Duration of Restart Period Needed to Recycle with Optimal Performance: Phase II

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

December 2010

FOREWORD

As part of the FMCSA-mandated Investigation into Motor Carrier Practices to Achieve Optimal CMV Driver Performance (IDIQ Research and Technology Program, DTMC75-07-D-00006), a laboratory study was conducted between September 19, 2008, and November 18, 2009, to examine the duration of restart period that would be needed to recycle to the work force with optimal performance. Based on the results of this study, a second, Phase II, study was conducted between February 26 and October 31, 2010, to examine an additional experimental condition. This technical report presents the design, methods, research findings, and conclusions of the Phase II study.

The most important finding was that a restart period containing two biological nights (58 hours in duration as implemented in this study), relative to a restart period with only one biological night (34 hours per the present hours of service regulations), may improve the effectiveness of the restart period for nighttime driving operations, yielding a greater potential for recovery from fatigue before recycling to the work force. This technical report may be of interest to anyone interested in fatigue and its management in commercial motor vehicle operations and other modes of transportation. This is the final report of the study.

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16. Abstract

The objective of this research project was to determine the effectiveness, for nighttime work periods, of a restart period containing two biological nights, relative to the 34-hour restart provision in the hours of service regulations governing property-carrying Commercial Motor Vehicle drivers. A sample of 12 healthy subjects was studied in an in-residence laboratory study with frequent testing of cognitive performance and driving performance on a high-fidelity driving simulator. For the primary analysis for this Phase II study, a within-subjects comparison was made between two 5-day (14-hour/day) nighttime work periods separated by two biological nights operationalized in this study as a 58-hour restart period. For secondary analyses, between-subjects comparisons were made with the data from the preceding Phase I study, in which the restart period was 34 hours in accordance with the present hours of service regulations, and conditions with either daytime or nighttime work periods were examined. In all conditions, subjects were on a daytime schedule during the restart period. The two-night restart provision tested in the Phase II study was more effective at maintaining optimal performance across the two 5-day nighttime work periods than was the 34-hour restart condition with nighttime work periods of the Phase I study, although not as effective as was observed in the 34-hour restart condition with daytime work periods of the Phase I study. This stresses the importance of considering circadian effects on sleep and performance in hours of service regulations, and indicates that depending on the circadian timing of the work periods, a restart period containing two biological nights may be a substantive improvement over a 34-hour restart period with regard to the potential to recycle to the work force with optimal performance.

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biological nights, circadian rhythm, commercial motor vehicle, fatigue, HOS, hours of service, performance, restart, sleep, worker recycling	**No restrictions**

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Unclassified	**Unclassified**		

SI* (MODERN METRIC) CONVERSION FACTORS

Table of APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME	Note: Volumes greater than 1000 L shall be shown in m^3	
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		Force and Pressure or Stress		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Table of APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE	Temperature is in exact degrees	
°C	Celsius	1.8C + 32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force & Pressure or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009)

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LIST OF ABBREVIATIONS

Acronym	**Definition**
ANOVA	analysis of variance
CDDT	cardinal direction decision task
CMV	commercial motor vehicle
DSST	digit–symbol substitution task
ECG	Electrocardiogram
EEG	Electroencephalogram
EFFR	effort rating scale
EMG	Electromyogram
EOG	Electrooculogram
FMCSA	Federal Motor Carrier Safety Administration
HOS	Hours of Service
IDIQ	indefinite delivery/indefinite quantity
KSS	Karolinska Sleepiness Scale
ms	Milliseconds
N1	non-REM sleep stage 1
N2	non-REM sleep stage 2
N3	slow-wave sleep (non-REM sleep stage 3)
PANAS	Positive Affect Negative Affect Schedule
PERF	performance rating scale
PSG	Polysomnography
PVT	psychomotor vigilance test
REM	rapid eye movement (sleep)
REML	REM latency
SL	sleep latency
SWS	slow-wave sleep

Acronym	**Definition**
SWSL	slow-wave sleep latency
VASM	visual analog scale of mood

EXECUTIVE SUMMARY

The objective of this Phase II research project was to determine the recuperative effectiveness of a restart provision that contained two biological nights of sleep as compared to the current 34-hour restart provision that only affords time for one biological night sleep in the Hours-of-Service (HOS) regulations governing freight-carrying commercial motor vehicle (CMV) drivers in the context of nighttime work schedules. An in-residence laboratory study was conducted to address this issue.

For operational purposes of this study, a 58-hour restart period was used because it allowed the opportunity for two full nights of sleep. However, when considering the findings of this study in operational scheduling practices, the restart period does not necessarily need to be 58 hours in duration—the critical factor is that the restart period should include two opportunities for nighttime sleep as opposed to sleeping during the day.

A sample of 12 healthy male subjects was studied in a within-subjects comparison of two 5-day work periods separated by a restart period. The two 5-day work periods entailed nighttime wakefulness and work (14-hour/day) and daytime sleep. The restart break involved temporarily transitioning back to a daytime schedule.

The main goal of the study was to evaluate whether the tested restart period was effective at maintaining performance. To this end, performance on a variety of cognitive performance tasks and on a high-fidelity driving simulator was measured throughout the study. The primary performance outcome measure was the number of lapses (reaction times greater than 500 milliseconds [ms]) on a 10-minute psychomotor vigilance test (PVT), which is a validated metric of the performance consequences of fatigue.

Average PVT performance in the 5-day work period after the restart break was not significantly different from that in the 5-day work period before the restart break, indicating that the restart period was effective at maintaining performance. However, there was a transient, modest degradation of performance on the day immediately following the restart period. Further, the restart period was only partially effective with respect to other outcome measures, including lane deviation in a high-fidelity driving simulator.

Secondary analyses compared the study results to the effects of a 34-hour restart period as examined previously in the Phase I research project. These analyses indicated that, in the context of nighttime wake/work schedules, the tested restart break was an improvement over the 34-hour duration across a range of outcome measures. The extra sleep opportunity (i.e., second biological night) associated with the tested restart period appeared to be responsible for this improvement.

Overall, the tested restart condition of the Phase II study was more effective at maintaining optimal performance across two 5-day nighttime work periods than was the 34-hour restart condition with nighttime work periods of the Phase I study, although not as effective as was observed in the 34-hour restart condition with daytime work periods of the Phase I study.

The study findings highlight the importance of considering the principles of sleep/wake physiology and circadian effects on fatigue and performance in HOS regulations. This final

report describes the methodology and the results of the Phase II research study, and provides further conclusions and recommendations.

1. INTRODUCTION

1.1 OBJECTIVE

The objective of this Phase II project was to determine whether a restart period involving two biological nights of sleep would be more effective in restoring performance in individuals working night shifts under the hours of service regulations (HOS) governing property-carrying commercial motor vehicle (CMV) drivers than the current 34-hour restart provision. Building on the Phase I project, which evaluated the 34-hour restart using two groups of drivers, one operating in the daylight and one at night, this new study with nocturnal duty periods and a restart period that includes two biological nights was undertaken using a within-subjects in-laboratory experimental study design with testing of cognitive performance task and high-fidelity driving simulator performance.

1.2 BACKGROUND

The current FMCSA hours of service regulations for property-carrying CMV drivers prescribe that drivers: 1) may drive 11 hours in a 14-hour window after coming on duty following 10 consecutive hours off duty; 2) may not drive after 60/70 hours on duty in 7/8 consecutive days; and 3) may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty (the 34-hour restart rule). However, the 34-hour restart rule only partially addresses circadian rhythms in both performance and sleep propensity.[1,2]

The Phase I research project showed that while the 34-hour restart was effective at maintaining performance in individuals working daytime duty periods, it was generally not effective at maintaining performance in individuals scheduled to be awake during the night. The primary outcome variable was performance on the well-validated, 10-minute psychomotor vigilance test (PVT),[3] which was administered eight times per duty period. Subjects were randomized to one of two study conditions. In the “best case” condition involving daytime duty periods, PVT performance was statistically indistinguishable during the “week” (5 days with 14 duty hours per day) before and after a 34-hour restart period. In contrast, in the “worst case” condition involving nighttime duty periods, PVT performance was significantly degraded during the “week” after the 34-hour restart period. The findings of Phase I are documented in the final technical report of that study.[4]

The total duration of the sleep opportunities in the 34-hour restart period was the same for the “worst case” condition as for the “best case” condition. However, the 34-hour restart period in the “worst case” condition included only one biological night (i.e., nocturnally placed sleep opportunity), whereas the 34-hour restart period in the “best case” condition included two biological nights. It is possible that extending the restart period in the “worst case” condition to include two biological nights—effectively adding 24 hours off-duty and making it a 58-hour restart period—would provide sufficient recuperation to maintain pre-restart performance levels during the post-restart duty periods. There is no literature on the number of biological nights that would provide full recovery from the fatiguing effects of prior night work, and only limited published evidence concerning the number of biological nights needed to recover from sustained sleep restriction over daytime duty days[5–10] in which performance during duty days following the recovery period was not considered.

For operational purposes of this study, a 58-hour restart duration was used as the duration because it provides night-time drivers with the opportunity for two full nights of sleep. However, when considering the findings of this study in operational scheduling practices, the restart period does not necessarily need to be 58 hours in duration—the critical factor is that the restart period should include two opportunities to sleep during the night, as opposed to sleeping during the day.

The FMCSA has been seeking scientific studies to evaluate the efficacy of the current 34-hour restart rule and to provide information in support of possible revisions to this rule based on scientific evidence. In the present Phase II project, the researchers investigated the effectiveness, for nighttime operations, of a two-biological-night restart period.

1.3 PHASE II PROJECT TASKS

The following tasks were completed for this project:

Task 1: Submit work plan and conduct kick-off meeting.

The investigators wrote a work plan for the project providing details for each of the project tasks. The work plan specified the laboratory research in detail and provided a basis for Task 2. Note that, since the study design was driven entirely by the previously peer-reviewed design used in Phase I, a peer-review committee meeting was planned for the end of the project only. The investigators conferred with the Government sponsors and provided an overview of the project and the planned strategy. A presentation was given outlining the project tasks and the estimated timeline (March 1, 2010).

Task 2: Obtain Institutional Review Board approval.

The investigators submitted a protocol to the Institutional Review Board of Washington State University, which subsequently approved the study (March 10, 2010).

Task 3: Conduct laboratory research.

An in-laboratory evaluation of two 5-day nighttime work periods separated by a restart period was conducted, as described in detail in the Methods section below (completed July 1, 2010).

Task 4: Data reduction and analysis.

Primary statistical testing involved a within-subjects comparison of performance in the first 5-day work period vs. the second 5-day work period, as described in detail in the Methods section below (completed September 4, 2010).

Task 5: Submit draft final report.

A draft final project report was written that detailed the methodology and the study results (September 30, 2010).

Task 6: Conduct peer review committee meeting.

The investigators convened a meeting of the peer review committee—previously constituted for Phase I—via teleconference. The peer review committee members were provided with copies of the draft final report in advance of the meeting (October 28, 2010).

Task 7: Submit final project report and technical brief.

To complete the project, the final version of the Technical Report was submitted. In addition, a technical brief was produced and shared with the Government sponsors (October 31, 2010).

2. METHODS

2.1 EXPERIMENTAL DESIGN OF THE PHASE II STUDY

During the course of the study, volunteer subjects were housed, and all experiments were run, in an in-residence sleep and performance research facility. A within-groups comparison of two 5-day work periods separated by a restart period (containing two biological nights) was conducted. Figure 1 illustrates the design of the study, and compares it to the two conditions examined in the earlier Phase I study. All conditions had equal amounts of scheduled work (simulator driving and performance testing), scheduled wakefulness, and scheduled sleep; however, in Phase II, each 5-day work period was preceded by an additional 24-hour period with no scheduled work. The two conditions of Phase I differed in the timing of the sleep/wake/work periods, in that the “worst-case” condition entailed nighttime wakefulness and work (and daytime sleep) during the two 5-day work periods, whereas the “best-case” condition entailed daytime wakefulness and work (and nighttime sleep) throughout the study. The Phase II study involved only nighttime wakefulness and work (and daytime sleep) during the two 5-day work periods, but extended the restart period by 24 hours. As shown in Figure 1, this 58-hour restart period, like the 34-hour restart period in the “worst-case” condition of Phase I, involved transitioning back to a daytime schedule.

The Phase II study began with a day for practicing performance testing procedures and practicing driving in the high-fidelity driving simulator. The day ended with 10 hours of time in bed for baseline sleep (day 1). This was followed by an additional rest day with 14 hours of scheduled wakefulness and 10 hours time in bed for baseline sleep (day 2), reflecting the extended rest period that should precede the first 5-day work period in the restart paradigm of Phase II. The next day included a 5-hour scheduled napping period for transitioning to a nighttime work schedule (day 3). Subsequently, subjects were exposed to the first 5-day nighttime work period, in which there were five 14-hour duty periods with simulator driving and performance testing, each separated by 10 hours of daytime time in bed for sleep (days 4–8). This first nighttime work period was followed, after the accumulation of 70 hours of duty time, by a restart period, which would be longer than required by the current HOS regulations but was the purpose of the Phase II study to investigate its potential effectiveness.

During the restart period, subjects transitioned back to a daytime schedule (days 8–10). The restart period began with a 5-hour scheduled napping period, followed by a 7-hour off-duty period of wakefulness and a 10-hour nocturnal sleep period. Then there was an additional rest day with 14 hours of scheduled wakefulness and 10 hours time in bed for sleep, reflecting the 24-hour extension of the rest period in the restart paradigm of Phase II as compared to a 34-hour restart period. This was followed by a 7-hour off-duty period of wakefulness, and another 5-hour scheduled napping period to transition back to a nighttime schedule for the second work period. Thus, the restart period included a total of 30 hours of time in bed for sleep and 28 hours of wakefulness. After the restart period, subjects were exposed to the second 5-day nighttime work period (days 11–15), which was identical to the first nighttime work period. After the accumulation of 70 hours of duty time, the schedule ended with a day that included a 5-hour scheduled napping period for transitioning back to a daytime schedule (day 15), and finally a recuperation day beginning with 10 hours of time in bed for recovery sleep (day 16).

The “worst case” and “best-case” conditions of Phase I are described in detail in the final report of the Phase I study.(4)

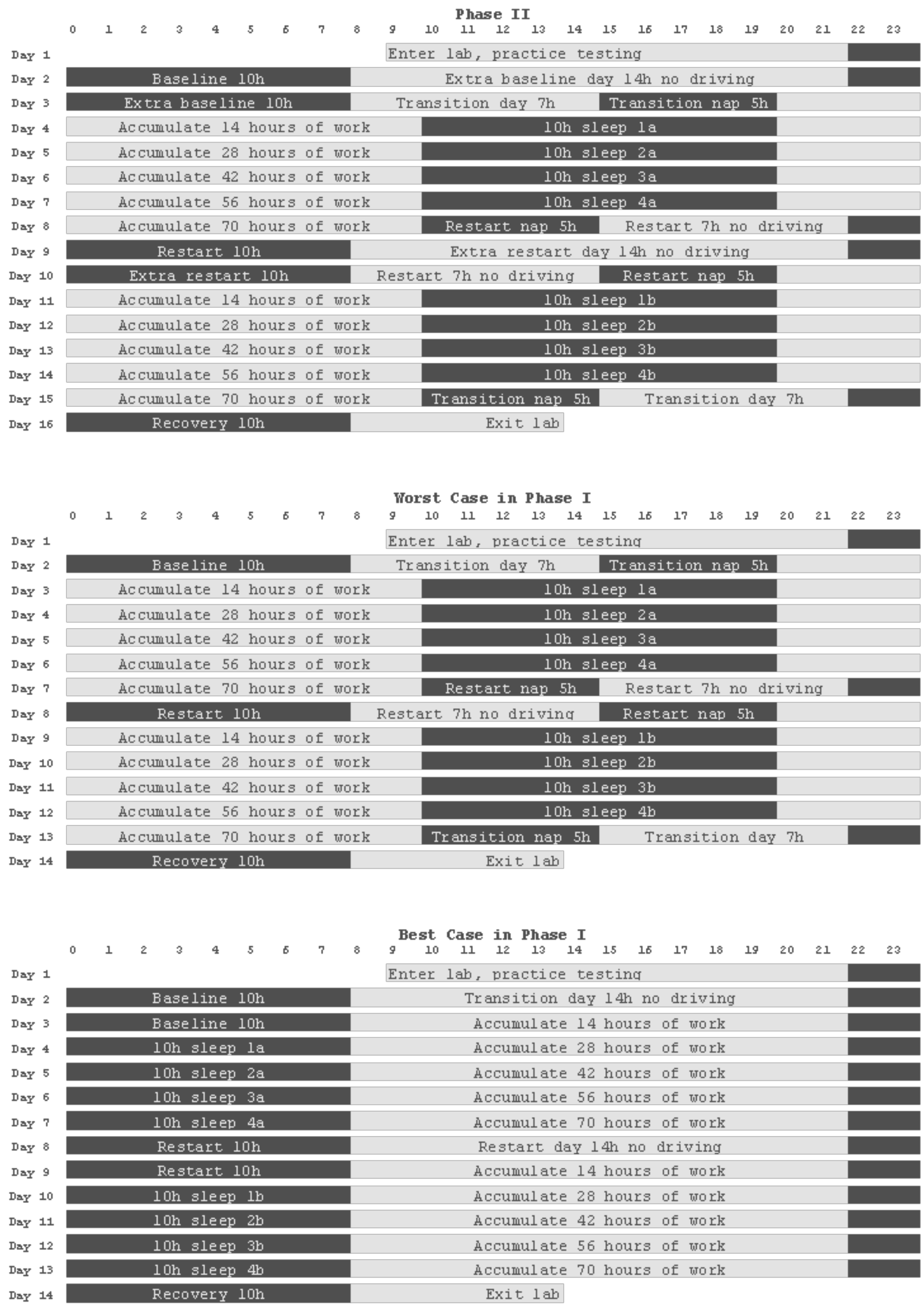

Figure 1. Chart. Study design for the Phase II condition (top schematic), and for the previously completed Phase I “worst-case” (middle schematic) and “best-case” (bottom schematic) conditions, with hours of the day (midnight to midnight) progressing from left to right (see top numbers), days of the study progressing from top to bottom (see left side), gray indicating scheduled wakefulness, and black indicating scheduled sleep periods.

The experiment was conducted in an in-residence facility which includes a state-of-the-art sleep research laboratory and a high-fidelity job task simulation laboratory connected to form a single contiguous, isolated space with a high degree of laboratory control for the precise and efficient investigation of fatigue and performance responses to prescribed sleep/wake/work schedules. The facility contains a sleep suite (four bedrooms, lounge area, medical exam room, monitoring room, and two full baths), a simulation laboratory with two high-fidelity driving simulators and several other critical job task simulators, and office and work space for investigators, post-doctoral fellows, graduate students, undergraduate research assistants, and technical personnel. The laboratory is fully equipped and staffed for polysomnographic recording of sleep and for computer- and simulator-based measurement of performance during long-term (days to weeks) in-residence studies.

Subjects were in the laboratory continuously for a total of 365 hours (16 days, 15 nights). They were monitored continuously by direct observation or, when they were in their room for performance testing or for sleep, through a camera system (with infrared light for observation in darkness during scheduled sleep). No visitors, phone calls, text messaging, email, Internet, live radio and television, or other external, potentially confounding influences were allowed inside the laboratory; only the trained research assistants interacted with the subjects. During scheduled sleep periods, lights in the bedrooms were off and subjects were not permitted to engage in any activities other than sleeping (or resting if they could not sleep). Ambient temperature was kept at 72 ± 2 degrees F, and light levels during scheduled wakefulness were fixed at below 50 lux. Meals were served at regular intervals, and breakfast, lunch, and dinner were shifted by 12 hours during nighttime wake periods.

2.2 MEASUREMENTS

During the 5-day work periods, four times per duty day, subjects drove a 40-minute route on a high-fidelity driving simulator widely used to train professional drivers. Additional hardware and software were developed and installed which enabled the capturing of driving performance data at high resolution, so as to allow utilization of this training device as a research tool.[11] Furthermore, a standardized driving scenario was employed, involving rural highway driving with five to seven randomly located encounters with pedestrians or dogs crossing the road, as previously used in the Phase I study. Braking responses to the unexpected crossing events were recorded to capture any lapses of attention. In addition, 10 straight, uneventful road segments in the scenario (“straightaways”) were used to extract non-confounded data on lane deviation and other performance measures potentially indicative of fatigued driving. The speed limit throughout the scenario was 55 mi/h.

The following outcome variables were extracted for each simulator drive: average and variability (standard deviation) of speed in the straightaways; lane deviation (standard deviation of lane position) in the straightaways; reaction time of braking for the pedestrian/dog crossing events; total number of braking errors (i.e., braking unnecessarily in the straightaways, or braking more than once or not at all around the pedestrian/dog crossing events); and fuel use (as calculated by the simulator’s internal fuel use model) across the straightaways.

Each 40-minute driving simulator session was preceded and followed by a 10-minute PVT, which is a simple reaction-time task with high stimulus density. It is a well-validated and widely used standard assay of fatigue.[3] As in previous studies[12–14] including the Phase I study, the number of performance lapses was extracted, with performance lapses being defined as reaction times greater than 500 milliseconds (ms). Because of high sensitivity to fatigue and favorable statistical properties,[15] these PVT lapse counts were used as the primary outcome measure.

Other assessments of cognitive function were performed as well during the study. Each driving simulator session (with preceding and subsequent PVT bout) was paired with administration of a brief (~12-minute) neurobehavioral test battery. The battery included computerized versions of the Karolinska Sleepiness Scale[16] (KSS); a visual analog scale of mood[13] (VASM); the Positive Affect Negative Affect Schedule[17] (PANAS), which is a measure of positive and negative emotion; a digit symbol substitution task[18] (DSST); performance and effort rating scales[19] (PERF and EFFR, respectively); and a cardinal direction decision task[20] (CDDT). The KSS, VASM, PANAS, PERF, and EFFR yielded subjective assessments of sleepiness, mood, and effort. For each, an overall score was extracted, except for the PANAS, for which both positive and negative affect scores were determined. The DSST involved matching numbers to symbols. The computer screen showed a key with a set of nine symbols, each with a corresponding digit (1–9). When given a symbol in another, fixed location on the screen, subjects were required to type its corresponding number. After the response, a new symbol was presented immediately. The number of correct responses in the 3-minute task duration was extracted, yielding a measure of cognitive throughput. The CDDT required participants to make judgments about the location of a target on a map. The stimulus consisted of a first-person view where a single target was highlighted in a set of eight objects arranged in a circular target field. This view was presented adjacent to an allocentric perspective (i.e., a map with the target field at the center), which indicated the viewing perspective. The task was to identify the portion of the target field containing the target. A total of 25 trials were presented per test bout, and responses were self-paced. From the number of attempts needed to complete them the number of error responses was calculated (i.e., the number of attempts minus 25), which served as the outcome measure.

Figure 2 shows the timing of the 1-hour blocks consisting of a 10-minute PVT, 40-minute simulator driving, and 10-minute PVT, as marked by the asterisk triplets. Figure 2 also shows the timing of the brief neurobehavioral test bouts, as marked by lower-case x symbols. On off-duty days, no driving occurred, but the neurobehavioral test battery was administered a few times, augmented with a 10-minute PVT (as marked with capital X symbols). This off-duty performance monitoring served to gauge fatigue levels during the baseline, restart, and recovery periods bracketing the two 5-day work periods; they were not used for the present analyses. Driving simulator and performance testing practice occurred on the first day; these practice sessions were also not used for analysis. Driving and neurobehavioral testing in the Phase II study was analogous to that in the Phase I study conditions.

Two driving simulators were available in the laboratory and up to four subjects could be participating in the study at a given time. Therefore, subjects were randomly assigned consistently either to do the PVT/driving/PVT block first and undergo the neurobehavioral testing second, or the other way around. There was always a 45-minute break between the PVT/driving/PVT blocks and the neurobehavioral test bouts. Figure 2 illustrates the simulator driving and performance testing schedule for the subjects who underwent the PVT/driving/PVT block first and the neurobehavioral testing second.

During scheduled sleep periods, sleep stages were recorded using digital equipment (Nihon Kohden, Foothill Ranch, CA) for polysomnography (PSG). Scalp and skin electrodes were used to record brain waves (bipolar electroencephalogram, EEG), eye movement (electrooculogram, EOG), muscle activity (submental electromyogram, EMG), and heart beats (electrocardiogram, ECG). The EEG electrodes were placed at frontal (F3, F4), central (C3, C4), and occipital (O1, O2) locations, referenced against the mastoids (M1, M2). Sleep stages were scored using standard criteria promulgated by the American Academy of Sleep Medicine.[21] Every third or fourth day, electrodes were removed to give subjects an opportunity to take a shower and to heal any skin irritation that might have occurred due to electrode attachment. Figure 2 shows which sleep periods were recorded.

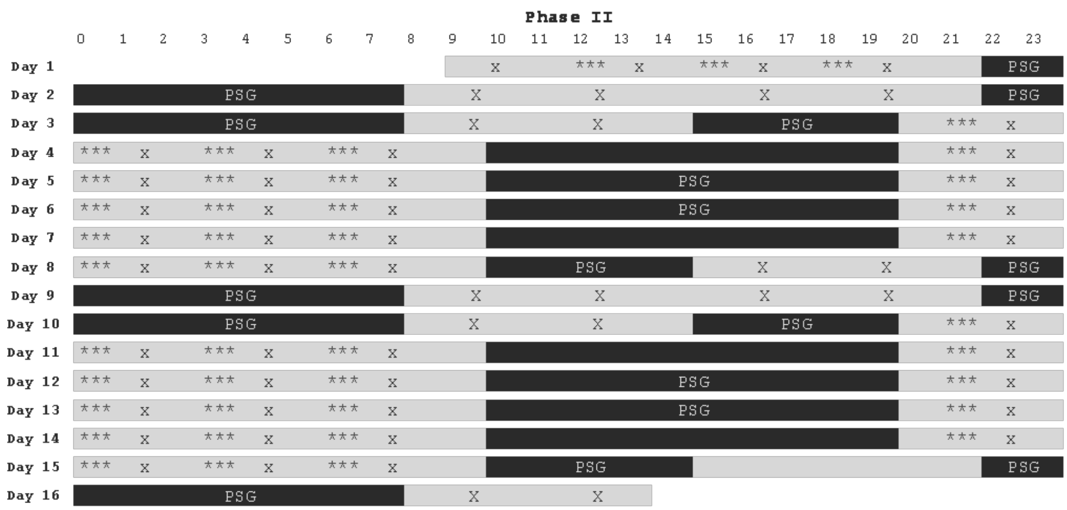

Figure 2. Chart. Measurement scheme for the Phase II study, with hours of the day (midnight to midnight) progressing from left to right (see top numbers); days of the study progressing from top to bottom (see left side); gray indicating scheduled wakefulness; black indicating scheduled sleep periods; triple asterisks marking 40-minute driving simulator sessions each preceded and followed by a 10-minute psychomotor vigilance test (PVT); lower-case x marking brief neurobehavioral test bouts; capital X marking brief neurobehavioral test bouts augmented with a PVT (during off-duty days); and PSG denoting polysomnography (i.e., sleep recordings).

2.3 STATISTICAL METHODS AND POWER CALCULATION

The primary statistical design involved within-subjects comparison of performance during the first 5-day work period with performance during the second 5-day work period (i.e., repeated measures). The researchers employed a one-way mixed-effects analysis of variance (ANOVA) and focused on the effect of work period (session). This tests the null hypothesis that the restart period is effective at maintaining performance, using subjects as their own controls. Additional analyses, used to help interpret the main results, involved two-way mixed-effects ANOVA of session by day (to look at changes over days within sessions), and two-way mixed-effects ANOVA of session by time of day (to examine the effects of circadian timing). The primary outcome measure we considered was PVT lapses (see above). Additional neurobehavioral outcomes and driving simulator performance outcomes (accounting for subjects' assignment to either simulator number 1 or 2) were used for secondary analyses.

Data from $N = 12$ subjects were available for analysis. This sample size equates that of each of the Phase I study conditions. In that earlier study, the primary hypothesis testing involved an interaction effect, which is inherently less statistical powerful than the main effect on which hypothesis testing in the present Phase II study is based. Phase I was powered to achieve at least 95 percent statistical power to reject the null hypothesis at a type I error rate of $\alpha = 0.05$ (one-sided), and yielded statistically significant results. As such, it was expected that $N = 12$ should suffice to reject the null hypothesis that the tested restart period is effective at maintaining performance (i.e., that there is no change in performance from the pre-restart session to the post-restart session), at 95 percent statistical power, if in reality the 58-hour restart period was actually not effective at maintaining performance.

The Phase II study was designed based on, and conducted following completion of, the Phase I study, and as such a direct comparison between the data from the two studies has the potential to be confounded by order effects. This is particularly relevant for the data from the driving simulators, which underwent maintenance between the two studies and as a consequence were calibrated slightly differently in Phase II. Compared to Phase I, there were also more stringent criteria for the population from which the subjects in Phase II were drawn (see below), which could have resulted in study differences presenting as order effects as well. With potential order effects in mind, secondary data analyses were performed to compare the data from Phase II with those from the "worst case" condition of Phase I; and to compare the data from Phase II with those from the "best case" condition of Phase I (see Figure 1). These secondary analyses mimicked the primary analyses, but added study condition as an effect, and focused on testing the interactions with condition.

To help interpret the study findings, secondary analyses were also performed to compare the polysomnographic measures of sleep in Phase II with those in each of the two conditions in Phase I. These comparisons were driven by which combinations of sleep periods corresponded best with each other between the study conditions (see Figure 1). A series of one-way ANOVAs was performed for comparison of the first (10-hour) baseline night in the Phase II study with same in the Phase I "worst-case" and "best-case" conditions; comparison of the first and second (10-hour) baseline nights plus the first (5-hour) transition nap in Phase II with the first (10-hour) baseline night plus the first (5-hour) transition nap in the Phase I "worst-case" condition and with the first and second (10-hour) baseline nights in the Phase I "best-case" condition; comparison of the sum of the two polysomnographically recorded (10-hour) sleep periods in the first 5-day work period between the juxtaposed conditions; comparison of the combination of the two (5-hour) transition naps and two (10-hour) nocturnal sleep periods in the restart period with the combination of the two (5-hour) transition naps plus the (10-hour) nocturnal sleep period in the 34-hour restart period of the Phase I "worst-case" condition and with the combination of the two (10-hour) nights in the 34-hour restart period of the Phase I "best-case" condition; comparison of the sum of the two polysomnographically recorded (10-hour) sleep periods in the second 5-day work period between the juxtaposed conditions; and comparison of the (5-hour) transition nap plus the (10-hour) recovery night at the end of the Phase II study with same at the end of the Phase I “worst-case” condition and with the (10-hour) recovery night at the end of the Phase I “best-case” condition. Furthermore, mixed-effects ANOVAs were performed to compare the two work periods (sessions) in the Phase II study.

2.4 SUBJECT RECRUITMENT AND SCREENING

Subjects in the Phase II study were healthy young individuals in the age range from 22 to 40 years. The sample was drawn from the same population as that from which the Phase I study sample had been drawn. This population was selected because of their relative homogeneity in sleep/wake and circadian physiology (e.g., minimal aging effects and no sleep disorders), which is beneficial (and necessary) for obtaining sufficient statistical power to demonstrate any effects of the restart period on performance. If any performance impairments are found in this population, then even greater deficits would be expected in the more heterogeneous population of CMV drivers.

The inclusion/exclusion criteria for the Phase II study were the same as for Phase I, except that females were not included. Further, only non-obese subjects were included from whom blood samples could be drawn. These additional criteria were necessary because the Phase II study also served as an active control condition for another study, which focuses on glucose metabolism and neuroendocrine effects of split sleep schedules (not discussed here). Note that male/female differences in sleep and performance are generally negligible compared to naturally occurring non-sex-related individual differences,[13,22] so the exclusion of females in the Phase II study should not be problematic for making comparisons with the Phase I study.

The full list of inclusion/exclusion criteria is as follows:

1. Physically and psychologically healthy (i.e., no clinical disorders and/or illnesses), as determined by physical exam, history, and questionnaires.
2. No current medical or drug treatment (excluding oral contraceptives), as determined by history and questionnaire.
3. No clinically significant abnormalities in blood and urine, and free of traces of drugs, as determined by blood chemistry and urinalysis, as well as a urine drug test upon entering the study.
4. Free of traces of alcohol, as verified with a breathalyzer during screening and upon entering the study.
5. No history of psychiatric illness, as determined by history and questionnaire.
6. No history of drug or alcohol abuse in the past year, and no history of methamphetamine abuse, as determined by history and questionnaire.
7. Not a current smoker, as determined by questionnaire.
8. No history of moderate to severe brain injury, as determined by history and questionnaire.
9. No history of a learning disability, as determined by questionnaire.

10. Not susceptible to simulator adaptation syndrome, as determined by supervised test driving of the simulator followed by questionnaire and interview.
11. No previous adverse reaction to sleep deprivation, as determined by history and questionnaire.
12. Not vision-impaired (unless corrected to normal), as determined by questionnaire.
13. No sleep or circadian disorder, as determined by history, suite of questionnaires, and baseline polysomnography.
14. Good habitual sleep, between 6 and 10 hours in duration, as determined by questionnaire and verified with wrist actigraphy and diary in the week before the study.
15. Regular bedtimes, habitually getting up between 6 and 9 a.m., as determined by questionnaire and verified with actigraphy and diary in the week before the study.
16. Neither an extreme morning-type nor an extreme evening-type, as determined by questionnaire.
17. No travel across time zones within one month of entering the study, as determined by questionnaire.
18. No shift work within one month of entering the study, as determined by questionnaire.
19. Native English speaker, as determined by questionnaire.
20. Proficient driver, as determined by valid driver's license and supervised test driving of the simulator.
21. Age from 22 to 40 years, as verified by date of birth on driver's license.
22. Male gender.
23. Veins suitable for intravenous catheter insertion.
24. No history of problems with blood draws or blood donation.
25. Not donated blood within two months of entering the study, and not planning to donate blood within two months after the study.
26. Body mass index (BMI) less than 30.
27. Not a participant in the Phase I study.

Prospective subjects were recruited with advertisements in local newspapers and on the Internet. A total of 411 individuals responded to the advertisements and were interviewed by telephone. Those who met key selection criteria such as age were screened during two laboratory-based screening sessions, beginning with an informed consent procedure. Screening procedures included a physical exam, blood and urine samples, supervised test driving of the simulator, and a variety of questionnaires (see inclusion/exclusion criteria above).

A total of 17 subjects completed the study. However, 5 subjects were found to be non-compliant on the PVT, which provided the primary outcome measure for the study, and other performance tests. These subjects exhibited a grand average of 7.4 lapses on the PVT, whereas the other subjects in the sample showed a grand average of only 1.7 lapses (standard deviation: 2.6). The non-compliant subjects were therefore a priori removed from the data set and their data were not subjected to analysis. As such, data were available for $N = 12$ subjects. They were healthy male subjects who met all the inclusion/exclusion criteria; their ages were 22–39 (mean ± standard deviation: 26.5 ± 5.5). A power calculation (see above) had shown that a sample size of $N = 12$ should suffice to reject the null hypothesis that the restart period is effective at maintaining performance, at 95 percent statistical power, if in reality the restart period was actually not effective at maintaining performance.

3. RESULTS

3.1 PERFORMANCE OUTCOMES

3.1.1 Primary Performance Outcome

The primary outcome measure for the study was the number of lapses on the psychomotor vigilance test (PVT). The primary statistical analysis focused on the effect of session (pre-restart vs. post-restart 5-day work period), collapsed over days and times of day within sessions. This interaction tests the null hypothesis that the restart period is effective at maintaining performance. In agreement with the null hypothesis, the effect of session for PVT lapses was not statistically significant ($F_{1,945} = 0.17$, $p = 0.68$). Figure 3 shows the Phase II results, superimposed on those from Phase I ("worst case" and "best case" conditions). Interactions of condition by session in secondary analyses showed that the restart period of the Phase II study was more effective at maintaining performance that the 34-hour restart period in the "worst case" nighttime work condition of Phase I ($F_{1,1971} = 12.73$, $p < 0.001$), but not significantly different from the 34-hour restart period in the "best case" daytime work condition of Phase I ($F_{1,1969} = 0.99$, $p = 0.32$).

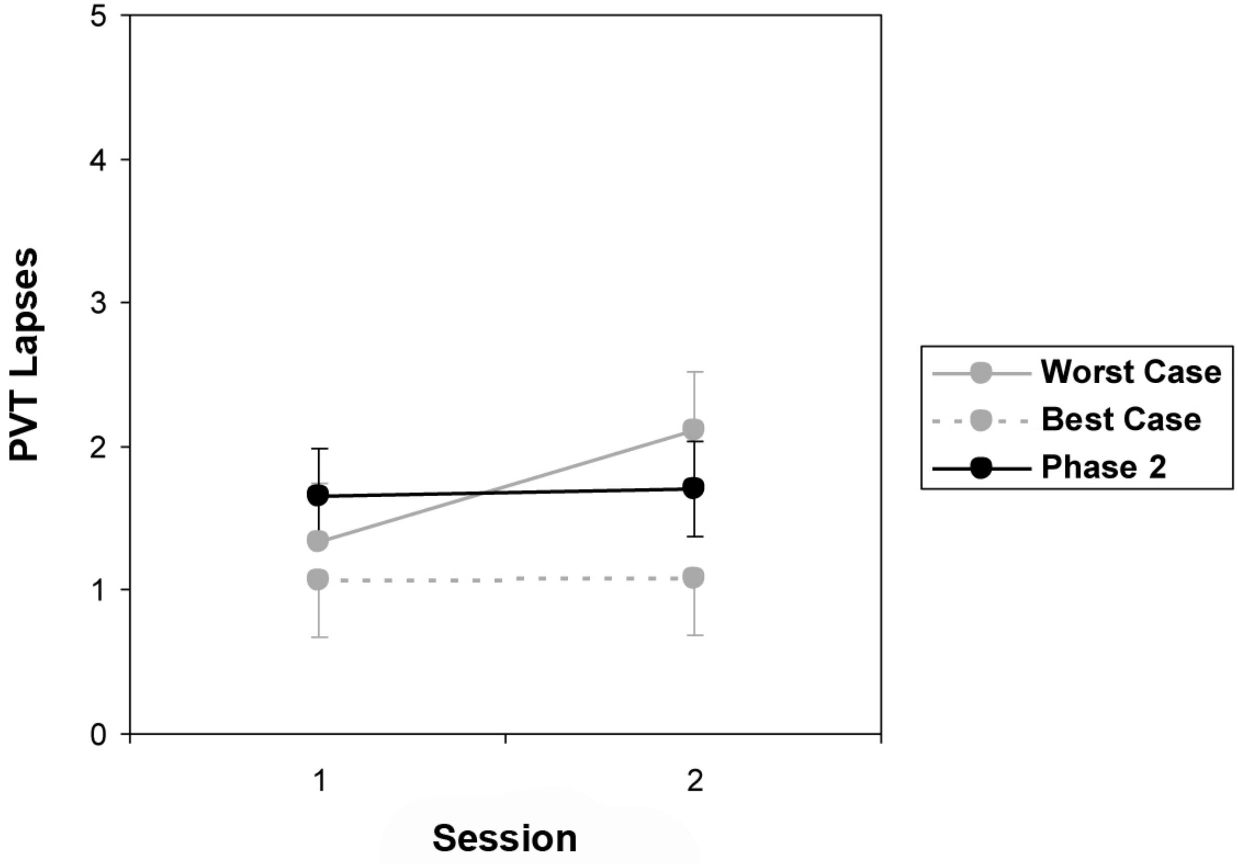

Figure 3. Graph. Lapses (number of reaction times greater than 500 ms) on the 10-minute PVT in the pre-restart 5-day work period (session 1) as compared to the post-restart 5-day work period (session 2) for the Phase II study. For comparison, the equivalent data from the Phase I "worst-case" and "best-case" conditions also are shown. The higher the number, the greater degree of performance impairment. Error bars indicate standard error derived from mixed-effects ANOVA.

In order to look at changes in performance over days within sessions, a further analysis of PVT lapses in the Phase II study investigated the interaction of session by day, collapsed over time of day. This two-way interaction showed a trend to significance ($F_{4,937} = 2.21$, $p = 0.066$). The main effect of day was statistically significant ($F_{4,937} = 3.60$, $p = 0.006$). Figure 4 displays the Phase II data by day, again superimposed on the Phase I data. The figure reveals that the increased effectiveness of the tested restart period over the 34-hour restart period for nighttime work schedules comes at the cost of a moderate decrease in performance on the day immediately following the restart period. This day displayed 0.8 ± 0.2 more lapses compared to the average of the other days in the pre- and post-restart work periods (post-hoc contrast: $t_{937} = 3.79$, $p < 0.001$).

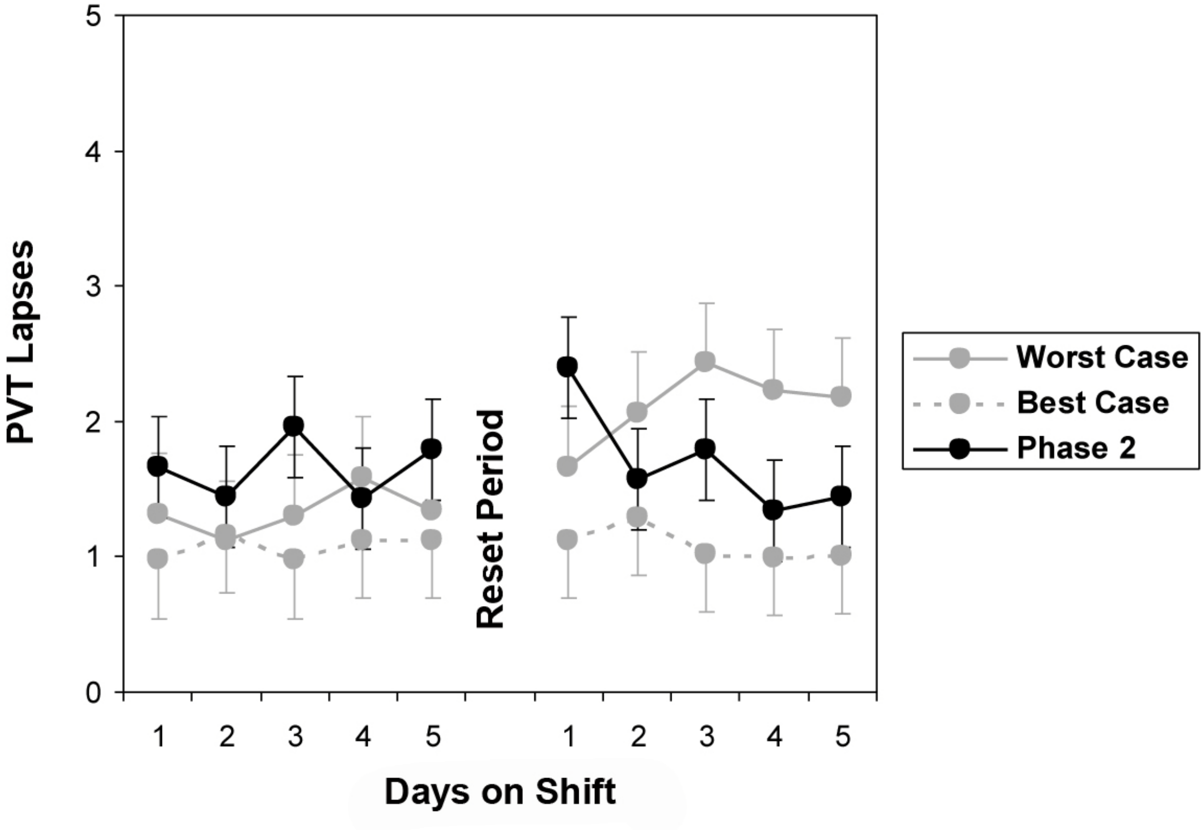

Figure 4. Graph. Lapses on the 10-minute PVT as a function of days in the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher the number, the greater degree of performance impairment. Error bars indicate standard error derived from mixed-effects ANOVA.

In order to study performance as a function of time of day, another secondary analysis of PVT lapses investigated the interaction of session by time of day, collapsed over days within each session. The two-way interaction was not statistically significant ($F_{7,931} = 1.40$, $p = 0.20$), although there was a significant main effect of time of day ($F_{7,931} = 26.14$, $p < 0.001$). Figure 5 displays the Phase II data as a function of time of day (collapsed over days within each work period), superimposed on the Phase I data. The figure shows that the time-of-day effect was similar in the nighttime work conditions (i.e., Phase II and "worst case" condition in Phase I), with performance degrading progressively across time of night, regardless of the duration of the restart period.

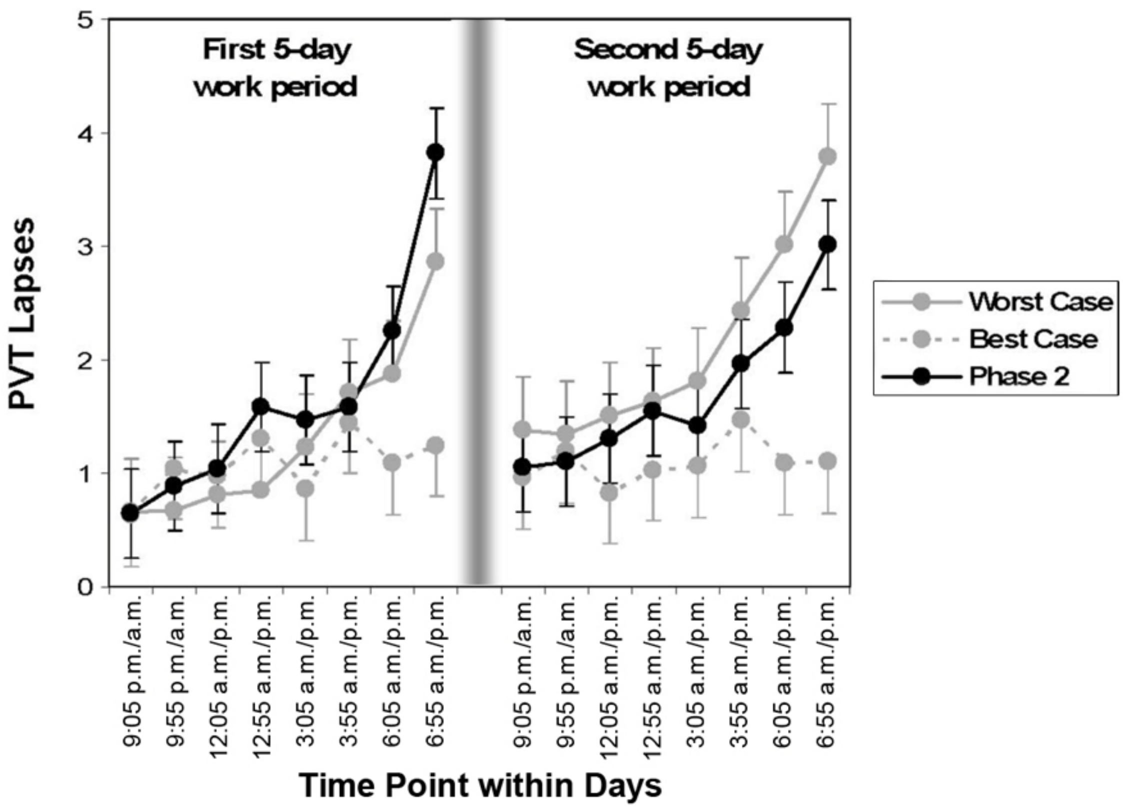

Figure 5. Graph. Lapses on the 10-minute PVT as a function of time of day, collapsed over the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher the number, the greater degree of performance impairment. Error bars indicate standard error derived from mixed-effects ANOVA. Times of day are through the night (9:05 p.m.–6:55 a.m.) for the Phase II study and for the Phase I "worst-case" condition, and through the day (9:05 a.m.–6:55 p.m.) for the Phase I "best-case" condition; 1 hour should be added for subjects who were assigned to performance testing first and driving second.

3.1.2 Secondary Performance Outcomes

Secondary performance outcomes were derived from a computerized neurobehavioral test battery which included, in order of presentation, the KSS, VASM, PANAS (both subscales were analyzed), DSST, PERF, EFFR, and CDDT. Results for these outcome measures are presented here in that order.

For the KSS, the primary analysis focusing on the main effect of session (collapsed over days and over times of day within sessions) yielded a non-significant effect ($F_{1,467} = 0.92$, $p = 0.34$). Figure 6 displays the Phase II results, superimposed on those from Phase I. Interactions of condition by session in secondary analyses showed that the restart period of the Phase II study was not significantly more effective at maintaining subjective sleepiness levels than the 34-hour restart period in the "worst case" nighttime work condition of Phase I ($F_{1,972} = 0.31$, $p = 0.58$), but did not show an increase in sleepiness after the restart period as observed in the "best case" daytime work condition of Phase I ($F_{1,1012} = 5.76$, $p = 0.017$).

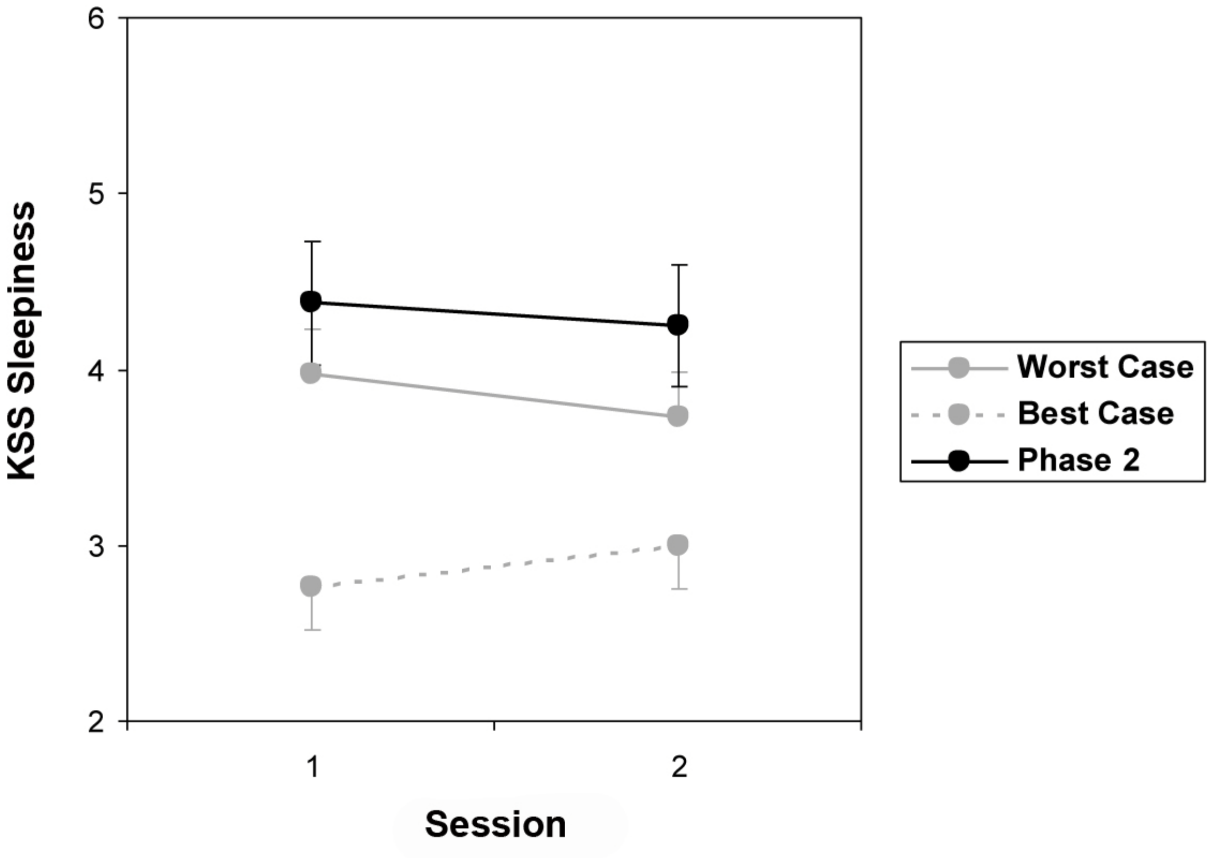

Figure 6. Graph. Subjective sleepiness score on the KSS in the pre-restart 5-day work period (session 1) as compared to the post-restart 5-day work period (session 2) for the Phase II study. For comparison, the equivalent data from the Phase I "worst-case" and "best-case" conditions also are shown. The higher the number, the greater the degree of subjective sleepiness. Error bars indicate standard error derived from mixed-effects ANOVA.

In order to investigate changes in subjective sleepiness over days within sessions, a further analysis of the KSS examined the interaction of session by day, collapsed over time of day. The two-way interaction was not statistically significant ($F_{4,459} = 0.60$, $p = 0.66$). However, the main effect of day was significant ($F_{4,459} = 4.11$, $p = 0.003$). Figure 7 displays the data by day, revealing that the pattern of subjective sleepiness changes across days was essentially the same in the nighttime work conditions regardless of the duration of the restart period.

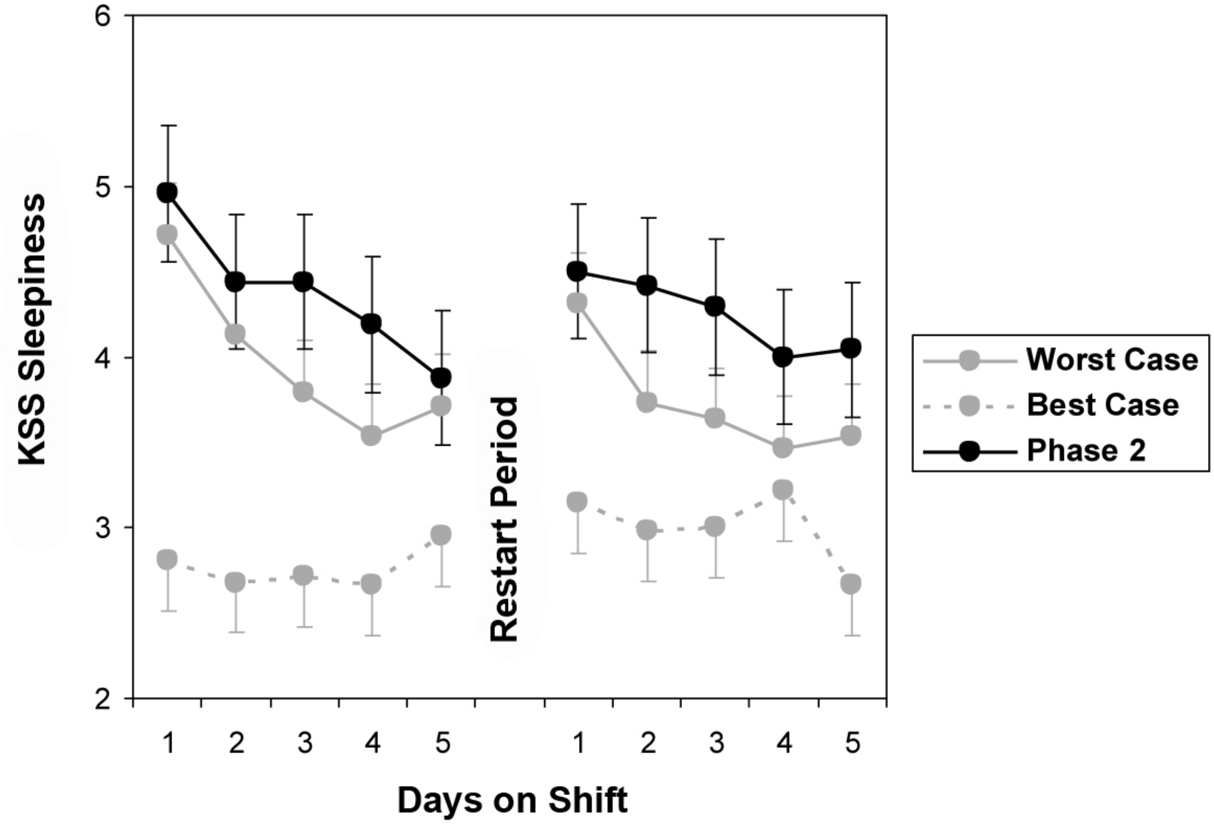

Figure 7. Graph. Subjective sleepiness on the KSS as a function of days in the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher the number, the greater degree of subjective sleepiness. Error bars indicate standard error derived from mixed-effects ANOVA.

In order to investigate subjective sleepiness as a function of time of day, a final analysis of the KSS examined the interaction of session by time of day, collapsed over days within each 5-day work period session. The two-way interaction was not statistically significant ($F_{3,461} = 0.35$, $p = 0.79$), although there was a significant main effect of time of day ($F_{3,461} = 73.08$, $p < 0.001$). Figure 8 displays the data as a function of time of day (collapsed over days within each work period), revealing that the pattern of subjective sleepiness as a function of time of day was similar in the nighttime work conditions regardless of the duration of the restart period.

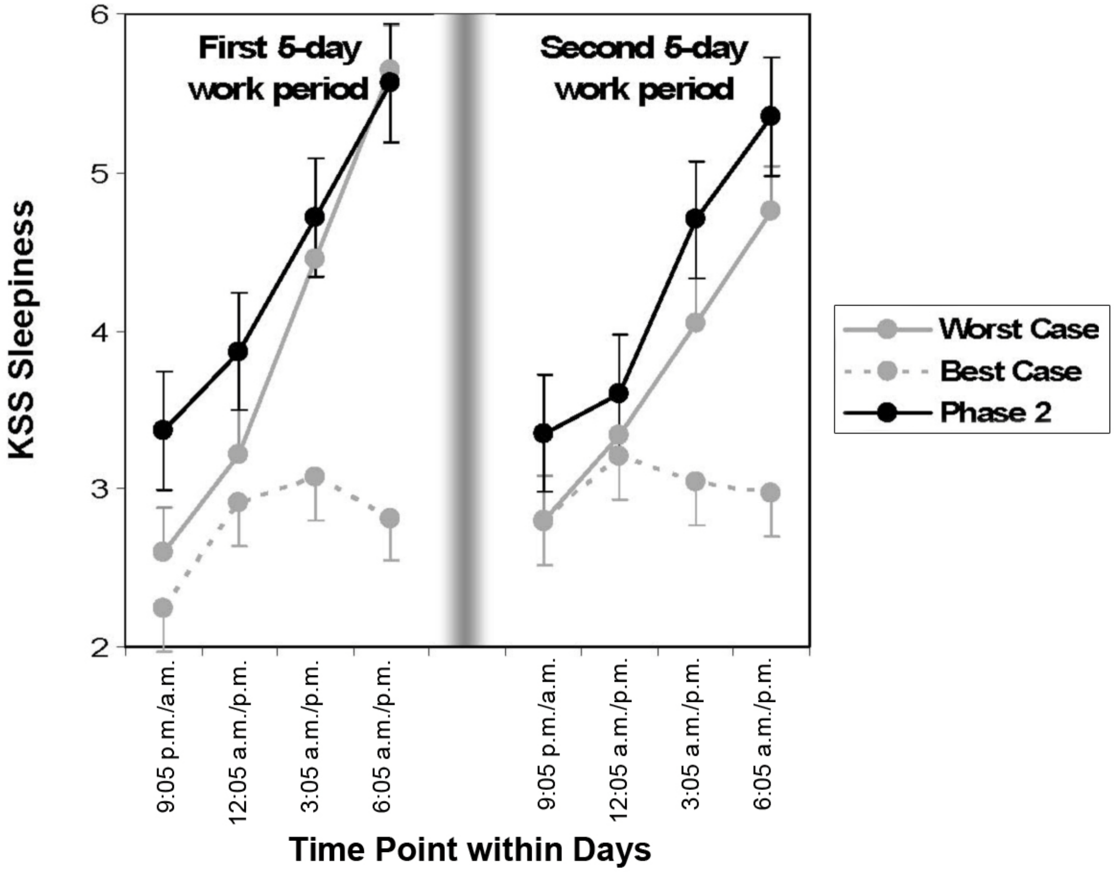

Figure 8. Graph. Subjective sleepiness on the KSS as a function of time of day, collapsed over the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher the number, the greater the degree of subjective sleepiness. Error bars indicate standard error derived from mixed-effects ANOVA. Times of day are through the night (9:05 p.m.–6:05 a.m.) for the Phase II study and for the Phase I "worst-case" condition, and through the day (9:05 a.m.–6:05 p.m.) for the Phase I "best-case" condition; 1 hour should be added for subjects who were assigned to performance testing first and driving second.

For the VASM, which is an assay of subjective mood (ranging from elated to depressed), the primary analysis focusing on the effect of session (collapsed over days and over times of day within sessions) yielded a trend to significance ($F_{1,467}$ = 2.71, p = 0.010), indicative of a slight improvement of mood (more elated) after the restart period as compared to before. Interactions of condition by session in secondary analyses showed that the restart period of the Phase II study was more beneficial for subjective mood that the 34-hour restart period in the "worst case" nighttime work condition of Phase I ($F_{1,973}$ = 7.30, p = 0.007) as well as the "best case" daytime condition of Phase I ($F_{1,1012}$ = 9.88, p = 0.017). Figure 9 displays these findings.

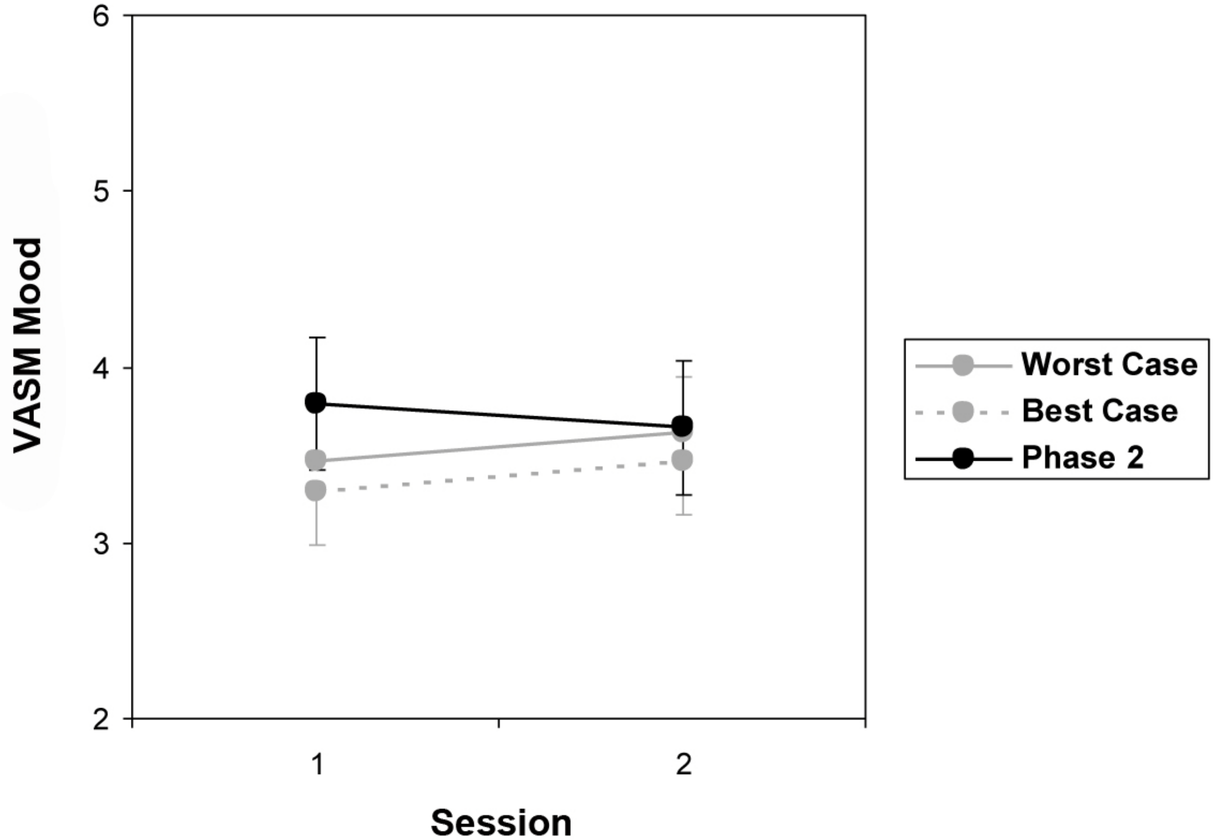

Figure 9. Graph. Subjective mood score on the VASM in the pre-restart 5-day work period (session 1) as compared to the post-restart 5-day work period (session 2) for the Phase II study. For comparison, the equivalent data from the Phase I "worst-case" and "best-case" conditions also are shown. The higher numbers on the scale correspond to more depressed mood.

In order to investigate changes in subjective mood over days within sessions in the Phase II study, a further analysis of the VASM examined the interaction of session by day, collapsed over time of day. The two-way interaction was not statistically significant ($F_{4,459} = 0.37$, $p = 0.83$). However, the main effect of day was significant ($F_{4,459} = 3.22$, $p = 0.013$). Figure 10 displays the data by day, revealing a steady improvement in mood across the days of the Phase II study, which was not seen in either condition of the Phase I study. It should be noted that subjects in the Phase I study could be randomized to either daytime work ("best case" condition) or nighttime work ("worst case" condition), whereas subjects in the Phase II study were certain that they would have to perform nighttime work. Thus, the subjects' prior expectations may have differed between the studies, which could explain the modest difference in the temporal profiles of subjective mood.

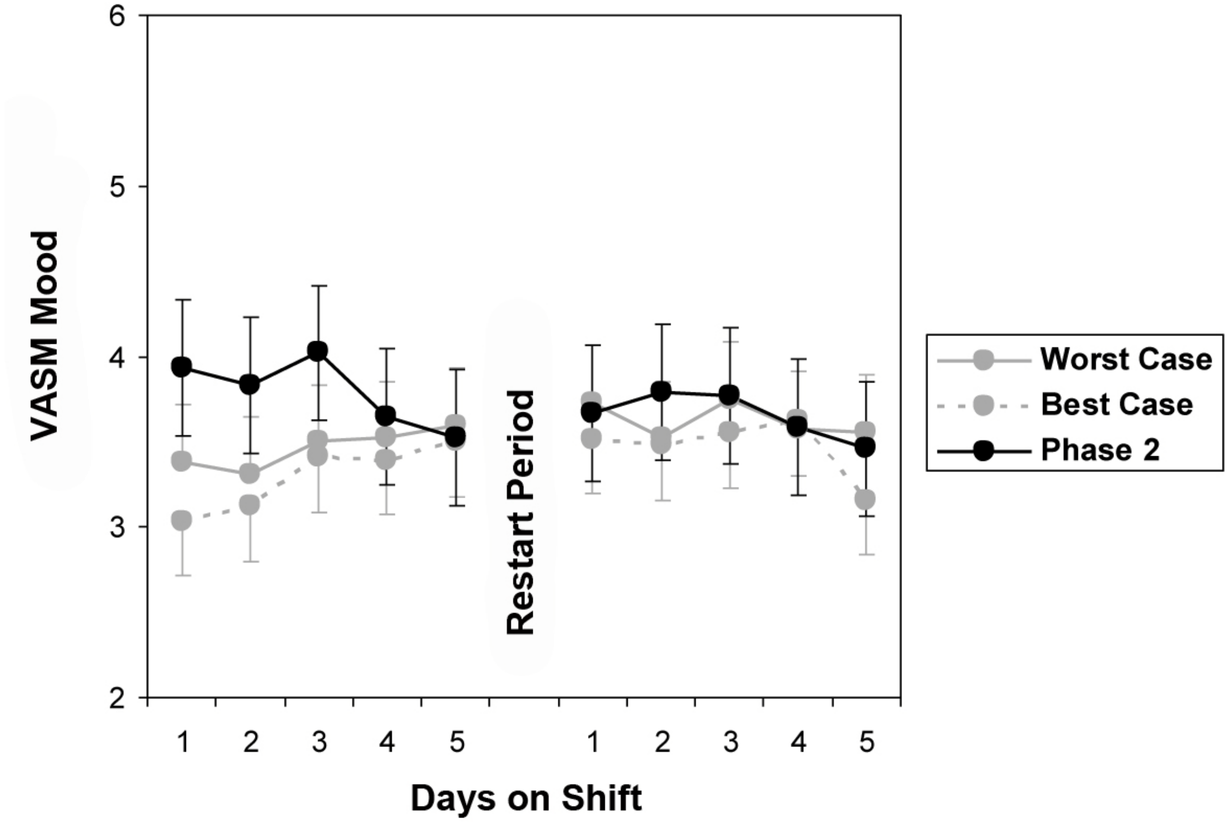

Figure 10. Graph. Subjective mood on the VASM as a function of days in the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher numbers on the scale correspond to more depressed mood.

In order to investigate subjective mood as a function of time of day, a further analysis of the VASM examined the interaction of session by time of day, collapsed over days within each 5-day session. The two-way interaction showed a trend to significance ($F_{3,461} = 2.13$, $p = 0.094$), and there was a significant main effect of time of day ($F_{3,461} = 5.24$, $p = 0.002$). Figure 11 displays the data as a function of time of day (collapsed over days within each work period), revealing that the pattern of subjective mood as a function of time of day was similar in the nighttime work conditions regardless of the duration of the restart period.

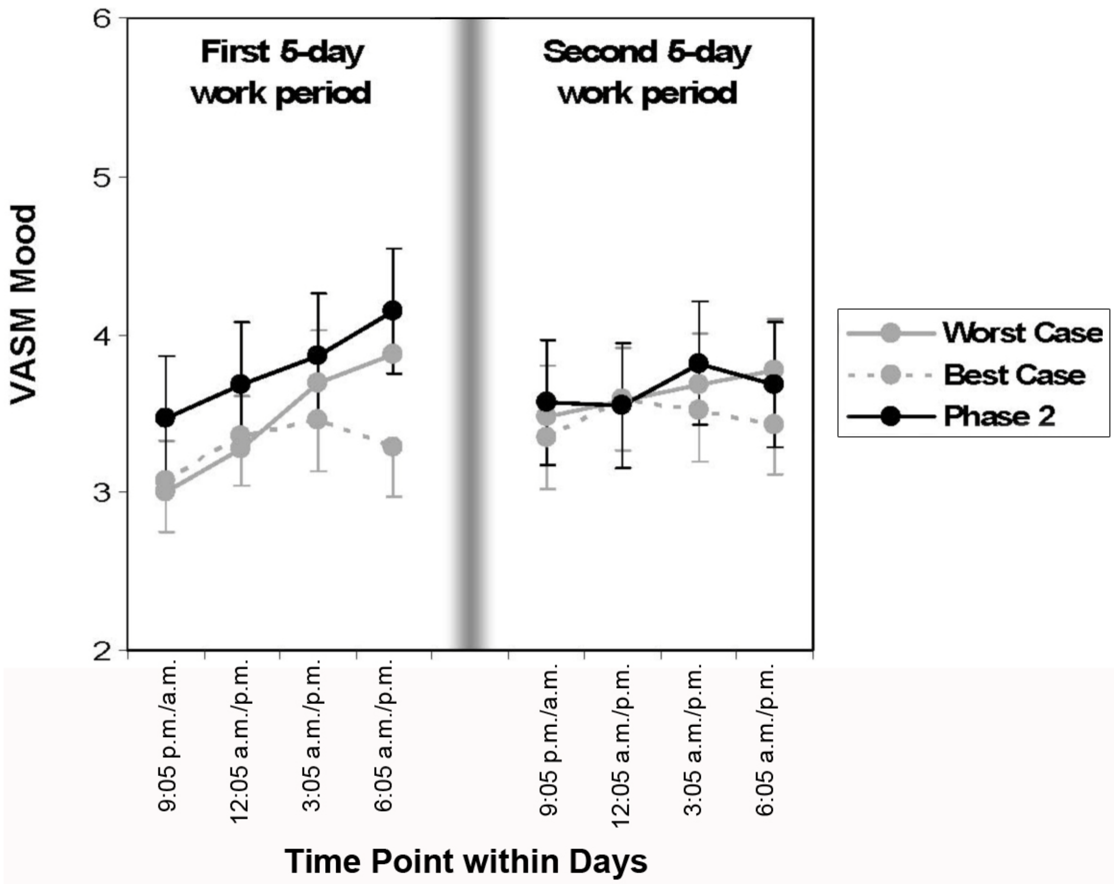

Figure 11. Graph. Subjective mood on the VASM as a function of time of day, collapsed over the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher numbers on the scale correspond to more depressed mood. Times of day are through the night (9:05 p.m.–6:05 a.m.) for the Phase II study and for the Phase I "worst-case" condition, and through the day (9:05 a.m.–6:05 p.m.) for the Phase I "best-case" condition; 1 hour should be added for subjects who were assigned to performance testing first and driving second.

For the positive affect scale of the PANAS, the primary analysis focusing on the main effect of session yielded non-significance ($F_{1,467} = 1.70$, $p = 0.19$). Interactions of condition by session in secondary analyses showed that the restart period of the Phase II study was modestly more effective (i.e., a trend to significance) for maintaining positive affect than the 34-hour restart period in the "worst case" nighttime work condition of Phase I ($F_{1,973} = 3.49$, $p = 0.062$), but not significantly different compared to the "best case" daytime work condition of Phase I ($F_{1,1012} = 1.10$, $p = 0.29$).

These patterns were further elucidated in an analysis examining the interaction of session by day, which was not statistically significant ($F_{4,459} = 1.37$, $p = 0.24$). Figure 12 displays the data by day, revealing that positive affect was stable across days and similar in the nighttime work conditions of the Phase I and II studies, but slightly degraded compared to the daytime work condition of the Phase I study.

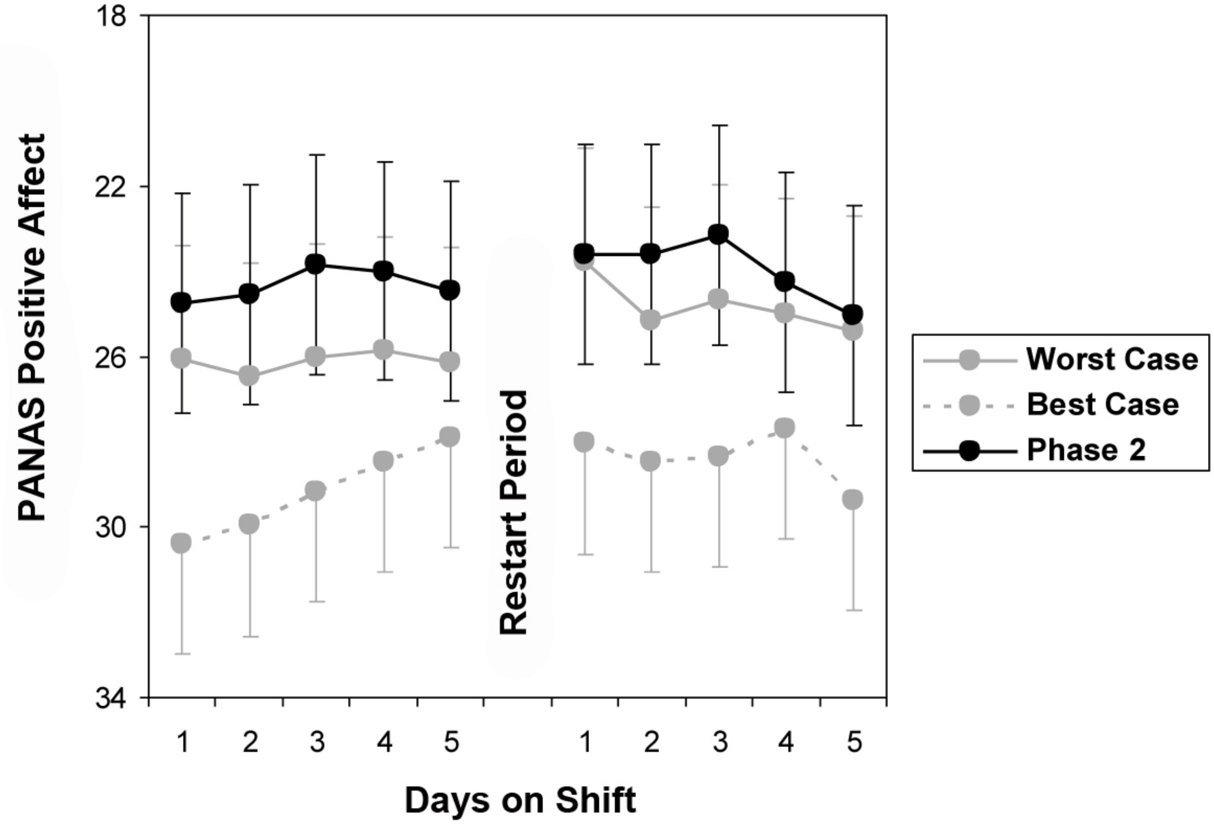

Figure 12. Graph. Positive affect score on the PANAS as a function of days in the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The vertical scale is inverted; the lower numbers correspond to less positive affect.

Examination of PANAS positive affect (positive emotion) as a function of time of day, collapsed over days within each 5-day session, showed no significant interaction of session by time of day ($F_{3,461}$ = 0.97, p = 0.40), but there was a significant main effect of time of day ($F_{3,461}$ = 28.30, p < 0.001). In this regard, the positive affect data mirrored those of subjective sleepiness, (i.e., the higher the subjective sleepiness, the lower the positive emotion),as shown in Figure 8.

The primary analysis of negative affect on the PANAS in the Phase II study revealed a statistically significant, albeit small, increase of negative affect from before to after the restart period. Interactions of condition by session in secondary analyses showed no significant interaction with the "worst case" nighttime work condition of Phase I ($F_{1,973}$ = 0.85, p = 0.36), nor with the "best case" daytime condition of Phase I ($F_{1,1012}$ = 0.79, p = 0.37). Analysis of the Phase II negative affect data by day, collapsed over time of day, showed no significant interaction of session by day ($F_{4,459}$ = 1.46, p = 0.21). Likewise, analysis of these data by time of day, collapsed over days, showed no significant interaction of session by time of day ($F_{3,461}$ = 1.38, p = 0.25), but there was a significant main effect of time of day ($F_{3,461}$ = 4.67, p = 0.003). Figure 13 shows that negative affect increased slightly as a function of time of day regardless of whether the study condition involved nighttime or daytime work—suggesting that this effect was actually associated with how long the subject had been awake.

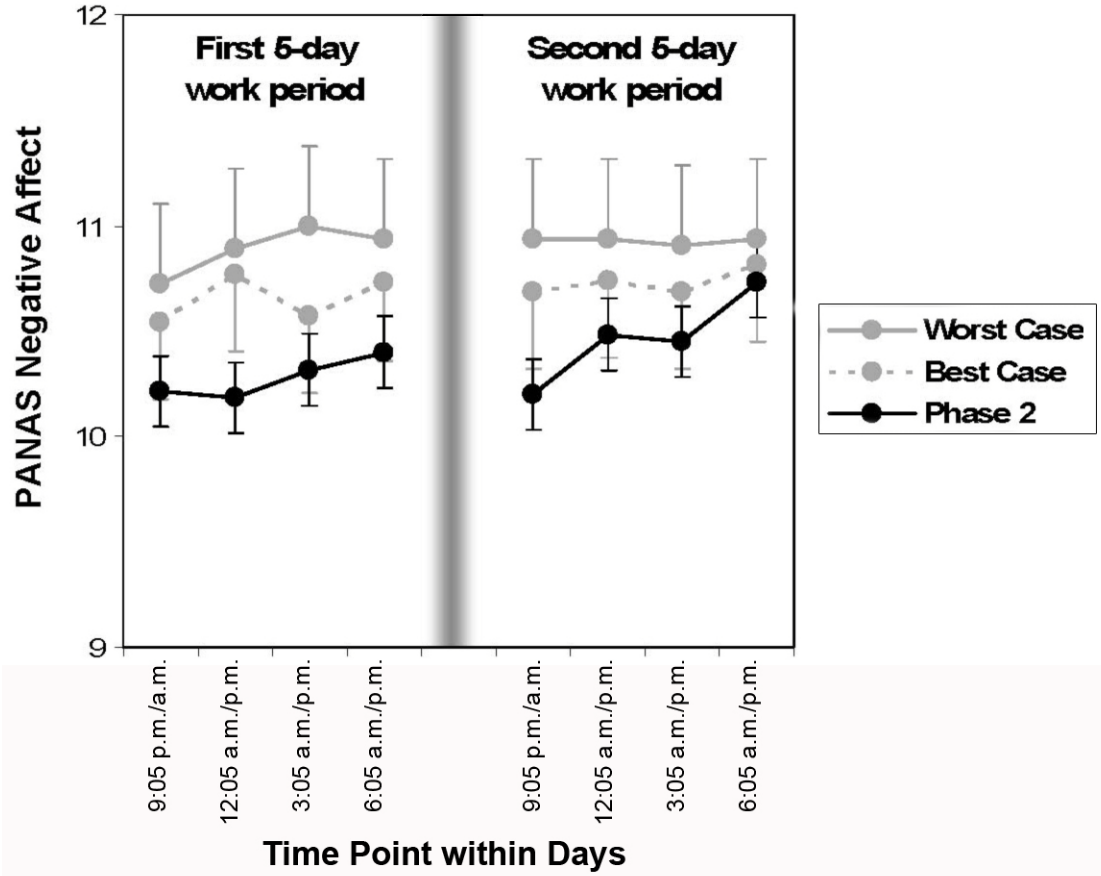

Figure 13. Graph. Negative affect score on the PANAS as a function of time of day, collapsed over the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher numbers correspond to greater negative affect. Times of day are through the night (9:05 p.m.–6:05 a.m.) for the Phase II study and for the Phase I "worst-case" condition, and through the day (9:05 a.m.–6:05 p.m.) for the Phase I "best-case" condition; 1 hour should be added for subjects who were assigned to performance testing first and driving second.

For the number of correct responses on the DSST, the primary analysis focusing on the effect of session (collapsed over days and over times of day within sessions) yielded a statistically significant effect of session ($F_{1,467} = 134.74$, $p < 0.001$) attributable to the well-known learning curve associated with this task. Figure 14 displays these data, showing that performance on the DSST improved significantly across the study regardless of study (Phase I or II) or condition (nighttime or daytime work). Indeed, secondary analyses showed no significant interaction with the "worst case" nighttime work condition of Phase I ($F_{1,972} = 0.62$, $p = 0.43$), nor with the "best case" daytime condition of Phase I ($F_{1,1012} = 0.11$, $p = 0.74$).

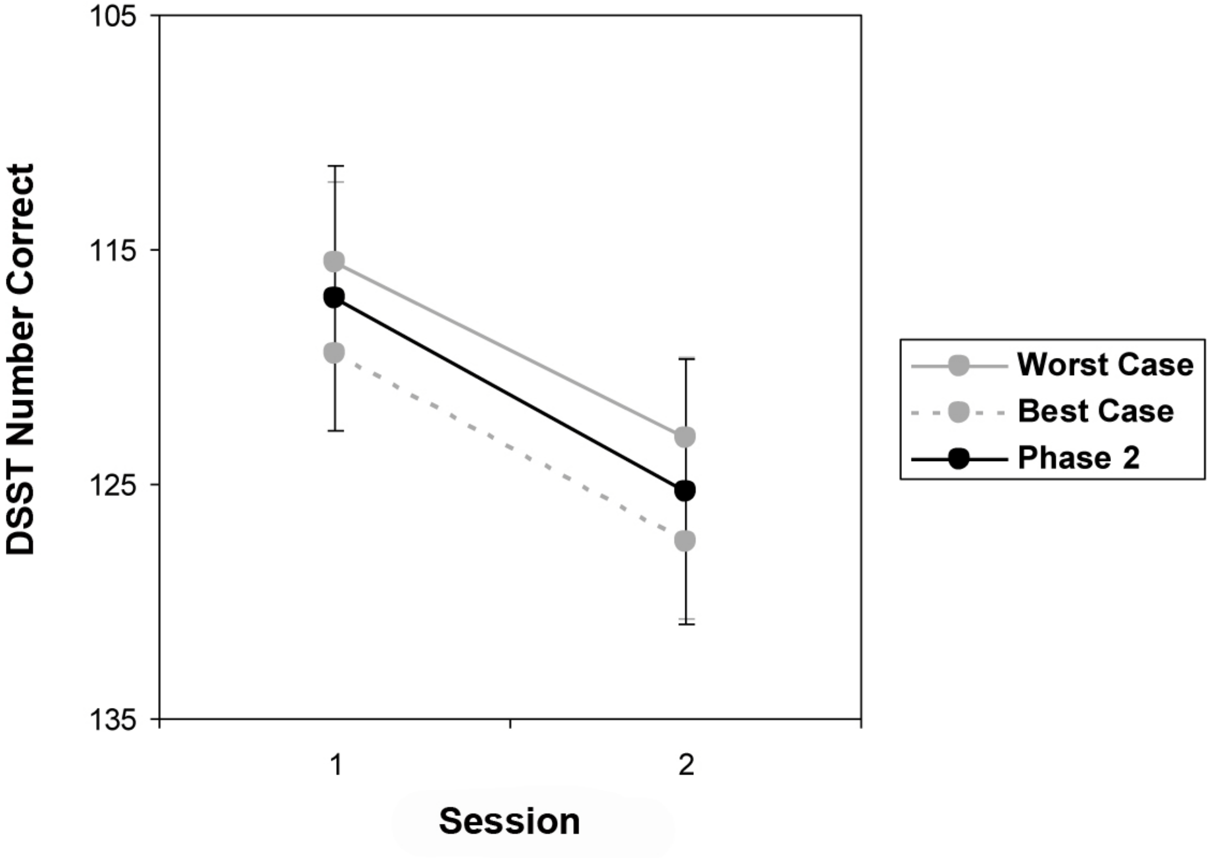

Figure 14. Graph. Number of correct responses on DSST in the pre-restart 5-day work period (session 1) as compared to the post-restart 5-day work period (session 2) for the Phase II study. For comparison, the equivalent data from the Phase I "worst-case" and "best-case" conditions also are shown. The lower numbers correspond to greater performance impairment.

The learning curve on the DSST was borne out further in analyses by day, which showed a significant main effect of day ($F_{4,459} = 10.04$, $p < 0.001$) and a significant interaction of session by day ($F_{4,459} = 3.41$, $p = 0.009$); and by time of day, which showed a significant main effect of time of day ($F_{3,461} = 3.41$, $p = 0.018$), although there was no significant interaction of session by time of day ($F_{3,461} = 1.54$, $p = 0.20$). DSST performance in the Phase II study was equivalent to that seen in either condition of the Phase I study whether examined by session (Figure 14), by day within sessions (Figure 15) or by time of day.

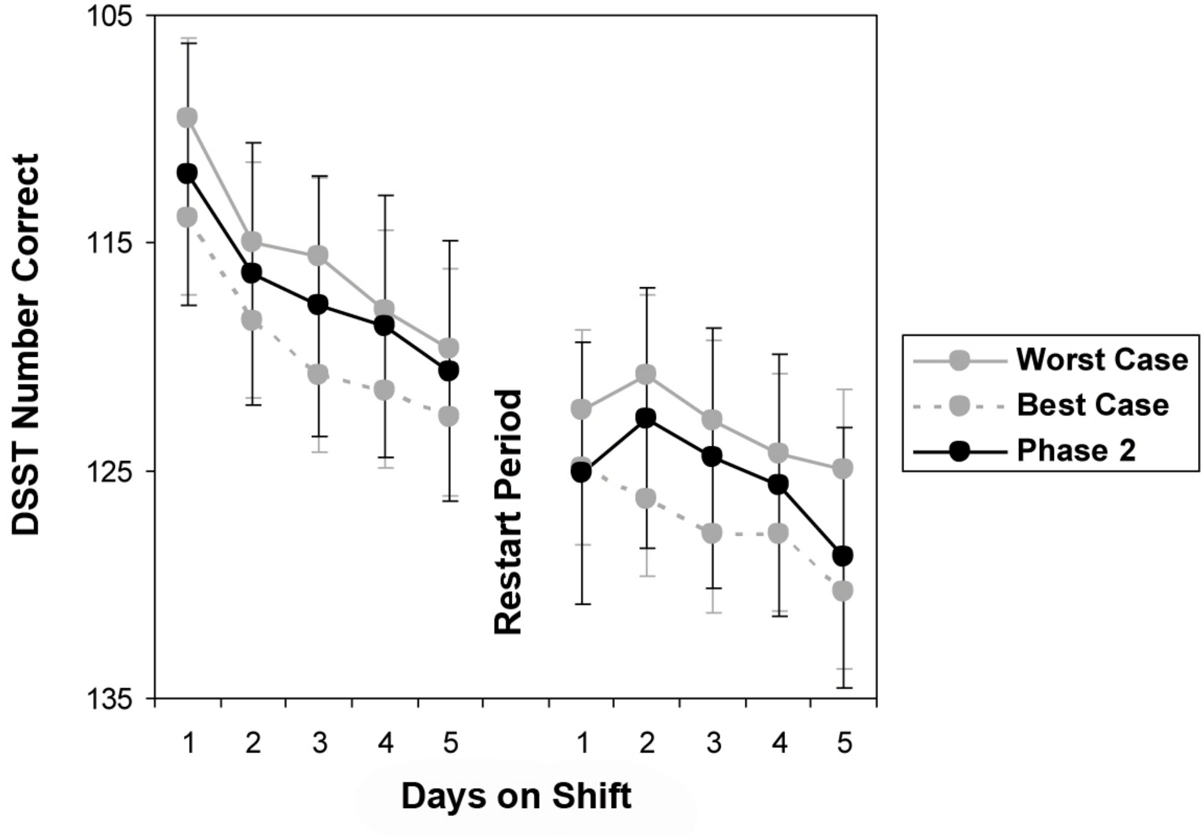

Figure 15. Graph. Number of correct responses on DSST as a function of days in the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The lower numbers correspond to greater performance impairment.

For the PERF administered near the end of each neurobehavioral test bout, the primary analysis focusing on the effect of session (collapsed over days and over times of day within sessions) yielded no significant effect of session ($F_{1,467} = 1.34$, $p = 0.25$). Secondary analyses showed no significant interaction with the "worst case" nighttime work condition of Phase I ($F_{1,973} = 1.58$, $p = 0.21$), nor with the "best case" daytime condition of Phase I ($F_{1,1012} = 0.85$, $p = 0.36$). Analysis of the Phase II PERF data by day, collapsed over time of day, showed no significant interaction of session by day ($F_{4,459} = 0.51$, $p = 0.73$). Further, analysis of these data by time of day, collapsed over days, showed no significant interaction of session by time of day ($F_{3,461} = 0.39$, $p = 0.76$). In other words, there were no relevant statistically significant effects for how subjects rated their performance; these data are therefore not shown in a graph.

For the EFFR administered near the end of each neurobehavioral test bout, the primary analysis focusing on the effect of session (collapsed over days and over times of day within sessions) also yielded no significant effect of session ($F_{1,467} = 0.05$, $p = 0.83$). Secondary analyses showed no significant interaction with the "worst case" nighttime work condition of Phase I ($F_{1,973} = 0.02$, $p = 0.90$), nor with the "best case" daytime condition of Phase I ($F_{1,1012} = 1.97$, $p = 0.16$). Analysis of the EFFR data of the Phase II study by day, collapsed over time of day, showed no significant interaction of session by day ($F_{4,459}$ = 0.35, p = 0.84). However, analysis of these data collapsed over days showed a trend to significance for the interaction of session by time of day ($F_{3,461}$ = 2.16, p = 0.092), and there was a significant main effect of time of day ($F_{3,461}$ = 4.37, p = 0.005). As shown in Figure 16, subjective effort to perform in the Phase II study increased as a function of time of day before the restart period, whereas this effect was attenuated after the restart period.

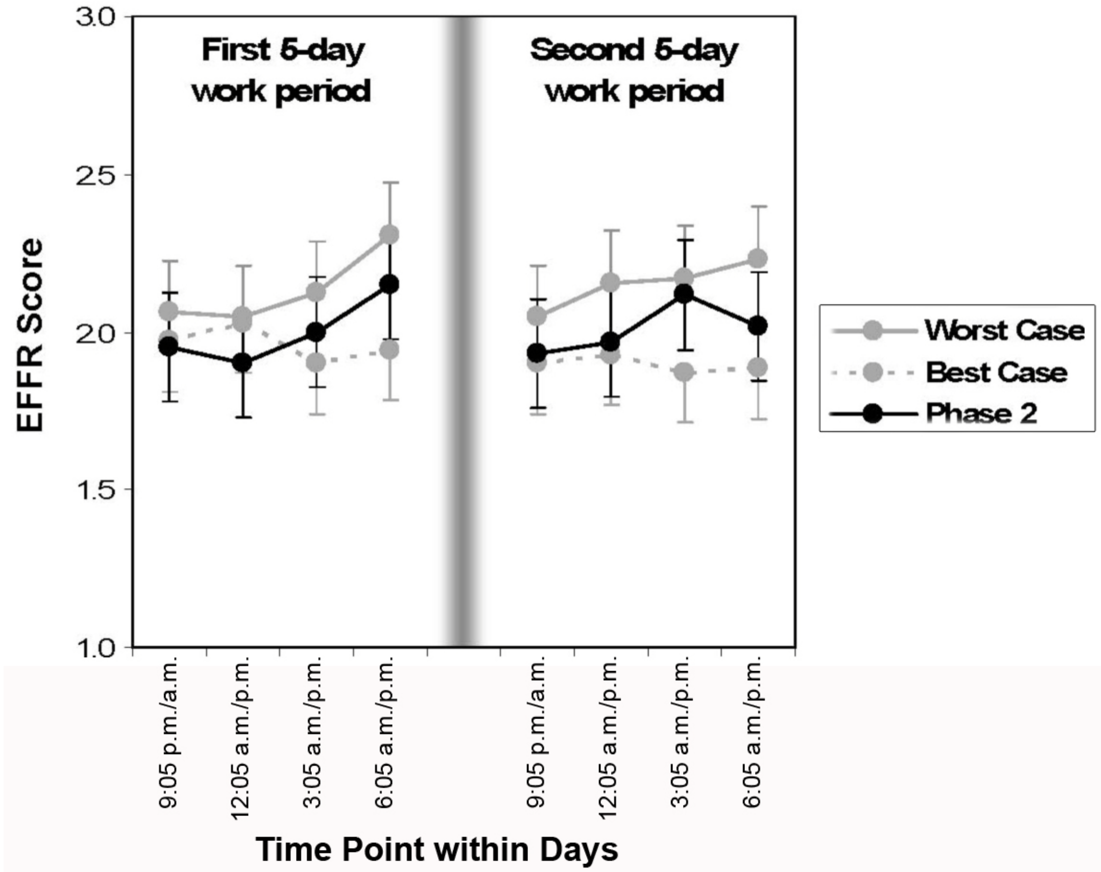

Figure 16. Graph. Subjective effort score on the EFFR as a function of time of day, collapsed over the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher numbers correspond to greater subjective effort. Times of day are through the night (9:05 p.m.–6:05 a.m.) for the Phase II study and for the Phase I "worst-case" condition, and through the day (9:05 a.m.–6:05 p.m.) for the Phase I "best-case" condition; 1 hour should be added for subjects who were assigned to performance testing first and driving second.

For the number of error responses on the CDDT, the primary analysis focusing on the effect of session (collapsed over days and over times of day within sessions) yielded no statistically significant effect of session ($F_{1,467}$ = 1.24, p = 0.27). Secondary analyses showed no significant interaction with the "worst case" nighttime work condition of Phase I ($F_{1,973}$ = 0.11, p = 0.74), but there was a significant interaction of condition by session for when comparing the Phase II study with the "best case" daytime condition of Phase I ($F_{1,1012}$ = 4.83, p = 0.028). Figure 17 shows these data, revealing that performance on the CDDT improved (i.e., fewer errors) in the course of the study particularly in the daytime work condition ("best case") of Phase I, which was however not evident in the Phase II data.

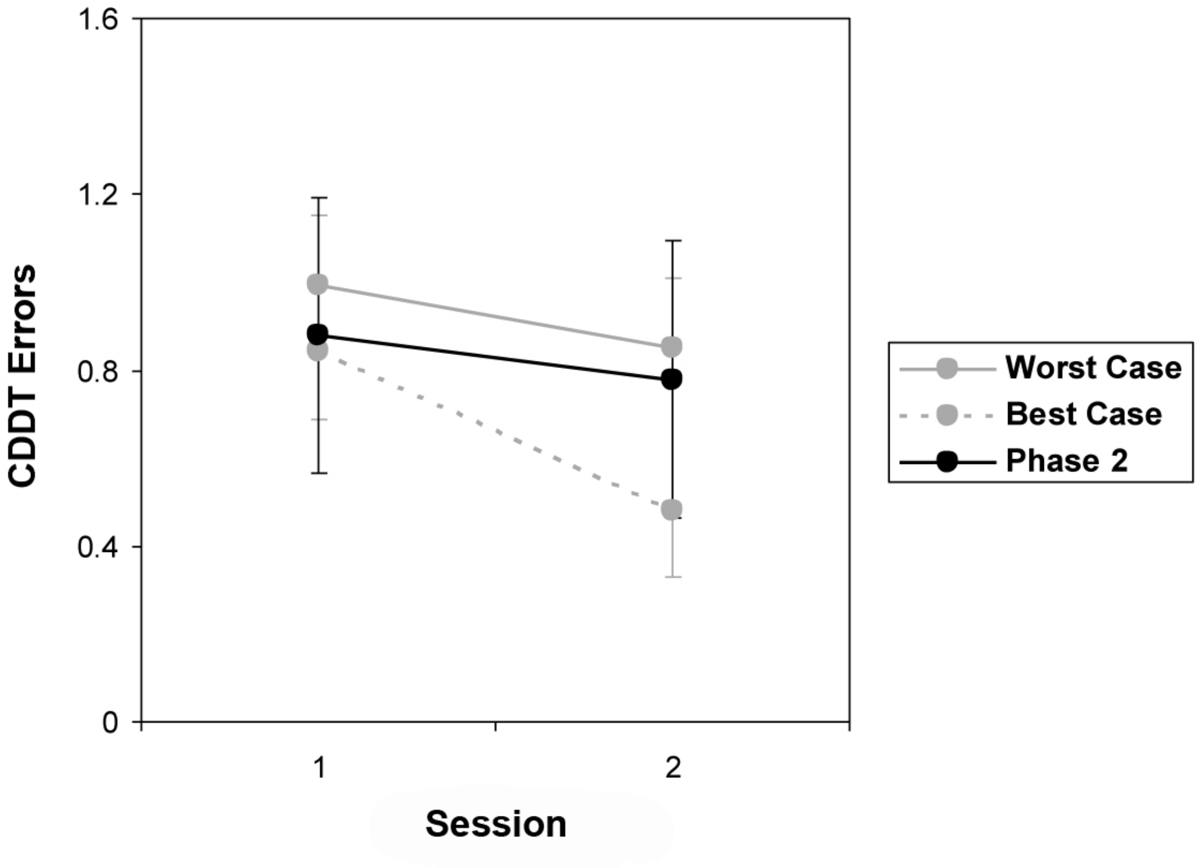

Figure 17. Graph. Number of error responses on the CDDT in the pre-restart 5-day work period (session 1) as compared to the post-restart 5-day work period (session 2) for the Phase II study. For comparison, the equivalent data from the Phase I "worst-case" and "best-case" conditions also are shown. The higher number corresponds to greater performance impairment.

Analysis of the CDDT data by day, collapsed over time of day, showed no significant interaction of session by day ($F_{4,459}$ = 1.56, p = 0.18). Analysis by time of day, collapsed over days, showed no significant interaction of session by time of day either ($F_{3,461}$ = 1.03, p = 0.38).

3.1.3 Simulator Driving Performance

Driving simulator outcome variables were subjected to the same primary and secondary analyses as were the cognitive performance outcomes described above, but subjects' assignment to simulator number 1 or number 2 was added as a covariate to account for possible simulator hardware differences.

For average driving speed in the straightaways, the primary analysis focusing on the effect of session (collapsed over days and over times of day within sessions) yielded a significant effect of session ($F_{1,466}$ = 84.44, p < 0.001). Figure 18 displays this finding, showing that subjects in the Phase II study stayed close to the speed limit of 55 mi/h, but exhibited a small increase in average speed from before to after the restart period. Figure 18 also shows the results of the Phase I study. Secondary analysis showed that average speed was greater and also increased more, statistically significantly, in Phase II compared to the "worst case" nighttime driving condition of Phase I (effect of condition: $F_{1,971} = 5.03$, $p = 0.025$; interaction of condition by session: $F_{1,971} = 13.35$, $p < 0.001$). Similarly, average speed was greater (trend to significance) and increased more (significantly) in Phase II than in the "best case" daytime driving condition of Phase I (effect of condition: $F_{1,931} = 2.97$, $p = 0.085$; interaction of condition by session: $F_{1,931} = 28.55$, $p < 0.001$).

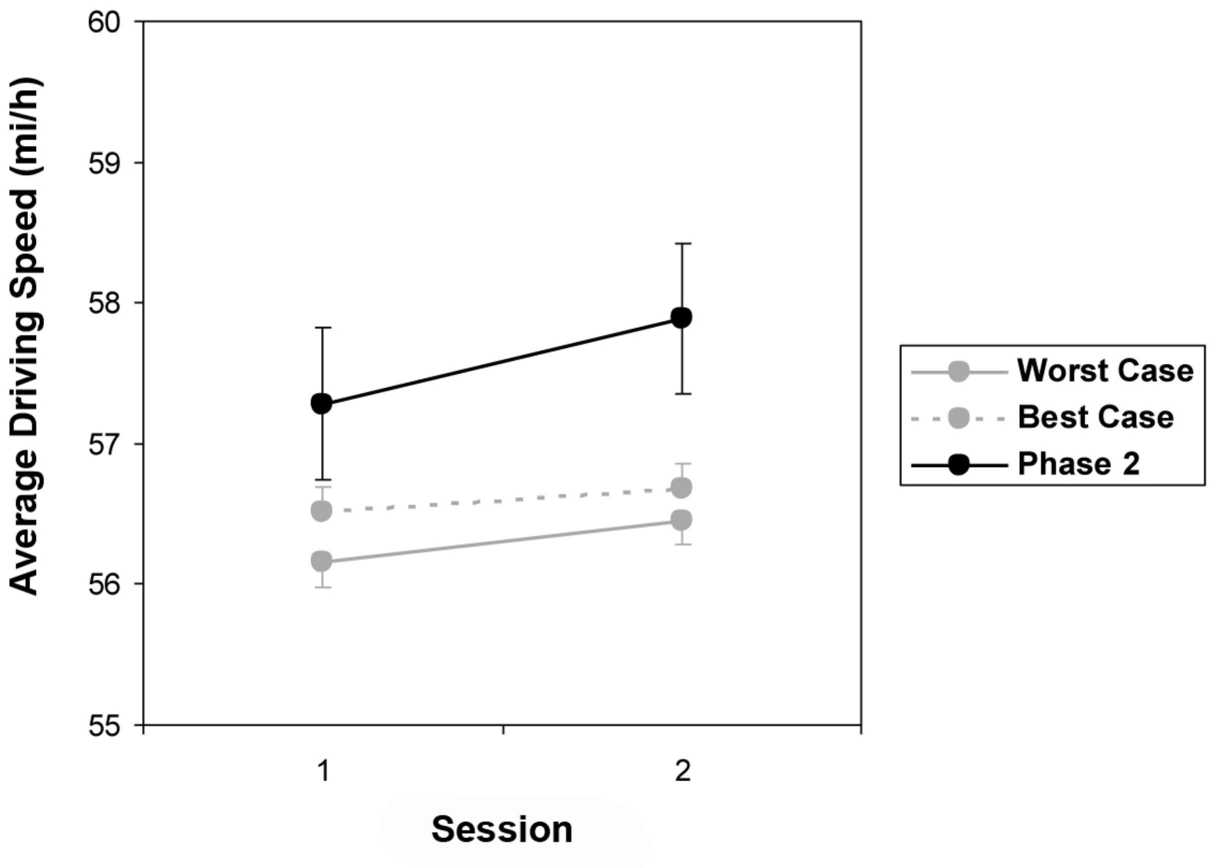

Figure 18. Graph. Average simulator driving speed in the pre-restart 5-day work period (session 1) as compared to the post-restart 5-day work period (session 2) for the Phase II study. For comparison, the equivalent data from the Phase I "worst-case" and "best-case" conditions also are shown. Error bars indicate standard error derived from mixed-effects ANOVA (controlling for simulator assignment).

In order to investigate changes in average driving speed over days within sessions, a further analysis examined the interaction of session by day, collapsed over time of day. The two-way interaction was not statistically significant ($F_{4,458} = 0.53$, $p = 0.71$). However, the main effect of day was significant ($F_{4,458} = 10.68$, $p < 0.001$), reflecting a progressive increase of average speed across days throughout the experiment. Figure 19 displays the data by day.

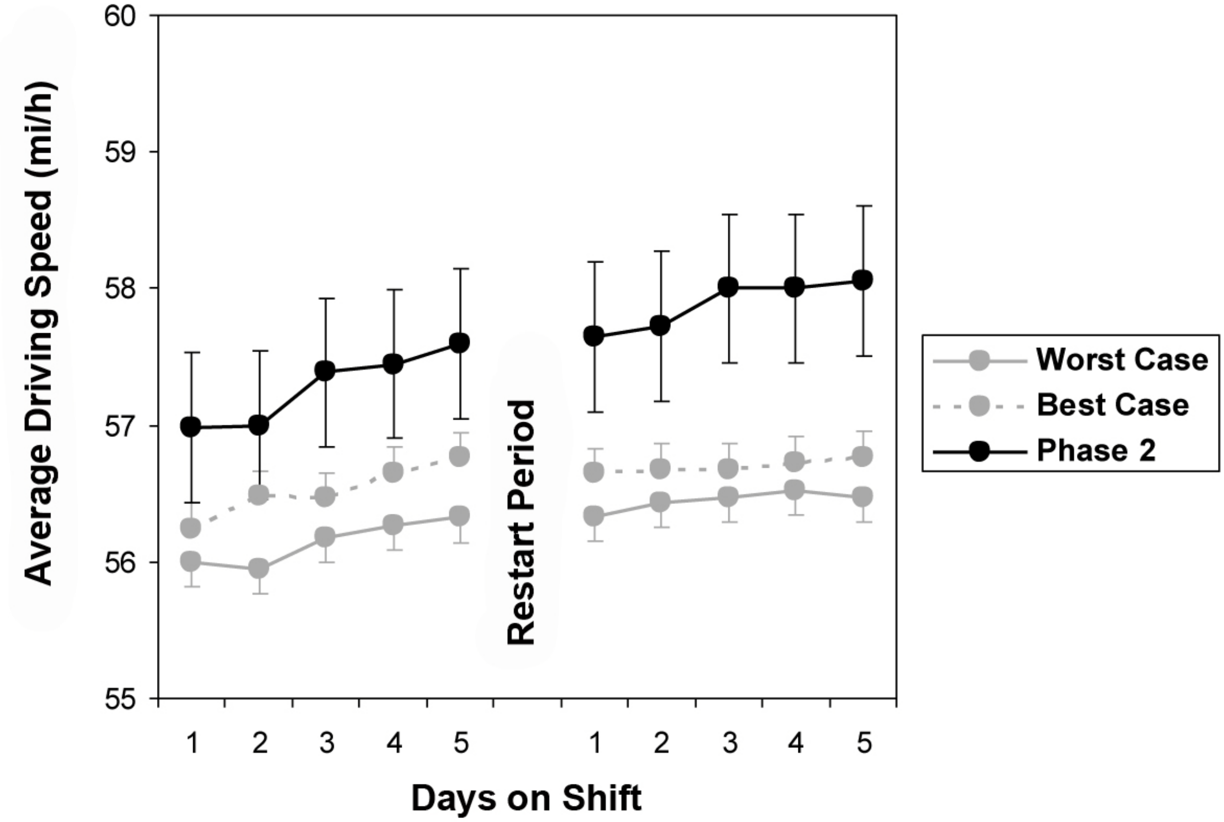

Figure 19. Graph. Average simulator driving speed as a function of days in the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown.

In order to investigate average driving speed as a function of time of day, the interaction of session by time of day, collapsed over days within each 5-day work period session, was examined. The two-way interaction was not statistically significant ($F_{3,460} = 0.92$, $p = 0.43$), nor was the main effect of time of day ($F_{3,460} = 1.25$, $p = 0.29$).

For variability (standard deviation) of driving speed across the straightaways, the primary analysis of the effect of session (collapsed over days and over times of day within sessions) yielded a significant effect of session ($F_{1,466} = 4.44$, $p = 0.036$). Interactions of condition by session in secondary analyses showed no significant interaction with the "worst case" nighttime work condition of Phase I ($F_{1,971} = 2.24$, $p = 0.13$), but there was a trend to significance for the interaction with the "best case" daytime condition of Phase I ($F_{1,931} = 2.97$, $p = 0.085$). A further analysis of the Phase II data, examining the interaction of session by day collapsed over time of day, showed no significant interaction ($F_{4,458} = 0.81$, $p = 0.52$). However, there was a significant main effect of day ($F_{4,458} = 3.78$, $p = 0.005$). Figure 20 displays the Phase II results by day, superimposed on the Phase I results for comparison. Speed variability decreased marginally but steadily across the days of the study in both the Phase I and Phase II studies, suggesting a minor practice effect in driving the simulator. Examination of the interaction of session by time of day in the Phase II data, collapsed over days within each 5-day work period session, showed no significant interaction ($F_{3,460} = 0.59$, $p = 0.62$).

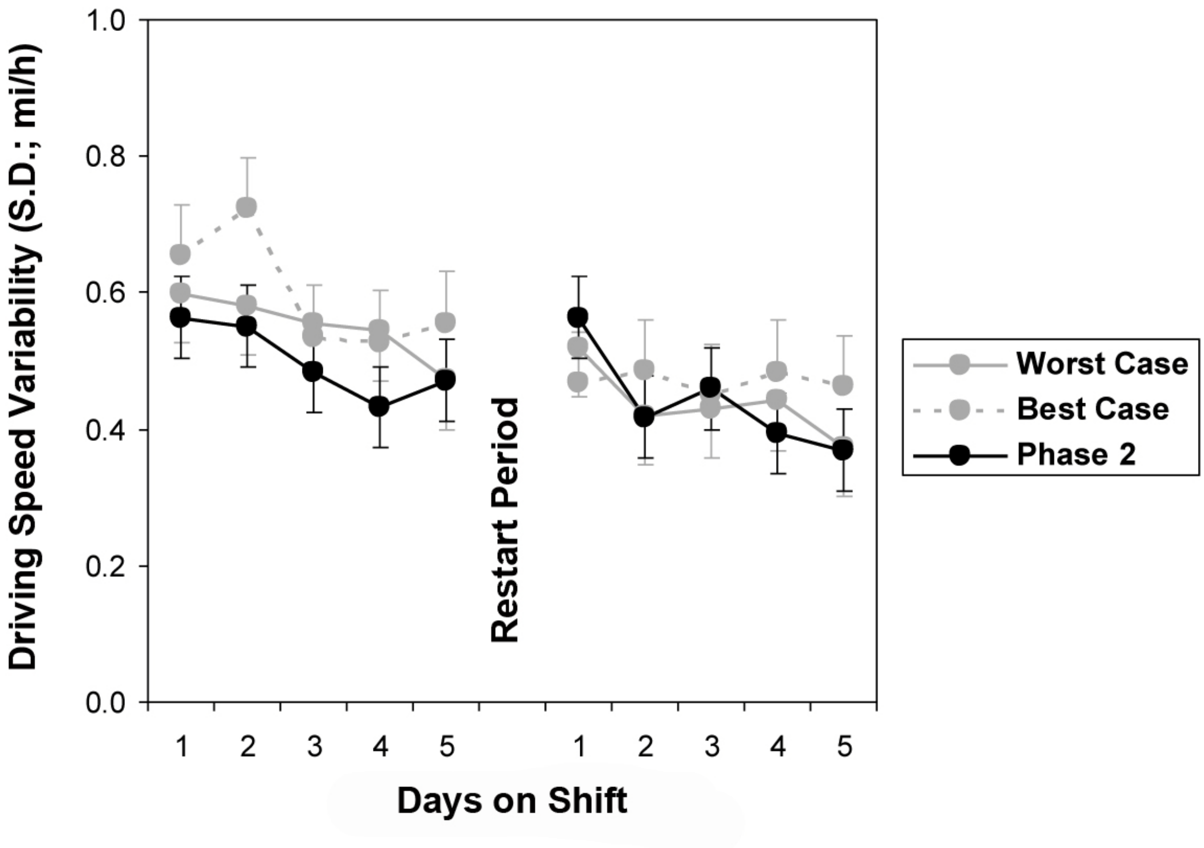

Figure 20. Graph. Variability (standard deviation) of simulator driving speed as a function of days in the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown.

For lane deviation (standard deviation of lane position) in the straightaways, the primary analysis of the effect of session (collapsed over days and over times of day within sessions) yielded a significant effect of session ($F_{1,466} = 18.44$, $p < 0.001$). Interactions of condition by session in secondary analyses showed no significant interaction with the "worst case" nighttime work condition of Phase I ($F_{1,971} = 0.03$, $p = 0.85$). However, there was a significant interaction of condition by session between the Phase II data and the "best case" daytime condition of Phase I ($F_{1,931} = 8.87$, $p = 0.003$). A further analysis of the Phase II data, examining the interaction of session by day, collapsed over time of day, showed no significant interaction ($F_{4,458} = 0.46$, $p = 0.77$), but there was a trend for the main effect of day ($F_{4,458} = 2.11$, $p = 0.078$). Figure 21 displays the Phase II results by day, superimposed on the Phase I results for comparison. Lane deviation decreased steadily across the days of the study in both the Phase I and Phase II studies, indicative of a practice effect in driving the simulator. Figure 21 reveals that the Phase II lane deviation data resembled those of the "worst case" nighttime condition of Phase I. Examination of the interaction of session by time of day in the Phase II data, collapsed over days within each 5-day work period session, showed no significant interaction ($F_{3,460} = 2.03$, $p = 0.11$).

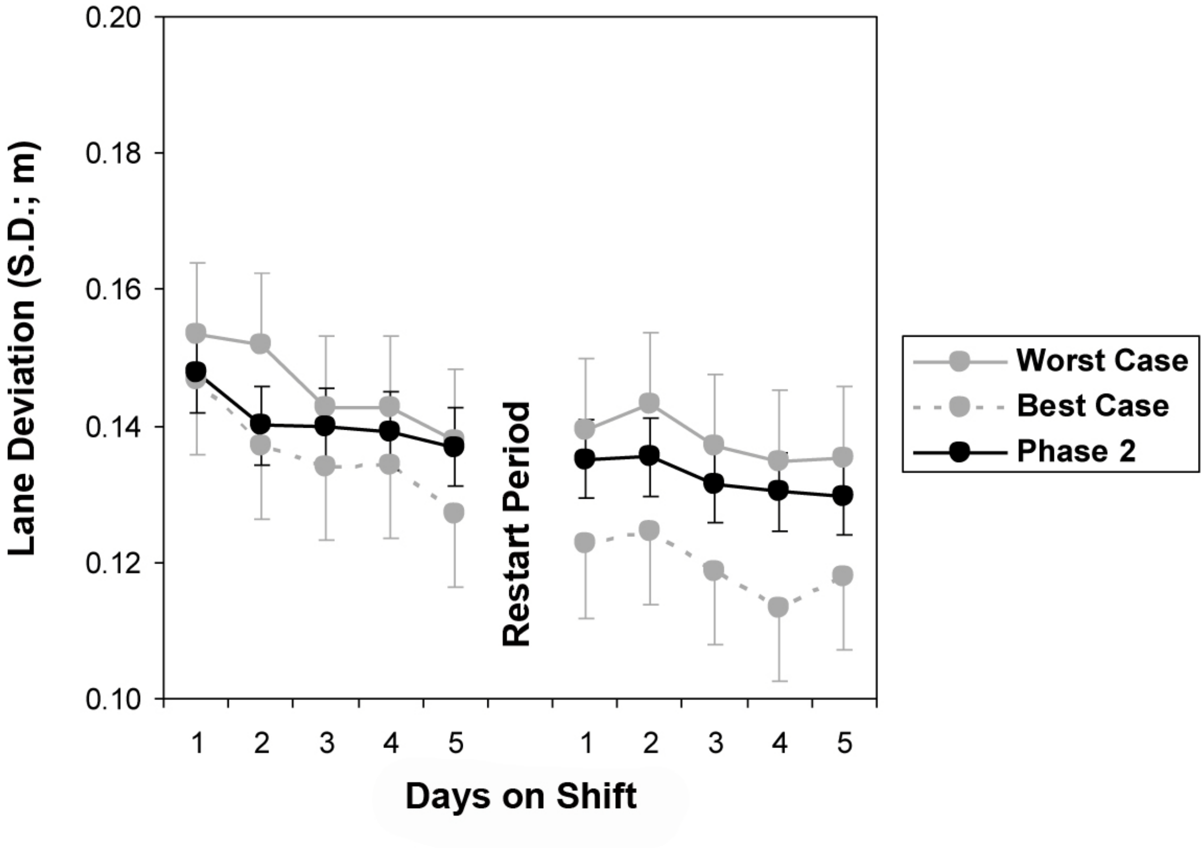

Figure 21. Graph. Lane deviation (standard deviation of lane position) on the driving simulator as a function of days in the 5-day work periods before and after the restart period in the Phase II study. For comparison, the equivalent data for the Phase I "worst-case" and "best-case" conditions also are shown. The higher numbers correspond to greater performance impairment.

For the reaction time of emergency braking for the pedestrian/dog crossing events during simulator driving, the primary analysis of the effect of session (collapsed over days and over times of day within sessions) yielded a small but significant effect of session ($F_{1,466}$ = 4.00, p = 0.046). Examination of the interaction of session by day, collapsed over time of day, yielded a trend for the interaction effect ($F_{4,458}$ = 2.15, p = 0.074). However, examination of the interaction of session by time of day, collapsed over days within each 5-day work period session, yielded no significant interaction ($F_{3,460}$ = 0.46, p = 0.71). Figure 22 shows the data by day, suggesting a modest practice effect. Comparisons with the Phase I data were not made because of required simulator maintenance between the two studies, which affected the brake hardware calibration and thereby caused an absolute reaction time change irrelevant to the investigation of restart effects.

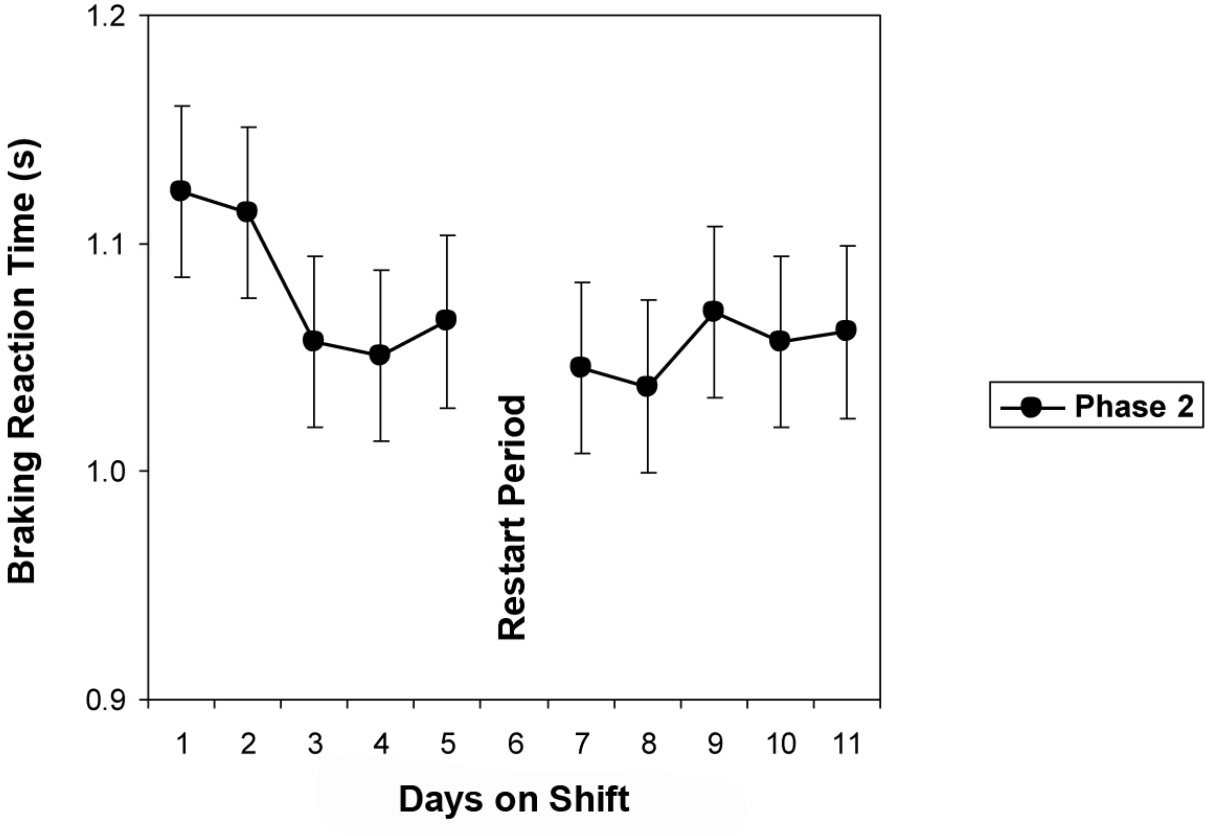

Figure 22. Graph. Reaction time of emergency braking for pedestrian/dog crossing events on the driving simulator, as a function of days in the 5-day work periods before and after the restart period in the Phase II study.

For braking errors (i.e., braking unnecessarily in the straightaways, or failing to brake or braking more than once around the pedestrian/dog crossing events), the primary analysis of the effect of session (collapsed over days and over times of day within sessions) yielded a non-significant effect of session ($F_{1,466} = 0.31$, $p = 0.58$). Interactions of condition by session in secondary analyses showed no significant interaction with the "worst case" nighttime work condition of Phase I ($F_{1,971} = 1.56$, $p = 0.21$), and no significant interaction with the "best case" daytime condition of Phase I ($F_{1,931} = 0.44$, $p = 0.51$). Further analysis of the Phase II data, examining the interaction of session by day collapsed over time of day, showed no significant interaction ($F_{4,458} = 1.60$, $p = 0.17$). Examination of the interaction of session by time of day, collapsed over days within each 5-day work period session, showed no significant interaction ($F_{3,460} = 1.29$, $p = 0.28$) either.

Finally, for computed (simulated) fuel use, the primary analysis of the effect of session (collapsed over days and times of day within sessions) yielded a significant session effect ($F_{1,466} = 10.12$, $p = 0.002$). Examination of the interaction of session by day, collapsed over time of day, yielded no significant interaction effect ($F_{4,458} = 0.66$, $p = 0.62$). However, examination of the interaction of session by time of day, collapsed over days within each 5-day work period session, yielded a trend for an interaction effect ($F_{3,460} = 2.55$, $p = 0.055$) as well as a trend for a main effect of time of day ($F_{3,460} = 2.38$, $p = 0.069$). Figure 23 shows the data by time of day, revealing that fuel use increased modestly over time of day, but improved slightly overall after the restart break, probably due to a practice effect. Comparisons with the Phase I data were not made because of required simulator maintenance between the two studies, which turned out to have affected the fuel use calibration and thereby caused an absolute difference in fuel efficiency irrelevant to the investigation of restart effects.

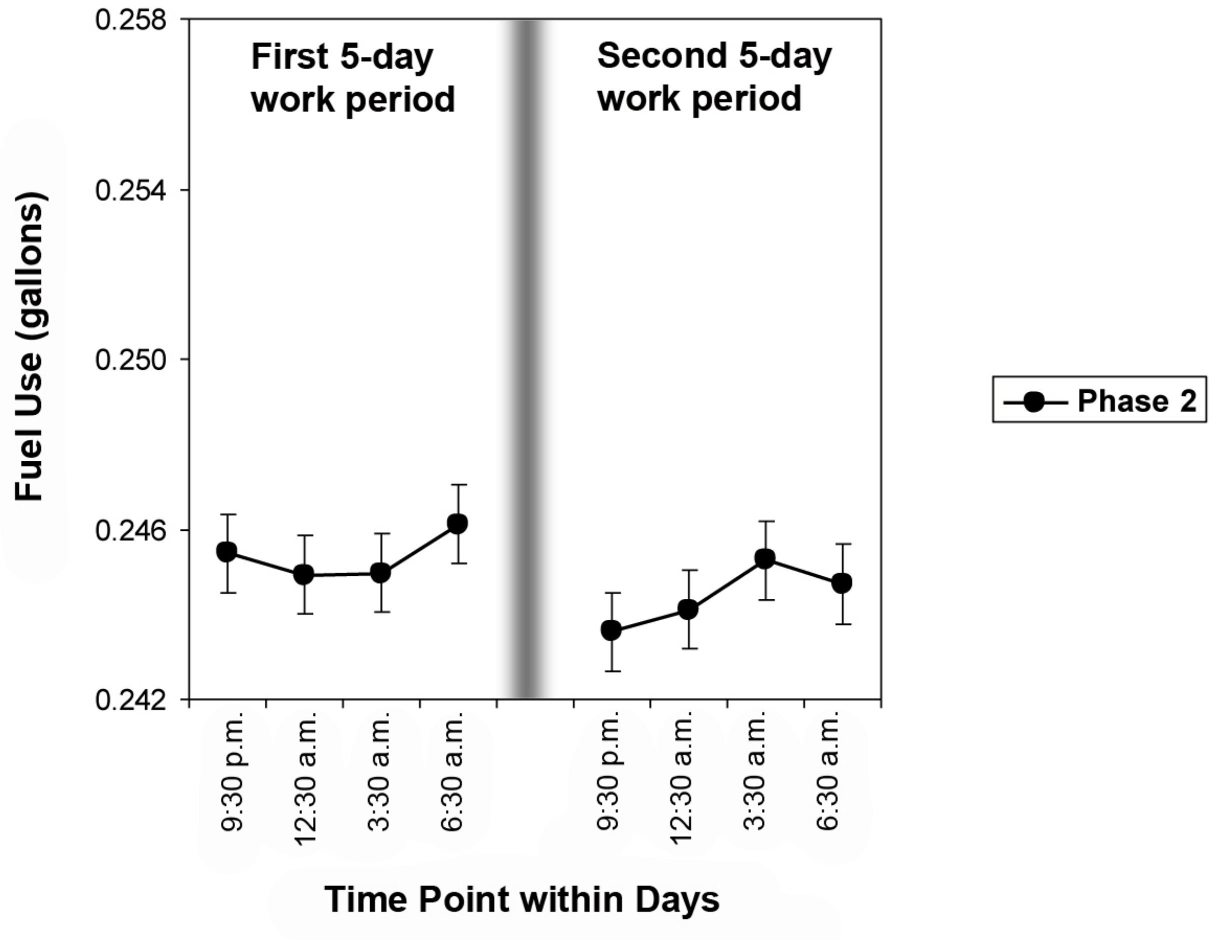

Figure 23. Graph. Computed fuel use on the driving simulator as a function of time of day, collapsed over the 5-day work periods before and after the restart period. Note that 1 hour should be added to each time point for subjects who were assigned to performance testing first and driving second.

3.2 SLEEP AND POLYSOMNOGRAPHY

Data from the sleep recordings in the Phase II study are compared to those of the Phase I study to gain further insight into the effectiveness of the two-biological-night restart period relative to the currently mandated 34-hour restart period. Figure 24 illustrates the primary comparisons being made between the Phase II study and the “worst-case” and “best-case” conditions of the Phase I study for polysomnographic measures of sleep. Besides comparison of the first 10-hour night that the two conditions had in common (performed solely for control purposes), these focused on comparison of the combined baseline sleep periods ("Baseline"); the combined two polysomnographically recorded 10-hour sleep periods in the first 5-day work period ("Session 1"); the combined sleep periods during the restart break ("Restart"); the combined two polysomnographically recorded 10-hour sleep periods in the second 5-day work period ("Session 2"); and the combined sleep periods during the recovery days at the end of the study ("Recovery").

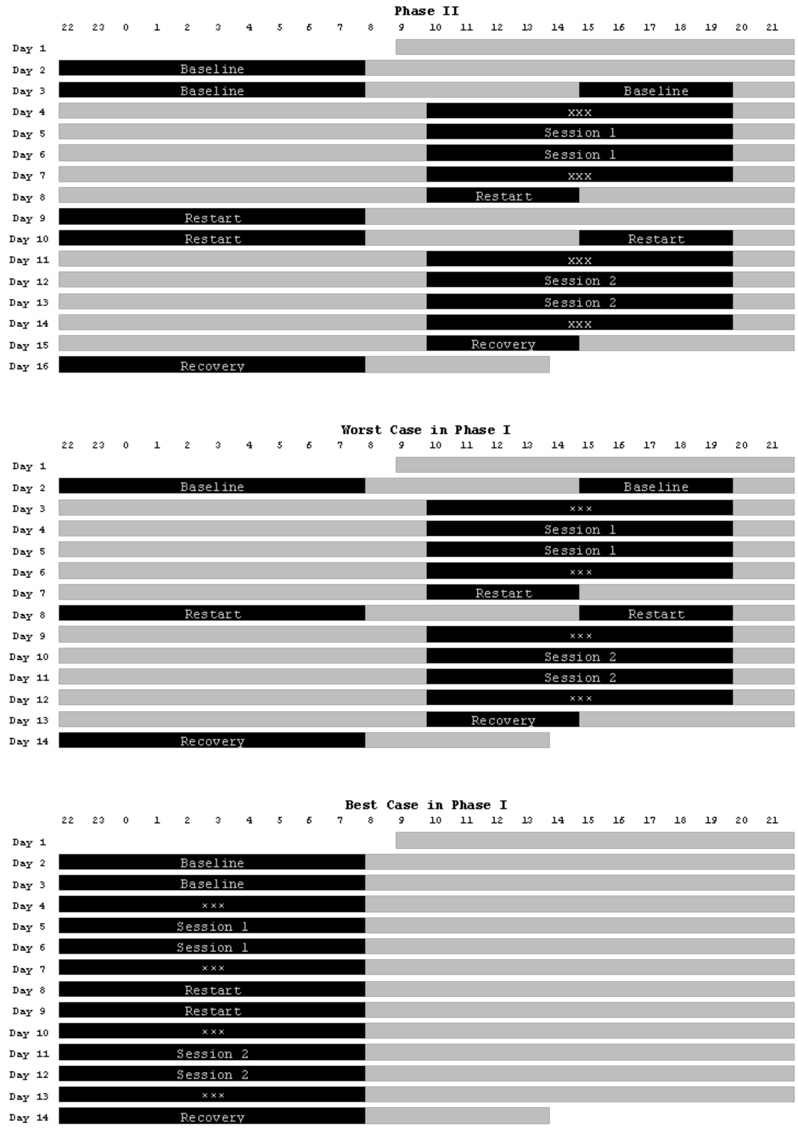

Figure 24. Chart. Comparison scheme for the polysomnographically recorded sleep periods in the Phase II study (top) and in the Phase I "worst-case" (middle) and "best-case" (bottom) conditions, with hours of the day progressing from left to right (see top numbers), days of the study progressing from top to bottom (see left side), gray indicating scheduled wakefulness, black indicating scheduled sleep periods, and ××× marking sleep periods that were not recorded polysomnographically. Days are shown from 10 p.m. to 10 p.m. (rather than from midnight to midnight) for easier visual comparison of the scheduled sleep periods. Text labels indicate which sleep periods were combined to form the Baseline, Session 1, Restart, Session 2, and Recovery periods that were being compared between the two conditions.

Total time in bed varied by experimental condition and across the comparisons. This is depicted in Figure 25. In total, the Phase II study contained 20 hours of time in bed more than each of the Phase I conditions, of which 10 hours fell in the extra day of the restart period added in Phase II.

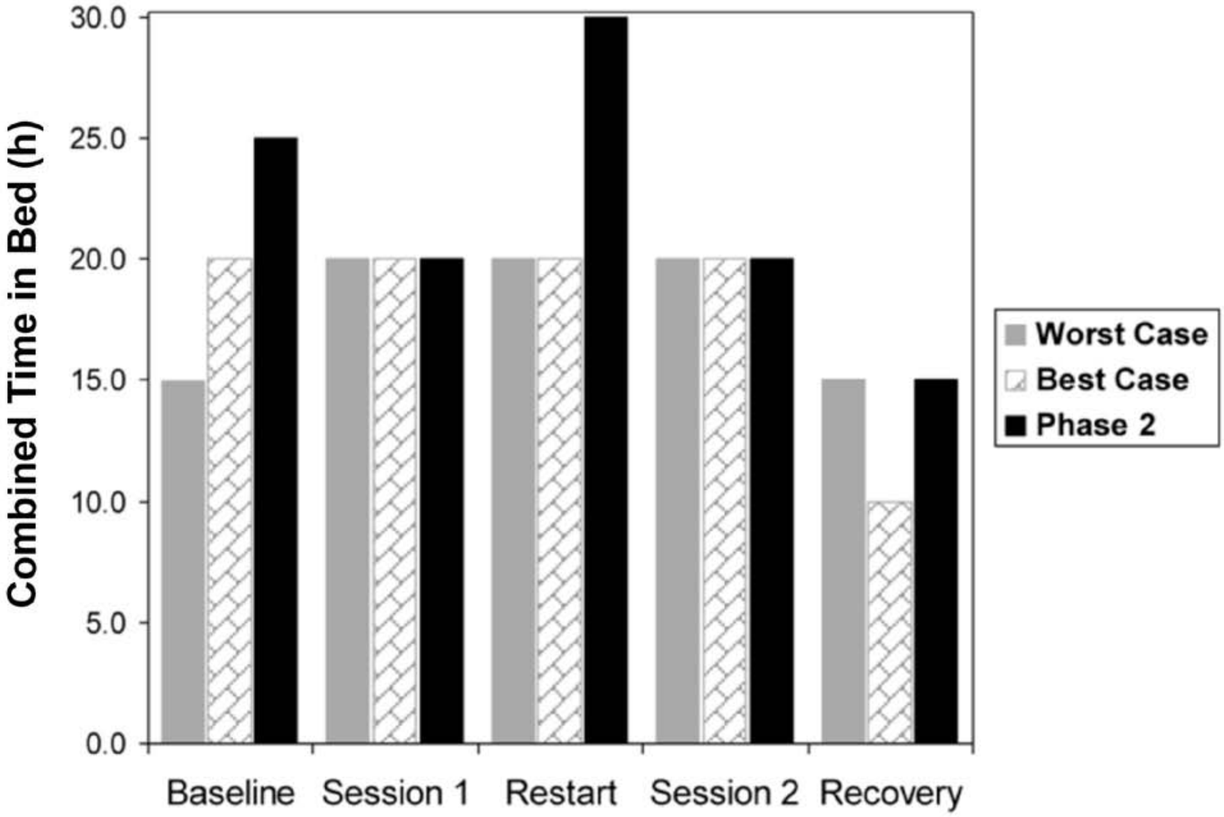

Figure 25. Graph. Combined time in bed during the Phase 2 Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, comparing them with the Phase I "worst-case" and "best-case" conditions.

During the first (10-hour) baseline night, which the three experimental conditions had in common, there were no statistically significant differences between the conditions in total sleep time ($F_{2,35} = 2.11$, $p = 0.14$), non-rapid eye movement (non-REM) stage 1 sleep (N1; $F_{2,35} = 0.88$, $p = 0.42$), non-REM stage 2 sleep (N2; $F_{2,35} = 2.03$, $p = 0.15$), slow-wave sleep (SWS or N3; $F_{2,35} = 0.87$, $p = 0.43$), REM ($F_{2,35} = 2.33$, $p = 0.11$), sleep latency (SL; $F_{2,35} = 1.60$, $p = 0.22$), slow-wave sleep latency (SWSL; $F_{2,35} = 1.80$, $p = 0.18$), and REM latency (REML; $F_{2,35} = 1.02$, $p = 0.37$). Thus, the three subject groups were not significantly different in these indices of baseline sleep architecture.

Figure 26 shows the comparisons for total sleep time between the Phase II study and the "best-case" and "worst-case" conditions of the Phase I study across the time course of the experiments. As expected given the differences in Baseline time in bed, the three groups differed significantly in their combined Baseline total sleep time ($F_{2,35} = 67.13$, $p < 0.001$). They were also significantly different during the Session 1 period ($F_{2,34} = 20.49$, $p < 0.001$), with subjects in the "best case" condition of Phase I getting the most total sleep time and subjects in Phase II getting the least. During the Restart period, the groups were again significantly different ($F_{2,35} = 15.95$, $p < 0.001$), with the subjects in Phase II getting the most total sleep time by design. They were significantly different once more during the Session 2 period ($F_{2,35} = 6.83$, $p = 0.003$), with subjects in the "best case" condition of Phase I getting the most total sleep time and subjects in Phase II getting the least, like in the Session 1 period. During the recovery period, the groups were significantly different as well ($F_{2,35} = 10.85$, $p < 0.001$), with the Phase II and Phase I "worst case" groups obtaining more total sleep time than the Phase I "best case" condition, as was expected given the differences in recovery time in bed.

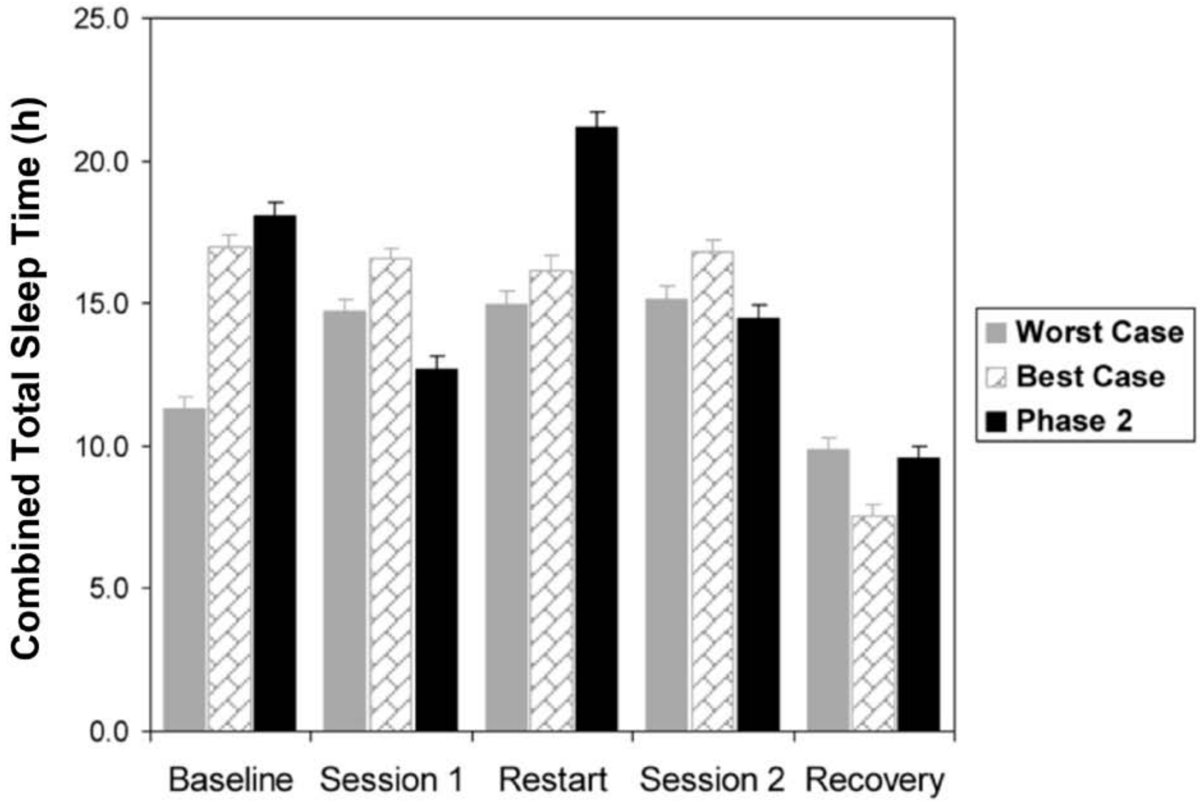

Figure 26. Graph. Combined total sleep time during the Phase II Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, and compares them with the "worst-case" and "best-case" conditions of the Phase I study.

In a mixed-effects ANOVA of total sleep time comparing the 5-hour nap at the beginning of the restart period to the 5-hour nap at the end of the restart period in the Phase II study, there was a significant effect of nap ($F_{1,11} = 55.86$, $p < 0.001$). Nap total sleep time decreased significantly from before the restart break compared to after the restart break, by 1.9 ± 0.3 hours (mean ± standard error). Further, in a mixed-effects ANOVA of combined total sleep time comparing Session 1 to Session 2 in the Phase II study, there was a significant effect of session ($F_{1,10} = 6.63$, $p = 0.028$). Total sleep time increased significantly after the restart break compared to before the break, by 0.9 ± 0.3 hours per day (mean ± standard error).

Figure 27 shows the comparisons for slow-wave sleep (non-REM sleep stage N3) between the Phase II study and the "best-case" and "worst-case" conditions of the Phase I study across the time course of the experiments. The three groups differed significantly in their combined Baseline N3 ($F_{2,35} = 7.42$, $p = 0.002$), with the subjects in Phase II getting the most. They did not differ significantly in their combined N3 for the Session 1 period ($F_{2,34} = 0.83$, $p = 0.44$). They did differ significantly for the Restart period ($F_{2,35} = 13.49$, $p < 0.001$), with the subjects in Phase

II getting the most N3. They again did not differ significantly for the Session 2 period ($F_{2,35}$ = 1.81, p = 0.18). However, they did as well differ significantly in their combined N3 during the Recovery period ($F_{2,35}$ = 4.04, p = 0.026), with the Phase II subjects once more exhibiting the most N3 sleep. In a mixed-effects ANOVA of combined N3 comparing Session 1 to Session 2 in the Phase II study, there was no significant effect of session ($F_{1,10}$ = 0.07, p = 0.79), indicating that N3 in the Phase II study was stable across the restart break.

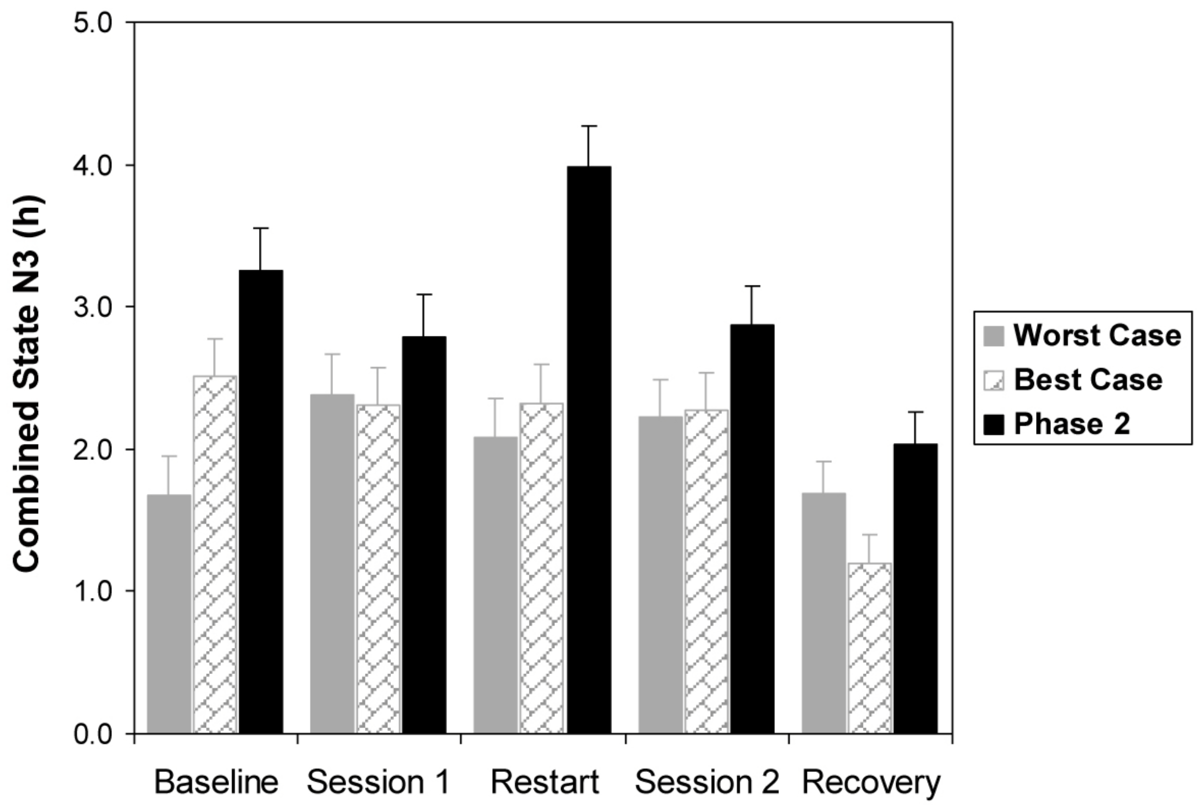

Figure 27. Graph. Combined slow-wave sleep (non-REM sleep stage N3) during the Phase II Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, and compares them with the "worst-case" and "best-case" conditions in the Phase I study.

Figure 28 shows the comparisons for REM sleep between the Phase II study and the "best-case" and "worst-case" conditions of the Phase I study across the time course of these experimental conditions. The three groups differed significantly in their combined Baseline REM ($F_{2,35}$ = 28.55, p < 0.001). Subjects in Phase II obtained slightly less REM sleep than those in the "best case" condition of Phase I, despite having greater Baseline time in bed; whereas subjects in the "worst case" condition of Phase I obtained considerably less REM sleep. The three groups also differed significantly in their combined REM sleep for the Session 1 period ($F_{2,34}$ = 7.31, p = 0.002), with subjects in the Phase II study expressing the least REM sleep. They also differed significantly for the Restart period ($F_{2,35}$ = 5.26, p = 0.010), with the subjects in Phase II getting the most REM sleep (in accordance with the extra sleep period they received in the restart). The groups did not differ significantly for the Session 2 period ($F_{2,35}$ = 1.52, p = 0.23). However, they tended to a significant difference during the Recovery period ($F_{2,35} = 3.23$, $p = 0.052$). In a mixed-effects ANOVA of combined REM sleep comparing Session 1 to Session 2 in the Phase II study, there was significant effect of session ($F_{1,10} = 5.84$, $p = 0.036$), which indicated that the expression of REM sleep was substantively increased after the restart break relative to before.

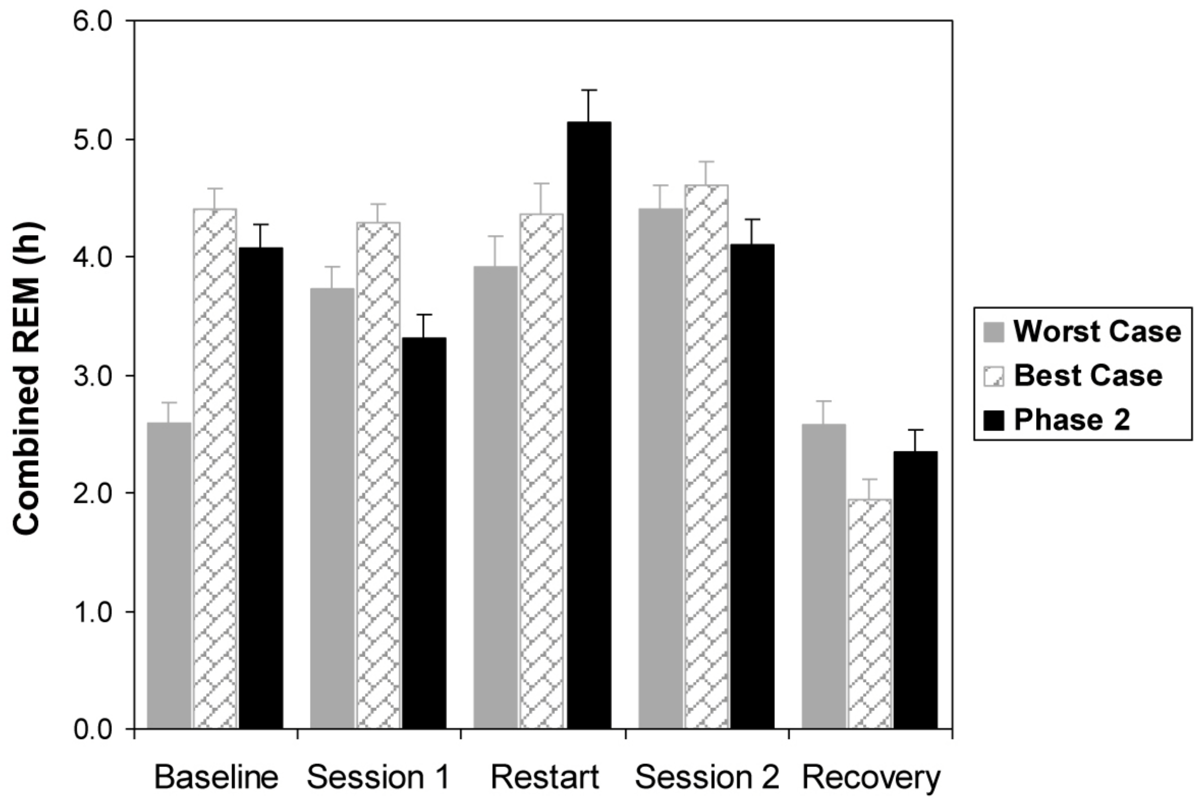

Figure 28. Graph. Combined REM sleep during the Phase II Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, and compares them with the "worst-case" and "best-case" conditions in the Phase I study.

Figure 29 shows the comparisons for non-REM sleep stage N2 between the Phase II study and the "best-case" and "worst-case" conditions of the Phase I study across the time course of these experimental conditions. The three groups differed significantly in their combined Baseline N2 ($F_{2,35} = 26.08$, $p < 0.001$), with the subjects in Phase II and in the "best case" condition of Phase I obtaining considerably more N2 than those in the "worst case" condition of Phase I. The three groups also differed significantly in their combined stage N2 sleep for the Session 1 period ($F_{2,34} = 12.92$, $p < 0.001$), with subjects in the Phase II study exhibiting the least. They again differed significantly for the Restart period ($F_{2,35} = 15.46$, $p < 0.001$), with the subjects in Phase II getting the most stage N2 sleep (in accordance with the extra sleep period they received). The groups differed significantly for the Session 2 period also ($F_{2,35} = 8.07$, $p = 0.001$), with the subjects in Phase II showing the least N2. There was a trend to significance for a difference during the Recovery period ($F_{2,35} = 2.96$, $p = 0.065$). In a mixed-effects ANOVA of combined stage N2 sleep comparing Session 1 to Session 2 in the Phase II study, there was no significant effect of session ($F_{1,10} = 2.30$, $p = 0.16$).

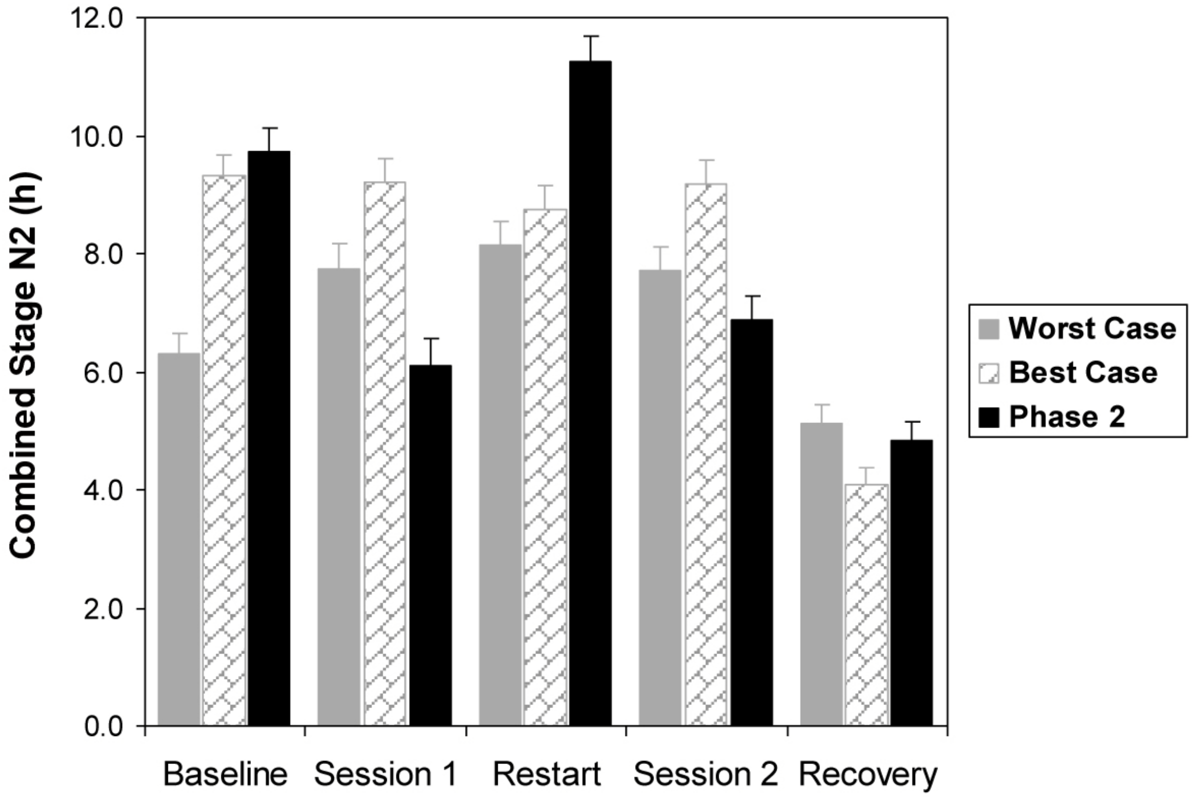

Figure 29. Graph. Combined non-REM sleep stage N2 during the Phase II Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, and compares them with the "worst-case" and "best-case" conditions in the Phase I study.

Figure 30 displays the comparisons for non-REM sleep stage N1 between the Phase II study and the "best-case" and "worst-case" conditions of the Phase I study. There was a trend for a difference between the three groups in their combined Baseline N1 ($F_{2,35} = 2.69$, $p = 0.082$). The three groups differed significantly in their combined stage N1 sleep for the Session 1 period ($F_{2,34} = 3.91$, $p = 0.030$), with subjects in the Phase II study exhibiting the least. They did not differ significantly for the Restart period ($F_{2,35} = 0.08$, $p = 0.92$). The groups also did not differ significantly for the Session 2 period ($F_{2,35} = 1.30$, $p = 0.29$). However, there was a significant difference between the three groups during the Recovery period ($F_{2,35} = 3.58$, $p = 0.039$), with the subjects in the Phase II study and in the "best case" condition of the Phase I study showing less N1 than those in the "worst case" condition of the Phase I study. In a mixed-effects ANOVA of combined stage N1 sleep comparing Session 1 to Session 2 in Phase II, there was no significant effect of session ($F_{1,10} = 1.85$, $p = 0.20$).

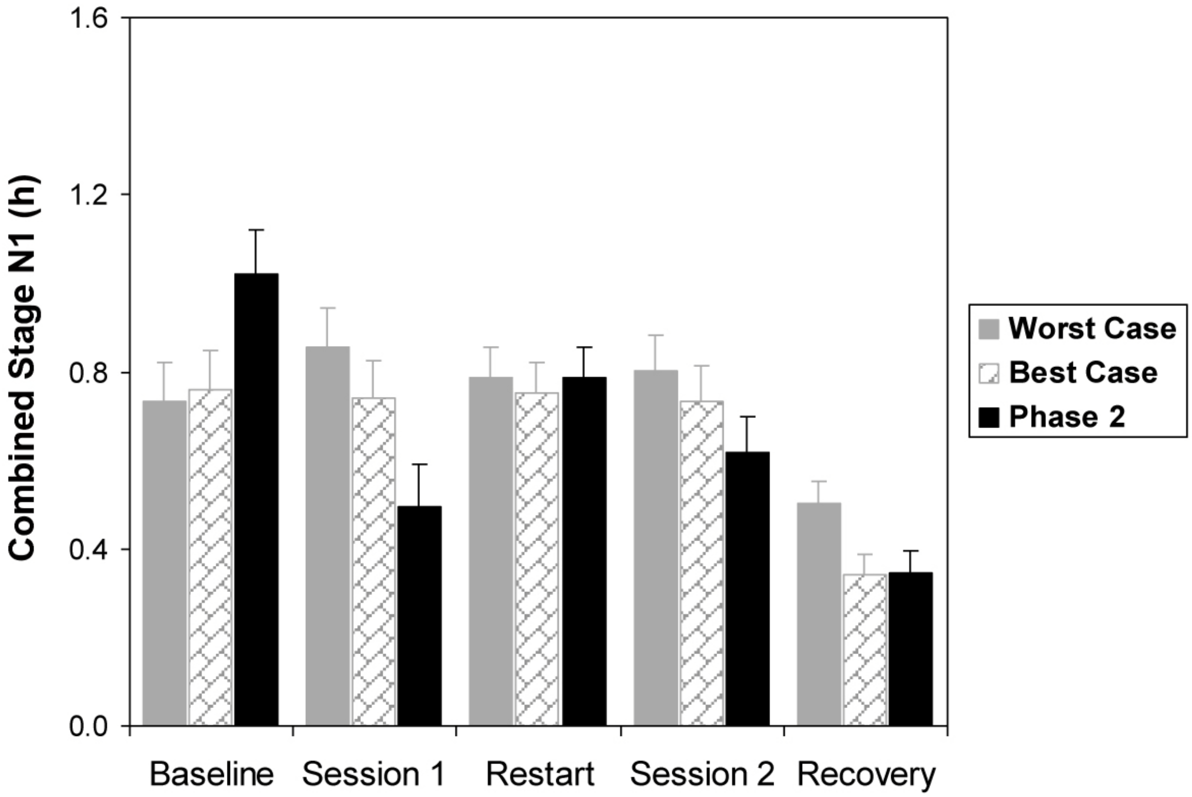

Figure 30. Graph. Combined non-REM sleep stage N1 during the Phase II Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, and compares them with the “worst-case” and “best-case” conditions in the Phase I study.

For sleep latency (SL), slow-wave sleep latency (SWSL), and REM latency (REML), analyses focused on averages within the Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods. Averages are more relevant for latency variables than combined totals as used above for the sleep stages.

For average SL, the comparisons between the Phase II study and the “best-case” and “worst-case” conditions of Phase I are shown in Figure 31. There was no statistically significant difference between the groups during the Baseline period ($F_{2,35} = 1.60$, $p = 0.22$). However, there was a significant group difference during the Session 1 period ($F_{2,34} = 21.91$, $p < 0.001$), with subjects in the Phase II study and in the “worst case” condition of the Phase I study falling asleep considerably faster than those in the “best case” condition of Phase I. During the Restart period, the difference between the groups was again non-significant ($F_{2,35} = 1.13$, $p = 0.33$). In the Session 2 period, the same significant group difference appeared as in Session 1 ($F_{2,35} = 36.37$, $p < 0.001$). A significant group difference persisted through the Recovery period ($F_{2,35} = 7.77$, $p = 0.002$), with the subjects in the Phase I “worst case” condition and particularly the subjects in Phase II study falling asleep faster than the Phase I “best case” controls. In mixed-effects ANOVA of average SL comparing Session 1 to Session 2 in Phase II, there was no significant effect of session ($F_{1,10} = 0.86$, $p = 0.37$).

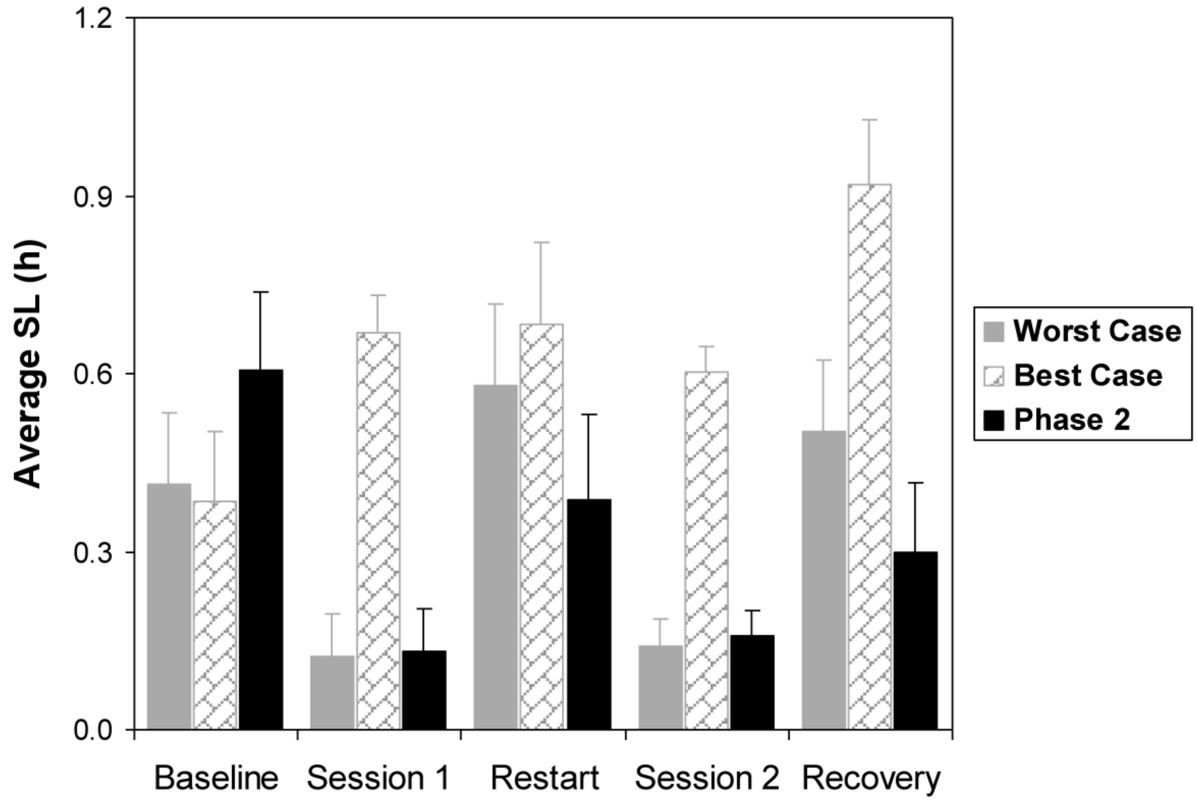

Figure 31. Graph. Average SL during the Phase II Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, and compares them with the "worst-case" and "best-case" conditions in the Phase I study.

For average SWSL, the comparisons between the Phase II study and the "best-case" and "worst-case" conditions of Phase I are shown in Figure 32. There were no statistically significant differences between the groups during the Baseline period ($F_{2,35}$ = 1.18, p = 0.32) and Session 1 period ($F_{2,34}$ = 0.52, p = 0.60). There was a statistically significant difference during the Restart period ($F_{2,32}$ = 6.01, p = 0.006), with SWSL being longer in the "worst case" condition of the Phase I study, and to a lesser extent in the Phase II study, than in the "best case" condition of the Phase I study. There were no statistically significant differences between the groups during the Session 2 period ($F_{2,35}$ = 0.71, p = 0.50), where it should be noted that there was in outlier in Phase II, which pulled up the average for that group. There was also no significant difference between the three groups during the Recovery period ($F_{2,35}$ = 0.15, p = 0.86). In mixed-effects ANOVA of average SWSL comparing Session 1 to Session 2 in the Phase II study, there was no significant effect of session ($F_{1,10}$ = 0.96, p = 0.35).

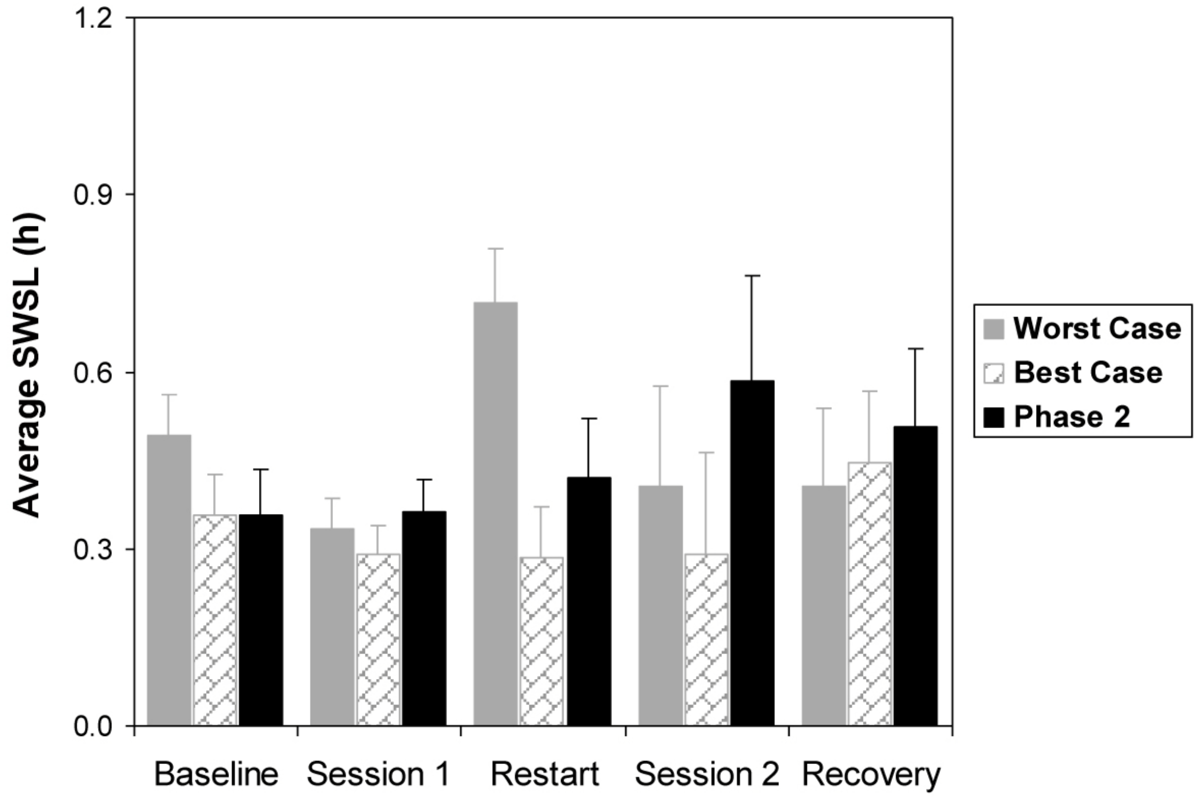

Figure 32. Graph. Average SWSL during the Phase II Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, and compares them with the "worst-case" and "best-case" conditions in the Phase I study.

For average REML, the comparisons between Phase II and the "best-case" and "worst-case" conditions of Phase I are shown in Figure 33. There was no significant difference between the groups during the Baseline period ($F_{2,35} = 1.99$, $p = 0.15$). However, there was a significant group difference during the Session 1 period ($F_{2,34} = 5.36$, $p = 0.010$), with REML in the Phase II study and in the "worst case" condition of the Phase I study being shorter than in the "best case" condition of the Phase I study. There was no statistically significant difference between the groups during the Restart period ($F_{2,33} = 2.24$, $p = 0.12$). During the Session 2 period, the same significant group difference appeared as during Session 1 ($F_{2,35} = 5.82$, $p = 0.007$). There was no significant difference between the three groups during the Recovery period ($F_{2,35} = 2.27$, $p = 0.12$). Finally, in mixed-effects ANOVA of average REML comparing Session 1 to Session 2 in the Phase II study, there was no significant effect of session ($F_{1,10} = 0.19$, $p = 0.67$).

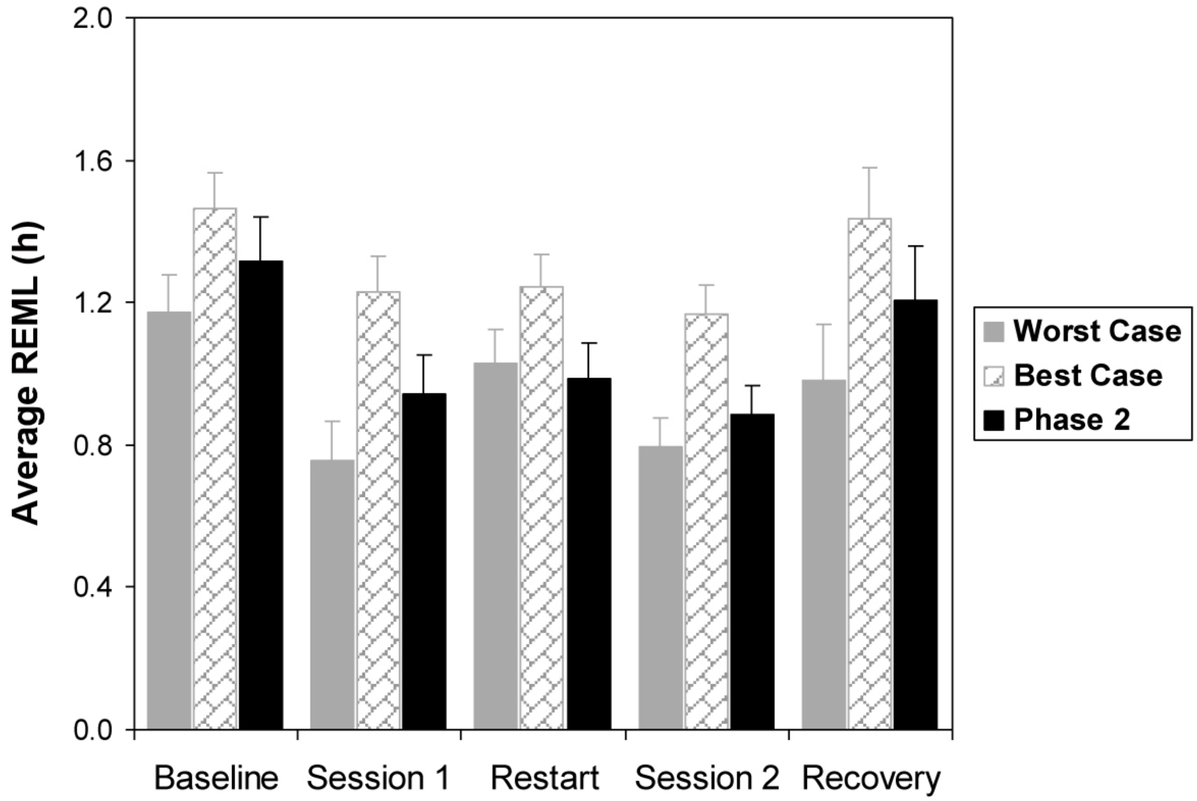

Figure 33. Graph. REML during the Phase II Baseline, Session 1, Restart, Session 2, and Recovery sets of sleep periods, and compares them with the "worst-case" and "best-case" conditions in the Phase I study.

4. CONCLUSIONS

4.1 KEY FINDINGS

This Phase II study followed up on the findings of Phase I, which revealed that the effectiveness of the 34-hour restart provision in the HOS regulations governing freight-carrying CMV drivers depends on circadian timing. Specifically, the Phase I study revealed that 34 hours off duty was insufficient to restore performance for a 5-day work schedule involving nighttime wakefulness (and daytime sleep), while transitioning back to a daytime schedule during the restart period. The Phase II study investigated whether for such a schedule, extending the restart period by 24 hours, to include an additional biological night, would result in greater recuperation. In keeping with the experimental procedures established in Phase I, an in-residence laboratory research study was conducted in Phase II to examine the effects of restart period involving two biological nights of sleep using the results of Phase I for reference.

Running the study in the laboratory (as opposed to in the field) helped to eliminate environmental confounds, allowed for the use of sensitive laboratory performance measures, simplified the logistics, and moderated the sample size requirement as corroborated by a power calculation performance in advance of the study. A sample of $N = 12$ healthy subjects was studied in a within-groups comparison of two 5-day (14-hour/day) nighttime work periods, separated by a restart period during which subjects transitioned back to a daytime schedule (see Figure 1). Performance on cognitive performance tasks and on a high-fidelity driving simulator was measured throughout the study (see Figure 2). The main goal was to evaluate whether the restart period was effective at maintaining performance from one 5-day nocturnal work period to the next.

The primary performance measure for the study was the number of lapses (reaction times greater than 500 ms) on a 10-minute PVT, which was administered eight times per day in the working periods. The study data showed no significant difference in PVT lapses between the pre-restart and post-restart work periods overall, indicating that the restart period was effective at maintaining performance (see Figure 3). Thus, the null hypothesis that the restart period would be effective at maintaining performance was not rejected.

A caveat to this finding is that there was a transient, modest degradation of performance on the day immediately following the restart period (Figure 4). This effect was not seen in Phase I following the 34-hour restart period, suggesting that the increased effectiveness of the restart period for nighttime work schedules comes at the cost of minor difficulty to re-adjust to a nighttime schedule after the daytime-oriented restart break. If a nighttime wake schedule were to be maintained during the restart period, it is possible that gradual circadian adjustment would have occurred, potentially eliminating the post-restart transient performance degradation. The real-world utility of this possibility is questionable, though, as it is improbable that many individuals would elect to maintain a permanent night shift schedule if given the choice.[23,24]

The effectiveness of the restart period in maintaining performance overall across the two 5-day work periods does not imply that there were no performance deficits during these nocturnal work periods. In agreement with key principles of sleep/wake physiology,[14,25] PVT performance deteriorated during each nighttime waking period (Figure 5). However, the level of nocturnal performance deterioration was not significantly greater after the restart period than before. This is in contrast with the 34-hour restart period examined in the Phase I study, which was not as effective at preserving performance across two 5-day nighttime work periods. As such, extending the restart period from 34 hours to the test restart period containing two biological nights constituted an improvement with regard to the effectiveness of the restart period in the context of nighttime work schedules.

As discussed in detail in the final report of the Phase I study,[4] there are limitations to the conclusions that can be drawn from the Phase I and II studies. Important for the interpretation of the findings from the Phase II study is the fact that transition sleep opportunities were scheduled as part of the tested restart period. These essentially served as prophylactic naps, which are known to be effective countermeasures for cognitive performance impairment.[26,27] It is possible that without such strategic napping, performance following the restart period would have shown increasing deficits. It should also be noted that the research subjects were carefully screened healthy young males. Had the researchers studied a sample with sleep apnea or other medical conditions, the expected performance deficits would have been greater. This study does not reveal whether the tested restart period would have been equally effective in maintaining performance levels for such samples. Even so, the conclusion that for nighttime drivers, 58 hours (two biological nights) is an improvement over 34 hours (one biological night) for the duration of the restart period would still be expected to hold.

4.2 ANCILLARY FINDINGS

Subjects in the Phase II study did not show any significant changes in subjective sleepiness and in positive affect from before to after the tested restart period, although negative affect was slightly increased after the restart. In this regard, the tested restart appeared slightly more effective at maintaining positive effect (Figure 12), and equally effective at maintaining subjective sleepiness (Figure 7) and negative affect (emotion) (Figure 13) vis-à-vis the 34-hour restart period in the nighttime work condition of Phase I. In Phase II there was, however, a slight improvement of mood (more elated) after the restart period compared to before, which was an improvement relative to the observations in Phase I (Figure 10). As the mood improvement was observed throughout the Phase II study, it may involve a non-specific rather than a restart effect. Relevant in this regard is the fact that subjects in the Phase I study were randomized to either daytime or nighttime work, whereas subjects in the Phase II study were certain that they would have to perform nighttime work. Thus, subjects' prior expectations may have differed between the studies, which could explain the difference in the temporal profiles of subjective mood between the Phase I and Phase II studies.

On the digit symbol substitution task (DSST) and the cardinal direction decision task (CDDT), subjects showed expected practice effects (Figures 14 and 17). DSST performance in the Phase II study was equivalent to that seen in either of the two conditions in the Phase I study. CDDT performance in the Phase II study was similar to that seen in the Phase I nighttime work condition, but the Phase I daytime work condition showed greater improvement from practice following the restart break. These secondary findings sketch a mixed picture regarding the effectiveness of the restart break for cognitive recuperation following 5 days of night work.

Evidence is increasing that the effects of sleep loss and circadian misalignment vary as a function of the components of cognition (e.g., attention, working memory) involved in performing a given task.[13,28–31] It is therefore not surprising that the results for the DSST and the CDDT did not line up with those for the PVT, and this was observed in the Phase I study as well. The results for the PVT, which measures reaction time and sustained attention, may ultimately be more significant for CMV drivers, as may be the driving simulator results discussed next.

Average speed on the straightaways in the driving simulator scenarios increased slightly but progressively over the days of the Phase II study (Figure 19), and although the subjects stayed close to the speed limit of 55 mi/h, the speed increase over days was a little bigger than what was seen in the Phase I study. The variability in driving speed across the straightaways in the Phase II study decreased steadily over days (Figure 20), just like in the Phase I study. There was also a slight improvement in the reaction time for emergency braking (Figure 22) and in fuel efficiency (Figure 23) from before to after the restart period in the Phase II study. These effects are likely associated with subjects becoming more familiar with the driving simulators over time, rather than being an effect of the restart break. However, in the daytime work ("best case") condition of the Phase I study, the restart break was associated with a continuing decline of lane deviation (standard deviation of lane position) across the straightaways, which was significantly diminished in the nighttime work ("worst case") condition of the Phase I study and also in the Phase II study (Figure 21). Thus, the tested restart break of Phase II did not confer any additional benefit over the 34-hour restart break for this aspect of driving performance in a nighttime work schedule.

It should be noted that the driving simulator scenarios (roads, routes, events, conditions, etc.) were standardized, with randomized pedestrian/dog crossing events, across the driving performance time points of the Phase II study (using the same scenarios as employed in Phase I). The scenarios did not control for the lower traffic density or reduced visibility typically associated with nighttime driving. As such, the driving simulator findings should be interpreted as indicative of basal capability for driving rather than actual driving performance in the real world. Further research is needed to study the effectiveness of the restart break in terms of real-world driving performance, safety, and cost.

For the interpretation of the Phase II study findings on cognitive performance and subjective experiences, it is useful to consider the effects of the experimental sleep/wake/work schedule on sleep duration and structure. The subjects in the Phase II study were given an additional 10-hour nocturnal sleep opportunity during the restart break compared to their counterparts in the Phase I study. Owing to circadian effects on sleep propensity,[32] this resulted in only 5.0 ± 0.7 (mean ± standard error) hours more total sleep time during the restart break in Phase II than in the daytime work ("best case") condition of Phase I, and 6.2 ± 0.7 (mean ± standard error) hours more total sleep time during the restart break in Phase II than in the nighttime work ("worst case") condition of Phase I (see Figure 26). The 5-hour transition nap at the end of the restart break in Phase II exhibited only 2.5 ± 0.2 hours total sleep time, which was 1.9 ± 0.3 hours shorter (mean ± standard error) than in the 5-hour transition nap at the beginning of the restart break. This may in part explain why PVT performance on the day immediately following the restart period was relatively impaired. Remarkably, for the work days when sleep was recorded polysomnographically, total sleep time during the 5-day work period following the restart break was 0.9 ± 0.3 hours per day longer (mean ± standard error) than total sleep time during the 5-day work period preceding the restart break of the Phase II study. The correct interpretation of this pre/post change in total sleep time, which was not seen in either condition of the Phase I study, is not clear.

Sleep structure predominantly displayed the usual, physiologically driven effects of sleep/wake history and circadian timing.[32–34] Briefly, there was a high degree of preservation of stage N3 (slow-wave) sleep in the Phase I and II studies regardless of condition or day (Figure 27), as has also been reported in sustained sleep restriction experiments.[5,12,35] Changes in REM sleep (Figure 28) and stage N2 sleep (Figure 29) paralleled those in total sleep time. Interestingly, subjects in the Phase II study expressed comparatively little N1 sleep overall (Figure 30), suggesting relatively good sleep quality even during the daytime sleep periods. Their average sleep latencies resembled those seen in the nighttime work ("worst case") condition of Phase I (Figure 31), and were indicative of increased pressure for sleep during the 5-day nighttime work periods. As already discussed, this did not result in more sleep (Figure 26); thus, subjects in the nighttime work conditions experienced early awakenings (i.e., difficulty maintaining sleep), which is due to the growing circadian pressure for wakefulness across daytime sleep periods. The average latencies to REM sleep of the subjects in Phase II also resembled those seen in the nighttime work ("worst case") condition of Phase I (Figure 33), and reflected the increased pressure for REM sleep from circadian rhythm during the two 5-day nighttime work periods.

In the Phase II study, as in Phase I, no single sleep stage could be identified as being responsible for the performance impairments associated with nighttime work. Therefore, we believe that overall curtailment of total sleep time is the main cause of observed performance deficits in both studies, and that the increased total sleep time in the restart break of Phase II (i.e., the additional biological night) is the primary reason for this condition's edge over the 34-hour restart break in the nighttime work condition of Phase I in relation to its effectiveness in maintaining aspects of cognitive performance.

5. RECOMMENDATIONS

Although this study specifically examined the effectiveness of a 58-hour restart period, it is important to note that the restart period included two biological nights of sleep. Given what is currently known about sleep, circadian rhythms and cognitive performance, it is clear that the observed benefits of the 58-hour restart period (relative to 34 hours) were not simply a function of having increased time off. Rather, they were due to the fact that the 58-hour restart allowed for two sleep periods with circadian timing conducive for sleep (i.e., nighttime on the biological clock). Therefore, when considering the findings of this study in operational scheduling practices, the restart period does not necessarily need to be 58 hours in duration—the critical factor is that the restart period should include two opportunities for sleep during biological night.

On the basis of the results of the study as described in this report, a number of specific recommendations and suggestions can be made.

1. The key finding of this Phase II laboratory research study was that, with regard to maintaining performance in subjects assigned to a nighttime wake/work schedule, restart break containing two biological nights constituted an improvement over the presently mandated 34-hour duration for the restart provision in the HOS regulations governing property-carrying CMV drivers as studied in Phase I. However, the restart break was not universally as effective at maintaining performance for subjects assigned to a nighttime wake/work schedule as was the presently mandated 34-hour restart break for subjects assigned to a daytime wake/work schedule. For HOS regulations, this highlights the importance of taking into account circadian timing of the sleep/wake/work schedule.
2. Given that two biological nights for the restart break represented an improvement over 34 hours for nighttime wake/work schedules, but would be excessively inefficient for daytime wake/work schedules (where 34 hours would suffice to include two biological nights), it is important to delineate the time-of-day boundaries of what constitutes a nighttime (as opposed to a daytime) schedule. Furthermore, consideration of how to deal with mixed nighttime/daytime schedules is needed. Specifying a rule that requires a restart break that is at least 34 hours in duration but also contains at least two biological nights could be a viable approach, provided it be specified clearly what exactly constitutes a biological night. Mathematical models of fatigue and performance[36–38] may be useful to quantitatively address this issue.
3. Objective performance and subjective sleepiness and mood outcomes varied in the extent to which they were preserved during the experimental 5-day nocturnal work period following the restart break. Thus, whereas the duration of the tested restart break was more effective at maintaining waking function than the 34-hour duration previously studied in Phase I, whether the effectiveness was sufficient depended on which outcome measure was considered. For lane deviation during simulated driving, which may have been the most operationally relevant outcome measure in this laboratory study, the restart break was not fully effective as compared to the daytime work condition studied previously in Phase I. However, whether increasing the duration of the restart period even more would make a substantive difference is not certain, as circadian factors may prevent further improvement in nighttime work schedules. (Continuing a nighttime schedule during the restart period might overcome this problem, but in real-world operations it is

not likely that many individuals would elect to maintain a permanent night schedule if given the choice.)

4. The research subjects in this study were healthy young adults with no sleep disorders, and their scheduled sleep times were protected from outside interruptions. However, sleep apnea and other medical conditions are common among CMV drivers. Furthermore, drivers may experience logistical difficulties protecting time to sleep because of family and other responsibilities; and they may obtain less or degraded sleep when sleeping in a sleeper berth or in unfamiliar environments. Nevertheless, it would still be expected to hold that the tested restart period entails a relative improvement over the current 34 hour restart period in the context of nighttime operations. That said, validation of the study findings in a sample of CMV drivers in a real-world field study is important.
5. Performance deficits in the nighttime work periods increased as a function of time of night, and the sleep curtailment underlying these deficits involved difficulty maintaining sleep rather than difficulty initiating sleep. No matter how effective the restart break is at maintaining performance across work periods, it nevertheless remains true that nighttime work is associated with performance deficits due to the circadian drive for sleepiness at night and the circadian-mediated difficulty obtaining enough sleep during the day.(1) Strategic napping (i.e., split sleep schedules) would be a powerful fatigue countermeasure in this context. Adapting HOS regulations to allow for greater flexibility in split sleep schedules should be considered.
6. In their review of the Phase I study, the peer review committee underwrote the following suggestion for follow-up research that were not addressed in the Phase II study:
    a. Document the effectiveness of a restart break if optimal combinations of anchor sleep and naps (i.e., split sleep) are placed at circadian-appropriate times during both duty days and during the restart period. There is considerable interest in CMV operations to explore the possibilities of strategic use of split sleep schedules. It would make sense to examine split sleep schedules in relation to the restart provision of the HOS regulations.
    b. Investigate whether caffeine would improve performance under nighttime work conditions. There is an outstanding need to investigate the effectiveness of caffeine for counteracting fatigue in CMV operations. A placebo-controlled study of caffeine effects in the context of the restart provision would help to address this issue.

Further recommendations relevant with regard to the restart provision in the HOS regulations governing freight-carrying CMV drivers can be found in the final report of the Phase I study.(4)

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