether legal or illegal, over-the-counter or prescription. Use of drugs (legal or illegal) will not necessarily exclude you from the present study, since the information you provide will be used only to determine whether these substances may still be in your body. You may not use tobacco or nicotine products (cigarettes, cigars, pipes, chewing tobacco, etc.,) before or during the study. You will be asked to give a urine sample at different times during the study so that we can determine whether you are free of alcohol, nicotine, drugs, etc. One exception is that women should continue to use prescription contraceptives (birth control in the form of pills, injections, or implants) during the course of the study. Let us know today whether you are using any type of prescription contraceptives.

So that we can verify your sleep schedule, you must first come to the laboratory, and an activity recorder (wrist actigraph) will be placed on your non-dominant wrist. You must wear the recorder for seven nights prior to the start of the study. The recorder is about the size of a wrist watch. You must wear the recorder at all times except when taking a shower or bath.

If you comply with wearing the actigraph and drug/alcohol/caffeine restrictions, you will be eligible to participate in the next phase of the study. For this phase, you must report to the laboratory no later than 08:00 a.m. on the first day (Day 1) of the study (usually a Saturday). Your wrist actigraph will be removed and you will be given another one to wear for the next 14 days. Study procedures will be reviewed with you, then weight, height and "vitals" (blood pressure, heart rate and temperature) will be recorded. You will be asked to provide a urine sample for urine drug screening. If you are a woman, a small sample of blood also will be drawn to conduct a serum pregnancy test. Because hormonal fluctuations during pregnancy may affect your sleep, performance, and/or mood, the serum pregnancy test must indicate that you are not pregnant. If you are found to be pregnant, you will be excluded from participation, but will receive compensation as outlined below in the section entitled, "PAYMENT." Next, some sensors or "electrodes" will be placed on your scalp and facial areas using gauze pads soaked in a sticky substance. Chest electrodes will be placed using sticky patches. The electrodes allow us to determine whether you are awake or asleep. The electrodes are not painful in any way, but they may feel uncomfortable at times. You will wear these electrodes for the duration of the study. Wires from the electrodes go to a portable tape recorder that you wear on a belt during the entire study. After electrodes are put on, you will be transported to the General Clinical Research Center (GCRC) of Johns Hopkins Bayview in Baltimore, Maryland. You will remain at GCRC for the next 14 days.

SUBJECT INITIALS/DATE_____ **WITNESS INITIALS/DATE**_____

SUBSTITUTE DA FORM 5305-R, FOR THOSE VOLUNTEERING FOR THEMSELVES ONLY, FEB 92

EFFECTS OF WORK/REST SCHEDULES ON DRIVER PERFORMANCE

After arrival at GCRC, you will practice some tests from the Walter Reed Performance Assessment Battery or "PAB." The PAB is a series of computer-generated tests that measure various aspects of performance, mood, attention, and memory. You respond to questions and test items presented on the screen by pressing letters or numbers on the keyboard or keypad. You do not need computer or typing skills to perform these tests. The PAB tests take about 15 minutes to complete.

Another computer-generated test that you will take is called the synthetic work task or "SYNWORK." It consists of 4 tasks similar to the PAB tests discussed above, but all 4 tasks are presented at the same time. You have to switch your attention from one task to the other. You use a "mouse" device to enter your responses. Again, you do not need computer or typing skills to perform these tests. SYNWORK takes 15 minutes to complete.

You will also be tested on a computerized driving simulator called STISIM. You will sit in front of a computer screen with a steering wheel, horn, turn signal, and foot pedals. You will be asked to follow a computer-generated driving route over 2-lane and 4-lane highways, in traffic. "Driving" the route on the STISIM takes about 60 minutes.

Another test is called a sleep latency test. In this test, you are allowed up to 20 minutes to fall asleep while lying down in a quiet, darkened room. As soon as you fall asleep, you are awakened and the test is over.

Other tests include salivary hormones (substances produced naturally by your body), urinary cortisol (cortisol also is a hormone), and an immune function test (a test of your body's ability to protect itself from possible infection). To evaluate levels of hormones in your saliva, you will be asked to provide a saliva sample twice per day. For urinary cortisol, you will be asked to provide a urine sample every time you urinate - for this test to be accurate, we must collect all of the urine you produce throughout the entire study. Therefore, each time you urinate, the entire sample will be collected. The immune function test is similar to a tuberculin (TB) test and is performed several times during the experimental sleep schedule: a small patch with prongs will be pressed onto the surface of the skin on your arm. The prongs contain small amounts of harmless substances to which your body reacts, and your skin responses to these substances are read 48 hours later.

Throughout the study, meals and snacks will be provided at scheduled times. Urine samples will be taken at unannounced times for drug screening. You will be allowed 8 hours of sleep per night following testing on Days 1 and 2 (i.e., for 2 nights). Following testing on Days 3 through 12 (i.e., for 8 nights), you will be allowed either 9, 7, 5, or 3 hours of sleep per night. During any waking time, tests and procedures will occur on a 3-hour cycle. Each cycle will include measurement of vital signs, and one or more of the following tests: a vision test, the sleep latency test, a group decision task (a task which you perform with other study participants), and the 3 computerized performance tests described above. You will be videotaped periodically during some of the tests. You will be kept quite busy during each cycle, but you will have some free time at the end of each cycle when you can relax, read, watch TV, play electronic or board games, etc.

Following Days 11 through 14 (i.e., for 4 nights), you will be allowed 8 hours of sleep per night, followed the next day by the 3-hour test cycle. After the final day of testing (Day 14), you will be transported back to the Department of Behavioral Biology. You will be allowed another 8-hour night of sleep. On Day 15, you will be awakened at 0710 hours, allowed breakfast, and given a physical exam. The electrodes and actigraph will be removed and you will be allowed to shower. The study will then be reviewed with you. You will be released from the study at approximately 09:30 a.m. However, if you are experiencing any difficulties at that time, you may be asked to remain for further observation and/or sleep.

During the study, strenuous activity, exercising, telephone calls (except to arrange a ride home), and visitors are not allowed. A staff member will be with you at all times. The medical supervisor will oversee all medical procedures and will be on call during the study.

POSSIBLE RISKS, INCONVENIENCES, AND SIDE EFFECTS

If you ever had certain infectious diseases, cardiovascular diseases, high blood pressure, respiratory diseases, asthma, renal diseases, stomach/intestine diseases, certain allergies/immunological disorders, blood disorders, cancer, endocrine/metabolic disorders, skin disorders, neurological disorders, head injury, epilepsy, adverse drug reactions, narrow angle glaucoma, prostate enlargement, a history of sleep disorders including narcolepsy (inability to stay awake during your normal waking hours), sleep apnea (repeated, disruptive pauses in breathing during sleep), nocturnal myoclonus (repeated, disruptive leg movements during sleep), or sleep/wake cycle disorders, certain psychiatric or mental health disorders, current use of antidepressants or benzodiazepines, or if you think you are pregnant or might

become pregnant before participation, you should not participate. For your own safety, you must tell the person performing your physical examination today of any medical or psychiatric problems you now have, or have had in the past, no matter how minor.

Risks from the study procedures are minor. You may feel physical, emotional or mental changes after sleep deprivation. These reactions are expected to go away before you leave the laboratory. A little less than 4 teaspoons of blood will be drawn during today's physical exam, and if you are a woman, an additional 1 teaspoon will be drawn the day of the study. The total amount of blood drawn is well below the amount drawn during a blood donation (for example, by the Red Cross). Other risks with a blood draw include pain where the needle is inserted, bruising, blood clot, and inflammation of the vein. However, serious problems are very uncommon. Inflammation of soft tissue, infection, blood clots, and air bubbles can also happen but are very uncommon. The electrodes may cause some skin irritation. This is minor and goes away. Taking the tests noted above may be frustrating, and the laboratory may seem confining, but these feelings go away. You may or may not experience any of these effects. There are no known risks associated with either the salivary hormones or urinary cortisol tests. Risks of the immune function test are minor. A small reaction similar to a mosquito bite may appear at the site of the test a few minutes later, but usually disappears rapidly. One or two days after the test, highly sensitive people may get a small blister with minor pain and drainage. Ice or medicated creams can be applied to the skin to relieve this reaction. This reaction disappears on its own, and leaves no scars - a slight discoloration of the skin can sometimes last for several weeks, but this also normally disappears completely.

Should you participate, you are authorized all necessary medical care for injury or disease that results from your participation in this research study.

On the day of participation, if the investigator determines that you should not participate because of illness, etc., we will try to schedule you for another date, depending on available study spaces. If you do not participate within 6 months of your physical exam, you must have another physical exam (including urine and blood tests) before you can participate.

PAYMENT

You will be paid $140 for wearing the actigraph seven days prior to the study and adhering to all rules and restrictions outlined in this consent form (outlined above). An additional $3864 will be paid for completing the remainder of the study and adhering to all rules and restrictions outlined in this consent form. Your participation is completely voluntary, and you may withdraw at any time without penalty or loss of benefits to which you are otherwise entitled. However, if you withdraw (drop out) from the study once it has begun, or are withdrawn by the investigator once it has begun because you took drugs, alcohol, caffeine, nicotine, etc., you did not follow pre-study or study procedures, and/or you withheld any kind of information, you will be paid $140.00 for the pre-study portion, plus $7.00 per hour for any time you completed in the study, but you will not be eligible for the $3864. Results from the last urine drug screen are not available to the investigator until after you have completed the study - however, if any drugs, alcohol, nicotine, etc., are detected in your urine, you will be notified and paid at a rate of $7.00 per hour for completing the study but you will not be eligible for the $3864. If you are a woman and the serum pregnancy test reveals that you are pregnant, you will be withdrawn from the study on Day 2 (when results become available), and paid $140 for the pre-study portion plus a flat fee of $168.00 for your time in the study.

If the investigator determines that you are ineligible for any reason before you participate, or you cannot participate for any other reason (for example, scheduling conflicts), you will not be paid for your time during the screening visit.

CONFIDENTIALITY

All data are considered private and confidential, and observations, responses, and other personal data are coded so that personal identification is not possible. Representatives of the U.S. Army Medical Research and Materiel Command, the Federal Highway Administration, the General Clinical Research Center, and the Science Applications International Corporation may inspect the records of this research. Representatives of Northrop Grumman will be allowed access to videotapes made of subjects during computer testing. Information found on USAMRMC Form 60-R (Volunteer Registry Data form) will be stored at the U.S. Army Medical Research and Materiel Command for future notification purposes.

You will receive a copy of this consent form for your own records.

SUBJECT INITIALS/DATE_____ **WITNESS INITIALS/DATE**_____

SUBSTITUTE DA FORM 5305-R, FOR THOSE VOLUNTEERING FOR THEMSELVES ONLY, FEB 92

EFFECTS OF WORK/REST SCHEDULES ON DRIVER PERFORMANCE

I do _____ do not _____ *(check one & initial)* consent to the inclusion of this form in my outpatient medical treatment record.

SIGNATURE OF VOLUNTEER: _____

DATE: _____

PERMANENT ADDRESS OF VOLUNTEER: _____

_____

_____

TYPED NAME OF WITNESS: _____

SIGNATURE OF WITNESS: _____

DATE: _____

REVERSE OF SUBSTITUTE DA FORM 5303-R, FEB 92

SUBJECT INITIALS/DATE_____ WITNESS INITIALS/DATE_____

SUBSTITUTE DA FORM 5305-R, FOR THOSE VOLUNTEERING FOR THEMSELVES ONLY, FEB 92

Dear Study Participant:

To assist the nurses in completing an admissions data base for your admission to the GCRC, please complete the following questionnaire. All information will be kept confidential, however if there are any questions you feel uncomfortable with you may leave them unanswered and discuss them with the admitting nurse. All the questions are used solely to give the medical staff a baseline assessment on your health status prior to admission to the hospital so that we would be able to identify any changes during your hospital stay. Some questions will relate to physical and mental health, the others can be used to assess your ability to understand instructions. Thanks for your assistance!

Name _____ Date _____
Allergic to any food or drugs? _____
_____
Taking any medications including vitamins?_____
_____

NUTRITION
On any special diet? _____
Any weight change recently? _____ In what time period? _____
Have you noticed any swallowing difficulties? _____
Any nausea or vomiting? _____
Do you wear dentures? _____ Upper_____ Lower_____ Both _____

ELIMINATION
Any symptoms of constipation? _____ diarrhea? _____
How often do you have a bowel movement? _____
Do you have any problems when urinating? _____
_____

SENSORY
Do you wear glasses? _____ Contact lenses? _____
Any hearing problems? _____
Any numbness anywhere? _____

SKIN/ MOBILITY
Any rashes? _____ Any tattoos? _____ Any cuts on your skin?_____
Any problems walking? _____

BEHAVIORAL HEALTH
How many hours of sleep do you normally get at night? _____
Use any sleep aids? _____
Are you a smoker? _____ How much? _____
Any recent loss in your life? _____
Major change? _____

Hobbies?_____

Do you drink alcohol? _____ How much? _____

Drug History? _____

SOCIAL SYSTEM

Emergency contact _____ Relationship _____

Phone number _____

Live at home with _____

Your religion? _____

Your occupation? _____

What language do you primarily speak? _____

Any other languages? _____

What level of education have you completed?

Any concerns you would like to discuss with the nurse or doctor?

_____

_____

_____

_____

Any medical problems now or in the past? _____

_____

_____

_____

PRELIMINARY SLEEP QUESTIONNAIRE

SUBJECT NAME:_____ DATE: _____/_____/_____

1. At what time do you normally go to bed at night on
   - week nights (Sun-Thur)? _____ AM PM
   - weekends (Fri-Sat)? _____ AM PM

2. What time do you typically awaken on
   - weeks (Mon-Fri)? _____ AM PM
   - weekends (Sat-Sun)? _____ AM PM

3. How long does it typically take you to fall asleep at night?
   - on week nights (Sun-Thur)? _____ MINUTES HOURS
   - on weekends (Fri-Sat)? _____ MINUTES HOURS

4. Do you typically feel sleepy during the day? YES NO
   - At what time do you feel sleepiest? _____ AM PM
   - At what time do you feel most alert? _____ AM PM

5. Is daytime sleepiness currently a problem for you? YES NO
   - If yes, explain how daytime sleepiness currently affects your life.

   _____
   _____

6. Have you ever worked a rotating shift? YES NO
   - If yes, describe your job including the hours of each shift, how often you were required to shift, and the dates of your employment (for example, 3 shifts: 8:00 AM - 4:00 PM, 4:00 PM - 12:00, 12:00 - 8:00 AM, shifted every 2 weeks, held job from June 1984 to September 1984).

   _____
   _____
   _____

7. Do you ever experience difficulty falling asleep? YES NO
   - If yes, how often? _____ per week _____ per month

8. To the best of your knowledge, do you often do any of the following during sleep? If others have told you that you do any of these, then please circle "YES"

   - talk.....YES NO
   - walk.....YES NO
   - kick your legs.....YES NO
   - snore..... YES NO
   - make unusual movements.....YES NO
   - wet the bed (since age 7).....YES NO
   - grind your teeth.....YES NO

If you answered yes to any item on Question #8, please describe, including an estimate of how often you engage in each behavior during sleep, who told you about the behavior(s) (roommate, parent, etc.), and when the behavior(s) first started. THERE IS ROOM ON THE NEXT PAGE TO WRITE.

Standard Form 88
Revised 10/75
General Services Administration
Interagency Comm. on Medical Records
FPMR 101-11.806-3

REPORT OF MEDICAL EXAMINATION

(1.) LAST NAME—FIRST NAME—MIDDLE NAME	2. GRADE AND COMPONENT OR POSITION	(3.) IDENTIFICATION NO. (SSN)
	XXXXXXXXXXXXXXXX	

(4.) HOME ADDRESS (*Number, street or R.F.D.; city or town, State and ZIP Code*)	5. PURPOSE OF EXAMINATION	(6.) DATE OF EXAMINATION
	RESEARCH STUDY	

(7.) SEX	(8.) RACE	9. TOTAL YEARS GOVERNMENT SERVICE	10. AGENCY	11. ORGANIZATION UNIT
		MILITARY XXXXXXXX CIVILIAN XXXXX	XXXXXXX	XXXXXXXXXXXXXXXXXXX

(12.) DATE OF BIRTH	(13.) PLACE OF BIRTH	14. NAME, RELATIONSHIP, AND ADDRESS OF NEXT OF KIN
		XXXXXXXXXXXXXXXXXXXXXXXXXXXXX

15. EXAMINING FACILITY OR EXAMINER, AND ADDRESS	16. OTHER INFORMATION
WRAIR, Washington, DC 20307-5100	XXXXXXXXXXXXXXXXXXXXXXXXXXXXX

17. RATING OR SPECIALTY	TIME IN THIS CAPACITY (*Total*)	LAST SIX MONTHS
XXXXXXXXXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXX	XXXXXXXXXX

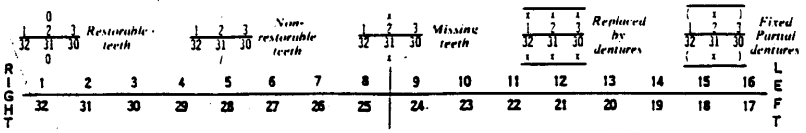
CLINICAL EVALUATION

NORMAL	(*Check each item in appropriate column; enter "NE" if not evaluated.*)	ABNORMAL
	18. HEAD, FACE, NECK AND SCALP	
	19. NOSE	
	20. SINUSES	
	21. MOUTH AND THROAT	
	22. EARS—GENERAL (*Ext. & ext. canals; Auditory acuity under items 70 and 71*)	
	23. DRUMS (*Perforation*)	
	24. EYES—GENERAL (*Visual acuity and refraction under items 19, 60 and 67*)	
	25. OPHTHALMOSCOPIC	
	26. PUPILS (*Equality and reaction*)	
	27. OCULAR MOTILITY (*Associated parallel movements, nystagmus*)	
	28. LUNGS AND CHEST (*Include breasts*)	
	29. HEART (*Thrust, size, rhythm, sounds*)	
	30. VASCULAR SYSTEM (*Varicosities, etc.*)	
	31. ABDOMEN AND VISCERA (*Include hernia*)	
	32. ANUS AND RECTUM (*Hemorrhoids, fistulae; Prostate, if indicated*)	
	33. ENDOCRINE SYSTEM	
	34. G-U SYSTEM	
	35. UPPER EXTREMITIES (*Strength, range of motion*)	
	36. FEET	
	37. LOWER EXTREMITIES (*Except feet; Strength, range of motion*)	
	38. SPINE, OTHER MUSCULOSKELETAL	
	39. IDENTIFYING BODY MARKS, SCARS, TATTOOS	
	40. SKIN, LYMPHATICS	
	41. NEUROLOGIC (*Equilibrium tests under item 72*)	
	42. PSYCHIATRIC (*Specify any personality deviation*)	
	43. PELVIC (*Females only*) (*Check how done*) ☐ VAGINAL ☐ RECTAL	

NOTES. (*Describe every abnormality in detail. Enter pertinent item number before each comment. Continue in item 73 and use additional sheets if necessary.*)

(*Continue in item 73*)

44. DENTAL (*Place appropriate symbols, shown in examples, above or below number of upper and lower teeth.*)



REMARKS AND ADDITIONAL DENTAL DEFECTS AND DISEASES

LABORATORY FINDINGS

45. URINALYSIS: A. SPECIFIC GRAVITY		46. CHEST X-RAY (*Place, date, film number and result*)
B. ALBUMIN	D. MICROSCOPIC	
C. SUGAR		

47. SEROLOGY (*Specify test used and result*)	(48.) EKG	49. BLOOD TYPE AND RH FACTOR	50. OTHER TESTS

88-118

MEASUREMENTS AND OTHER FINDINGS

51. HEIGHT	52. WEIGHT	53. COLOR HAIR	54. COLOR EYES	55. BUILD: ☐ SLENDER ☐ MEDIUM ☐ HEAVY ☐ OBESE	56. TEMPERATURE

57. BLOOD PRESSURE (*Arm at heart level*)						58. PULSE (*Arm at heart level*)				
A. SITTING	SYS. / DIAS.	B. RECUMBENT	SYS. / DIAS.	C. STANDING (3 min.)	SYS. / DIAS.	A. SITTING	B. AFTER EXERCISE	C. 2 MIN. AFTER	D. RECUMBENT	E. AFTER STANDING 3 MIN.

59. DISTANT VISION		60. REFRACTION			61. NEAR VISION	
RIGHT 20/	CORR. TO 20/	BY	S.	CX	CORR. TO	BY
LEFT 20/	CORR. TO 20/	BY	S.	CX	CORR. TO	BY

62. HETEROPHORIA (*Specify distance*)

ES° EX° R. H. L. H. PRISM DIV. PRISM CONV. CT PC PD

63. ACCOMMODATION		64. COLOR VISION (*Test used and result*)	65. DEPTH PERCEPTION (*Test used and score*)	UNCORRECTED
RIGHT	LEFT			CORRECTED
66. FIELD OF VISION		67. NIGHT VISION (*Test used and score*)	68. RED LENS TEST	69. INTRAOCULAR TENSION

70. HEARING			71. AUDIOMETER								72. PSYCHOLOGICAL AND PSYCHOMOTOR (*Tests used and score*)
RIGHT WV	/15 SV	/15		250 *256*	500 *512*	1000 *1024*	2000 *2048*	3000 *2896*	4000 *4096*	6000 *6144*	8000 *8192*	
LEFT WV	/15 SV	/15	RIGHT									
			LEFT									

73. NOTES (*Continued*) AND SIGNIFICANT OR INTERVAL HISTORY

(*Use additional sheets if necessary*)

74. SUMMARY OF DEFECTS AND DIAGNOSES (*List diagnoses with item numbers*)

75. RECOMMENDATIONS—FURTHER SPECIALIST EXAMINATIONS INDICATED (*Specify*)

76. A. PHYSICAL PROFILE					
P	U	L	H	E	S

77. EXAMINEE (*Check*)

A. ☐ IS QUALIFIED FOR
B. ☐ IS NOT QUALIFIED FOR

B. PHYSICAL CATEGORY

78. IF NOT QUALIFIED, LIST DISQUALIFYING DEFECTS BY ITEM NUMBER

A	B	C	E

79. TYPED OR PRINTED NAME OF PHYSICIAN	SIGNATURE	
80. TYPED OR PRINTED NAME OF PHYSICIAN	SIGNATURE	
81. TYPED OR PRINTED NAME OF DENTIST OR PHYSICIAN (*Indicate which*)	SIGNATURE	
82. TYPED OR PRINTED NAME OF REVIEWING OFFICER OR APPROVING AUTHORITY	SIGNATURE	NUMBER OF ATTACHED SHEETS

☆ U.S. GOVERNMENT PRINTING OFFICE : 1977—O-241-530 #3375

STANDARD FORM 93
REV. OCTOBER 1974
GSA FPMR 101–11.8

APPROVED
OFFICE OF MANAGEMENT AND BUDGET No. 29- R0191

REPORT OF MEDICAL HISTORY

(THIS INFORMATION IS FOR OFFICIAL AND MEDICALLY-CONFIDENTIAL USE ONLY AND WILL NOT BE RELEASED TO UNAUTHORIZED PERSONS)

1. LAST NAME—FIRST NAME—MIDDLE NAME		2. SOCIAL SECURITY OR IDENTIFICATION NO.
3. HOME ADDRESS *(No. street or RFD, city or town, State, and ZIP CODE)*		4. POSITION *(title, grade, component)*
5. PURPOSE OF EXAMINATION	6. DATE OF EXAMINATION	7. EXAMINING FACILITY OR EXAMINER, AND ADDRESS *(Include ZIP Code)*

8. STATEMENT OF EXAMINEE'S PRESENT HEALTH AND MEDICATIONS CURRENTLY USED *(Follow by description of past history, if complaint exists)*

9. HAVE YOU EVER *(Please check each item)*

YES	NO	*(Check each item)*
		Lived with anyone who had tuberculosis
		Coughed up blood
		Bled excessively after injury or tooth extraction
		Attempted suicide
		Been a sleepwalker

10. DO YOU *(Please check each item)*

YES	NO	*(Check each item)*
		Wear glasses or contact lenses
		Have vision in both eyes
		Wear a hearing aid
		Stutter or stammer habitually
		Wear a brace or back support

11. HAVE YOU EVER HAD OR HAVE YOU NOW *(Please check at left of each item)*

YES	NO	DON'T KNOW	*(Check each item)*	YES	NO	DON'T KNOW	*(Check each item)*	YES	NO	DON'T KNOW	*(Check each item)*
			Scarlet fever, erysipelas				Cramps in your legs				"Trick" or locked knee
			Rheumatic fever				Frequent indigestion				Foot trouble
			Swollen or painful joints				Stomach, liver, or intestinal trouble				Neuritis
			Frequent or severe headache				Gall bladder trouble or gallstones				Paralysis (include infantile)
			Dizziness or fainting spells				Jaundice or hepatitis				Epilepsy or fits
			Eye trouble				Adverse reaction to serum, drug,				Car, train, sea or air sickness
			Ear, nose, or throat trouble				or medicine				Frequent trouble sleeping
			Hearing loss				Broken bones				Depression or excessive worry
			Chronic or frequent colds				Tumor, growth, cyst, cancer				Loss of memory or amnesia
			Severe tooth or gum trouble				Rupture/hernia				Nervous trouble of any sort
			Sinusitis				Piles or rectal disease				Periods of unconsciousness
	X		Hay Fever				Frequent or painful urination				Allergies, Drug
			Head injury				Bed wetting since age 12				Allergies, Food
			Skin diseases				Kidney stone or blood in urine				
			Thyroid trouble				Sugar or albumin in urine				
			Tuberculosis				VD—Syphilis, gonorrhea, etc.				
			Asthma				Recent gain or loss of weight				
			Shortness of breath				Arthritis, Rheumatism, or Bursitis				
			Pain or pressure in chest				Bone, joint or other deformity				
			Chronic cough				Lameness				
			Palpitation or pounding heart				Loss of finger or toe	12. FEMALES ONLY: HAVE YOU EVER			
			Heart trouble				Painful or "trick" shoulder or elbow				Been treated for a female disorder
			High or low blood pressure				Recurrent back pain				Had a change in menstrual pattern

13. WHAT IS YOUR USUAL OCCUPATION?

14. ARE YOU *(Check one)*

☐ Right handed ☐ Left handed

93–102

YES	NO	CHECK EACH ITEM YES OR NO. EVERY ITEM CHECKED YES MUST BE FULLY EXPLAINED IN BLANK SPACE ON RIGHT	
		15. Have you been refused employment or been unable to hold a job or stay in school because of: A. Sensitivity to chemicals, dust, sunlight, etc.	
		B. Inability to perform certain motions.	
		C. Inability to assume certain positions.	
		D. Other medical reasons *(If yes, give reasons.)*	
		16. Have you ever been treated for a mental condition? *(If yes, specify when, where, and give details).*	
		17. Have you ever been denied life insurance? *(If yes, state reason and give details.)*	
		18. Have you had, or have you been advised to have, any operations? *(If yes, describe and give age at which occurred.)*	
		19. Have you ever been a patient in any type of hospitals? *(If yes, specify when, where, why, and name of doctor and complete address of hospital.)*	
		20. Have you ever had any illness or injury other than those already noted? *(If yes, specify when, where, and give details.)*	
		21. Have you consulted or been treated by clinics, physicians, healers, or other practitioners within the past 5 years for other than minor illnesses? *(If yes, give complete address of doctor, hospital, clinic, and details.)*	
		22. Have you ever been rejected for military service because of physical, mental, or other reasons? *(If yes, give date and reason for rejection.)*	
		23. Have you ever been discharged from military service because of physical, mental, or other reasons? *(If yes, give date, reason, and type of discharge: whether honorable, other than honorable, for unfitness or unsuitability.)*	
		24. Have you ever received, is there pending, or have you applied for pension or compensation for existing disability? *(If yes, specify what kind, granted by whom, and what amount, when, why.)*	

I certify that I have reviewed the foregoing information supplied by me and that it is true and complete to the best of my knowledge.
I authorize any of the doctors, hospitals, or clinics mentioned above to furnish the Government a complete transcript of my medical record for purposes of processing my application for this employment or service.

TYPED OR PRINTED NAME OF EXAMINEE	SIGNATURE

NOTE: HAND TO THE DOCTOR OR NURSE, OR IF MAILED MARK ENVELOPE "TO BE OPENED BY MEDICAL OFFICER ONLY."
25. Physician's summary and elaboration of all pertinent data *(Physician shall comment on all positive answers in items 9 through 24. Physician may develop by interview any additional medical history he deems important, and record any significant findings here.)*

TYPED OR PRINTED NAME OF PHYSICIAN OR EXAMINER	DATE	SIGNATURE	NUMBER OF ATTACHED SHEETS

REVERSE OF STANDARD FORM 93

☆ U.S.G.P.O:1979-311-153(5102)

Name _____

INSTRUCTIONS: This is a questionnaire. On the questionnaire are groups of statements. Please read the entire group of statements in each category. Then pick out the one statement in that group which best describes the way you feel today, that is, **right now!** Circle the number beside the statement you have chosen. If several statements in the group seem to apply equally well circle each one.

Be sure to read all the statements in each group before making your choice.

1. 0 I do not feel sad
   1 I feel sad or blue
   2 I am blue or sad all the time and I can't snap out of it
   3 I am so sad or unhappy that I can't stand it

2. 0 I am not particularly pessimistic or discouraged about the future
   1 I feel discouraged about the future
   2 I feel I have nothing to look forward to
   3 I feel that the future is hopeless and that things cannot improve

3. 0 I do not feel like a failure
   1 I feel I have failed more thatn the average person
   2 As I look back on my life, all I can see is a lot of failures
   3 I feel I am a complete failure as a person (parent, husband, wife)

4. 0 I am not particularly dissatisfied
   1 I don't enjoy things the way I used to
   2 I don't get satisfaction out of anything anymore
   3 I am dissatisfied with everything

5. 0 I don't feel particularly guilty
   1 I feel bad or unworthy a good part of the time
   2 I feel quite guilty
   3 I feel as though I am very bad or worthless

6. 0 I don't feel disappointed in myself
   1 I am disappointed in myself
   2 I am disgusted with myself
   3 I hate myself

7. 0 I don't have any thoughts of harming myself
   1 I feel I would be better off dead
   2 I have definite plans about committing suicide
   3 I would kill myself if I had the chance

8. 0 I have not lost interest in other people
   1 I am less interested in other people than I used to be
   2 I have lost most of my interest in other people and have little feeling for them
   3 I have lost all of my interest in other people and don't care about them at all

9. 0 I make decisions about as well as ever
   1 I try to put off making decisions
   2 I have great difficulty in making decisions
   3 I can't make any decisions at all anymore

10. 0 I don't feel I look any worse than I used to
    1 I am worried that I am looking old or unattractive
    2 I feel that there are permanent changes in my appearance and they make me look unattractive
    3 I feel that I am ugly or repulsive looking

11. 0 I can work about as well as before
    1 It takes extra effort to get started at doing something
    2 I have to push myself very hard to do anything
    3 I can't do any work at all

12. 0 I don't get any more tired than usual
    1 I get tired more easily than I used to
    2 I get tired from doing anything
    3 I get too tired to do anything

13. 0 My appetite is no worse than usual
    1 My appetite is not as good as it used to be
    2 My appetite is much worse now
    3 I have no appetite at all any more

NAME _____

WALTER REED ARMY INSTITUTE OF RESEARCH
PERSPECTIVES-ON-LIFE SCALE (POLS)

INSTRUCTIONS: Below are statements about life that people often feel differently about. Circle a number to show how you feel about each one. Read the items carefully, and indicate how much you think each one is true in general. There are no right or wrong answers; just give your own honest opinions.

NOT AT ALL TRUE	A LITTLE TRUE	QUITE TRUE	COMPLETELY TRUE
0	1	2	3

1. Most of my life gets spent doing things that are worthwhile. 0 1 2 3
2. Planning ahead can help avoid most future problems. 0 1 2 3
3. Trying hard doesn't pay, since things still don't turn out right..... 0 1 2 3
4. No matter how hard I try, my efforts usually accomplish nothing..... 0 1 2 3
5. I don't like to make chages in my everyday schedule..... 0 1 2 3
6. The "tried and true" ways are always best..... 0 1 2 3
7. Working hard doesn't matter, since only the bosses profit by it. 0 1 2 3
8. By working hard you can always achieve your goals..... 0 1 2 3
9. Most working people are simply manipulated by their bosses..... 0 1 2 3
10. Most of what happens in life is just meant to be..... 0 1 2 3
11. It's usually impossible for me to change things at work..... 0 1 2 3
12. New laws should never hurt a person's pay-check..... 0 1 2 3
13. When I make plans, I'm certain I can make them work..... 0 1 2 3
14. It's very hard for me to change a friend's mind about something. 0 1 2 3
15. It's exciting to learn something about myself..... 0 1 2 3
16. People who never change their minds usually have good judgement... 0 1 2 3
17. I really look forward to my work..... 0 1 2 3
18. The politicians run our lives..... 0 1 2 3
19. If I'm working on a difficult task, I know when to seek help. 0 1 2 3
20. I won't answer a question until I'm really sure I understand it. 0 1 2 3

NOT AT ALL TRUE 0	A LITTLE TRUE 1	QUITE TRUE 2	COMPLETELY TRUE 3

21. I like a lot of variety in my work. 0 1 2 3
22. Most of the time, people listen carefully to what I say 0 1 2 3
23. Daydreams are more exciting than reality for me..... 0 1 2 3
24. Thinking of yourself as a free person just leads to frustration 0 1 2 3
25. Trying your best at work really pays off..... 0 1 2 3
26. My mistakes are usually very difficult to correct..... 0 1 2 3
27. It bothers me when my daily routine gets interrupted..... 0 1 2 3
28. It's best to handle most problems by just not thinking of them. 0 1 2 3
29. Most good athletes and leaders are born, not made. 0 1 2 3
30. I often wake up eager to take up my life wherever it left off. 0 1 2 3
31. Lots of times, I don't really know my own mind..... 0 1 2 3
32. I respect rules because they guide me. 0 1 2 3
33. I like it when things are uncertain or unpredictable 0 1 2 3
34. I can't do much to prevent it if someone wants to harm me 0 1 2 3
35. People who do their best should get full support from society..... 0 1 2 3
36. Changes in routine are interesting to me..... 0 1 2 3
37. People who believe in individuality are only kidding themselves. 0 1 2 3
38. I have no use for theories that are not closely tied to facts. 0 1 2 3
39. Most days, life is really interesting and exciting for me..... 0 1 2 3
40. I want to be sure someone will take care of me when I'm old 0 1 2 3
41. It's hard to imagine anyone getting excited about working. 0 1 2 3
42. What happens to me tomorrow depends on what I do today 0 1 2 3
43. If someone gets angry at me, it's usually no fault of me..... 0 1 2 3
44. It's hard to believe people who say their work helps society..... 0 1 2 3
45. Ordinary work is just too boring to be worth doing..... 0 1 2 3

LEEDS QUESTIONNAIRE

Name_____

INSTRUCTIONS: Please read each statement, and then pick the one response that best describes the way you feel today, at this time. Circle the number beside the response you have chosen.

1. I feel miserable and sad.
   0) not at all 1) not much 2) sometimes 3) definitely

2. I get very frightened or panic feelings for apparently no reason at all.
   0) not at all 1) not much 2) sometimes 3) definitely

3. I still enjoy the things I used to.
   0) definitely 1) sometimes 2) not much 3) not at all

4. I am restless and can't keep still.
   0) not at all 1) not much 2) sometimes 3) definitely

5. I feel anxious when I go out of the house on my own.
   0) not at all 1) not much 2) sometimes 3) definitely

6. I have lost interest in things.
   0) not at all 1) not much 2) sometimes 3) definitely

7. I am more irritable than usual.
   0) not at all 1) not much 2) sometimes 3) definitely

8. I wake early and then sleep badly for the rest of the night.
   0) not at all 1) not much 2) sometimes 3) definitely

9. I have a good appetite.
   0) definitely 1) sometimes 2) not much 3) not at all

10. I feel life is not worth living.
    0) not at all 1) not much 2) sometimes 3) definitely

Please turn page over.

11. I get palpitations, or a sensation of 'butterflies' in my stomach or chest.
0) not at all 1) not much 2) sometimes 3) definitely

12. I feel scared or frightened.
0) not at all 1) not much 2) sometimes 3) definitely

Scores

*Scale I:*_____ *Scale II:*_____

APPENDIX 2: DRIVER DEMOGRAPHIC INFORMATION

3-HOUR SLEEP GROUP

Age	Gender	Ethnicity	Truck Type	Trailers	Experience w/ Tractor Trailers
24	f	Biracial(blk&wht)	?	Doubles	2 years
28	m	African American	3/4 ton for Distributors	Dry Van	4.5 years
31	m	African American	Cabover	48 ft., Dry Van	2 years 8 months
32	m	Caucasian	Conventional, Single-Unit	42 & 48 ft., Dry Van	11 years
33	m	Caucasian	Conventional	53 ft., Dry Van, Reefer	13 years
34	f	Caucasian	Cabover	53 ft.	6 months
35	m	Caucasian	Dump Truck	25 ft., Flatbed	5 years
35	m	Caucasian	Single-Unit	n/a	5 years
36	f	Caucasian	Step Van, Gruman	n/a	8 years
37	f	Caucasian	Step Van		14 years
41	m	Caucasian	Conventional	48 ft, dry van	17 years
42	m	Caucasian	Cabover	48 ft. ,dry van	16 years
44	m	Caucasian	Conventional	48 ft., tanker	14 years
46	f	African American	Reefer	48 ft.	3 years
48	m	Caucasian	Conventional	34 ft, belly or end-dump	10 years
52	m	Caucasian	Conventional	53 ft., Dry Van	20 years
55	m	Caucasian	Conventional	53 ft., Dry Van	31 years
55	f	Caucasian	Conventional	53 ft., Dry Van	13 years

Age Range: 24-55 **Mean Age: 39.333** **Median Age: 36.5**

5-HOUR SLEEP GROUP

Age	Gender	Ethnicity	Truck Type	Trailers	Experience w/ tractor trailers
24	m	Caucasian	Single-Unit	8-10ft., Dry Van, Belly/end-dump	0
24	m	African American	Dump Truck		6 months
27	m	Caucasian	Dump Truck	20ft. Trailer	1 year
28	m	Caucasian	Conventional	53ft., reefer	5 months
31	m	Caucasian	.	.	.
31	m	African American	Single-Unit	0	4 months
31	m	Caucasian	Conventional	0	10 years
31	m	African American	Single-Unit	24 ft., reefer	0
31	m	African American	Small Bus & Limo		0
31	m	Caucasian	Conventional	53 ft., reefer	4 years 8 months
37	m	African American	.	.	.
37	m	African American	Conventional	49 ft., reefer	15 years
39	m	African American	Conventional	45 ft., Dry Van	15 years
44	f	Caucasian	.	.	.
48	f	Caucasian	Conventional	48 ft., Flatbed	4.5 years
59	m	Caucasian	Conventional	28 ft.	3 years 6 months

Age Range: **24-59** **Mean Age:** **34.563** **Median Age:** **31**

7-HOUR SLEEP GROUP

Age	Gender	Ethnicity	Truck Type	Trailers	Experience w/ tractor trailers
25	m	African American	Cabover	48/53 ft., Dry Van	4 years
27	m	African American	Conventional	20 ft., Dumptruck	0
31	m	Caucasian	Conventional	0	0
32	m	Caucasian	.	.	.
34	m	Caucasian	Conventional	48 ft., Flatbed	17 years
37	f	Caucasian	Gruman	n/a	0
38	m	Caucasian	Conventional, Single-Unit	n/a	0
40	m	Caucasian	Conventional, Dump Truck	20 ft.	0
43	f	Caucasian	Sedan/ Light Truck	0	1 year
43	f	Hispanic	Conventional	48 or 60 ft., dry van, tanker, belly or end-dump	7 years
45	m	Caucasian	Cabover	48-53 ft., Dry Van	3 years
46	m	Caucasian	Conventional	53 ft., reefer	19 years
50	f	Caucasian	Conventional	40 ft., reefer	5 years
50	m	Caucasian	Conventional	53 ft., Dry Van	28 years
57	m	Caucasian	Bus	n/a	0
62	m	Caucasian	Conventional	Various	30 years

Age Range: 25-62 **Mean Age: 41.250** **Median Age: 41.5**

9-HOUR SLEEP GROUP

Age	Gender	Ethnicity	Truck Type	Trailers	Experience w/ tractor trailers
27	m	Caucasian	Single Axel Dump	28 & 40 ft.End-dump	7 years
30	m	African American	Conventional	48 ft., Walking Floor	16 years
30	m	Caucasian	Fire Eng, Medic Unit Tanker, Ladder Truck	Tanker	0
32	m	Caucasian	Conventional, Single-unit, Bus	40 ft., Dry Van, Tanker, Flatbed	4 years
33	m	Caucasian	Conventional	45 ft, reefer, dry van	13 years
37	m	Caucasian	Conventional	45 ft., Dry Van, Reefer, Tanker	16 years
38	m	Caucasian	Conventional, Cabover	45 ft., Tanker	20 years
40	m	Caucasian	Conventional	45 & 48 ft., Dry Van, Tanker, Flatbed	3 years
40	m	Caucasian	Single-Unit, Dump Truck, Lift Truck	belly or end-dump	.
41	f	African American	Bus	n/a	0
42	f	Caucasian	conventional	n/a	0
43	m	Caucasian	Conventional	45 ft., Tanker	12 years
48	m	Caucasian	Cabover	flatbed, 48 ft.	34 years
48	m	Caucasian	conventional	48 ft., reefer	8 months
50	f	Caucasian	Bus	n/a	0
54	f	African American	Bus	n/a	0

Age Range: 27-54 **Mean Age: 39.563** **Median Age: 40**

APPENDIX 3: SIMULATOR-DRIVING SCENARIO SPECIFICATIONS

Length: 18,500 feet (≈ 35 miles)

Duration: Nominally 45 minutes

Speed Limits: 35 and 55 mi/h

Road Widths: 2, 4 and 6 lanes. Lane widths 12 feet.

EVENT FREQUENCIES/DENSITIES:

Intersections: 20 per scenario, density higher in 35 mi/h zones, none on 6-lane roads.

Signal Lights: at roughly half the intersections (n=8), more frequent in 35-mi/h zones. At least one but no more than two requiring a stop, with location semi-randomized.

Pedestrians: Only at selected town intersections. Only one case where collision possible.

Stop Signs: One per scenario on 35-mi/h segment near terminal.

Cross Traffic: Average of 2.5 cross-traffic vehicles per intersection (range 0 to 5). Typically traveling at distances and speeds so as to avoid collisions if the driver maintains the speed limit. Approximately one instance per scenario where this was not the case and driver must speed or slow down, semi-randomized across days.

Approaching Vehicles: (≈130) Average 1 per ≈1,400 feet but wide dispersion, from 0 to 3 on-screen at once on 2-lane, more on 4 and 6. Traveling near current speed limit (i.e., ±5 mi/h). None crossed into subject's lane.

Forced Pass: ≈10 per scenario, where lead car in subject's lane is going ≈40 mi/h in 55 mi/h zone, or ≈25 mi/h in 35 mi/h zone. At least one on 2-lane road requires awaiting oncoming car; at least one on 4-lane requires awaiting takeover from rear.

Overtakes: ≈12 per scenario, where car approaches from rear and passes. Approximately half occur at or after a change in the number of lanes, where the subject must merge in high-speed traffic.

Curves: 14 per scenario, balanced for Left and Right with 2 radii (1,000' and 3,333') and lengths (1,000' and 2,500') except that 6-lane segments have only the longer, more gentle curves.

Buildings: "Many." Higher density in 35-mi/h zones. Included generic blocks with and without windows, some with parking lots, "farm houses," loading dock, gas stations, etc., for variety.

Secondary Task: 10 trials per scenario (5 left, 5 right), semi-randomly spaced at nominal locations of 18, 36, 53, 69, 85, 105, 126, 145, 157, and 175 thousand feet .

Data Segments: As indicated in the table on p. A3-3, the STISIM scenario consisted of a simulated driving distance of 185,000 ft. Some aspects of driving performance such as Collisions & Accidents were recorded continuously across the entire simulated driving scenario. However, other aspects of driving performance (i.e., second-by-second and averaged performance variables) were collected and stored only for specified 4,000-ft-long portions (segments) of the scenario. These data segments were initiated at the following "distances driven" (i.e., from the beginning of the scenario): 8,000 ft, 33,000 ft, 52,000 ft, 91,000 ft, 128,000 ft, 141,000 ft, and 174,000 ft. Data segments were located "between" potentially confounding events like passing, merging, and decelerating/accelerating.

SIGN PLACEMENT AND SPACING

In general, road signs and markings complied with the guidelines outlined in the FHWA 1988 edition of the Manual On Uniform Traffic Control Devices, for Streets and Highways (MUTCD). Where hardware/software characteristics of the simulator made literal compliance impractical, the intent rather than the letter of the guide was followed.

Speed-Limit Signs: Spaced every 5,000 feet in 55-mi/h zones, and every 3,000 feet in 35-mi/h zones (i.e., nominally 60 seconds apart). Also 1,000 feet beyond major intersections, resetting the "counter."

Lane Ends, Merge Left Signs: 700 feet ahead in 55-mi/h zones, and 400 feet ahead in 35-mi/h zones. When both were used in 55-mi/h zones, they were at 1,000 and 500 feet.

Cross Road, Stop Ahead, Signal Ahead, Ped-Xing: 450 feet in 55-mi/h zone, 150 feet in 35-mi/h zones.

Turn or Curve Ahead Signs: 300 feet in 55-mi/h zones, 200 feet in 35-mi/h zones.

Overhead Signs: Cross bar 17 feet above the road, posts 6 feet off the road, post width 6 inches but having no depth. Bottom of signs 15 feet above road. (this is less than specified in the MUTCD but more consistent with the predetermined height and offset of the signal lights and posts supplied with STISIM).

TOWNS

First town: 3 Intersections and 1 Signal Light. Second town: 4 Intersections and 3 Signal Lights, one with pedestrians. Lights remained or became green if driver observed speed limit (one exception when randomized across days). Streets were 4-lane 35-mi/h with a few parked cars on each side of street to force use of center lane. Moving and stationary approaching and cross-traffic vehicles for variety to differentiate the 2 towns. First town was near the start of its 15,000-foot road segment, other near the end, separated from the data collection segments, preceded and followed by sharp curves to hide graphics generation, with trees turned off before and back on after.

SEGMENT TYPE AND ORDER

Location (ft In Scenario)	Length (ft)	Number of Lanes	Speed (mi/h)	I	SL	Curve	A	V	Remarks
				--(number of occurrences in Segment)--					
000	5,000	4	35	1	0	l	11	6	depot, many bldgs, 1 curve to move mt.out of view, no trees
5,000	10,000	4	55	1	1	r	2	2	BSAV (begin saving data) at 8,000 ft
15,000	15,000	6	55	0	0	L	9	6	1FP, Jersey walls force left
30,000	15,000	4	55	1	0	R	15	5	1FP, reduce speed ahead BSAV at 33,000 ft
45,000	15,000	4	35	5	3	l,r	10	12	1FP, Town between sharp curves, BSAV at 52,000 ft
60,000	20,000	4	55	1	0	-	24	17	FP, lane ends sign, and merge left sign
80,000	25,000	2	55	2	0	L,R	7	5	2FP, Middle, rural, BSAV at 91,000 ft
105,000	20,000	4	55	1	1	-	6	10	1FP, reduce speed ahead
125,000	15,000	4	35	5	1	r,l	14	5	1FP, Town, BSAV @128,000 ft
140,000	15,000	4	55	1	1	r	12	7	1FP, BSAV at 141,000 ft
155,000	15,000	6	55	0	0	R	0	4	1FP, Barrels force left
170,000	10,000	4	55	1	1	L	5	6	BSAV at 174,000 ft
180,000	5,000	4	35	1	0	l	4	3	many bldgs, 0 trees, depot
185,000'	End								

I	=	**I**ntersections
SL	=	**S**ignal **L**ights
l,r,L,R	=	small & Large radius **l**eft & **r**ight Curves
A	=	**A**pproaching vehicles
V	=	Advancing **V**ehicles
FP	=	**F**orced **P**ass
BSAV	=	**B**egin **Sav**ing data for 4000 ft segments

APPENDIX 4: ANALYSIS OF VARIANCE TABLES, PHASE II DEPENDENT MEASURES

All statistical analyses represented by the tables in this Appendix were performed using a mixed within- (repeated measures, e.g., Day, Time of Day) and between-subjects (Sleep Group) analysis of variance (ANOVA). Repeated-measures (within subjects) factors are those for which multiple measurements were taken from each individual across time. Greenhouse-Geisser (G-G) corrected probabilities were used to determine statistical significance for all repeated-measures factors. (Repeated-measures analyses result in a reduced error term which can, in some instances, inappropriately inflate the probability of detecting significant differences between means. The G-G correction reduces the likelihood of detecting spurious differences between means for repeated-measures factors—and its use is currently common in the behavioral sciences.)

Source tables listed for physiological and quantitative sleep measures give the actual G-G epsilon correction factor (under the heading, "GGI") as well as the corrected G-G probability (under the heading, "*p* value"). Source tables for performance measures give both the uncorrected (under the heading "*p*") as well as the corrected G-G probability (under the heading "G-G").

Occasionally, technical difficulties during data collection resulted in missing data points. These missing data points are reflected in, and account for, between-measure variations in the degrees of freedom of the error terms.

SOURCE TABLES FOR NIGHTTIME SLEEP VARIABLES

ANOVA summary table for Nighttime Total Sleep (sum of Stages 1, 2, SWS, and REM) – Minutes

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	1288246.00	2713.69	474.72	3, 61	----	< .05
Night	143595.92	536.87	267.47	10, 610	0.6128	< .05
Sleep Group x Night	71921.33	536.87	133.97	30, 610	0.6128	< .05

Simple Main Effects Source – Night	MS effect	MS error	F-value	df	GGI	*p* value
3-hr group	288083.38	536.87	536.60	10, 610	0.6128	< .05
5-hr group	73502.89	536.87	136.91	10, 610	0.6128	< .05
7-hr group	6238.48033	536.87	11.62	10, 610	0.6128	< .05
9-hr group	10252.19	536.87	19.10	10, 610	0.6128	< .05

Simple Main Effects Source – Sleep Group	MS effect	MS error	F-value	df	GGI	*p* value
Baseline	868.81	1098.79	0.79	3, 61	----	NS
E1	295287.31	368.20	801.98	3, 61	----	< .05
E2	307869.31	140.41	2192.71	3, 61	----	< .05
E3	279283.42	535.54	521.50	3, 61	----	< .05
E4	292401.70	497.60	587.63	3, 61	----	< .05
E5	276408.01	508.93	543.12	3, 61	----	< .05
E6	282038.84	342.67	823.07	3, 61	----	< .05
E7	267980.52	687.18	389.97	3, 61	----	< .05
R1	1010.86	1201.87	0.84	3, 61	----	NS
R2	544.84	1008.25	0.54	3, 61	----	NS
R3	3765.69	1692.94	2.22	3, 61	----	0.09

ANOVA summary table for Nighttime Recuperative Sleep (sum of Stages 2, SWS, and REM) – Minutes

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	804026.00	4716.22	170.48	3, 61	----	< .05
Night	119370.18	831.28	143.6	10, 610	0.65	< .05
Sleep Group x Night	48329.83	831.28	58.14	30, 610	0.65	< .05

Simple Main Effects Source - Night	MS effect	MS error	F-value	df	GGI	*p* value
3-hr group	219257.38	831.28	263.76	10, 610	0.65	< .05
5-hr group	52513.55	831.28	63.17	10, 610	0.65	< .05
7-hr group	4621.85	831.28	5.56	10, 610	0.65	< .05
9-hr group	2757.21	831.28	3.32	10, 610	0.65	< .05

Simple Main Effects Source - Sleep Group	MS effect	MS error	F-value	df	GGI	*p* value
Baseline	788.86	1504.54	0.52	3, 61	----	NS
E1	189381.96	696.61	271.86	3, 61	----	< .05
E2	197761.09	745.72	265.19	3, 61	----	< .05
E3	173.724	1248.17	139.18	3, 61	----	< .05
E4	201788.06	787.04	256.39	3, 61	----	< .05
E5	172803.25	561.19	307.92	3, 61	----	< .05
E6	177227.84	738.56	239.97	3, 61	----	< .05
E7	168781.55	1105.49	152.68	3, 61	----	< .05
R1	1510.02	2306.47	0.65	3, 61	----	NS
R2	166.04	1204.44	0.14	3, 61	----	NS
R3	3390.95	2130.78	1.59	3, 61	----	NS

ANOVA summary table for Nighttime Stage 1 Sleep – Minutes

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	64231.89	2088.74	30.75	3, 61	----	< .05
Night	1911.10	324.76	5.88	10, 610	0.52	< .05
Sleep Group x Night	3071.34	324.76	9.46	30, 610	0.52	< .05

Simple Main Effects Source - Night	MS effect	MS error	F-value	df	GGI	*p* value
3-hr group	5059.08	324.76	15.58	10, 610	0.52	< .05
5-hr group	2374.81	324.76	7.31	10, 610	0.52	< .05
7-hr group	587.61	324.76	1.81	10, 610	0.52	NS
9-hr group	3343.01	324.76	10.29	10, 610	0.52	< .05

Simple Main Effects Source - Sleep Group	MS effect	MS error	F-value	df	GGI	*p* value
Baseline	10.83	470.35	0.02	3, 61	----	NS
E1	12607.75	411.99	30.60	3, 61	----	< .05
E2	15877.78	520.42	30.51	3, 61	----	< .05
E3	13712.22	890.68	15.40	3, 61	----	< .05
E4	8848.62	312.17	28.35	3, 61	----	< .05
E5	14645.11	311.29	47.05	3, 61	----	< .05
E6	13047.01	287.46	45.39	3, 61	----	< .05
E7	15017.34	478.57	31.38	3, 61	----	< .05
R1	294.55	655.25	0.45	3, 61	----	NS
R2	530.60	275.03	1.93	3, 61	----	NS
R3	353.54	723.16	0.49	3, 61	----	NS

ANOVA summary table for Nighttime Stage 2 Sleep – Minutes

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	336055.89	4905.99	68.5	3, 61	----	< .05
Night	79376.54	867.13	91.54	10, 610	0.51	< .05
Sleep Group x Night	23286.13	867.13	26.85	30, 610	0.51	< .05

Simple Main Effects Source - Night	MS effect	MS error	F-value	df	GGI	*p* value
3-hr group	122027.73	867.13	140.73	10, 610	0.51	< .05
5-hr group	29332.57	867.13	33.83	10, 610	0.51	< .05
7-hr group	5489.75	867.13	6.33	10, 610	0.51	< .05
9-hr group	670.76	867.13	0.77	10, 610	0.51	NS

Simple Main Effects Source - Sleep Group	MS effect	MS error	F-value	df	GGI	*p* value
Baseline	1162.21	1557.66	0.75	3, 61	----	NS
E1	81544.77	977.81	83.4	3, 61	----	< .05
E2	87939.71	1056.16	83.26	3, 61	----	< .05
E3	71769.33	1139.07	63.01	3, 61	----	< .05
E4	87788.03	779.13	112.68	3, 61	----	< .05
E5	81073.24	964.07	84.09	3, 61	----	< .05
E6	83412.81	831.91	100.27	3, 61	----	< .05
E7	68518.47	1270.51	53.93	3, 61	----	< .05
R1	490.48	1898.88	0.26	3, 61	----	NS
R2	2332.90	1193.37	1.95	3, 61	----	NS
R3	2885.21	1908.69	1.51	3, 61	----	NS

ANOVA summary table for Nighttime Stage Slow Wave Sleep – Minutes

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	3431.48	4871.09	0.7	3, 61	----	NS
Night	395.39	218.88	1.81	10, 610	0.69	0.09
Sleep Group x Night	202.32	218.88	0.92	30, 610	0.69	NS

NOTE: Simple main effects were not computed due to lack of statistical significance for Sleep Group x Night interaction.

ANOVA summary table for Nighttime Stage REM – Minutes

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	91788.20	2478.04	37.04	3, 61	----	< .05
Night	4665.69	394.13	11.84	10, 610	0.61	< .05
Sleep Group x Night	4653.03	394.13	11.81	30, 610	0.61	< .05

Simple Main Effects Source – Night	MS effect	MS error	F-value	df	GGI	*p* value
3-hr group	14755.26	394.13	37.44	10, 610	0.61	< .05
5-hr group	3176.48	394.13	8.06	10, 610	0.61	< .05
7-hr group	300.66	394.13	0.76	10, 610	0.61	NS
9-hr group	1238.41	394.13	3.14	10, 610	0.61	< .05

Simple Main Effects Source - Sleep Group	MS effect	MS error	F-value	df	GGI	*p* value
Baseline	687.10	746.81	0.92	3, 61	----	NS
E1	19610.90	518.47	37.82	3, 61	----	< .05
E2	20526.07	591.69	34.69	3, 61	----	< .05
E3	18511.09	638.38	29.00	3, 61	----	< .05
E4	19489.29	416.36	46.81	3, 61	----	< .05
E5	18970.55	411.19	46.14	3, 61	----	< .05
E6	18249.15	519.59	35.12	3, 61	----	< .05
E7	20323.65	357.55	56.84	3, 61	----	< .05
R1	329.92	996.48	0.33	3, 61	----	NS
R2	1573.56	590.68	2.66	3, 61	----	0.06
R3	47.22	632.18	0.07	3, 61	----	NS

SOURCE TABLES FOR OBJECTIVE ALERTNESS – LATENCY TO SLEEP (MSLT)

ANOVA summary table for Latency to Stage 1 Sleep in Minutes, All Subjects

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	967.31	91.94	10.52	3, 62	----	< .05
Day	76.24	21.46	3.55	10, 620	0.74	< .05
Time of Day	651.28	45.00	14.47	1, 62	----	< .05
Sleep Group x Day	58.12	21.46	2.71	30, 620	0.74	< .05
Sleep Group x Time of Day	249.3	45.00	5.54	3, 62	----	< .05
Day x Time of Day	22.11	15.19	1.46	10, 620	0.84	NS
Sleep Group x Day x Time of Day	16.30	15.19	1.07	10, 620	0.84	NS

Simple Main Effects Source - Day	MS effect	MS error	F-value	df	GGI	*p* value
3-hr group	54.91	21.46	2.56	10, 620	0.74	< .05
5-hr group	161.13	21.46	7.51	10, 620	0.74	< .05
7-hr group	17.35	21.46	0.81	10, 620	0.74	NS
9-hr group	18.00	21.46	0.84	10, 620	0.74	NS

Simple Main Effects Source - Sleep Group	MS effect	MS error	F-value	df	GGI	*p* value
Baseline	7.35	41.57	0.18	3, 62	----	NS
E1	43.01	28.70	1.50	3, 62	----	NS
E2	362.14	14.73	24.58	3, 62	----	< .05
E3	169.63	33.92	5.00	3, 62	----	< .05
E4	75.98	19.06	3.99	3, 62	----	< .05
E5	206.18	15.19	13.58	3, 62	----	< .05
E6	193.75	20.42	9.49	3, 62	----	< .05
E7	172.42	27.38	6.30	3, 62	----	< .05
R1	49.88	42.92	1.16	3, 62	----	NS
R2	154.12	37.19	4.14	3, 62	----	< .05
R3	114.04	25.45	4.48	3, 62	----	< .05

ANOVA summary table for Latency to Stage 1 Sleep in Minutes, Nonpathologically Sleepy Subjects Only

Source	MS effect	MS error	F-value	df	GGI	*p* value
Group	1054.54	65.37	16.13	3, 38	----	< .05
Day	113.50	20.13	5.64	10, 380	0.77	< .05
Time of Day	662.46	38.08	17.40	1, 38	----	< .05
Group x Day	71.28	20.13	3.54	30, 380	0.77	< .05
Group x Time of Day	269.27	38.08	7.07	3, 38	----	< .05
Day x Time of Day	19.94	15.96	1.25	10, 380	0.70	NS
Group x Day x Time of Day	17.52	15.96	1.10	30, 380	0.70	NS

Simple Main Effects Source - Day	MS effect	MS error	F-value	df	GGI	*p* value
3-hr group	57.42	20.13	2.85	10, 380	0.77	< .05
5-hr group	222.99	20.13	11.08	10, 380	0.77	< .05
7-hr group	19.69	20.13	0.98	10, 380	0.77	NS
9-hr group	46.12	20.13	2.29	10, 380	0.77	< .05

Simple Main Effects Source - Sleep Group	MS effect	MS error	F-value	df	GGI	*p* value
Baseline	46.09	34.44	1.34	3, 38	----	NS
E1	86.45	29.10	2.87	3, 38	----	NS
E2	273.09	13.77	19.83	3, 38	----	< .05
E3	228.49	33.30	6.86	3, 38	----	< .05
E4	102.86	20.29	5.07	3, 38	----	< .05
E5	173.34	12.52	13.84	3, 38	----	< .05
E6	143.16	17.02	8.41	3, 38	----	< .05
E7	143.15	21.81	6.56	3, 38	----	< .05
R1	200.29	33.84	5.92	3, 38	----	< .05
R2	221.07	33.29	6.64	3, 38	----	< .05
R3	152.38	17.28	8.82	3, 38	----	< .05

SOURCE TABLES FOR MICROSLEEP ANALYSIS: NUMBER OF MICROSLEEP EVENTS, DURATION OF MICROSLEEP, AND AMOUNT OF MICROSLEEP

ANOVA summary table for Microsleep Analysis – Number of Microsleep Events.

Source	MS	df_1	Df_2	MSe	F	*p*	G-G
Sleep Group	1.06	3	61	2.75	0.38	0.7650	--------
Day	0.56	10	610	0.42	1.34	0.2063	0.2185
Sleep Group x Day	0.37	30	610	0.42	0.88	0.6594	0.6420

ANOVA summary table for Microsleep Analysis – Duration of Microsleep.

Source	MS	df_1	Df_2	MSe	F	*p*	G-G
Sleep Group	0.74	3	61	1.43	0.52	0.6693	--------
Day	0.35	10	610	0.51	0.68	0.7399	0.7056
Sleep Group x Day	0.60	30	610	0.51	1.18	0.2392	0.2575

ANOVA summary table for Microsleep Analysis – Amount of Microsleep.

Source	MS	df_1	Df_2	MSe	F	*p*	G-G
Sleep Group	29.72	3	61	188.64	0.16	0.9244	--------
Day	39.20	10	610	23.88	1.64	0.0913	0.1215
Sleep Group x Day	26.80	30	610	23.88	1.12	0.3007	0.3206

SOURCE TABLES FOR SUBJECTIVE SLEEPINESS

ANOVA summary table for Stanford Sleepiness Scale – Sleepiness Score.

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	73.85	24.20	3.05	3, 56	-----	< .05
Day	4.09	0.62	6.58	10, 560	0.53	< .05
Time of Day	2.61	0.61	4.27	3, 168	0.77	< .05
Sleep Group x Day	2.75	0.62	4.42	30, 560	0.53	< .05
Sleep Group x Time of Day	1.46	0.61	2.39	9, 168	0.77	< .05
Day x Time of Day	0.41	0.23	1.79	30, 1680	0.49	< .05
Sleep Group x Day x Time of Day	0.24	0.23	1.03	90, 1680	0.49	NS

SOURCE TABLES FOR SERIAL ADDITION/SUBTRACTION: ACCURACY, SPEED, AND THROUGHPUT

ANOVA summary table for Serial Add/Subtract Task – Accuracy Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	4535.21	3	62	3194.88	1.42	0.2456	--------
Day	213.05	10	620	62.56	3.41	0.0002	0.0068
Sleep Group x Day	154.56	30	620	62.56	2.47	0.0000	0.0028
Time	45.54	3	186	29.12	1.56	0.1996	0.2036
Time x Sleep Group	17.29	9	186	29.12	0.59	0.8011	0.7858
Time x Day	59.69	30	1860	30.53	1.96	0.0015	0.0281
Time x Day x Sleep Group	39.91	90	1860	30.53	1.31	0.0305	0.1146

ANOVA summary table for Serial Add/Subtract Task – Speed Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	11562.66	3	62	8241.24	1.40	0.2504	--------
Day	1969.42	10	620	79.25	24.85	0.0000	0.0000
Sleep Group x Day	223.17	30	620	79.25	2.82	0.0000	0.0001
Time	140.76	3	186	38.90	3.62	0.0142	0.0159
Time x Sleep Group	40.18	9	186	38.90	1.03	0.4153	0.4145
Time x Day	1396.85	30	1860	57.84	24.15	0.0000	0.0000
Time x Day x Sleep Group	63.59	90	1860	57.84	1.10	0.2502	0.3119

ANOVA summary table for Serial Add/Subtract Task – Throughput Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	16893.47	3	62	9692.74	1.74	0.1677	--------
Day	1822.31	10	620	76.09	23.95	0.0000	0.0000
Sleep Group x Day	287.93	30	620	76.09	3.78	0.0000	0.0000
Time	178.79	3	186	35.66	5.01	0.0023	0.0027
Time x Sleep Group	28.81	9	186	35.66	0.81	0.6095	0.6042
Time x Day	1401.46	30	1860	54.20	25.86	0.0000	0.0000
Time x Day x Sleep Group	62.80	90	1860	54.20	1.16	0.1515	0.2341

Tukey's Studentized Range Test for Serial Add/Subtract Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	ACCURACY	SPEED	THROUGHPUT
Baseline	9 hr – 5 hr	n.s. among sleep groups	5 hr – 3 hr
Experiment 1	n.s. among sleep groups	9 hr – 5 hr	9 hr – 5 hr
Experiment 2	n.s. among sleep groups	9 hr – 5 hr 7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr
Experiment 3	9 hr – 5 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr
Experiment 4	9 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr 7 hr – 3 hr	9 hr – 5 hr 7 hr – 5 hr 7 hr – 3 hr
Experiment 5	9 hr – 5 hr 9 hr – 3 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr 7 hr – 3 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr 7 hr – 3 hr
Experiment 6	9 hr – 5 hr 9 hr – 3 hr 7 hr - 5 hr	9 hr – 5 hr 7 hr – 3 hr 7 hr – 3 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr 7 hr – 3 hr
Experiment 7	9 hr – 5 hr 9 hr – 3 hr 7 hr – 3 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr 7 hr – 3 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr 7 hr – 3 hr
Recovery 1	9 hr – 5 hr 9 hr – 3 hr	n.s. among sleep groups	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr 7 hr – 3 hr
Recovery 2	9 hr – 5 hr 9 hr – 3 hr	9 hr – 5 hr 7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr
Recovery 3	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr	7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr

Tukey's Studentized Range Test for Serial Add/Subtract Task

Significant Time of Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	ACCURACY	SPEED	THROUGHPUT
0900	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	n.s. among sleep groups	5 hr – 3 hr
1200	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr	9 hr – 5 hr	9 hr – 5 hr
1500	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr
2100	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr

SOURCE TABLES FOR WILKINSON 4-CHOICE: ACCURACY, SPEED, AND THROUGHPUT

ANOVA summary table for Wilkinson 4-Choice Task – Accuracy Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	251.44	3	62	87.79	2.86	0.0438	--------
Day	25.70	10	620	5.03	5.11	0.0000	0.0020
Sleep Group x Day	7.27	30	620	5.03	1.45	0.0603	0.1714
Time	2.22	1	62	1.71	1.30	0.2588	--------
Time x Sleep Group	3.34	3	62	1.71	1.95	0.1306	--------
Time x Day	2.38	10	620	1.94	1.22	0.2724	0.2940
Time x Day x Sleep Group	2.36	30	620	1.94	1.21	0.2044	0.2500

ANOVA summary table for Wilkinson 4-Choice Task – Speed Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	143716.81	3	62	23248.49	6.18	0.0010	--------
Day	14470.53	10	620	514.38	28.13	0.0000	0.0000
Sleep Group x Day	59336.73	30	620	514.38	3.33	0.0000	0.0010
Time	293.79	1	62	380.42	0.77	0.3829	--------
Time x Sleep Group	286.97	3	62	380.42	0.75	0.5240	--------
Time x Day	4861.45	10	620	233.54	20.82	0.0000	0.0000
Time x Day x Sleep Group	418.26	30	620	233.54	1.79	0.0064	0.0466

ANOVA summary table for Wilkinson 4-Choice Task – Throughput Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	143884.12	3	62	22202.18	6.48	0.0007	--------
Day	12216.64	10	620	499.10	24.48	0.0000	0.0000
Sleep Group x Day	1777.09	30	620	499.10	3.56	0.0000	0.0004
Time	235.54	1	62	384.71	0.61	0.4369	--------
Time x Sleep Group	276.57	3	62	384.71	0.72	0.2715	--------
Time x Day	4469.78	10	620	228.19	19.59	0.0000	0.0035
Time x Day x Sleep Group	427.83	30	620	228.19	1.87	0.0035	0.0328

Tukey's Studentized Range Test for Wilkinson 4-Choice Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	ACCURACY	SPEED	THROUGHPUT
Baseline	n.s. among sleep groups	5 hr – 3 hr	7 hr – 3 hr 5 hr – 3 hr
Experiment 1	n.s. among sleep groups	7 hr – 3 hr 5 hr – 3 hr	7 hr – 3 hr 5 hr – 3 hr
Experiment 2	n.s. among sleep groups	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 3	7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 4	n.s. among sleep groups	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 5	7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 6	9 hr – 5 hr 9 hr – 3 hr 7 hr - 5 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 7	9 hr – 3 hr 7 hr - 5 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 1	9 hr – 5 hr 7 hr - 5 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 2	9 hr – 5 hr 7 hr – 5 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 3	9 hr – 5 hr 7 hr – 5 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr

Tukey's Studentized Range Test for Wilkinson 4-Choice Task

Significant Time-of-Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	ACCURACY	SPEED	THROUGHPUT
1000	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
1600	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr

SOURCE TABLES FOR 10-CHOICE REACTION TIME: ACCURACY, SPEED, AND THROUGHPUT

ANOVA summary table for 10-Choice Reaction Time Task – Accuracy Measure.

Source	**MS**	**df_1**	**df_2**	**MSe**	**F**	***p***	**G-G**
Sleep Group	307.29	3	62	116.42	2.64	0.0573	--------
Day	26.07	10	620	12.14	2.15	0.0194	0.0628
Sleep Group x Day	24.23	30	620	12.14	2.00	0.0014	0.0170
Time	33.73	3	186	9.65	3.50	0.0167	0.0202
Time x Sleep Group	16.35	9	186	9.65	1.69	0.0929	0.1013
Time x Day	13.83	30	1860	9.13	1.51	0.0367	0.1459
Time x Day x Sleep Group	9.83	90	1860	9.13	1.08	0.2983	0.3660

ANOVA summary table for 10-Choice Reaction Time Task – Speed Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	8299.73	3	62	7640.19	1.09	0.3616	--------
Day	1671.30	10	620	54.69	30.56	0.0000	0.0000
Sleep Group x Day	201.46	30	620	54.69	3.68	0.9993	0.0000
Time	43.30	3	186	28.44	1.52	0.2102	0.2116
Time x Sleep Group	71.57	9	186	28.44	2.52	0.0096	0.0106
Time x Day	644.30	30	1860	36.98	17.42	0.0000	0.0000
Time x Day x Sleep Group	72.10	90	1860	36.98	1.95	0.0000	0.0002

ANOVA summary table for 10-Choice Reaction Time Task – Throughput Measure.

Source	**MS**	**df_1**	**df_2**	**MSe**	**F**	***p***	**G-G**
Sleep Group	9399.51	3	62	7623.67	1.23	0.3054	--------
Day	1626.90	10	620	62.52	26.02	0.0000	0.0000
Sleep Group x Day	250.53	30	620	62.52	4.01	0.0000	0.0000
Time	42.00	3	186	33.11	1.27	0.2866	0.2867
Time x Sleep Group	83.61	9	186	33.11	2.53	0.0094	0.0103
Time x Day	619.04	30	1860	37.89	16.34	0.0000	0.0000
Time x Day x Sleep Group	73.65	90	1860	37.89	1.94	0.0000	0.0002

Tukey's Studentized Range Test for 10-Choice Reaction Time Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	ACCURACY	SPEED	THROUGHPUT
Baseline	9 hr – 5 hr 5 hr – 3 hr	n.s. among sleep groups	n.s. among sleep groups
Experiment 1	n.s. among sleep groups	n.s. among sleep groups	n.s. among sleep groups
Experiment 2	n.s. among sleep groups	9 hr – 3 hr	9 hr – 3 hr
Experiment 3	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr
Experiment 4	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr
Experiment 5	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 6	9 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 7	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 1	9 hr – 3 hr	9 hr – 3 hr	9 hr – 3 hr
Recovery 2	9 hr – 5 hr 9 hr – 3 hr	n.s. among sleep groups	n.s. among sleep groups
Recovery 3	n.s. among sleep groups	n.s. among sleep groups	n.s. among sleep groups

Tukey's Studentized Range Test for 10-Choice Reaction Time Task

Significant Time-of-Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	ACCURACY	SPEED	THROUGHPUT
0900	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	n.s. among sleep groups	5 hr – 3 hr
1200	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr	9 hr – 5 hr	9 hr – 5 hr
1500	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr
2100	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr

SOURCE TABLES FOR PSYCHOMOTOR VIGILANCE (PVT): SPEED AND LAPSES

ANOVA summary table for Psychomotor Vigilance Task – Speed Measure.

Source	MS	df_1	df_2	Mse	F	*p*	G-G
Sleep Group	153.35	3	62	5.00	30.70	0.0000	--------
Day	12.06	10	620	1.26	9.58	0.0000	0.0000
Sleep Group x Day	5.35	30	620	1.26	4.25	0.0000	0.0000
Time	0.08	3	186	0.17	0.49	0.6920	0.6629
Time x Sleep Group	0.12	9	186	0.17	0.73	0.6773	0.6562
Time x Day	1.07	30	1860	0.19	5.62	0.0000	0.0000
Time x Day x Sleep Group	0.58	90	1860	0.19	3.04	0.0000	0.0000

ANOVA summary table for Psychomotor Vigilance Task – (LOG) Lapses Measure.

Source	MS	df_1	df_2	Mse	F	*p*	G-G
Sleep Group	256.09	3	62	6.23	41.13	0.0000	--------
Day	13.32	10	620	1.64	8.13	0.0000	0.0000
Sleep Group x Day	5.15	30	620	1.64	3.14	0.0000	0.0003
Time	0.01	3	186	0.35	0.02	0.9961	0.9949
Time x Sleep Group	0.26	9	186	0.35	0.75	0.6657	0.6584
Time x Day	1.69	30	1860	0.34	4.99	0.0000	0.0000
Time x Day x Sleep Group	0.93	90	1860	0.34	2.76	0.0000	0.0000

Tukey's Studentized Range Test for Psychomotor Vigilance Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	SPEED	(LOG) LAPSES
Baseline	n.s. among sleep groups	n.s. among sleep groups
Experiment 1	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 2	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 3	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 4	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 5	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 6	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 7	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 1	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 2	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 3	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr

Tukey's Studentized Range Test for Psychomotor Vigilance Task

Significant Time-of-Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	SPEED	(LOG) LAPSES
0930	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 5 hr 7 hr – 3 hr 5 hr – 3 hr
1230	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr
1530	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr 7 hr – 5 hr 5 hr – 3 hr
2130	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr

SOURCE TABLES FOR SYNTHETIC WORK TASK (SYNWORK): TOTAL SCORE

ANOVA summary table for Synthetic Work Task – Total Score Measure.

Source	SS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	7575267	3	62	5053254	1.50	0.2236	--------
Day	1397155	10	620	67839	20.60	0.0000	0.0000
Sleep Group x Day	358053	30	620	67839	5.28	0.0000	0.0000
Time	226337	3	186	50745	4.46	0.0047	0.0096
Time x Sleep Group	18138	9	186	50745	0.36	0.9536	0.9247
Time x Day	1093809	30	1860	42563	25.70	0.0000	0.0000
Time x Day x Sleep Group	68537	90	1860	42563	1.61	0.0003	0.0210

Tukey's Studentized Range Test for Synthetic Work Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	TOTAL SCORE
Baseline	9 hr – 7 hr
Experiment 1	9 hr – 7 hr
Experiment 2	n.s. among sleep groups
Experiment 3	9 hr – 7 hr 9 hr – 3 hr
Experiment 4	9 hr – 3 hr
Experiment 5	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 6	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 7	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 1	9 hr – 3 hr
Recovery 2	9 hr – 3 hr 9 hr – 5 hr
Recovery 3	n.s. among sleep groups

Tukey's Studentized Range Test for Synthetic Work Task

Significant Time-of-Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	TOTAL SCORE
0915	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr
1215	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr
1515	9 hr – 3 hr 9 hr – 5 hr 9 hr – 7 hr 7 hr – 3 hr 5 hr – 3 hr
2115	9 hr – 3 hr 9 hr – 7 hr 5 hr – 3 hr

SOURCE TABLES FOR SIMULATOR-DRIVING SPEED (55 mi/h AND 35 mi/h), LANE VARIABILITY, AND ACCIDENTS

ANOVA summary table for Simulator-Driving Task – Mean 55-mi/h Speed Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	1019.14	3	62	103.22	9.87	0.0000	--------
Day	73.62	10	620	8.95	8.22	0.0000	0.0000
Time	67.14	3	186	6.15	10.91	0.0000	0.0000
Day x Sleep Group	27.79	30	620	8.95	3.10	0.0000	0.0002
Time x Sleep Group	7.00	9	186	6.15	1.14	0.3383	0.3416
Day x Time	7.05	30	1860	3.70	1.61	0.0197	0.0899
Day x Time x Sleep Group	3.70	90	1860	4.38	0.84	0.8515	0.7218

ANOVA summary table for Simulator-Driving Task – Mean 55-mi/h Speed Measure.

Within-Group Comparisons.

Source	Sleep Group	MS	df_1	df_2	MSe	F	*p*
Day	9 Hour	8.9806	10	660	3.4440	2.61	0.0041
	7 Hour	8.5947	10	660	4.8095	1.79	0.0595
	5 Hour	4.8541	10	660	5.0040	0.97	0.4683
	3 Hour	142.0866	10	748	16.7106	8.50	0.0000
Time of day	9 Hour	5.9542	3	660	3.4440	1.73	0.1597
	7 Hour	19.7808	3	660	4.8095	4.11	0.0066
	5 Hour	26.0795	3	660	5.0040	5.21	0.0015
	3 Hour	38.1249	3	748	16.7106	2.28	0.0779
Day x Time of day	9 Hour	2.0141	30	660	3.4440	0.58	0.9635
	7 Hour	3.3143	30	660	4.8095	0.69	0.8945
	5 Hour	2.1465	30	660	5.0040	0.43	0.9970
	3 Hour	11.0903	30	748	16.7106	0.66	0.9161

ANOVA summary table for Simulator-Driving Task – Mean 35-mi/h Speed Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	11132.15	3	62	582.42	19.11	0.0000	--------
Day	625.08	10	620	40.04	15.61	0.0000	0.0000
Time	128.90	3	186	14.72	8.76	0.0000	0.0001
Day x Sleep Group	360.36	30	620	40.04	9.00	0.0000	0.0000
Time x Sleep Group	18.74	9	186	14.72	1.27	0.2539	0.2674
Day x Time	11.40	30	1860	13.18	0.86	0.6778	0.5754
Day x Time x Sleep Group	13.78	90	1860	13.18	1.05	0.3678	0.3999

ANOVA summary table for Simulator-Driving Task – Mean 35-mi/h Speed Measure.

Within-Group Comparisons.

Source	Sleep Group	MS	df_1	df_2	MSe	F	*p*
Day	9 Hour	19.7034	10	660	8.0138	2.46	0.0069
	7 Hour	8.5947	10	660	4.5851	1.14	0.3323
	5 Hour	65.8747	10	660	28.1012	2.34	0.0101
	3 Hour	1700.193	10	748	81.9901	20.74	0.0001
Time of day	9 Hour	9.7167	3	660	8.0138	1.21	0.3043
	7 Hour	4.6535	3	660	4.5851	1.01	0.3855
	5 Hour	88.5654	3	660	28.1012	3.15	0.0245
	3 Hour	86.8016	3	748	81.9901	1.06	0.3660
Day x Time of day	9 Hour	6.7565	30	660	8.0138	0.84	0.7082
	7 Hour	3.6176	30	660	4.5851	0.79	0.7834
	5 Hour	7.8782	30	660	28.1012	0.28	1.0000
	3 Hour	35.7536	30	748	81.9901	0.44	0.9966

Tukey's Studentized Range Test for Speed in Simulator-Driving Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	SPEED (55 mi/h)	SPEED (35 mi/h)
Baseline	n.s. among sleep groups	n.s. among sleep groups
Experiment 1	9 hr – 3 hr 7 hr – 3 hr	n.s. among sleep groups
Experiment 2	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr
Experiment 3	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 4	9 hr – 3 hr 7 hr – 3 hr 7 hr – 5 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 5	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 6	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 7	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr
Recovery 1	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 2	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr
Recovery 3	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr

Tukey's Studentized Range Test for Speed in Simulator-Driving Task

Significant Day Differences Within Sleep Groups ($p < .05$)

SLEEP GROUP	SPEED (55 mi/h)	SPEED (35 mi/h)
9 Hour	Baseline < Rec 3 Exp 2 < Rec 3	Exp 1,2,3,4 < Rec 3
7 Hour	n. s. differences between days	n. s. differences between days
5 Hour	Baseline < Rec 2 Exp 1 < Exp 3, Rec 2 Exp 2 < Rec 2	Baseline < Exp 7, Rec 2
3 Hour	Baseline < Exp 7, Rec 2,3 Exp 1,2 < Exp 7, Rec 2,3 Exp 4 < Exp 7, Rec 3 Exp 5,6 < Rec 3 Rec 1 < Rec 3	Baseline < Exp 3,4,5,6,7, Rec 1,2,3 Exp 1 < Exp 3,4,5,6,7, Rec 1,2,3 Exp 2 < Exp 4,5,6,7, Rec 1,2,3 Exp 3 < Exp 6, Rec 2,3 Exp 4 ,5 < Rec 3

Tukey's Studentized Range Test for Speed in Simulator-Driving Task

Significant Time-of-Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	SPEED (55 mi/h)	SPEED (35 mi/h)
0740	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr
1040	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr
1340	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr
1940	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr

Tukey's Studentized Range Test for Speed in Simulator-Driving Task

Significant Time-of-Day Differences Within Sleep Groups ($p < .05$)

SLEEP GROUP	SPEED (55 mi/h)	SPEED (35 mi/h)
9 Hour	n. s. differences between times	n. s. differences between times
7 Hour	n. s. differences between times	n. s. differences between times
5 Hour	n. s. differences between times	n. s. differences between times
3 Hour	1940 > 1340,1040,740	1940 > 740

ANOVA summary table for Simulator-Driving Task – Speed Variability Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	210.35	3	62	56.27	3.74	0.0155	--------
Day	14.40	10	620	4.93	2.92	0.0014	0.0050
Time	9.59	3	186	6.26	1.53	0.2074	0.2160
Segment	708.93	6	372	12.41	57.14	0.0000	0.0000
Day x Sleep Group	8.83	30	620	4.93	1.79	0.0064	0.0167
Time x Sleep Group	7.71	9	186	6.26	1.23	0.2771	0.2881
Segment x Sleep Group	31.80	18	372	12.41	2.56	0.0005	0.0056
Day x Time	6.73	30	1860	4.10	1.64	0.0155	0.0601
Day x Segment	8.80	60	3720	3.78	2.33	0.0000	0.0007
Time x Segment	10.92	18	1116	3.66	2.98	0.0000	0.0016
Day x Time x Sleep Group	4.50	90	1860	4.09	1.10	0.2483	0.3063
Day x Segment x Sleep Group	4.55	180	3720	3.78	1.20	0.0367	0.1381
Time x Segment x Sleep Group	3.98	54	1116	3.66	1.09	0.3129	0.3481
Day x Time x Segment	4.88	180	11160	3.60	1.36	0.0012	0.0994
Day x Time x Segment x Sleep Group	4.45	540	11160	3.60	1.24	0.0002	0.0737

ANOVA summary table for Simulator-Driving Task – Speed Variability Measure.

Within-Group Comparisons

Source	Sleep Group	MS	df_1	df_2	MSe	F	*p*
Day	9 Hour	1.5432	10	4620	2.8205	0.55	0.8574
	7 Hour	6.7529	10	4620	3.4895	1.94	0.0363
	5 Hour	3.3541	10	4620	3.8590	0.87	0.5617
	3 Hour	30.3863	10	5236	5.9682	5.09	0.0000
Time of day	9 Hour	10.7512	3	4620	2.8205	3.81	0.0096
	7 Hour	5.3443	3	4620	3.4895	1.53	0.2040
	5 Hour	12.5960	3	4620	3.8590	3.26	0.0204
	3 Hour	3.5751	3	5236	5.9682	0.60	0.6156
Segment	9 Hour	189.0480	6	4620	2.8205	67.03	0.0000
	7 Hour	265.9105	6	4620	3.4895	76.20	0.0000
	5 Hour	153.7573	6	4620	3.8590	39.84	0.0000
	3 Hour	191.7447	6	5236	5.9682	32.13	0.0000
Day x Time of day	9 Hour	4.3276	30	4620	2.8205	1.53	0.0315
	7 Hour	4.1625	30	4620	3.4895	1.19	0.2162
	5 Hour	5.1546	30	4620	3.8590	1.34	0.1045
	3 Hour	6.68062	30	5236	5.9682	1.12	0.2986
Day x Segment	9 Hour	4.5467	60	4620	2.8205	1.61	0.0020
	7 Hour	5.8681	60	4620	3.4895	1.68	0.0008
	5 Hour	4.2948	60	4620	3.8590	1.11	0.2573
	3 Hour	7.8631	60	5236	5.9682	1.32	0.0515
Time of day x Segment	9 Hour	3.2419	18	4620	2.8205	1.15	0.2959
	7 Hour	5.0320	18	4620	3.4895	1.44	0.1014
	5 Hour	10.5175	18	4620	3.8590	2.73	0.0001
	3 Hour	4.0399	18	5236	5.9682	0.68	0.8374
Day x Time of Day x Segment	9 Hour	4.1063	180	4620	2.8205	1.46	0.0001
	7 Hour	4.7120	180	4620	3.4895	1.35	0.0015
	5 Hour	3.9151	180	4620	3.8590	1.01	0.4337
	3 Hour	5.5379	180	5236	5.9682	0.93	0.7444

ANOVA summary table for Simulator-Driving Task – Mean Lane-Position Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	277.32	3	62	129.85	2.14	0.1047	--------
Day	13.75	10	620	1.79	7.67	0.0000	0.0000
Time	2.49	3	186	1.32	1.53	0.1327	0.1582
Segment	144.41	6	372	2.51	57.61	0.0000	0.0000
Day x Sleep Group	6.69	30	620	1.79	3.73	0.0000	0.0000
Time x Sleep Group	1.24	9	186	1.32	0.94	0.4907	0.4646
Segment x Sleep Group	3.28	18	372	2.51	1.31	0.1792	0.2229
Day x Time	0.78	30	1860	0.55	1.20	0.2097	0.2844
Day x Segment	0.50	60	3720	0.41	1.20	0.1398	0.2455
Time x Segment	0.53	18	1116	0.39	1.46	0.0971	0.1317
Day x Time x Sleep Group	0.55	90	1860	0.65	0.85	0.8341	0.6996
Day x Segment x Sleep Group	0.41	180	3720	0.42	0.98	0.5725	0.5264
Time x Segment x Sleep Group	0.39	54	1116	0.36	1.08	0.3309	0.3498
Day x Time x Segment	0.36	180	11160	0.38	0.94	0.7187	0.5565
Day x Time x Segment x Sleep Group	0.36	540	11160	0.38	0.93	0.8744	0.6529

ANOVA summary table for Simulator-Driving Task – Mean Lane-Position Measure.

Within-Group Comparisons.

Source	Sleep Group	MS	df_1	df_2	MSe	F	*p*
Day	9 Hour	0.3259	10	4620	0.5540	0.59	0.8249
	7 Hour	1.1748	10	4620	0.9603	1.22	0.2700
	5 Hour	7.9720	10	4620	1.0189	7.82	0.0000
	3 Hour	25.6702	10	5236	1.1631	22.07	0.0000
Time of day	9 Hour	0.0743	3	4620	0.5540	0.13	0.9397
	7 Hour	1.8233	3	4620	0.9603	1.90	0.1274
	5 Hour	0.8989	3	4620	1.0189	0.88	0.4494
	3 Hour	3.5476	3	5236	1.1631	3.05	0.0274
Segment	9 Hour	23.4567	6	4620	0.5540	42.34	0.0000
	7 Hour	24.7389	6	4620	0.9603	25.76	0.0000
	5 Hour	46.8774	6	4620	1.0189	46.01	0.0000
	3 Hour	61.5589	6	5236	1.1631	52.92	0.0000
Day x Time of day	9 Hour	0.2326	30	4620	0.5540	0.42	0.9978
	7 Hour	0.3422	30	4620	0.9603	0.36	0.9995
	5 Hour	0.6918	30	4620	1.0189	0.68	0.9061
	3 Hour	1.2083	30	5236	1.1631	1.04	0.4078
Day x Segment	9 Hour	0.2834	60	4620	0.5540	0.51	09994
	7 Hour	0.2742	60	4620	0.9603	0.29	1.0000
	5 Hour	0.4454	60	4620	1.0189	0.44	1.0000
	3 Hour	0.7743	60	5236	1.1631	0.64	0.9862
Time of day x Segment	9 Hour	0.2772	18	4620	0.5540	0.50	0.9594
	7 Hour	0.4567	18	4620	0.9603	0.48	0.9690
	5 Hour	0.3389	18	4620	1.0189	0.33	0.9962
	3 Hour	0.6463	18	5236	1.1631	0.56	0.9317
Day x Time of Day x Segment	9 Hour	0.2089	180	4620	0.5540	0.38	1.0000
	7 Hour	0.3067	180	4620	0.9603	0.32	1.0000
	5 Hour	0.3766	180	4620	1.0189	0.37	1.0000
	3 Hour	0.5488	180	5236	1.1631	0.47	1.0000

ANOVA summary table for Simulator-Driving Task – Lane-Position Variability Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	185.39	3	62	30.96	3.74	0.0012	--------
Day	7.68	10	620	0.74	10.44	0.0000	0.0000
Time	8.15	3	186	1.02	7.96	0.0001	0.0005
Segment	56.22	6	372	0.64	57.14	0.0000	0.0000
Day x Sleep Group	4.84	30	620	0.74	6.57	0.0000	0.0000
Time x Sleep Group	0.77	9	186	1.02	0.77	0.6407	0.5942
Segment x Sleep Group	2.61	18	372	0.64	4.08	0.0000	0.0005
Day x Time	0.58	30	1860	0.30	1.93	0.0019	0.0337
Day x Segment	0.28	60	3720	0.17	1.68	0.0009	0.0441
Time x Segment	0.50	18	1116	0.17	2.92	0.0000	0.0014
Day x Time x Sleep Group	0.41	90	1860	0.30	1.35	0.0186	0.0961
Day x Segment x Sleep Group	0.21	180	3720	0.17	1.27	0.0093	0.1028
Time x Segment x Sleep Group	0.13	54	1116	0.17	0.77	0.8836	0.8017
Day x Time x Segment	0.16	180	11160	0.15	1.08	0.2258	0.3620
Day x Time x Segment x Sleep Group	0.16	540	11160	0.15	1.07	0.1335	0.3287

ANOVA summary table for Simulator-Driving Task – Lane Position Variability Measure. Within-Group Comparisons.

Source	Sleep Group	MS	df_1	df_2	MSe	F	*p*
Day	9 Hour	0.4829	10	4620	0.1230	3.93	0.0000
	7 Hour	0.8938	10	4620	0.2257	3.96	0.0000
	5 Hour	3.991	10	4620	0.3092	12.91	0.0000
	3 Hour	17.7113	10	5236	0.5384	32.89	0.0000
Time of day	9 Hour	3.9397	3	4620	0.1230	32.03	0.0000
	7 Hour	3.3619	3	4620	0.2257	14.89	0.0000
	5 Hour	2.1976	3	4620	0.3092	7.11	0.0001
	3 Hour	0.7020	3	5236	0.5384	1.30	0.2712
Segment	9 Hour	5.1098	6	4620	0.1230	41.54	0.0000
	7 Hour	13.0298	6	4620	0.2257	57.72	0.0000
	5 Hour	15.6318	6	4620	0.3092	50.56	0.0000
	3 Hour	31.7722	6	5236	0.5384	59.01	0.0000
Day x Time of day	9 Hour	0.0538	30	4620	0.1230	0.44	0.9967
	7 Hour	0.3227	30	4620	0.2257	1.43	0.0607
	5 Hour	0.3517	30	4620	0.3092	1.14	0.2769
	3 Hour	1.1225	30	5236	0.5384	2.85	0.0005
Day x Segment	9 Hour	0.0591	60	4620	0.1230	0.48	09998
	7 Hour	0.1112	60	4620	0.2257	0.49	0.9997
	5 Hour	0.2251	60	4620	0.3092	0.73	0.9431
	3 Hour	0.5466	60	5236	0.5384	1.02	0.4436
Time of day x Segment	9 Hour	0.2442	18	4620	0.1230	1.99	0.0078
	7 Hour	0.1666	18	4620	0.2257	0.74	0.7739
	5 Hour	0.2163	18	4620	0.3092	0.70	0.8148
	3 Hour	0.2576	18	5236	0.5384	048	0.9678
Day x Time of Day x Segment	9 Hour	0.0783	180	4620	0.1230	0.64	1.0000
	7 Hour	0.0867	180	4620	0.2257	0.38	1.0000
	5 Hour	0.1927	180	4620	0.3092	0.62	1.0000
	3 Hour	0.2953	180	5236	0.5384	0.55	1.0000

Tukey's Studentized Range Test for Simulator-Driving Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	SPEED VARIABILITY	MEAN LANE POSITION	LANE POSITION VARIABILITY
Baseline	n.s. among sleep groups	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr
Experiment 1	n.s. among sleep groups	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 7 hr – 5 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 5 hr 7 hr – 5 hr
Experiment 2	9 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr 7 hr – 5 hr
Experiment 3	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr 7 hr – 5 hr
Experiment 4	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr 7 hr – 5 hr
Experiment 5	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr 7 hr – 5 hr
Experiment 6	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr 7 hr – 5 hr
Experiment 7	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr 7 hr – 5 hr
Recovery 1	n.s. among sleep groups	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 5 hr	9 hr – 3 hr 7 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr
Recovery 2	9 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 5 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr
Recovery 3	9 hr – 3 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 5 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 7 hr 9 hr – 5 hr

Tukey's Studentized Range Test for Simulator-Driving Task

Significant Time-of-Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	SPEED VARIABILITY	MEAN LANE POSITION	LANE POSITION VARIABILITY
0900	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	n.s. among sleep groups	5 hr – 3 hr
1200	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr	9 hr – 5 hr	9 hr – 5 hr
1500	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr	9 hr – 5 hr 7 hr – 5 hr
2100	9 hr – 7 hr 9 hr – 5 hr 9 hr – 3 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr	9 hr – 5 hr 9 hr – 3 hr 7 hr – 5 hr

Tukey's Studentized Range Test for Simulator-Driving Task

Significant Day Differences Within Sleep Groups ($p < .05$)

SLEEP GROUP	SPEED VARIABILITY	MEAN LANE POSITION	LANE POSITION VARIABILITY
9 Hour	n.s. between days	n.s. between days	Baseline < Exp 2, 3, 4, 5, 6, 7, R1, R2, R3
7 Hour	n.s. between days	n.s. between days	Baseline, Exp 1, 2, 3, 4, 5 < Exp 6,7, R1,R2,R3
5 Hour	n.s. between days	Baseline, Exp 1, 2, 3, 4, R1,R2,R3 < Exp 5,6,7	Baseline < Exp 2, 3, 4, 5, 6, 7, R1, R2, R3 Exp 1,2,3,4,R1,R2,R3 < Exp 5,7
3 Hour	Baseline < Exp 3,4,5,6,7	Baseline < Exp 2, 3, 4, 5, 6, 7, R1, R2, R3 Exp 1,2,R1,R2,R3 < Exp 5,7	Baseline < Exp 2, 3, 4, 5, 6, 7, R2, R3 Exp 1, R1 <, Exp 3,4,5,6,7 Exp 2,R2,R3 < Exp 5,6,7 Exp 3, 4 < Exp 5, 7

Tukey's Studentized Range Test for Simulator-Driving Task

Significant Time-of-Day Differences Within Sleep Groups ($p < .05$)

TIME OF DAY	SPEED VARIABILITY	MEAN LANE POSITION	LANE POSITION VARIABILITY
9 Hour	740 < 1040, 1340	n. s. between time of day	740, 1040, 1340 < 1940
7 Hour	n. s. between time of day	n. s. between time of day	740, 1040, 1940 < 1340
5 Hour	740, 1040, 1340 < 1940	n. s. between time of day	740, 1940 < 1340
3 Hour	n. s. between time of day	740 < 1040, 1340, 1940	n. s. between time of day

Tukey's Studentized Range Test for Simulator-Driving Task

Significant Segments Differences Within Sleep Groups ($p < .05$)

TIME OF DAY	SPEED VARIABILITY	MEAN LANE POSITION	LANE POSITION VARIABILITY
9 Hour	Seg 2, 4 < Seg 1, 5, 6, 7 Seg 3 < 1, 6, 7	Seg 3 < Seg 1,2,4,5, 6, 7 Seg 1, 5 < Seg 4, 6, 7 Seg 2, 4 < 6, 7	Seg 1,2,3,4,5 < Seg 6,7 Seg 5 < Seg 1 2, 3, 4
7 Hour	Seg 2 < Seg 1, 5, 6, 7 Seg 3, 4, 5 < Seg 1, 6, 7 Seg 1, 7 < 6	Seg 1,2,3, 4,5,6 < Seg 7 Seg 1, 3 < 4, 6	Seg 1,2,3,4,5,6 < Seg 7 Seg 1,2,3, 4,5 < Seg 6 Seg 1,2,3,4 < Seg 5 Seg 1,2,3 < Seg 4
5 Hour	Seg 1,2,3,4,5,7 < Seg 6 Seg 2, 4 < Seg 1, 3, 5, 7 Seg 5 < Seg 1,7 Seg 3 < Seg 7	Seg 1,2,3,4,5,6 < Seg 7 Seg 1, 3 < Seg 4, 6 Seg 2, 5 < Seg 6	Seg 1,2,3,4,5,6 < Seg 7 Seg 1 < Seg 4, 5, 6 Seg 2, 3, 4 < Seg 5, 6
3 Hour	Seg 2, 4 < Seg 1,3,5, 6, 7 Seg 1 < Seg 3, 6, 7 Seg 5 < 6	Seg 1, 3 < Seg 2,4,5, 6, 7 Seg 2, 4 < Seg 5, 6, 7 Seg 5, 6 < 7	Seg 1 < Seg 2,3,4,5,6 ,7 Seg 2, 3, 4 < Seg 5, 6, 7 Seg 2 < Seg 4

ANOVA summary table for Simulator-Driving Task – Number of Accidents Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	4.90	3	61	0.72	6.75	0.0005	--------
Day	0.63	10	610	0.12	5.18	0.0000	0.0000
Sleep Group x Day	0.27	30	610	0.12	2.20	0.0003	0.0021
Time	0.10	3	183	0.09	1.16	0.3249	0.3235
Time x Sleep Group	0.18	9	183	0.09	2.09	0.0321	0.0373
Time x Day	0.15	30	1830	0.10	1.55	0.0286	0.0762
Time x Day x Sleep Group	0.13	90	1830	0.10	1.38	0.0125	0.0490

Tukey's Studentized Range Test for Number of Accidents in Simulator-Driving Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	NUMBER OF ACCIDENTS
Baseline	n.s. among sleep groups
Experiment 1	9 hr – 5 hr
Experiment 2	n.s. among sleep groups
Experiment 3	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 4	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 5	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 5 hr
Experiment 6	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Experiment 7	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
Recovery 1	n.s. among sleep groups
Recovery 2	n.s. among sleep groups
Recovery 3	n.s. among sleep groups

Tukey's Studentized Range Test for Number of Accidents in Simulator-Driving Task

Significant Day Differences Within Sleep Groups ($p < .05$)

SLEEP GROUP	NUMBER OF ACCIDENTS
9 Hour	n. s. differences between days
7 Hour	n. s. differences between days
5 Hour	n. s. differences between days
3 Hour	Baseline, Exp 1, 2, Rec 1, 2, 3 < Exp 3,4,5,6,7 Exp 3,4,6,7 < Exp 5 Exp 3,4,6 < Exp 7 Exp 3,4, < Exp 6

Tukey's Studentized Range Test for Number of Accidents in Simulator-Driving Task

Significant Time-of-Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	NUMBER OF ACCIDENTS
0740	9 hr – 3 hr 5 hr – 3 hr
1040	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
1340	9 hr – 3 hr 7 hr – 3 hr
1940	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr 9 hr – 5 hr

Tukey's Studentized Range Test for Number of Accidents in Simulator-Driving Task

Significant Time-of-Day Differences Within Sleep Groups ($p < .05$)

SLEEP GROUP	NUMBER OF ACCIDENTS
9 Hour	1340 > 1040, 740, 1940
7 Hour	n. s. differences between times
5 Hour	1340, 1940 > 740
3 Hour	1940, 1340 > 740

SOURCE TABLES FOR OCULOMOTOR FIT TEST: PUPIL DIAMETER AND SACCADIC VELOCITY

ANOVA summary table for Oculomotor (FIT) Task – Pupil Diameter (Ratio to Baseline) Measure.

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	0.1323	3	53	0.2730	0.48	0.6944	--------
Day	0.0202	10	530	0.0208	0.97	0.4699	0.4404
Sleep Group x Day	0.0216	30	530	0.0208	1.04	0.4149	0.4178
Time	0.0031	5	265	0.0035	0.88	0.4947	0.4825
Time x Sleep Group	0.0029	15	265	0.0035	0.84	0.6292	0.6136
Time x Day	0.0062	50	2650	0.0050	1.24	0.1193	0.2591
Time x Day x Sleep Group	0.0040	150	2650	0.0050	0.79	0.9687	0.7823

ANOVA summary table for Oculomotor (FIT) Task – Pupil Diameter (Ratio to Baseline) Measure, Within-Group Comparisons.

Source	Sleep Group	MS	df_1	df_2	MSe	F	*p*
Day	9 Hour	0.0039	10	857	0.0103	0.37	0.9580
	7 Hour	0.0055	10	792	0.0092	0.60	0.8137
	5 Hour	0.0129	10	858	0.0157	0.82	0.6073
	3 Hour	0.0361	10	990	0.0101	3.58	0.0001
Time of day	9 Hour	0.0282	5	857	0.0103	2.74	0.0184
	7 Hour	0.0253	5	792	0.0092	2.75	0.0178
	5 Hour	0.0378	5	858	0.0157	2.41	0.0352
	3 Hour	0.0324	5	990	0.0101	3.22	0.0069
Day x Time of day	9 Hour	0.0028	50	857	0.0103	0.28	1.0000
	7 Hour	0.0024	50	792	0.0092	0.27	1.0000
	5 Hour	0.0033	50	858	0.0157	0.21	1.0000
	3 Hour	0.0032	50	990	0.0101	0.32	1.0000

ANOVA summary table for Oculomotor (FIT) Task – Saccadic Velocity Measure (Ratio to Baseline).

Source	MS	df_1	df_2	MSe	F	*p*	G-G
Sleep Group	0.4733	3	53	0.1032	4.59	0.0063	--------
Day	0.0354	10	530	0.0350	1.01	0.4343	0.4168
Sleep Group x Day	0.0226	30	530	0.0350	0.64	0.9291	0.8530
Time	0.0072	5	265	0.0066	1.09	0.3656	0.3642
Time x Sleep Group	0.0047	15	265	0.0066	0.72	0.7607	0.7468
Time x Day	0.0155	50	2650	0.0086	1.81	0.0005	0.0233
Time x Day x Sleep Group	0.0101	150	2650	0.0086	1.18	0.0677	0.1827

ANOVA summary table for Oculomotor (FIT) Task – Saccadic Velocity Measure (Ratio to Baseline), Within-Group Comparisons.

Source	Sleep Group	MS	df_1	df_2	MSe	F	*p*
Day	9 Hour	0.0071	10	857	0.0119	0.60	0.8179
	7 Hour	0.0137	10	792	0.0151	0.91	0.5213
	5 Hour	0.4586	10	858	0.0128	1.68	0.0815
	3 Hour	0.0508	10	990	0.0155	3.28	0.0003
Time of day	9 Hour	0.0609	5	857	0.0119	5.12	0.0001
	7 Hour	0.0846	5	792	0.0151	5.61	0.0000
	5 Hour	0.0098	5	858	0.0128	0.77	0.5744
	3 Hour	0.0168	5	990	0.0155	1.08	0.3683
Day x Time of day	9 Hour	0.0059	50	857	0.0119	0.49	0.9988
	7 Hour	0.0088	50	792	0.0151	0.58	0.9911
	5 Hour	0.0068	50	858	0.0128	0.53	0.9971
	3 Hour	0.0122	50	990	0.0155	0.79	0.8577

Tukey's Studentized Range Test for Oculomotor (FIT) Task

Significant Day Differences Between Sleep Groups ($p < .05$)

DAY	PUPIL DIAMETER	SACCADIC VELOCITY
Baseline	n.s. among sleep groups	n.s. among sleep groups
Experiment 1	n.s. among sleep groups	7 hr – 3 hr
Experiment 2	5 hr – 3 hr	7 hr – 3 hr
Experiment 3	n.s. among sleep groups	n.s. among sleep groups
Experiment 4	9 hr – 5 hr 9 hr – 3 hr	n.s. among sleep groups
Experiment 5	n.s. among sleep groups	7 hr – 3 hr
Experiment 6	n.s. among sleep groups	7 hr – 3 hr
Experiment 7	n.s. among sleep groups	9 hr – 3 hr 7 hr – 3 hr
Recovery 1	n.s. among sleep groups	n.s. among sleep groups
Recovery 2	n.s. among sleep groups	n.s. among sleep groups
Recovery 3	n.s. among sleep groups	n.s. among sleep groups

Tukey's Studentized Range Test for Oculomotor Task

Significant Day Differences Within Sleep Groups ($p < .05$)

SLEEP GROUP	PUPIL DIAMETER	SACCADIC VELOCITY
9 Hour	n. s. differences between days	n. s. differences between days
7 Hour	n. s. differences between days	n. s. differences between days
5 Hour	n. s. differences between days	n. s. differences between days
3 Hour	Exp 3,5,7 < Rec 2,3	Baseline > Exp 7

Tukey's Studentized Range Test for Oculomotor (FIT) Task

Significant Time-of-Day Differences Between Sleep Groups ($p < .05$)

TIME OF DAY	PUPIL DIAMETER	SACCADIC VELOCITY
0735	7 hr – 5 hr	9 hr – 3 hr 7 hr – 3 hr 5 hr – 3 hr
1030	7 hr – 9 hr 7 hr – 5 hr 7 hr – 3 hr	9 hr – 3 hr 7 hr – 3 hr
1330	n. s. differences between groups	7 hr – 3 hr
1630	9 hr – 7 hr 9 hr – 5 hr 9hr – 3 hr	7 hr – 3 hr
1930	9 hr – 5 hr	n. s. differences between groups
2145	9 hr – 7 hr	7 hr – 3 hr

Tukey's Studentized Range Test for Oculomotor (FIT) Task

Significant Time-of-Day Differences Within Sleep Groups ($p < .05$)

SLEEP GROUP	PUPIL DIAMETER	SACCADIC VELOCITY
9 Hour	1330 > 1630	n. s. differences between times
7 Hour	1030 > 1630	n. s. differences between times
5 Hour	1330 > 735	n. s. differences between times
3 Hour	1630 > 1930	n. s. differences between times

SOURCE TABLES FOR HEALTH MEASURES: TYMPANIC TEMPERATURE, HEART RATE, SYSTOLIC BLOOD PRESSURE, DIASTOLIC BLOOD PRESSURE

ANOVA summary table for tympanic temperature – degrees in Celcius

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	6.97	8.77	0.79	3, 62	----	NS
Day	0.75	0.22	3.35	10, 620	0.66	< .05
Time of Day	36.88	0.30	122.72	4, 248	0.84	< .05
Sleep Group x Day	0.69	0.22	3.06	30, 620	0.66	< .05
Sleep Group x Time of Day	0.58	0.30	1.95	12, 248	0.84	< .05
Day x Time of Day	0.23	0.14	1.64	40, 2480	0.44	0.05
Sleep Group x Day x Time of Day	0.21	0.14	1.52	120, 2480	0.44	< .05

ANOVA summary table for heart rate – beats per minute

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	15676.14	2916.74	5.37	3, 62	----	< .05
Day	293.00	65.54	4.47	10, 620	0.70	< .05
Time of Day	5780.29	130.97	44.13	4, 248	0.69	< .05
Sleep Group x Day	65.88	65.54	1.01	30, 620	0.70	NS
Sleep Group x Time of Day	262.02	130.97	2.00	12, 248	0.69	0.05
Day x Time of Day	52.61	33.56	1.57	40, 2480	0.56	< .05
Sleep Group x Day x Time of Day	44.20	33.56	1.32	120, 2480	0.44	0.05

ANOVA summary table for systolic blood pressure – millimeters Hg

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	2571.89	5671.52	0.45	3, 62	----	NS
Day	417.45	122.66	3.40	10, 620	0.78	< .05
Time of Day	2342.84	123.64	18.95	4, 248	0.85	< .05
Sleep Group x Day	145.99	122.66	1.19	30, 620	0.78	NS
Sleep Group x Time of Day	207.03	123.64	1.67	12, 248	0.85	0.09
Day x Time of Day	70.50	82.81	0.85	40, 2480	0.60	NS
Sleep Group x Day x Time of Day	78.07	82.81	0.94	120, 2480	0.60	NS

ANOVA summary table for diastolic blood pressure – millimeters Hg

Source	MS effect	MS error	F-value	df	GGI	*p* value
Sleep Group	2134.88	2410.10	0.89	3, 62	----	NS
Day	46.58	43.84	1.06	10, 620	0.67	NS
Time of Day	614.01	46.21	13.29	4, 248	0.86	< .05
Sleep Group x Day	58.64	43.84	1.34	30, 620	0.67	NS
Sleep Group x Time of Day	11.24	46.21	0.24	12, 248	0.86	NS
Day x Time of Day	27.85	32.11	0.87	40, 2480	0.59	NS
Sleep Group x Day x Time of Day	33.09	32.11	1.03	120, 2480	0.59	NS

APPENDIX 5: PHASE 1 RECRUITMENT AND STUDY FORMS

PHASE 1 RECRUITMENT - TELEPHONE SCREENING CHECKLIST

Subject Name: _____

Caller Name: _____

Today's Date: _____/_____/_____

The attached questionnaire should be obtained after reciting to the caller the following statements:

The goal of this study is to get a general picture of the sleep habits of truckers, in particular, how they use their on and off duty time to obtain sleep. This information will be used to do further research on ways to effectively plan off-duty sleep, perhaps leading to improved regulations that currently limit on-duty time schedules. If you are asked and choose to participate, you will be mailed a more detailed questionnaire on your medical history, sleep habits, and more detailed instructions. You will also receive a volunteer consent form, and be mailed a wristwatch-like sleep recorder that you will wear for 20 continuous days. During that entire time, each day you will fill out a daily sleep log and a on-duty activity log. Payment for completing the project will be $300.

I am going to ask you several questions which are of a personal nature, and for the purpose of screening prospective candidates for this study. Please understand that your answer, which I am writing down, will be held in absolute confidence by the army. The questionnaire I am completing here will be filed in Dr. Redmond's office, and if you eventually do not participate in the study, it will be destroyed. If you do participate, it will become part of the study records, and be protected in confidence like any medical record.

Certain conditions may preclude your participation in this study, in particular, serious medical diseases, regular use of medications that affect sleep, or the presence of serious sleep disorders. To some extent, we are trying to balance certain factors in this study, in particular, between long haul drivers and short haul drivers. The following questions will help us decide if we should proceed with study in your case. Likewise, if you have any questions as we go along, feel free to ask, and I will do my best to find the answer for you.

TELEPHONE SCREENING CHECKLIST, Continued

Do you have a CDL? YES NO

Are you a Long Haul Driver ( ) Or Short Haul Driver ( ) ?

Telephone Number: Work: _____
Home: _____

Home Address: _____
(Street)

_____
(City) (State) (Zip)

What is your date of birth? _____/ _____/ _____
Month Day Year

What is your age? _____ (MUST BE 21-65 YEARS OF AGE)
(make sure that age matches with date of birth)

Are you an employee of the federal government or are you on active military duty?
YES NO

Do you smoke? YES NO If yes, how many packs per day? _____

Do you chew tobacco? YES NO If yes, what and how much? _____

How many cups of caffeinated coffee (___), tea (___), or cans of soda (___) do you drink a day, on the average?

How much alcohol do you normally drink in a week? _____

Have you ever had trouble with alcohol? YES NO

Do you have a current illness of any type? YES NO
If yes, what? _____

Are you currently on prescription medications of any type? YES NO
If yes, what? What for? _____

Are you currently taking over-the-counter medications of any type? YES NO
If yes, what? What for? _____

TELEPHONE SCREENING CHECKLIST, Continued

What is your height (ft/in)_____ and weight (lbs.) _____ ?

How many hours do you usually sleep each day?_____

Do you have any difficulty with sleep? YES NO
If yes, what kind? Medications?

Do you have or have you had significant illness (requiring regular medical attention or Hospitalization) as follows:
(Y-yes, N-no, D-don't know)
IF YES: GET DETAILS OF EVENT; THE YEAR, WHEN IT HAPPENED, AND MEDICATION IF ANY.

Y N D…..A head injury with loss of consciousness?
Y N D…..Frequent or sever headaches? (which kind?)
Y N D…..Dizziness or fainting spell?
Y N D…..Asthma, shortness of breath or lung trouble?
Y N D…..Heart trouble of any kind? (which kind?)
Y N D…..High or low blood pressure? (which one?)
Y N D…..Epilepsy, fits, or seizures?
Y N D…..Depression, panic, or anxiety?
Y N D…..Mental health problems of any kind?
Y N D…..Taken antidepressants or sleep medications?
Y N D…..Been hospitalized for injury or illness?
If yes, details:

DISPOSITION:

1. Call back for more information.

2. Set Appointment.

   DATE: _____ TIME: ___:___AM PM PLACE: _____

3. Excluded from the study for the following reason(s): _____

VOLUNTEER AGREEMENT AFFIDAVIT

For use of this form, see AR 70-25 or AR 40-38; the proponent agency is OTSG.

PRIVACY ACT OF 1974

Authority:	10 USC 3013, 44 USC 3101, and 10 USC 1071-1087
Principal Purpose:	To document voluntary participation in the Clinical Investigation and Research Program. SSN and home address will be used for identification and locating purposes.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the study will be used to document the study; implementation of medical programs; adjudication of claims; and for the mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this investigational study.

PART A — VOLUNTEER AFFIDAVIT

Volunteer Subjects in Approved Department of the Army Research Studies

Volunteers under the provisions of AR 40-38 and AR 70-25 are authorized all necessary medical care for injury or disease which is the proximate result of their participation in such studies.

I, _____ SSN _____,

having full capacity to consent and having attained my _____ birthday, do hereby volunteer to participate in A Dose/Response Study of Sleep and Wakefulness. Phase I: Actigraphic Assessment of CMV Drivers over Twenty Consecutive Days.
(Research study)

under the direction of Daniel P. Redmond, M.D.

conducted at Dept. of Behavioral Biology, Division of Neuropsychiatry, Walter Reed Army Institute of Research, Washington, DC 20307-5100 *(Name of institution)* phone: (301) 427-5521

The implications of my voluntary participation; duration and purpose of the research study; the methods and means by which it is to be conducted; and the inconveniences and hazards that may reasonably be expected have been explained to me by

Daniel P. Redmond, M.D. or qualified representative

I have been given an opportunity to ask questions concerning this investigational study. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or study-related injury, I may contact

Command Judge Advocate, U.S. Army Medical Research and Development Command

at Fort Detrick, Frederick, MD 21702-5012 (301)619-2065; DSN 343-2065
(Name, Address and Phone number — include Area Code)

I understand that I may at any time during the course of the study revoke my consent and withdraw from the study without further penalty or loss of benefits; however I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of the attending physician, such examinations are necessary for my health and well-being. My refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled.

ACTIGRAPHIC ASSESSMENT OF CMV DRIVERS OVER 20 CONSECUTIVE DAYS

PART B – TO BE COMPLETED BY INVESTIGATOR

INSTRUCTIONS FOR ELEMENTS OF INFORMED CONSENT: *(Provide a detailed explanation in accordance with Appendix C, AR 40-38 or AR 70-25.)*

You are asked to volunteer for a research study which will collect information regarding how much time you sleep over a 20-day period. Should you choose to volunteer, your participation will help determine how much off-duty time that commercial motor vehicle (CMV) drivers spend sleeping. After you read the following description of what will happen, we will discuss the entire procedure. As you read this consent form, if you are unsure about anything, please ask questions.

It is important that you understand that:

a. **YOUR PARTICIPATION IS COMPLETELY VOLUNTARY** and that you may withdraw from the study at any time without penalty or loss of benefits to which you are otherwise entitled.
b. Your participation in this study may be of no direct benefit to you, but knowledge gained by your participation may help others.

Information on monetary compensation for this study is found further below, in the section entitled "PAYMENT."

PROCEDURE

You must be between 21 and 65 years old to be considered for participation. Also, you must hold a valid CMV operator's license, and be currently employed only as a CMV driver. We must ensure that you are in good health. You will fill out some forms to gather background information. Every effort will be made to keep the results as confidential as possible, within the limits of the law.

In this study, you will be asked to wear a wrist-worn activity/sleep monitor ("actigraph") for 20 continuous days. The actigraph is about the size of a wrist watch, and is worn on the wrist. The actigraphs record the movements of your body during waking and sleep, and these movements are translated into sleep time and wake time. You will receive 1 actigraph today. You will wear this actigraph continuously for the first 10 days of your participation. On the 10th day, you will return here (Building 189, Walter Reed Army Institute of Research), to return the first actigraph and immediately put on the second one, wearing it for the next 10 days. At the end of the second 10-day period, you will again return to turn in the second actigraph. You will be given the exact dates for wearing and switching the actigraphs before you leave the laboratory today.

You should wear the actigraph during sleeping and all waking activities (except while showering, bathing, or swimming etc.), and always on the same wrist. You should not take the actigraph off for any other reason, for example, to engage in recreational sports. If you must remove the actigraph, you must call this laboratory and notify a technician of the circumstances.

As part of this study, you will also be asked to keep a "sleep diary." The sleep diary is a series of questions about when you awakened and went to sleep each day, how much caffeine and alcohol you consumed that day, etc. You will record these answers on a form each day, for the 20 days of the study. Also, you must provide a certified copy of your driving log book covering the 20 days that you wore the actigraph. You must return your sleep diary and copy of log book to the laboratory, along with the actigraph.

POSSIBLE RISKS, INCONVENIENCES, AND SIDE EFFECTS

If you are not currently in good mental and/or physical health, or if you have a history of sleep disorders including narcolepsy (inability to stay awake during your normal waking hours), sleep apnea (repeated, disruptive pauses in breathing during sleep), nocturnal myoclonus (repeated, disruptive leg movements during sleep), sleep/wake cycle disorders, you should not participate in this study. For your own safety, you must tell the person conducting this screening visit today of any medical or psychiatric problems you now have, or have had in the past, no matter how minor.

There are no known risks associated with wearing the actigraph or filling out the sleep diary.

Should you participate, you are authorized all necessary medical care for injury or disease that is a proximate result of your participation in this research study.

PAYMENT

If you complete the study and follow all instructions outlined in this consent form, you will be paid $300.00. Your participation is completely voluntary, and you may withdraw at any time without penalty or loss of benefits to which you are otherwise entitled. However, if you withdraw (drop out) from the study once it has begun, or are withdrawn by the investigator once it has begun because you did not follow study procedures, and/or you withheld any kind of information, you will be paid $5.00 per day for any time you completed in the study, but you will not be eligible for the $300.00. After you have completed the study, if it is determined that you did not wear the actigraphs for any part of the 20-day study (other than time you specifically notified us of), and/or information in your sleep diary or log book were falsified, you will be notified and paid a flat fee of $100.00 for completing the study but you will not be eligible for the $300.00.

If the investigator determines that you are ineligible for any reason before you participate, or you cannot participate for any other reason, you will not be paid for your time during the screening visit.

ACTIGRAPHIC ASSESSMENT OF CMV DRIVERS OVER 20 CONSECUTIVE DAYS

CONFIDENTIALITY

All data are considered private and confidential, and observations, responses, and other personal data are coded so that personal identification is not possible. Representatives of the U.S. Army Medical Research and Development Command and the Federal Highway Administration may inspect the records of this research. Information found on USAMRDC Form 60-R (Volunteer Registry Data form) will be stored at the U.S. Army Medical Research and Development Command for future notification purposes.

You will receive a copy of this consent form for your own records.

I do ☐ do not ☐ (check one & initial) consent to the inclusion of this form in my outpatient medical treatment record.

SIGNATURE OF VOLUNTEER	DATE
PERMANENT ADDRESS OF VOLUNTEER	TYPED NAME OF WITNESS
	SIGNATURE OF WITNESS / DATE

REVERSE OF SUBSTITUTE DA FORM 5303-R, FEB 92

WALTER REED ARMY INSTITUTE OF RESEARCH
PRELIMINARY SLEEP QUESTIONNAIRE

Please answer all of the following questions and bring this questionnaire with you to your appointment.

Name: _____ Date: _____

I. GENERAL SLEEP

Using the following rating scale, to what extent do you currently experience the following?

	None					Moderate				Severe
Daytime Sleepiness	1	2	3	4	5	6	7	8	9	10
Snoring or Other Breathing-Related	1	2	3	4	5	6	7	8	9	10
Difficulty Falling Asleep	1	2	3	4	5	6	7	8	9	10
Difficulty Staying Asleep	1	2	3	4	5	6	7	8	9	10
Walking, Talking, or Other Unusual Behaviors During Sleep	1	2	3	4	5	6	7	8	9	10
Daytime Deficits in Concentration, Memory, Motivation or Mood	1	2	3	4	5	6	7	8	9	10
Obtain too Little Sleep	1	2	3	4	5	6	7	8	9	10
Obtain too Much Sleep	1	2	3	4	5	6	7	8	9	10

Do any of the following factors typically affect (either positively or negatively) your level of daytii sleepiness, or the quality of your nighttime sleep? (Circle the ones that apply)

any type of food	a specific food	coffee
tea	sodas (e.g. cola)	alcohol
physical exercise	mental stress	anxiety/worry
physical fatigue	daytime nap	daytime rest

types of weather	heat	cold
noise	shift work	seasons
air travel	unfamiliar bed	adolescence
menstrual cycle	pregnancy	after pregnancy
menopause	weekends	holidays
some type of illness		

II. FALLING ASLEEP

1. Do you ever experience difficulty falling asleep? YES NO
   If yes, how often? _____ per week
   _____ per month

2. What time do you typically go to bed
   On weekdays (Sunday – Thursday nights) ? _____ AM PM

   On weekends (Friday – Saturday nights) ? _____ AM PM

3. At what time do you typically awaken
   On weekdays (Sunday – Thursday nights) ? _____ AM PM

   On weekends (Friday – Saturday nights) ? _____ AM PM

4. Do you often read or watch TV in bed before going to sleep? YES NO

   If yes, for how long do you typically engage in this activity before you decide to go to sleep? _____ Hours / Minutes

5. Once you decide to go to sleep, how long does it typically take you to fall asleep at night?

   On weekdays (Sunday – Thursday nights) ? _____ Hours / Minutes

   On weekends (Friday – Saturday nights) ? _____ Hours / Minutes

6. While falling asleep do you ever:

   - Notice that parts of your body startle or jerk? YES NO
   - Experience vivid dream-like scenes though you know that you are awake? YES NO

- Have thoughts racing through your mind?	YES	NO
- Feel sad or depressed?	YES	NO
- Have anxiety (worry about things) ?	YES	NO
- Feel afraid of not being able to sleep?	YES	NO
- Feel frustrated by your inability to sleep?	YES	NO
- Feel muscular tension?	YES	NO
- Experience "restless legs" (crawling or aching feelings, inability to keep legs still) ?	YES	NO
- Experience pain or physical discomfort?	YES	NO
- Often fall asleep in less than 5 minutes?	YES	NO
- Often take more than 30 minutes to fall asleep?	YES	NO

III. DURING SLEEP

1. How many hours of actual sleep do you get on a typical night? _____

2. How many times do you typically awaken during the night? _____

   a. At what times do you typically awaken? _____
   b. Do you get out of bed during awakenings? YES NO
      If yes, why do you get out of bed? _____
      _____

3. When you awaken during the night, how long does it typically take for you to return to sleep?
   _____ Hours / Minutes

4. What is the total time that you are awake during the night? _____

5. Why do you awaken during the night? _____

6. To the best of your knowledge, do you often do any of the following during sleep?

talk	YES	NO
walk	YES	NO
kick your legs	YES	NO
snore	YES	NO
make unusual movements	YES	NO
wet the bed (since age 7)	YES	NO
grind your teeth	YES	NO
fall our of bed	YES	NO

7. If you answered yes to any item in question 6, please describe including an estimate of how often you engage in each behavior during sleep, who told you about the behaviors (roommate, spouse, etc.) and when the behavior (s) first started.

_____

_____

_____

8. Is your sleep disturbed by any of the following?

asthma	YES	NO
persistent cough	YES	NO
regurgitation	YES	NO
panic	YES	NO
heartburn	YES	NO
difficulty breathing	YES	NO
need to urinate	0 1 2 3 4 5 6	times per night
nasal congestion	YES	NO
sweating	YES	NO
heart pounding	YES	NO
headache	YES	NO
muscle cramps	YES	NO
thrashing movements	YES	NO
racing thoughts, worries	YES	NO
restless legs / need to move	YES	NO
noises in sleep area	YES	NO
child / pet care needs	YES	NO
choking or need air?	YES	NO
bed-partner	YES	NO
heat or cold	YES	NO
light in sleep area	YES	NO
uncomfortable sleep surface	YES	NO
hunger or thirst	YES	NO

9. Do you consider yourself a LIGHT, NORMAL, or HEAVY sleeper?

IV. MORNING

1. Do you have difficulty awakening in the morning? YES NO

2. Are you ever confused, disoriented, or violent upon awakening in the morning? YES NO

3. Have you ever been unable to move (paralyzed) for several (10 – 30) seconds upon awakening in the morning? YES NO

4. Do you cough up sputum in the morning? YES NO

5. Do you wake up with a morning headache? YES NO

6. In the morning, when its time to get up, do you:

   a. need an alarm clock to wake you up? YES NO
      If yes, do you use the "snooze" button to get a few extra minutes of sleep? YES NO

   b. immediately feel refreshed? YES NO
   c. need coffee or a shower to feel alert? YES NO
   d. often have a dry mouth? YES NO
   e. often have a sore throat? YES NO

V. DAYTIME

1. Is daytime sleepiness currently a problem for you? YES NO

   If yes, describe how daytime sleepiness currently affects your life. (e.g., with what activities does it interfere?)

   _____

   _____

   _____

2. At what time of the day do you feel **most** alert? AM PM
3. At what time of day do you feel **least** alert? AM PM

4. Do you typically take more than two naps per month? YES NO
   (at least 5 minutes of duration)

5. During the past 6 months, have you experienced EITHER falling asleep or fighting sleepiness (e.g., struggling to stay awake) in the following situations:

   a. eating food? YES NO
   b. during intercourse? YES NO

c. talking on the phone? YES NO
d. in conversations at work? YES NO
e. in other conversations? YES NO
f. at meetings YES NO
g. talking in groups (e.g., w/guests at home)? YES NO
h. while driving a motor vehicle? YES NO
i. riding as a passenger (car, train, etc.)? YES NO
j. attending a lecture or performance? YES NO
k. reading a book (not in bed)? YES NO
l. listening to the radio or stereo? YES NO
m. watching television? YES NO
n. at the movies? YES NO

6. Have you fallen asleep in any other inappropriate settings in the past 6 months? YES NO

7. Do you ever:

   a. discover that you have performed some complex act such as driving a car to the wrong destination and not remembered doing it? YES NO

   b. find yourself doing things that make no sense (writing nonsense or mixing chocolate with gravy, etc.)? YES NO

VI. MEDICAL/SLEEP HISTORY

1. Have you ever worked on a rotating shift? YES NO

   If yes, describe the job including the hours of each shift, how often you were required to shift, and the dates of your employment.

   _____
   _____
   _____

2. As a child (up to age 16) did you have a problem with:

   a. getting to sleep at night? YES NO
   b. waking up in the morning? YES NO
   c. waking during the night? YES NO
   d. sleepiness during the day YES NO

3. Have any of your blood-relatives ever had chronic sleep-related problems? YES NO

4. How much alcohol do you typically drink? _____ per day _____ per week

5. Do you currently use any drugs or medication ? (include illegal, over-the-counter, and prescription drugs) YES NO

If yes, please list all medications or drugs, including amounts taken, and reason for taking these medications or drugs, below:

NAME	AMOUNT TAKEN	REASON

6. Do you typically drink caffeinated beverages each day? (e.g., coffee, tea, caffinated soft drinks) YES NO

8. Have you ever been diagnosed as having epilepsy or any other seizure disorder? YES NO

9. Does anyone in your family have epilepsy or any other seizure disorders? YES NO

10. Do you frequently faint? YES NO

11. Have you ever experienced muscle weakness in strong emotional situations? (e.g., during laughter, rage, etc.) YES NO

12. Have you ever fallen limp to the ground when excited? (without fainting or losing consciousness) YES NO

13. Do you suffer from dizzy spells? YES NO

14. Have you had a significant change in body weight? YES NO

If yes, weight GAIN or LOSS (circle one)
Over what period of time? _____

15. Please list current or previous medical problems, with special attention to lung, heart, psychiatric or nervous system disorders.

_____
_____
_____

16. List all past surgical procedures and dates:

_____
_____
_____

17. How much do you / did you smoke? _____

18. How often do you smoke within two hours of bedtime? _____

19. Were you born as part of a multiple birth? YES NO

20. What was your birth weight? _____ lbs.

21. Were there any unusual conditions of pregnancy or delivery?
(prolonged labor, forceps, blue baby, etc.) YES NO

If yes, describe:

_____
_____
_____

22. What is your present occupation? _____

23. What hours do you work? _____

24. How often do you engage in physical exercise? _____ per week/ per month

a. If you exercise regularly, what do you do for exercise? _____
(e.g., tennis, jogging, walking, etc.)
b. If you exercise, at what time of day do you exercise? _____
c. If you exercise, how long is a typical exercise session? _____

25. If your sleep/wake behavior is not adequately covered by the above questions, or if you have a sleep problem not adequately covered by the previous questions, briefly describe here:

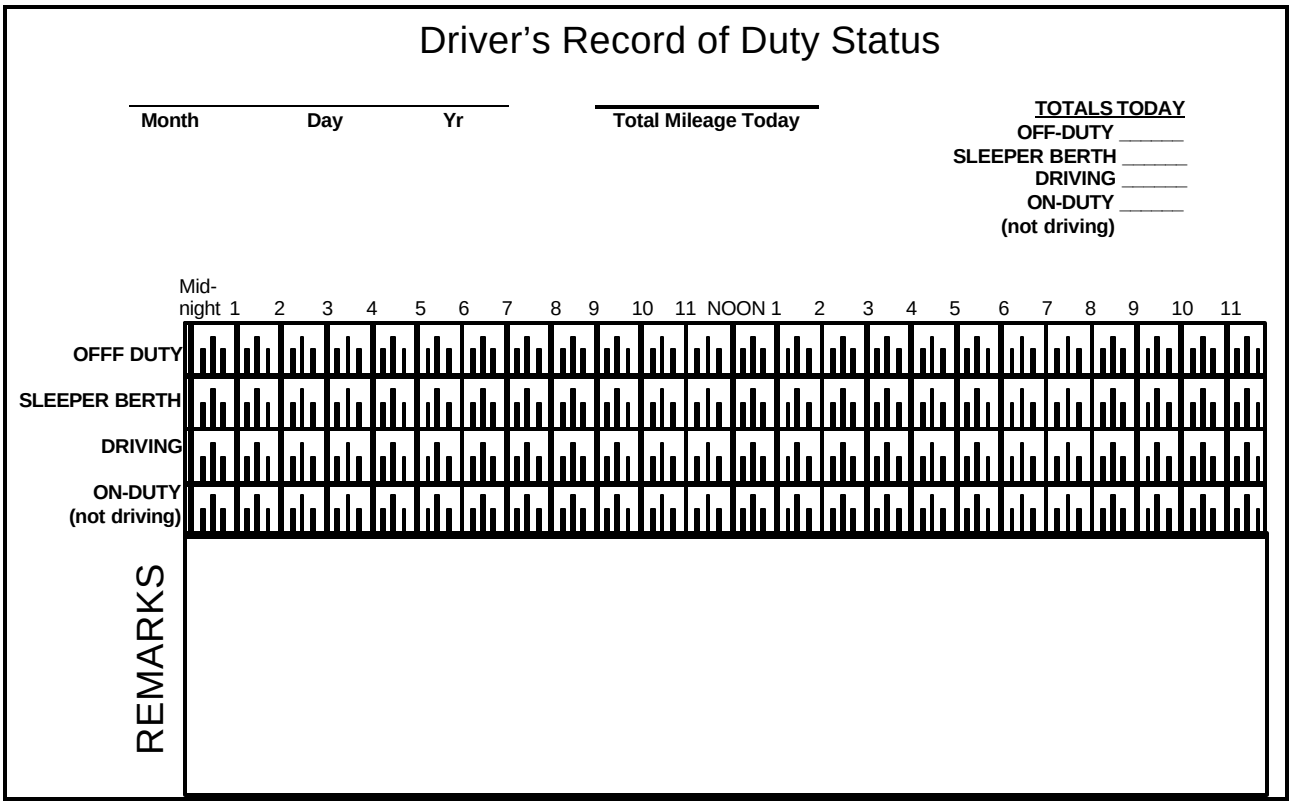
_____
_____
_____

PLEASE CHECK TO MAKE SURE THAT YOU HAVE ANSWERED ALL QUESTIONS AS FULLY AND ACCURATELY AS POSSIBLE.

DAILY SLEEP LOG

SUBJECT NAME:_____ **SSN#** _____-_____-_____

	1	2	3	4	5	6	7
TODAY'S DATE							
What time did you go to bed **last night**?							
Where did you sleep **last night**? (home, truck, motel, etc.)							
How long did it take you to fall asleep **last night**?							
How many times did you awaken during **last night**?							
What awakened you at these time? (noise, hunger, spontaneous,etc.)							
At what time did you awaken **this morning**?							
What awakened you **this morning**? (alarm, hunger, spontaneous, etc.)							
Did you have any caffeine **yesterday**? (coffee, tea, soda) What kind and how much?							
Did you have any alcoholic drinks **yesterday**? What and how much?							
Did you take any drugs/medications **yesterday**? What kind and how much?							
Did you take any nap **yesterday**? For how long and at what times?							
How did you feel when you awakened **this morning**?							


Driver's Record of Duty Status
Month
Day
Yr
Total Mileage Today
TOTALS TODAY
OFF-DUTY _____
SLEEPER BERTH _____
DRIVING _____
ON-DUTY _____
(not driving)
Mid-night 1 2 3 4 5 6 7 8 9 10 11 NOON 1 2 3 4 5 6 7 8 9 10 11
OFFF DUTY
SLEEPER BERTH
DRIVING
ON-DUTY (not driving)
REMARKS

ACTIGRAPH INSTRUCTIONS

A. REMOVE THE ACTIGRAPH ONLY WHEN SHOWERING, SWIMMING, OR WASHING DISHES, AND PUT IT BACK ON IMMEDIATELY AFTER. DO NOT SUBMERGE IT IN WATER OR ANY OTHER FLUID.

B. Although the actigraph is not an extraordinarily delicate instrument, it must still be handled with care. **DO NOT STRIKE IT AGAINST ANYTHING RIGIID AND DO NOT DROP IT.**

C. You will sign for the particular actigraph issued to you. It is a valuable piece of instrumentation, and you will be responsible for its safe return.

D. Wear the actigraph on your non-dominant wrist, i.e., if you are right-handed, wear it on your left wrist and vice versa if you are left-handed. You may wear a wrist band or folded bandana under the actigraph to provide additional comfort.

E. It may be considered an over-sized watch, worn on the wrist and forgotten about in day-to-day activities. In fact, carry on your activities as you normally do.

IF YOU HAVE ANY QUESTIONS OR NEED FURTHER INFORMATION PLEASE GIVE RICHARD CEPHUS OR JENNIFER BLUME A CALL AT 301-295-7826 MONDAY – FRIDAY FROM 10 AM – 5 PM AND AT 301-295-7080 (Richard's OFFICE AND ANSWERING MACHINE) AT ANY TIME.

APPENDIX 6: MONITORING SLEEP AND PREDICTING PERFORMANCE USING ACTIGRAPHY WITH EMBEDDED ON-LINE SLEEP-SCORING AND PERFORMANCE-PREDICTION ALGORITHMS/OUTPUTS (SLEEPWATCH-ACTIGRAPH)

A. BACKGROUND

HISTORICAL REVIEW OF SLEEP MEASUREMENT USING ACTIGRAPHY

Actigraphy was originally developed to objectively measure and quantify sleep based on body movements prior to the development of polysomnographic techniques. The first such study was performed by Szymansky (1922), who constructed a device that was sensitive to the gross body movements of subjects as they lay in bed. However, the advent of EEG recording techniques and their application to sleep (Loomis et al., 1937), and the institution of EEG-based standards for the scoring of sleep stages (Rechtschaffen and Kales, 1968), caused a shift in interest away from movement-based measurements of sleep.

Wrist-mounted actigraphy was developed in the 1970s and 1980s. This development caused a resurgence of interest in movement-based measurement of sleep. This interest also was fueled by technological advances that, for the first time, made portable measurement and recording of movement data over long periods (days, weeks, or even months) feasible. Furthermore, even with portable ambulatory EEG recorders, EEG-based measurement of sleep and wakefulness were neither logistically practicable nor cost-effective for determining basic sleep/wake rhythms in large numbers of subjects and/or when the study period of interest lasted several weeks or months.

With the development of technologically advanced actigraph components, the primary issue became the extent to which actigraphic measures of sleep/wake state were both reliable and valid (compared to the gold standard for recording sleep/wake, which is polysomnography). Several validation studies have subsequently been performed using different actigraph scoring

algorithms, subjects from various age ranges, varying sample sizes, and subjects with various sleep and/or movement-related disorders. These studies are reviewed below.

ACTIGRAPHY – RELIABILITY AND VALIDITY COMPARED TO POLYSOMNOGRAPHY

Because Phases I and II of this report included only adult subjects with no known movement- or sleep-related disorders, this review excludes clinical studies dealing exclusively with patient populations or children. For a recent review and discussion of these clinical issues, see Sadeh et al. (1995). In general, such studies indicate that wrist actigraphy is a valid and objective measure of sleep/wake state (Sadeh et al., 1995).

An early pilot study to address validation issues was conducted by Kripke et al. (1978). Using five normal subjects, excellent agreement was reported between actigraphically derived, manually scored, and polysomnographically determined measures of sleep duration. Kripke et al. (1978) reported a correlation coefficient of 0.98—a correlation even higher than a typical correlation between two well-trained individuals manually scoring a PSG (which is generally within the 0.90 range). Shortly thereafter, the same research group published results from a larger-scale validation study in which actigraphically and polysomnographically determined sleep/wake estimates were compared from a total of 102 nights. This study included data from 39 hospital patients and 63 individuals who were not patients (Mullaney et al., 1980). Overall, the two methods produced an agreement rate of 94.5% (i.e., 94.5% of the 1-minute epochs were manually scored correctly using actigraphic methods, with "blind" manual PSG scoring serving as the "gold standard"). When the subsample of hospital patients was excluded from the analyses, the agreement rate rose to 96.3%. Significant correlations were obtained in this study for a number of manually scored sleep parameters, including TST (r = 0.89) and minutes of wake time after sleep onset ("WASO," r = 0.70). Not all actigraphically determined sleep parameters were significantly correlated with their polysomnographically determined counterparts. For example, actigraphy proved relatively poor for specifying the actual number of discrete mid-sleep awakening events (r = 0.25).

Using college students as subjects (n = 14), Webster et al. (1982) reported an overall agreement rate of 93.9% between PSG and actigraphic measures of sleep/wake. This study

differs from those reported earlier, however. That is because, in this study, although PSG was scored manually, actigraphic records were scored automatically using a sleep/wake scoring algorithm. Thus, Webster et al. (1982) also published the first algorithm that could be used to automatically score actigraphic data. The latter was an important step since up to that point the labor-intensive and tedious task of manually scoring actigraphic data on an epoch-by-epoch basis at least partially obviated the advantages of the data collection technique.

ACTIGRAPHY – LIMITATIONS

Standard (conventional) actigraphic design represents an optimization of past technology based on two key considerations: (a) consistent reliability of the output data (counts of threshold crossings) as input for the detection of sleep/wake state transitions using validated weighted moving average algorithms such as that of Cole et al. (1992); and (b) size, weight, power requirement, and other electrical and electronic features realizable as a user-accepted device of reasonable cost. Currently, this optimization produces very sharp and deliberate limitations of the information originally contained in the movement signal and passed on to the scoring algorithm. As discussed in Redmond and Hegge (1985), there are four main areas of design constraint:

(1) the sensitivity of the sensor must be such as to respond to "normal" arm movements, but not be "swamped" by the waking movements of a very active person, or by sources of external noise and vibration. Information from very fine, subtle movement is sacrificed.
(2) the frequency response of the accelerometric sensor system is sharply confined to a band of 2 to 3 cycles per second (Hz). At the low end, this is to eliminate counts from undulating, slow-wave excursions of the sensor (e.g., due to breathing, or rocking of the device in the gravitational field, or vehicle motion) that are not actually due to motor activity. At frequencies above 3 Hz, this response helps eliminate false counts due to tremor, external noise and vibration, and "ringing" due to sharp impulses.
(3) the translation of a complex movement signal into a simple measure, readily computed and expressed digitally in microprocessors of 1985-1995 vintage, resulted in the use of threshold-crossing counts, but eliminated far more descriptive measures of the signal characteristics, such as duration, amplitude, and power.

(4) the use of extended (relative to movement rates) periods of measure, i.e., 1- or 2-minute bins, keeps data sets down to workable length in electronic memory, and matches the temporal scale expected by validated sleep/wake algorithms. This integration of sensor data over time smoothes over transient bursts of sensor activity, which may or may not be advantageous, depending on whether such transients are themselves physiologically relevant.

Recognizing that current usage of the actigraph thus filtered out a large portion of information contained in the original, raw movement signal, the actigraph was redesigned to permit the automated setting of alternate sensitivities (high[gain = 26] and low[5]), counting thresholds (high[24 mV] and low[6 mV]), and frequency response bands (0.1 to 1 Hz, 0.1 to 3 Hz, 0.1 to 9 Hz, 2 to 3 Hz, and 2 to 9 Hz). The design intent was to allow investigation of varied settings (or information content), while normal usage emulated the original, standardized settings of "High Gain, High Threshold," and 2- to 3-Hz bandwidth. In 1993, Elsmore and Naitoh compared the varied actigraph settings against PSG-scored sleep, using three actigraph/sleep algorithms (Sadeh et al., 1989). This report confirmed agreement with PSG sleep in the range of 79 to 93% for standard actigraph settings, using both Cole and Sadeh algorithms. However, the authors found that the broad-band frequency settings (0.1 to 3 or 9 Hz) and the low threshold setting produced such high counts in sleep as to render the standard algorithms useless.

The experience described above, others by Elsmore (1994), and those at Walter Reed point again to a fundamental limitation when using the actigraph to explore *outside* the bounds of optimization. The chosen settings for gain, threshold, and passband are arbitrary (albeit grounded in the original studies of Redmond and Hegge [1985]), with no means of readily adjusting them for comparison's sake while controlling for movement events (system input). Selection of a particular combination of passband, gain, threshold, and digital counting transform automatically selects out other features of the signal's complexity, potentially *distorting* the original information contained in it, as reported at the output. Systematic approach to this problem requires continuous access to the raw, unfiltered signal, and the computational means for parsing, manipulating, and statistically treating its information content.

In short, definitive treatment of wrist-movement characteristics vis-à-vis sleep-related events, and subsequent design of actigraphic devices capable of more than simple sleep/wake

discrimination, awaits: (a) systematic study of the fundamental contents of the sensor-signal driven by movement behavior, in both sleep and waking states; and (b) enabling technology for conducting such research and device development.

ACTIGRAPHY – SOLUTIONS

Increased Passband – Life Signs

There is considerable evidence that normally discarded information contained within the signal may be retrieved by current technology and may be empirically useful. For instance, it appears that threshold count data, taken from an actigraph set to pass at 0.1- to 3-Hz bandwidth, tends to settle during rest at a count at or near the heart rate (instead of zero, when passband of 2 to 3 Hz is used). Indeed, Conlan (personal communications, 1996 – 1998) has demonstrated that the sensor signal contains a very low-level ballistographic signature of the heartbeat, as well as a low-frequency variation suggestive of breathing movement, when not masked by larger amplitude movements. Furthermore, when the passband is set to the full range of 0.1 to 9 Hz, and sensitivity is maximized, the actigraph registers non-zero counts continuously, as long as the device is being worn. Precision Control Design, Inc. (maker of the AMA-32 actigraph; Robert Conlan, president, Precision Control Design, Inc.) exploits this phenomenon, calling it "LifeSign" data, using it to detect when the actigraph is off the wrist. The source of this data stream is uncertain and warrants further investigation since it appears to be biological in origin (Redmond, personal communications, 1996 – 1999). It may be related to "microvibrations," which were described in 1960 by Rohracher, but were never fully examined or put to useful purpose. According to Rohracher (1960), this low-level tremor occurs in the frequency band of 7.5 to 12.5 Hz, so it would be readily detected by the actigraph sensor at broad passband settings. While "outside the envelope" of standard actigraphy, the questions of whether extraction of heart rate, breathing rate, and microtremor is possible by this method, and whether that may be useful in discriminating sleep stages or sleep stage transitions, should be evaluated. Another aspect of these components is germane: a dependency on (sub)acoustic coupling of the sensor to the body mass that presumably conducts these signal components from their origins. If such conductivity

is mediated or modulated by muscle tone, then evaluation of these features may help in the discrimination of REM from NREM sleep.

Noise Signature

Considerable attention was given in original actigraph design to the rejection of interference due to extraneous noise, vibration, transients, and sensor signals not directly resulting from intentional motor activity. A blanket approach was taken, resulting in extensive suppression of potentially useful information along with noise, as discussed. Now, certain recent advances allow a more selective approach toward this problem. For one, Precision Control Design, Inc., has devised a sensor that separates torsional from linear components of the signal—torsional components are more associated with wrist movement, while linear components are more associated with vehicular motion artifact (implying the ability to detect a "noise signature"). Of more general importance is continuous access to the raw, unfiltered signal, which enables the selective identification of noise signatures and the process of true *noise cancellation* as opposed to suppression. Such processes are the mirror image of *information extraction*, both involving computational techniques that are currently under development and application. Computational enhancement of the "signal-to-noise ratio" will necessarily increase the information available for application development.

Digital Signal Processing

Recent technological advances have enabled the development of wrist actigraphs capable of digitizing the analog motion-sensor signal, thus providing continuous access to the raw data. This Digital Signal Processing (DSP) actigraph collects a continuous and complete record of the movement signal contained in a conventional actigraph's broad frequency passband of 0.1 to 9 cycles per second (or 13 Hz as modified). The signal is at 26.67 Hz, using a true 12-bit analog-to-digital converter, resulting in a dynamic range of ± 2048 voltage units, with a corresponding acceleration measurement resolution of 0.01 g over the frequency range of interest. It thus encompasses the full range of conventional actigraph capability, with none of the constraints on information throughput discussed earlier. Indeed, with appropriate computations, its output can be used to *synthesize and replicate* <u>any</u> of the conventional actigraph settings. Since all prior

actigraph sleep-scoring algorithms are based on such constraints, no algorithms exist that take advantage of more than a fraction of the information available from the DSP actigraph.

Technological Advances

Parallel technological progress has increased the computational power, while decreasing size and battery power requirements, of microcircuit designs to realize a new generation of actigraphs that employ signal processing and complex algorithms, previously found only in desktop and larger computers. These advances include the commercial availability of dedicated co-processor chips and the means for rapid and economical design and fabrication of Application Specific Integrated Circuits (ASICs). This means that fundamental signal-processing and information-management research can be conducted with the expectation that results can be employed in fieldable devices. To the extent that current economical and realistic design constraints require approximation or truncation of ideal processes, the latter can serve as benchmarks against which the approximations are defined and validated, and toward which advanced developments can be directed. In many respects, the practical, often-competing factors in design optimization are reduced to issues of software.

Computational Intelligence

Finally, computational methods required for rapid data acquisition, processing, and analysis are now available at the bench and operable by nonexperts in computational intelligence. Virtual Instrumentation systems, such as MATLAB and LABVIEW, will permit the concurrent processing of several data sets, with extraction of descriptive features of each and cross-comparison of features within or across sets. For instance, the Walter Reed laboratory has employed such tools for the rapid processing of EEG with bandpass filters, aimed toward the definition of sleep-onset and other sleep-related events in a metric that may prove to be independent of (and superior to) classical PSG scoring.

In sum, recent technological advances have enabled the development of wrist actigraphs capable of digitizing the full-range analog motion-sensor signal. This Digital Signal Processing (DSP) actigraph collects more of the information available in the movement signal than the simple

"number of zero-crossings" recorded by conventional actigraphs. Successful actigraph sleep-scoring algorithms to date have been based on the Conventional (#-of-zero-crossings) Actigraphs and some measure derived from counts above threshold. These have been limited to simple sleep vs. wake discriminations, with no capability to distinguish sleep stage changes (e.g., Stage 1 to Stage 2, or NREM to REM) in sleep itself and consequently no ability to discriminate recuperative from nonrecuperative sleep. There are no actigraph sleep-scoring algorithms that take advantage of the information available from the DSP Actigraph.

ACTIGRAPHY – OTHER CONSIDERATIONS

Whether distinguishing among sleep stages is of any theoretical or practical importance is debatable. As reviewed in the Introduction, there is currently no evidence that any one sleep stage (among stages 2, SWS, and REM) is more recuperative than the other in terms of sustaining cognitive performance and alertness. Necessity for distinguishing among sleep stages may be limited to the clinical arena in which, for example, REM sleep may be used as a diagnostic of a sleep or psychiatric disorder (e.g., REM onset daytime naps are indicative of narcolepsy, and short latency to REM sleep may be indicative of clinical depression).

One of the most challenging aspects of actigraphy scoring is the determination of sleep/wake transitions, with "sleep" in this instance defined as Stage 1. It is worth noting that distinguishing between wake and Stage 1 also is a problem with manually scored PSG—to a large extent, wake/Stage 1 discriminations account for less-than-perfect inter-rater as well as intra-rater reliabilities. A recent review indicated that the distinction between wake and Stage 1 may be unnecessary, since when Stage 1 is treated as wake rather than sleep, the predictive value of sleep in terms of next-day performance and alertness improves (Wesensten et al., 1999).

B. SCORING ACTIGRAPHICALLY RECORDED SLEEP

Directly relevant to the issue of the actigraph's validity and reliability is the way in which actigraph data are quantified. The algorithm, which has received the most attention and is likely the most widely used, is the Cole-Kripke sleep scoring algorithm (Cole et al., 1992). Other algorithms are briefly described further in the next section.

COLE-KRIPKE SLEEP-SCORING ALGORITHM

The Cole-Kripke algorithm was developed and tested in a study of 41 subjects (including 18 normal subjects and 23 subjects with a variety of psychiatric, sleep, and other disorders). Each subject wore an actigraph on the nondominant wrist, concomitant with a nocturnal PSG recording. Thirty-nine subjects were tested on 1 night only, and two were tested over 2 nights (for a total of 43 nights of data). Despite a wide range of diagnostic categories and ages in the subject sample, good agreement was obtained with manually scored PSG for several sleep parameters, including sleep percentage ($r = 0.82$) and sleep latency ($r = 0.90$). Overall percent agreement was 88%, comparable to the levels of agreement obtained by studies using less stringent tests in which data were collected throughout the entire day. Because the most challenging aspect of actigraphy scoring is the determination of sleep/wake transitions (which are most frequent during the nighttime sleep hours), the inclusion of daytime data would have produced even higher overall agreement rates.

OTHER SLEEP-SCORING ALGORITHMS

Other algorithms and methodologies for the automated scoring of actigraphy have also been described and tested (e.g., Jean-Louis et al., 1996; Sadeh et al., 1989; Zisapel et al., 1995), and each shows considerable promise, especially for scoring the sleep/wake states of patient records. Available scoring algorithms differ regarding several technical aspects—for example, the extent to which activity counts in previous and subsequent epochs influence the scoring of the current epoch. Variation among mathematical principles underlying each scoring algorithm. Despite these differences, each algorithm produces agreement rates with standard PSG scoring that fall within the 85% to 93% (and higher) range, even when subject samples are drawn from diverse patient populations. Thus, virtually all of the current actigraph-scoring algorithms provide rates of agreement with standard PSG comparable to agreement rates between two experienced manual scorers using standard PSG criteria.

LIMITATIONS OF CURRENT ALGORITHMS – WAKE VERSUS STAGE 1

In Section A (beginning on page A6-1), limitations of current, conventional actigraphy were discussed in detail. As noted, a current limitation of conventional actigraphy is the passband. Frequencies are truncated at both the high and low ends of the frequency spectrum for purposes of canceling (suppressing) noise artifact. Such truncation affects the sensitivity of the device.

Limitations of the actigraph itself necessarily determine the limitations of current scoring algorithms. As reviewed, currently available scoring algorithms were developed around these limitations and were devised to distinguish wake from "sleep" rather than among specific sleep stages. However, it is also true in the latter respect that the main limitation of currently available algorithms is the *reliability (consistency)* with which they distinguish wake from Stage 1. The available data suggest that currently available scoring algorithms tend to underestimate the amount of time spent in mid-sleep awakenings, or "wake after sleep onset."

Further complicating this limitation is the issue of whether the wake/Stage 1 distinction is critical (Wesensten et al., 1999). While such a distinction may have no practical relevance in the general population, this distinction may be critical in clinical settings (e.g., diagnosis of sleep apnea).

Currently available scoring algorithms will not apply to the digital signal processing or "DSP" actigraph. Use of this device will require development of a new set of scoring algorithms. It is anticipated that the sensitivity of this device will allow for subtle distinctions among sleep/wake stages—in part, perhaps, based on the "life signs" information described earlier.

Note: References for Appendix 6 are included in the General Reference list for this document.

APPENDIX 7: SUBTASK: INTERVIEW OF CMV PERSONNEL: AMOUNT OF TIME PROFESSIONAL DRIVERS SPEND SLEEPING

OVERVIEW

The Field Study contractual agreement with the Federal Motor Carrier Safety Administration, Department of Transportation, included an optional activity to interview no more than nine individuals regarding their opinions on the percentage of off-duty time a CMV driver spends sleeping. To this end, a staff member of the Department of Neurobiology and Behavior contacted eight professional drivers. The drivers were interviewed and queried on their opinions regarding amount of time professional drivers spent sleeping. Questionnaires and demographics forms administered to the drivers by telephone are provided in this appendix.

RESULTS

Driver Demographics

Gender. A total of four long-haul and four short-haul drivers were contacted. Of the long-haul drivers, two were male and two were female. All short-haul drivers were male.

Driving situation. One male long-haul and both female long-haul drivers were team drivers. All short-haul drivers drove individually.

Driving experience. The two male long-haul drivers had varied driving experience: one with 3 years and the other with 15 years, while both female long-haul drivers had comparable years of experience, i.e., 4.5 and 5 years. Two of the short-haul drivers had comparable experience of 4 and 5 years, while the other two were comparable, with 20 and 24 years of driving.

Vehicle. Short-haul drivers operated conventional single-unit trucks ranging from tankers to “dry van” and flatbed. Long-haul drivers operated conventional 45- to 49-foot tractor-trailers, all equipped with sleeper berths. None drove multiple-trailer combination vehicles.

Sleep Demographics

Nights away. Nights spent away from home ranged from nearly every day per month (28 – 31 days) to 14 days per month for the two male long-haul drivers. The two female long-haul drivers reported 16 and 22 nights away from home. In contrast, short-haul drivers did not spend any nights away from home. One of them did mention a negligible number of 2 to 3 nights in a year.

Off-duty sleep. Estimates of daily off-duty sleep for long-haul drivers ranged from 5 to 10 hours per night, while short-haul drivers claimed 5 to 7 hours per night.

TABLE 4-3 summarizes driver demographic information as well as sleep demographics for each driver interviewed.

Table 4-3. Driver demographics and sleep information.

Table4-3. Driver demographics and sleep info.								
DRIVER	**S-H Male**	**L-H Male**	**L-H Female**	**S-H Male**	**L-H Female**	**S-H Male**	**L-H Male**	**S-H Male**
Truck type	Conventional	Cabover	Conventional	Single-unit	Conventional	Single-unit	Conventional	Single-unit
Sleeper Berth?	no	yes	yes	no	yes	no	yes	no
Trailer length	48 ft	48 ft	48 ft	40 ft	45 ft	N/A	49 ft	22 ft
Trailer type	Tanker	Dry van; box	Flatbed	Dry van; tanker; flatbed	Flatbed		Reefer	Flatbed
Multiple trailer combo?	no	no	no	no	no	no	no	no
Combo Type								
Team or individual drive	Individual	Team	Team	Individual	Team	Individual	Individual	Individual
Driving school graduate?	no	yes	yes	no	no	no	no	no
Straight truck experience?	yes	no	no	yes	yes	yes	yes	no
Experience	20 yrs	3 yrs	4 1/2 yrs	4 yrs	5 yrs	5 yrs	15 yrs	24 yrs
Time w/current carrier	14 yrs	2 yrs	2 1/3 yrs	23 months	4 yrs	5 yrs	3 yrs	24 yrs
Nights away from home/month	2-3 times/year	28-31	22	0	16	0	14	0
Off-duty hours of sleep	6	10	8	7	8 1/2	5-6	6	7

Driver Opinions

Do Drivers Sleep More or Less than Other Adults?

The question of whether the interviewed truckers thought commercial drivers slept more or less than the average adult was almost unanimously answered as "commercial drivers sleep less." Only one short-haul driver responded "commercial drivers sleep more," and one long-haul driver qualified the response by saying that drivers obtain more sleep than the average adult if a team driver, but less than the average adult if not a team driver. When asked how much

less/more sleep drivers obtain, most interviewees responded that drivers obtain 2 to 4 hours less sleep than the average adult. The one short-haul and one long-haul driver who responded "more sleep" estimated 2 and 5 hours, respectively.

Are Drivers Obtaining Sufficient Sleep?

The response to this latter question was divided—both of the female drivers and one each of the male long-haul and short-haul drivers responded "no." When further questioned about why drivers were not obtaining sufficient sleep, the following reasons were given: (1) the long hours involved in loading and unloading the delivery; and (2) communicating with the dispatcher and the actual driving itself resulting in irregular schedules and mealtimes. Drivers were also asked what factors prevent drivers from getting enough sleep. Responses included were: (1) the irregular and excessive work hours and schedules in which body rhythm was not established; (2) missing family; (3) family demands and problems and accompanying stress; and (4) difficulty in sleeping and the desire for more time with children. Both female drivers voiced identical complaints that driving was stressful, with napping or meals taken on the run. In addition, they responded that delivery schedules and unloading were demanding and caused time constraints. An example of a demanding schedule given by one driver was a pick-up in Texas with expectation of delivery in Indiana the following morning.

Do Drivers "Sleep In" on Their Days Off?

Six of the eight interviewed drivers responded "yes" to this question. When asked how many extra hours are obtained, drivers responded with amounts that ranged from 1 to 4 hours. Although not specifically asked why extra sleep was obtained, several drivers spontaneously responded. Some drivers stated that it was a possibility because the driver was on his/her own schedule or in his/her own bed, and the environment was more relaxing for sleep than in the truck.

Are Drivers Obtaining Sufficient Sleep on Days Off?

When asked if they thought drivers were getting sufficient sleep during days off, all of the short-haul drivers replied "yes." However, only two long-haul drivers responded "yes." Of the two negative replies from long-haul drivers, one was given by a female driver who was also the only respondent giving reasons for this reply. She felt there was always something to do, causing inability to catch up or rest up. The latter was compounded by the desire to spend time with the family. When drivers were then asked what sorts of things prevent drivers from obtaining enough sleep during days off, reasons included family demands, socialization, errands and odd jobs to do, personal business to attend to, and hobbies.

Do You Obtain More/Less Sleep than Other Drivers During the Work Week?

Rather than formulate an opinion pertaining to most drivers, the drivers were asked to speak for themselves only regarding this question. Three out of the four long-haul drivers thought they obtained more sleep (ranging from one to two hours) than other drivers if driving alone, and five hours more sleep than other drivers if part of a team. In contrast, two of the four short-haul drivers responded that they thought they obtained less sleep than other drivers (1 to 4 hours less); the other two short-haul drivers thought they obtained more sleep than other drivers (1 to 2 hours more).

Do You Obtain More/Less Sleep than Other Drivers During Your Days Off?

The drivers were again asked to speak for themselves only regarding this question. Two of the long-haul drivers thought that they obtained more sleep than other drivers on their days off (1 to 4 hours more). The other two drivers thought they obtained less, but a specific amount was not given. Only one of the short-haul drivers responded with more sleep during days off. The remaining three drivers thought they obtained less sleep on days off (2 to 4 hours less).

TABLE 4-4 summarizes driver opinion information.

Table 4-4. Driver opinion information.

Table								
Type of drive	S-H Male	L-H Male	L-H F	S-H Male	L-H Fe	S-H Male	L-H Male	S-H Male
Sleep: more/less than average adult	less	more, if team; less if not	less	less	less	less	less	more
Amount more/less	2 hrs	5 hrs; 2 hrs	2 hrs	2 - 3 hrs	3 - 4 hrs	2-3 hrs	2 hrs	2-3 hrs
Reasons for more/less sleep			work schedule, demand of on time delivery from pickup	promised delivery time demand		Due to work schedule and workload. Not enough people for work demand, too much overtime.	48 hrs / week	Driving tends to make you more tired.
Sleep sufficient?	yes	yes	no	no	no	yes	no	yes
Insufficient sleep reasons		sufficient sleep as part of team & on weekends since no loads;gets 1 1/2 days off/weekend	wound up from picking up load and delivery; demand to get rest & delivery on time. Not eating right - eat only where available; keyed up from driving; require 1/2 hr to settle down.	tiredness shows up in driving as week progresses	due to loading & unloading time. Sat for 2 hrs and then found out there was no load. Sleep time is very varied. Have to wait load, then deliver on time.		Driving, getting load, & talking to dispatcher take 6 hrs, then legal driving is 10 hrs, so average 3-4 hrs per day of sleep.	
Reasons sleep prevented	excessive work hours; family demands	odd hrs;irregular schedule; can't adapt to rhythm; miss family	stress from driving; may nap when picking up load	combination of work & family schedule demands.	Has to do w/ delivery schedule. Schedule to unload is demanding	Combination of work demand and managing family.	Family demands, spend time with children.	Family demands, hobbies
Sleep in on days off?	yes	yes	yes; probably	yes	yes	yes	no	no
Amount sleep-in	3-4 hrs	3-4 hrs	2-3 hrs	3-4 hrs	1-2 hrs	2-3 hrs		
Explanation for Extra sleep		going on personal schedule	depend on home/family schedule		If in bed, sleep: 0000-800 or 900. More relaxed sleep than in truck.			Wake up at same time; may nap though
Sleep sufficient on days off?	yes	yes	no	yes; they better	yes	yes	no	yes

TABLE 4-5 provides summary statistics for driver demographics, sleep demographics, and driver opinion information. These data are collapsed across long/short-haul and male/female categories.

Table 4-5. Summary statistics for driver and sleep demographic information.

TYPE OF DRIVER	LONG HAULER	LONG HAULER	SHORT HAULER	SHORT HAULER
SEX	Male	Female	Male	Female
Number of Drivers in this category	2	2	4	0
Individual	1	0	4	0
Team	1	2	0	0
Experience	3yrs; 15 yrs	4 1/2 yrs; 5 yrs	20y; 4y; 5y; 24y	
Nights away	28-31; 14	22; 16	2-3x/yr; 0; 0; 0	
Off-duty sleep	10h; 6h	8h; 8.5h	6h; 7h; 5-6h; 7h	
QUESTIONNAIRE:				
More/less sleep?	more-team;less-indiv;less	less; less	less;less;less;more	
Amount more/less	5h;2h;2h	2h;3-4h	2h;2-3h;2-3h;2-3h	
Reasons more/less		Schedule;on time delivery	Delivery demand; schedule; workload; driving tiring	
Sleep sufficient?	yes;no	no; no	yes; no; yes; yes	
Reasons for insufficient sleep	loading,dispatcher,driving=16 hrs	loading,delivery,unloading demand;irreg meal & sleep.	Tiredness develops in driving as week progresses.	
Reasons sleep prevented	Irreg hours & schedule; body rhythm not adapted; miss family; family demands & problems /stress; trouble sleeping; need time w/ children.	Driving stressful; nap or meals on run. Delivery schedule & unloading demanding; time constraints; expectation for delivery stressful, i.e., pickup p.m. in TX, must deliver am IN. No meals.	Excessive work hours; family demands; no fixed week schedule; hobbies	
Sleep in during days off?	yes; no	yes; yes	yes;yes;yes;no	
Amount of sleep-in	3-4hrs;	2-3hrs; 1-2hrs	3-4 hrs; 3-4hrs; 2-3hrs;0	
Reasons for extra sleep	Going on personal schedule.	Depend on home/family schedule. Sleep in bed: 8-9hrs; more relaxed than truck.		
Sufficient sleep on days off?	yes;no	no; yes	yes; yes; yes; yes	
Reasons for insufficient days-off sleep		Always something to do; not able to catch up or rest up; want to spend time w/ family.		
Reasons days-off sleep prevented		Family demands; socializing	Errands; odd jobs; personals: family;hobbies; social life	
Comparison of sleep amounts w/ other drivers	More; 5hrs more w/ team. Less	More as team. More (1-2hrs)	Less (1 hr); more (1hr); less(3-4hrs); more (2hrs)	
Comparison of days off sleep amounts w/ other drivers	More (3-4hrs). Less	More (1-2 hrs). Less.	Less; less (2 hrs); less (3-4hrs);more	
Comments	** See interview responses			

Open Query

Six of the drivers responded to the query for any other information or opinions that they thought might be useful to the study. Their comments were as follows:

1. Sleep has to do with eating habits – eating at truck stops is not healthy. Serve healthy foods.
2. Need to take time to get rest during work week – knows many drivers that do not because of work schedule demands – loading, delivery.

3. All drivers in this program can legally only drive 10 hours after 8 consecutive hours off. It is impossible to do more. This research study [referring to the Sleep Dose/Response Study, in which this respondent participated] showed one driver that the sleep deprivation put drivers in danger. Before this study, this driver and others who participated wanted the law to change to the same as in Canada (13 to 15 driving hours); however, now he realizes that it would be dangerous to change the law. After seeing the effects of sleep deprivation, the driver realizes that more than 10 hours of driving is humanly impossible.
4. Rather see a change in hours-of-service. Would prefer 13 hours driving rather than 10. With 15 hours total on duty, allow more time to make delivery and loading/unloading. Usually at 6 p.m. you are not tired anyway.
5. If shippers and customers load quicker, give you more time to rest in evening; getting a load is very tiring. Typically, you wait one-half to one hour, but may exceed four hours. Ideal time is one-half hour to load.
6. Need to move away from 70-hour week. Keep drivers from getting proper sleep. Keep rest of it, but do away with 70-hour work week. Should be able to work 15 hour per day. Need for a rhythm.