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EFFECTS OF OPERATING PRACTICES ON COMMERCIAL DRIVER ALERTNESS

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This study was performed by Star Mountain, Inc., in cooperation with the American Trucking Association Foundation Trucking Research Institute.

16. Abstract

This report summarizes the results of a one-year effort to establish the interaction between operating practices in the trucking industry and driver performance, particularly with respect to safety and fatigue. Principal topics were:

LOADING AND UNLOADING ACTIVITIES as they influence the likelihood and magnitude of general driver fatigue.

DRIVER REST AND RECOVERY as it pertains to re-starting the cumulative weekly hours-on-duty clock.

LENGTH OF DUTY PERIOD (EXTEND DRIVING): In this study, simulator driving performance was measured using a 14 hours on/10 hours off schedule, with schedule breaks during the 14-hour duty cycle.

This study used simulator technology, which permitted safe operation in an environment that included planned safety challenges and precise measurement of driver response. The study drew the following conclusion:

1. The effects of loading and unloading were mixed. Immediately after a morning loading/unloading session, drivers' performance in crash-likely circumstances improved. Late-day loading/unloading sessions produced ambiguous results.

2. Drivers recovered baseline performance within 24 hours of the end of a driving week, and should be fit to resume duty after 36 hours.

3. A schedule of 14 hours on duty/10 hours off duty for a 5-day week did not appear to produce cumulative fatigue.

4. Incidental results worthy of further study are discussed.

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Final Report

Effects of Operating Practices on Commercial Driver Alertness

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Preface

The Federal Highway Administration (FHWA) Office of Motor Carrier and Highway Safety (OMCHS) places a high priority on human factors research with a special attention given to commercial driver fatigue and hours-of-service rules. The research project reported in this document was supported as part of OMCHS's Research and Technology program addressing driver fatigue, specifically, an assessment of the effects of drivers loading and unloading activities on development of driver fatigue.

Phase I of this study (reported separately in 1997) involved: a) a comprehensive literature review on the effects of expending physical energy on development of operator fatigue, b) a driver survey, and focus group interviews to understand driver loading/unloading requirements across the country, and c) a behavioral task analysis assessment of various driver loading and unloading scenarios.

The truck driver simulator-based experiment conducted in 1997-98, is reported here as the major portion of Phase II of the study, an assessment of the effects of the physical activity of loading/unloading on subsequent driver alertness. This experiment also measured and documented drivers' performance on a 14-hours-on-duty (with 12 hours driving)/10-hours-off-duty daily schedule and examined the "weekend" rest/recovery process over the 58-hour off-duty period between two successive weeks of simulated driving.

The two-phased project was conducted as part of a 1996 cooperative R&D agreement between FHWA-OMCHS and the American Trucking Associations' Foundation – Trucking Research Institute (ATAF-TRI), Alexandria, Virginia. TRI's project officers for oversight management of the project were Clyde E. Woodle and William C. Rogers, Ph.D. The entire project, including the simulator-based experiment reported here, was conducted on a TRI subcontract to a team of human factors researchers at Star Mountain, Inc. in Alexandria, Virginia: Timothy R. O'Neill, Ph.D., Gerald P. Krueger, Ph.D., Susan B. Van Hemel, Ph.D. and Adam L. McGowan. Robert J. Carroll, project manager and Ronald R. Knipling, Ph.D., Chief, Motor Carrier Research and Standards, Research Division, served as the Federal Highway Administration's project monitors.

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Finally, our special acknowledgment of the drivers whose long hours, heavy work, and steady, unflappable discipline and spirit of cooperation and teamwork made the successful completion of this project possible.

Executive Summary

This report summarizes the results of a one-year effort to establish the interaction between operating practices in the trucking industry and driver performance, particularly with respect to safety and fatigue. Principal topics were:

- **Loading and unloading activities** as they influence the likelihood and magnitude of general driver fatigue.
- **Driver rest and recovery** as it pertains to considerations of the issue of re-starting the cumulative weekly hours-on-duty clock (duty clock restart).
- **Length of duty period (extended driving)**: Determining an appropriate standard duty time and how much rest or sleep truck drivers actually obtain. In this study, the degree of decrement in performance reasonably attributable to fatigue was measured using a 14 hours on-duty/10 hours off-duty daytime work schedule, with scheduled breaks during the 14-hour duty cycle.

Since the test objectives demanded an operating environment exceeding that permitted by current hours of service (HOS) standards, this study used simulator technology. The simulator approach permitted safe operation in an environment that included planned safety challenges and precise measurement of driver response. The study draws the following conclusions:

1. **The effects of loading and unloading are mixed**. Immediately after a morning loading/unloading session, drivers' performance in crash-likely circumstances improved, a finding consistent with interviews and focus groups that suggested a transient invigorating effect of physical exercise. Late-day loading/unloading sessions produced ambiguous results.
2. **Drivers recovered baseline performance within 24 hours of the end of a driving week, and should be fit to resume duty after 36 hours**. Though drivers do not appear to have accumulated significant sleep loss in the course of the study, there was an increase in measured sleep and a decrease in sleep latency on the first recovery day following the end of a driving week. This observation is supported by a variety of objective and subjective measures. However, we stress that this finding does *not* support resuming work after 24 hours of rest, since this would cause severe circadian disruption – a 36-hour break is the minimum acceptable.
3. **A daytime work schedule of 14 hours on-duty/10 hours off-duty for a 5-day week did not appear to produce cumulative fatigue**. Subjective sleepiness, psychomotor vigilance response, and some other measures showed a slight but statistically significant deterioration over the 5-day driving weeks, but performance on planned and unplanned driver challenge probes did not show cumulative deterioration. This conclusion is drawn from a typical day schedule of 0700-2100; results from other

schedules (e.g., a "night-shift" - not studied here) are likely to be confounded by circadian changes and other factors.

4. **Some** incidental results are worthy of further study. Among these are: a strong sensitivity of driver responses to driving safety challenge (safety probes) to break schedule, an apparent correlation of driver age and physical fitness to other measures, and variations in individual circadian cycle that interact with performance variables.

   The effect of the break schedule, particularly at mid-day, was extremely and unexpectedly dramatic. In effect, most drivers temporarily erased the effects of a long morning-early afternoon driving period, returning to the performance level at the beginning of the day. However, after the break, performance again declined. The result was two distinct periods of performance decline rather than one long deterioration. This and other questions of break quality, scheduling, and duration are worth closer examination.

Notes for non-statisticians:

This report will be read by a wide audience, including many who are conversant with transportation safety issues but lack a knowledge of statistical conventions. In most respects, this report can be easily interpreted without such a mathematical grounding, but two concepts should be generally understood.

First, statistical graphics in this report are generally "range-frame" designs, since this representation is useful for showing visible trends without the complication of deceptive non-zero origins. Readers should note the actual *y*-scale ranges shown, since some effects are subtler than they may appear at a glance.

Most graphs use "error bars" to show relative variability of mean values. The bars shown represent a range of +/1 one mean standard error. Standard error is a convenient way of showing in this report how much drivers' performance varied for a particular measure on a particular time or day.

Second, references made to *statistical significance* describe whether the results are likely to have occurred by chance. If, for example, driver performance for a certain measure appeared to change before and after a rest break, the statement that the change is "statistically significant" means that such a difference would be observed by chance alone very infrequently (generally less than five percent of the time). If an effect is non-significant, it means that, given the data we have in hand, we cannot be reasonably certain the results did not occur by chance.

Readers should also understand that statistical and practical significance are not quite the same. A statistically significant result can in some cases be obtained by mathematical procedure, but is too small to have practical significance. The finding of practical significance is based on expert analysis *after* statistical significance is demonstrated. For this reason, we use the term *non-significant* (not *insignificant*, which addresses practical magnitude) to describe an effect that fails the statistical test.

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1. Introduction

1.1 Background

The Federal Highway Administration's (FHWA) Office of Motor Carriers and Highway Safety (OMCHS) currently sponsors a multifaceted research program examining truck driver fatigue. The program includes approximately twenty research and applications projects including studies of driver on-the-road performance during lengthy drives, simulator studies of varying sleep schedules, epidemiological surveys of the incidence of sleep apnea among drivers, survey assessments of the availability of trucker rest stops, and others.

The project described here concerns an FHWA initiative to assess truck driver fatigue or alertness as affected by non-driving on-duty activities, such as loading and unloading. The principal question originally posed by FHWA and other interested parties was: *What effect does loading or unloading the truck have on truck driver alertness, performance, and/or fatigue during subsequent driving periods?* This notion, addressed in Phase I of this two-phase study, presumes there is a relationship between the time and physical labor (energy expended) by drivers in loading/unloading and driver alertness or fatigue.

1.2 Project history

This project was intended to address issues related to truck driver loading and unloading activities, and their relationship to the development of driver fatigue and consequent effects on driving alertness. The American Trucking Associations Foundation's Trucking Research Institute (TRI) and Star Mountain, Inc. (SMI), and the National Private Truck Council (NPTC) began Phase I of this loading/unloading project in mid-summer 1996 with the general notion or assumption that the physical labor (i.e. the physical energy expended) in loading and unloading trucks may be a sizable contributor to subsequent driver fatigue and therefore may adversely affect driver alertness and safety. Phase I was to characterize the operational practices currently in use, and use these results to define the experimental objectives and method.

1.2.1 **Study Plan.** The study approach established a sequential, phased research plan. In the first phase, the SMI researchers assembled information characterizing the issues of loading and unloading and other non-driving on-duty activities as they relate to driver fatigue. In a possible second phase, the initial plan called for performing controlled physiological measurements of driver loading and unloading activities to quantify the work in terms of energy expenditure. Phase II was to perform experimental studies of the effects of non-driving activities on fatigue in the driving situation, either on the road or in a simulator. The results of the first phase efforts suggested a different, more focused approach. The reasons for this shift in emphasis follow from the results of Phase I, Tasks 1 and 2.

1.2.2 Summary of Phase I tasks

The Phase I effort was conducted from August 1996 through June 1997, and comprised four tasks.

Task 1: Literature review and critique

In the first identified task (Phase I, Task 1) Star Mountain, Inc. reviewed and critiqued the scientific literature (physiological and behavioral), relating physical work in tasks similar to loading and unloading trucks to anticipated physiological and behavioral effects on operator alertness and performance.

Star Mountain researchers screened several technical literature data bases, accomplished library and on-line searches, and reviewed numerous technical articles and reports examining physiological and behavioral approaches to the study of physical fatigue, particularly that which develops from activities like loading and unloading.

The scientific literature survey and critique (product of Phase I, Task 1) is presented in a separate report (Krueger & Van Hemel, May 1997). In brief, the authors concluded:

- **The existing literature includes few studies that definitively address the influence of physical labor on general or mental fatigue**. It is presumed that physical work, of sufficient intensity, affects other performance variables as a component of fatigue, (See for example, Haslam & Abraham, 1987; Patton et al., 1989; Mays, 1993; Ainsworth & Bishop, 1971; and with particular respect to truck driving performance, Mackie & Miller, 1978) but this hypothesis has not been adequately tested.

- **The literature suggests that any effects of physical labor on general fatigue will be profoundly influenced by the general state of physical fitness and health of the driver**. It is concluded that drivers whose level of fitness is high will be more resistant to general fatigue prompted by physical labor than will drivers whose physical fitness and general health are not as good.

- **Full understanding of the contributions of physical labor to general fatigue cannot be obtained without carefully categorizing the tasks performed.** Both workload and the physical nature of the work are critical. (Task 2 identified differences in quantity and type of loading/unloading work performed.) The recommendation at this point in the study was for a measurement and categorization of physical energy expended in typical loading and unloading activities. We later decided that this task should be reconsidered after an intermediate study, described in Section 3, to assess whether loading and unloading have a significant effect at all.

Task 2: Characterization of trucking industry loading/unloading practices and procedures

A second task (Phase I, Task 2) included a number of focus group and interview sessions with truck drivers and trucking company safety directors or managers in various segments of the trucking industry (Van Hemel & Krueger, May 1997a). In this portion of the study we sought out information about current practices regarding driver loading/unloading and included available documentation on current industry practices, with the expectation that little documentation would be readily available on current industry practices related to loading and unloading.

SMI administered questionnaires and conducted structured interviews with drivers and with safety managers and other company officials in various segments of the trucking and bus industries. Driver and safety manager focus group meetings were conducted to discuss specific topics of driver loading/unloading and other activities drivers do while they are on duty, but not driving. The conclusions drawn from this task included the following:

1. **The frequency and amount of driver loading and unloading varies across trucking industry segments (defined by cargo type) and even within segments.** In most cargo categories, over-the-road drivers generally do not do substantial amounts of loading and unloading of their own trucks. In many settings people other than drivers (e.g. shipper and receiver personnel, dock workers, hired lumpers, helpers, and others) do most of the loading and unloading of trucks. Much of the loading is done with mechanical assistance in the form of fork lifts, electric pallet jacks, hydraulic cranes, gravity and air pneumatic suction feed mechanisms (e.g. at grain elevators, petroleum refineries), and is accomplished by personnel trained to operate that specific equipment to load or unload trucks. Drivers then, very often supervise the cargo handling for their trucks, and in some cases merely pick up or drop off trailers of cargo and are not even present for the cargo handling process.

2. **When truck drivers are involved in handling the cargo, they are more likely to be involved in the unloading than in the loading process.** In several industry segments, drivers pick up trucks or trailers pre-loaded and prepared by others, and simply proceed to drive the truck and trailer to the delivery destination. Upon reaching the delivery point, some drivers in a select number of freight commodity categories become involved in the unloading process; in some cases they accomplish all the unloading themselves.

3. **For commercial bus drivers on regularly scheduled routes loading and unloading passenger luggage is not a significant contributing factor to fatigue.** This may not be true, however, for charter drivers.

4. **Truck drivers most involved in handling freight and actually performing loading and unloading of their trucks were identified in two commodity groups: 1) household goods moving van drivers who do both loading and unloading, and 2) grocery haulers who tend to do more unloading than loading.** In the movement of household goods and other furniture, large numbers of van drivers are involved in frequent loading and unloading that results in substantial physical work. Many, but not all grocery industry drivers occasionally unload, breaking out items from pallets and repalletizing to fit store or warehouse requirements, or even completely unloading pallets piece by piece at grocery stores without delivery docks.

5. **From the focus group interviews it appears that when drivers discuss "loading and unloading," they often refer to it in a general sense, not only to their own physical labors associated with moving freight onto or off of a truck.** They are really referring to the "whole process of loading and unloading," including meeting dock appointments, waiting and moving the truck in queues, counting loaded items, processing cargo shipping or receiving paperwork (e.g. bills of lading, or chemical cargo analysis results). By far, there were many more complaints from drivers regarding the fatigue effects of frequent lengthy "waiting periods" for loading/unloading than complaints of getting tired from actually physically performing the loading and unloading of cargo.

6. **Driver perceptions of physical labor effects on fatigue are mixed.** In about a dozen focus groups and numerous individual interviews, Star Mountain analysts sampled the views of drivers, dispatchers, and managers in a wide range of industry segments on the matter of physical fatigue resulting from non-driving activities. When asked about the extent to which the physical labor of loading/unloading impacts driver alertness, if it contributes to development of driver fatigue, drivers gave mixed responses, but generally followed a pattern. Non-driving activities were held to be significant determiners of fatigue, but included a range of circumstances. Drivers reported two responses to physical loading and unloading:

   (a)physical fatigue contributing to an experience of general fatigue from the beginning of the run; and

   (b)a short-term invigorating experience of being "pumped up," frequently followed by an increase in general fatigue after the immediate effects wore off.

   Clearly, some drivers whose loading/unloading work necessitates much physical labor (e.g. household goods movers and some grocery haulers) assess that work as contributing to both physical fatigue and the general mental fatigue of concern to driving safety. Many of these drivers openly described how their long bouts (2-6 hr commonly reported) of physical work make them acutely tired, and how they must be careful not to overextend themselves when they drive over-the-road after such physical work. Sometimes their schedules or the need to locate rest areas do not permit much choice but to begin their long drives shortly after expending large amounts of physical energy in the loading/unloading process. These are the drivers most at risk that physical fatigue contributes to their general mental fatigue behind the wheel of the truck.

Thus, the effects of large amounts of physical labor preceding long haul driving are reported to vary, depending upon the cargo commodity being delivered, and upon other factors (e.g. delivery procedures, time-of-day of driving etc.).

Task 3: Behavioral task analysis of loading and unloading activities
The third task specified for Phase I included observation and video recording and analysis of drivers loading and unloading their trucks in normal work settings. The industry segments studied in this task (following results of Task 2) included furniture movers, grocery haulers, and tank truck operators. The notes and recordings were analyzed, and a taxonomy of loading and unloading tasks and activities was developed to guide further research. This analysis included estimates of frequency and duration of these tasks. (Van Hemel & Krueger, 1997b)

Task 4: Project briefing

Following completion of Tasks 1-3, the Star Mountain project team briefed the American Trucking Associations and the Federal Highway Administration on the findings of the completed tasks and the final methodology for Phase II. This approach was briefed and received final approval In September 1997.

1.3 Recommendations

The study team presented the following recommendations in a summary paper (Star Mountain, Inc. report on Phase I, Task 4a, June 1997):

1. It would not be fruitful for FHWA to expend large funding resources for field experimentation to examine long haul driver fatigue effects as a function of the *physical* labors of drivers loading and unloading trucks across most of the long haul trucking industry, because they simply do not engage in that activity consistently across large segments of the trucking industry; and

2. If FHWA decides to explore further the relationship between the physical labor of loading and unloading and driver fatigue, the grocery and household goods moving industry segments could offer a clear test case for exploring the extent to which loading and unloading contribute to driver fatigue.

   Measurement of loading and unloading effects should be examined in context of other variables that influence fatigue. The variable recommended was "rest and recovery time" following a nominal full work week of driving operations.

2. Phase II General research method.

This study was conducted using a truck driving simulator rather than an over-the road strategy for two reasons:

1. In order to investigate the effects of an extended duty period without risking unsafe driving conditions, and to offer better control of extraneous variables than could be obtained in an on-the-road study.

2. One major priority of this study was to identify safety outcomes rather than simple presence of driver fatigue. This required examination of driver performance in challenging, crash-likely situations, which cannot be induced safely as a part of on-the-road tests. The simulator software configuration allows such events to be triggered by the simulator operator, and the driver response to be evaluated based on outcome, simulator-mediated variables, and expert judgment.

2.1 Philosophy underlying this method.

This study differs from previous research efforts on driver fatigue in two critical ways:

First, this was not specifically a test of *fatigue* in the sense that earlier studies and experiments approach the problem. Star Mountain's underlying position is that "fatigue" is a *theoretical construct*, not an objective measure or definable condition suitable for direct study. The term fatigue is used cautiously or not at all in the discussions that follow, since the term is inadequately defined in the existing literature, and in uninformed or public discourse may mean any of a number of contradictory things. In any case, what is important to discover is not whether a driver is "fatigued," but rather *the degree of impairment of driving performance.*

This echoes cautions stated by the authors in other reports – the definition of fatigue used in a particular study can affect the study's conclusions in ways that can be misleading. There are two common ways of defining fatigue:

- **Fatigue as an internal state**. Some people use the word fatigue to refer to a hypothesized internal state or condition, or to the subjective feeling accompanying this state. Perhaps this is what most of us mean when we say someone is fatigued or tired. We are implying that something has happened inside us as a result of sustained work or exertion or lack of rest, that is experienced as a feeling that we call fatigue. This feeling may be experienced as a loss of the strength, interest, alertness, or motivation needed to continue doing what we have been doing. Such a definition of fatigue proposes an internal state that cannot be directly observed, but is *inferred from observables.*

- **Fatigue as a set of observable changes in behavior.** Since the internal state of fatigue cannot easily be observed or measured, except by asking people to report how

> they feel, others who are interested in studying fatigue choose to use the term to refer to the *observable effects* of sustained performance or lack of sleep on behavior. These scientists define and measure fatigue in terms of those changes in behavior. **It is this interpretation of fatigue we employ in these discussions.**

Past studies have, for example, made much of the appearance of drowsiness. But equating fatigue with overt signs of drowsiness leads into the dangerous trap of defining an event in terms of itself. As this study demonstrates, performance decrement often occurs independent of other signs of sleepiness, or the signs are too subtle to detect with any reliability.

Thus, the objective was to demonstrate the effects *on performance* of various operating practices and parallel conditions (e.g., time-of-day) usually considered contributors to fatigue, but to avoid the imprecision of focusing on a theoretical construct rather than on demonstrated responses. The only useful yardstick of fatigue is its influence on safety.

It follows from this approach that the critical measures examined must be *measures of performance*, not the appearance of fatigue per se. The simulator method allowed accurate monitoring of dozens of performance variables that may be expected to change with time on task, time-of-day, sleep loss, and task demands. These are generally measures of driving performance (e.g., shifting responses, lane keeping, speed maintenance) that may or may not be directly associated with safety.

This created a problem. Whether on the road or in a simulator, crash-likely conditions will occur very rarely. To judge the adequacy of driving response in a study of this type requires a relatively high frequency of crash-likely events. The simulator allows the introduction of deliberate probes (traffic events, crash-likely road conditions, indicators of mechanical failures) that require a driver response that can be evaluated for appropriateness. The central issue for this study was the degree to which drivers can respond to such challenges under different antecedent conditions – that is, are responses related to time on task, time-of-day, sleep loss, or task demands?

2.2 Objectives.

This study was designed to establish the effects of the following conditions on aggregate driver fatigue:

- Fatigue-related performance decrement resulting from **loading and unloading** of cargo and other physical exertions.
- Nonduty time (**rest and recovery**) required to reestablish baseline fitness for duty.
- A sustained 14 hours on/10 hours off schedule. **While the experimental design does not explicitly compare 14/10 to any other schedule, it does show the degree of performance decrement over a 2+ week epoch.**

3. Plan of test

This study addressed the selected research questions in a systematic and parsimonious way, using long haul driving activities performed in a simulator, and was structured to address duty/rest schedule, restart interval, and the effects of loading/unloading.

3.1 General approach.

This program addressed an analysis of two parallel research issues. The first addressed the effects of loading/unloading activities on fatigue, the second established a gradient of recovery time from a nominal 14/10, five-day work week. The experiment used a mixed between- and within-Subjects design that required each of 10 driver subjects to operate the simulator in simulated long haul runs for a period of 15 days, including two 58-hour "weekend" recovery periods, a 48-hour pretest interval for simulator training/familiarization, procedural briefings, and baseline measurements. Ten Subjects were run serially for an active testing period from September 1997 to May 1998. Table 1 illustrates the general design.

Group	Subjects	Days 1-2	Week 1 5 days	Recovery	Week 2 5 days	Recovery	Final day
1	5	Familiarization training	14 hours drive only	58 hr	14 hours drive/unload*	58 hr	14 hours drive only
2	5	Familiarization training	14 hours drive/unload*	58 hr	14 hours drive only	58 hr	14 hours drive only

*Drive/unload periods: In five-day "week," drive only on two days, drive and unload on three. "Unload" here refers to a period of loading or unloading cargo; we adopt this usage for simplicity and because unloading is far more common.

Table 1: General design. This program employed two groups of driver subjects to examine two main effects (loading/unloading activity and recovery time). These main effects are measured within subjects (loading/unloading is counterbalanced across the two-week data collection period). Groups are differentiated by the week in which loading/unloading occurs.

3.2 Conduct of testing

3.2.1 Subjects. Ten male drivers participated in this study. All were experienced CDL holders with long-haul experience. Drivers were screened for smoking (no smokers participated) and for general medical history; all completed a DOT physical and a cardiac stress test and were medically cleared for the experiment, including the loading and unloading activities. Drivers were also screened for susceptibility to simulator sickness.

During the course of screening, two candidate drivers dropped out for personal or medical reasons before the start of testing; one was disqualified for extreme susceptibility to simulator sickness. No drivers dropped out after data collection began.

Driver age ranged from 31 to 49, with a mean age of 43.2. Levels of physical fitness, judged by height/weight ratio and indications of overweight on medical screening varied widely, but no participant had difficulty completing the loading/unloading tasks.

The drivers were housed in an apartment near the test site for approximately 16 days each. They were not confined to the apartment or physically monitored during the duty week; however, they were instructed to get a good night's sleep each night at the apartment, and sleep behavior was verified by wrist activity monitor measurement. In general, drivers heeded these instructions; sleep behavior varied little during the driving weeks.
Each driver was paid an honorarium of $4,000, plus weekly food allowance of $100, with final payment contingent upon completion of the study.

3.2.2 General test procedure. A complete test cycle for each driver required 17 days. The flow of activities was as follows:

- **Pre-test sleep patterns.** To establish a rested state at the beginning of the experiment and to observe the driver's habitual sleep habits, each driver wore a wrist activity monitor for the 48 hours preceding the start of the experiment (that is, before Days 1 and 2). Several days before arrival, drivers were provided with wrist monitors[1] and instructions for their use; records during and immediately before the screening and familiarization period were used as a screening device for presence of undiagnosed sleep disorders and to verify that the driver began the test period nominally rested.

- **Days 1-2: Simulator and procedural familiarization.** This period included 4-5 hours per day of practice on the simulator and familiarization with Psychomotor Vigilance Task (PVT) and subjective fatigue rating scales.

- **Days 3-7 (week 1): Driving operations.** Five days (nominally "Monday" through "Friday") during which the drivers were held to a schedule of 14 hours on duty (12 hours driving plus scheduled breaks of 1.75 hours: 45 minutes for lunch and two 30-minute breaks in morning and evening) followed by 10 hours off duty. During 90-minute scheduled driving periods, performance measures were maintained and recorded and compiled into 10-second time periods. During nonduty periods (nights and "rest days"), drivers' activities were not controlled, but they were instructed to get a normal night's sleep; actual sleep was verified by wrist activity monitor.

  Half the drivers conducted simulated loading/unloading operations during this week for three days (see below) and no unloading in week 2 (though they worked a 14-hour duty day without unloading); the remaining drivers did the reverse: they did not unload in week 1 but did do so in week 2.

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[1] Wrist monitors employed in this study were Ambulatory Monitoring devices obtained on loan from the Walter Reed Army Institutes of Research to assure comparability with earlier studies. The Cole-Kripke sleep scoring algorithm was employed.

- **Days 8-9: Recovery time.** This period was of 58 hours duration, and approximated a traditional weekend, beginning about 10 – 10:30 PM on the fifth driving day and ending about 6:30 AM on the first driving day of the following week. During this period, the driver remained in his lodging, though allowed to leave the residence area for short trips to eat, exercise, or other normal activities. Sleep technicians monitored sleep latency and administered PVT tests and subjective rating scales at predetermined times (0900, 1300, 1700, and 2100) during the recovery period.

- **Days 10-14 (week 2): Driving operations.** This period was identical to week 1 except that unloading activity was counterbalanced: that is, drivers who did not unload in week 1 unloaded in week 2.

- **Days 15-16: Recovery time.** Identical to days 8-9.

- **Day 17: Final verification.** One last driving day (nominal "Monday" following the final full driving week) was conducted to verify full performance recovery from driving week 2. This was a full 14-hour work day.

Time	Scenario number	Event/failure	PVT	SSS
0700-0830	1	Fog	x	x
0830-1000	2	Blowout (or load/unload)		x
1000-1030	Break	Rest		
1030-1200	3	Brake pressure loss		x
1200-1330	4	Oil pressure drop		x
1330-1430	Break	Rest	x	
1430-1600	5	Lane cross		x
1600-1730	6	Traffic stop (or load/unload)		x
1730-1800	Break	Rest		
1800-1930	7	Merge squeeze		x
1930-2100	8	Engine overheat		x
2100-2115		PVT testing	x	

Table 2: Typical daily schedule. In this example, the driver begins at 0700 and drives two 90-minute scenarios followed by a 30-minute break; two more scenarios followed by a 60-minute break; two scenarios followed by a second 30-minute break; and a final two scenarios for a total of 12 hours driving and 1.75 hours of breaks. There were 12 scenarios, arranged randomly across days, eight scenarios for each driving day and six for each loading/unloading day. The second and sixth scenario periods were used for loading and unloading activities during the second, third, and fifth days of the loading week. One planned driving challenge probe (event/failure) was scheduled on a random basis for each driving scenario. PVT was administered at 0645, 1330, and 2100; Stanford Sleepiness Scale and Self-Rating Scale were administered at the end of each driving or loading/unloading period.

3.2.3 Objective 1: Loading and unloading activities. This effort addressed the direct and cumulative effects of physical labor on general/mental fatigue, using deterioration of driving performance measures as an indicator of magnitude of effect.

The underlying assumption of this experiment was that physical fatigue associated with moderate to heavy aerobic and anaerobic activity would result in an increased propensity for general or mental fatigue, demonstrated by deterioration of driving performance. Since the ultimate point of the entire FHWA fatigue research program is to reduce or manage the effects of fatigue on driving performance, we have focused primarily on indicators of deterioration of driving performance rather than indicators of fatigue *per se* and only secondarily on other measures (physiological and psychological indices). Our hypothesis envisioned two related effects on driving performance:

1. On a daily basis, performance on driving tasks immediately following loading/unloading activities would decline on a steeper gradient than driving performance not associated with loading and unloading. In essence, a driver would tire faster during periods of heavy physical activity, and his driving would deteriorate accordingly.

2. On a longer-term basis, heavy physical activity would create cumulative fatigue – in this case, over a full work week of driving and loading/unloading activities.

Loading/unloading task. The physical task used to simulate loading/unloading (more commonly *unloading*, since this activity seems to be more prevalent in the trucking industry segments and operational environments surveyed) was a generic activity based on extensive observation of industry loading/unloading practices (Van Hemel and Krueger, 1997) rather than an attempt to reproduce a specific scenario. The task required moving numbers of hand loads (44-pound weighted boxes) from one pallet to another without use of materiel handling equipment, then shuttling the load using a pallet jack to a second location, simulating common activities identified in Phase I, and repeating the process for 1.5 hours (Figure 3). Loads were identical in weight and volume, 1.5 cu. ft. "book boxes" common in the household goods moving industry, since these are of a convenient standard type and size and are small and convenient enough to load by hand without unusual biomechanical stress. Drivers were instructed to work at a comfortable rate.

1. During the periods corresponding with loading activities during the loading week, drivers conducted driving operations on the same schedule as the other two days – that is, twelve hours driving, two hours scheduled breaks.

2. *Speed control:* Adherence to city/highway speed limits, and pattern of changes. Continuous psychomotor feedback is sensitive to extended time on task and decline of attention.

Following distance: Number of safe and "too close" events. These incidents are influenced by decline in vigilance, long known to be associated with general/mental fatigue. *After the beginning of data collection, a miscoding was discovered in this variable that prevented inclusion of following distance as a variable.*

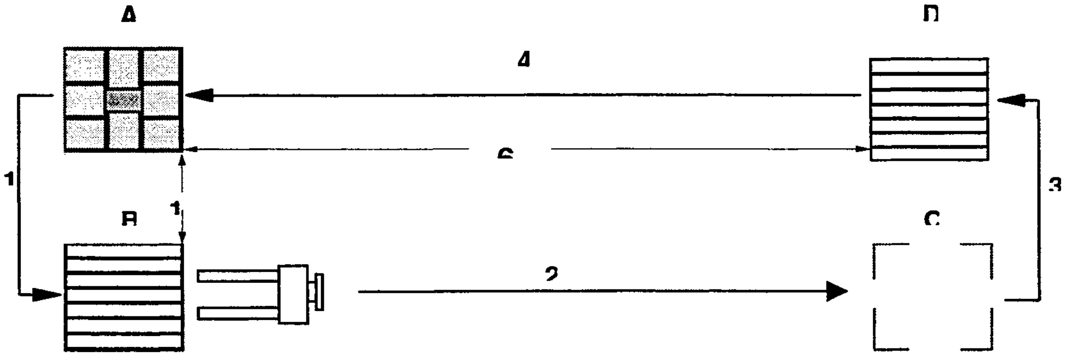

Figure 1: Loading and Unloading task. Two pallets were positioned at start at positions A and B; pallet at A was loaded with 32 1.5 cu. ft. packing boxes, each weighing approximately 19.5 kg. The driver (1) shifted all boxes from pallet A to pallet B, then (2) moved the loaded pallet to position C, using the pallet jack provided. He then shifted the boxes by hand to pallet C (3), then (4) moved pallet C by jack to position A. This process was repeated for 90 minutes.

Simulator variables. Driving performance measures were drawn from built-in parameters associated with the simulator (FAAC DTS-2000) plus computer generated video imagery of driver appearance. The DTS-2000 measures include:

3. *Lane position:* Excursions from lane criterion. Like speed control, this accompanies a decline in vigilance and psychomotor feedback.

4. *Shifting performance:* “Grinds” out of the number of gear shifts in a given analysis epoch, as well as engine stalls. Simulator operators/driver trainers inform us that this is a frequent event when drivers are fatigued or inexperienced; in effect, an experienced but fatigued driver performs in this way much like a novice driver, and the difference is discriminable by the simulator.

5. *Brake usage:* Temperature at average performance/peak performance. This variable is similar in origin and effect to 4 above. Drivers who are fatigued tend to exhibit a sloppiness that emerges as a change in brake application pattern.

6. *Response* (driving Computer-mediated scenarios) *probes*: potential cut off/lane merge – requiring driver response, evaluated for response time, accuracy, and appropriateness. These measure psychomotor response time by forcing a reaction.

NOTE: Response probes were used as a primary measure of driver performance, and represent a departure from typical studies of this type. The probes used included:

- *Traffic stop* (vehicle ahead of truck slowed or stopped in lane, requiring evasive maneuvers and/or application of brakes)

- *Lane cross* (oncoming vehicle on 2-lane highway drifted into truck's lane, requiring evasive action)

- *Merge squeeze* (truck driver required to detect and avoid collision when merging vehicle and vehicle on parallel path appear), requiring implementation of defensive driving maneuver.

- *Oil pressure drop* (oil pressure gauge on dash board panel indicating deceasing pressure, followed by engine noise and warning light) that, if not detected in a timely manner, can cause engine shutdown.

- *Air pressure drop* (brake air pressure drops on dash board gauge, followed by warning light) that, if not detected early, can cause loss of air brakes.

- *Engine overheat* (abnormal engine temperature indication on dash board gauge, followed by engine noise and warning light) that, if not detected early, can cause engine shutdown.

- *Tire blowout* (front tire blowout, requiring appropriate response to regain control and stop the vehicle)

- *Fog* (foggy conditions appear, requiring speed reduction).

Driver response was evaluated by expert trainers based on a three-point scale (Appendix H). Probes provided tests of driver vigilance, alertness, and response time.

7. *Video analysis:* Subjective examination of video record of driver during simulated driving operations. Since this is time- and labor-critical, examination was confined to samples taken from periods during which parallel indicators showed evidence of good or of poor performance.

Objective 2: Nonduty time (rest and recovery) required to reestablish baseline fitness for duty.

The second objective was a descriptive study of actual driver recovery process periods necessary to restore baseline levels following a full week of driving (14 hours on duty/10 hours off). Practical limitations on resources and driver time made a traditional repeated measures comparison of selected recovery periods (e.g., 12 hours, 18 hours, etc.) impractical because of the extended testing period required for each driver. The method used here focused on measures of sleep latency – that is, the time required to enter a sleep state – as an index of recovery.

A driver without cumulative fatigue or sleep debt will typically show a period from reclined and relaxed posture and intent to sleep to actual sleep onset that can be regarded as "baseline;" as fatigue and/or sleep debt accumulate, sleep latency will in general be shorter.

In simple terms, the more tired we are, the less time it takes us to fall asleep. It follows that over a period of nonduty recovery time, sleep latency will increase until the baseline is resumed (or the driver is unable to obtain verified sleep within 20 minutes, the generally accepted threshold time beyond which sleep is not likely to be obtained).

Sleep latency is traditionally measured by beginning a trial when the Subject is recumbent and relaxed, then monitoring critical physiological states, of which brain activity measured from scalp electrodes (EEG) is the most important, until conditions or events reliably associated with sleep are identified. The most common and accepted indicator of entry into sleep (usually Stage 2 sleep) is the appearance of brief high-frequency/high amplitude synchronous wave forms called "sleep spindles" and abrupt high-frequency discontinuities called K-complexes. Technicians who evaluated these outputs were trained in the technique used in similar studies by the Walter Reed Army Institute of Research. The EEG-determined latency was supplemented by PVT and subjective ratings of sleepiness.

Repeated sleep latency testing began at approximately 2130 after the completion of the fifth driving day of the duty week ("Friday night"). Measurement resumed the following morning, and continued at six-hour intervals (0900, 1300, 1700, 2100) until the driver retired on "Saturday" night, then resume again on "Sunday morning." Drivers were not awakened from naps or from a full night's sleep to collect experimental data.

Our reasonable presumption was that recovery would be signaled by return to a sleep latency appropriate for a rested person. The determination of what is "rested" for a particular driver rests on return to a baseline latency. In essence, a tired driver will, consistent with time of day, have a relatively short latency. When fully rested, his or her latency will asymptote (that is, will level out), subject only to predictable effects of the circadian rhythm.

Method. Sleep latency was judged subjectively by trained observers inspecting EEG output in real time, with sleep judged to have begun with the first reliable observation of sleep spindles and K-complexes (Stage 2). The drivers were in their apartment bed under comfortable sleeping conditions, with EEG measured from bipolar parietal and occipital electrodes. EEG signal was obtained using Oxford Medilog systems, with EEG digitally displayed in an adjoining room. The trials were ended after 20 minutes whether the drivers were asleep or awake.

PVT and subjective sleepiness rating were obtained immediately before sleep latency testing.

Objective 3: Effects of 14/10 driving schedule.

Time and funding constraints did not permit a comparison of a 14/10 duty schedule with the current standard or with other possible configurations; hence, this study could only detect evidence that the experimental schedule created cumulative performance deterioration.
The daily driving schedule ran from simulator engine start at 0700 to shutdown at 2100, a period of 14 hours broken by a 30-minute break at 1000, a 45-minute lunch break at 1345,

and a 30-minute break at 1730. Note that this provided 12 hours actual driving time in the 14-hour day, and that breaks were taken on the experimental schedule, not at the drivers' pleasure. This created schedule constraint on drivers, who are accustomed to taking breaks on their own schedules.

We considered allowing each driver a two hour "break budget" to be taken at drivers' judgment. However, this would have created another unrealistic and potentially troublesome conflict, as drivers might "spend" their break time early in the day, then be forced to drive without break during later scenarios. In any case, the actual driving time and total duty time had to be kept constant, as did scenario length; scheduled breaks seemed the lesser of two evils.

There were two likely measures for this objective: driving performance deterioration across a duty day and deterioration across a driving week. The first addresses the simple question of whether the time on task associated with a 14/10 schedule creates sufficient performance deterioration to constitute a clear risk. Since performance was measured for the full 14-hour period, a comparison is possible at the outset of the week with other combinations (e.g., does performance decline between the 10th hour and the 14th?). As the driving week progresses, however, the validity of such comparisons is complicated by cumulative effects of the 14/10 schedule, which can be assumed to differ in theory from those of a 10/8 or other schedule. Hence, it was necessary to examine both short-term (single day) results in the context of mid-term (five-day driving week) and longer-term (full 17 days of testing) trends.

4. Results

The experimental outcomes described here represent nearly complete data sets. Two scenario records were lost through computer error, but the effects of these omissions were minimal. Graphical results are displayed as range frame charts to avoid confusion or exaggeration associated with zero-origin axes.

4.1 Objective 1: Effects of loading and unloading

4.1.1 General. Effects of physical loading and unloading activities were mixed, reflecting similarities to the subjective estimates reported by Van Hemel and Krueger (1997).

4.1.2 Physical fatigue and probe performance. The most important effects of loading and unloading activities, if in fact they occur, are on a driver's ability to maintain vigilance, make decisions, and respond quickly and correctly to driving challenges. The results are shown below:

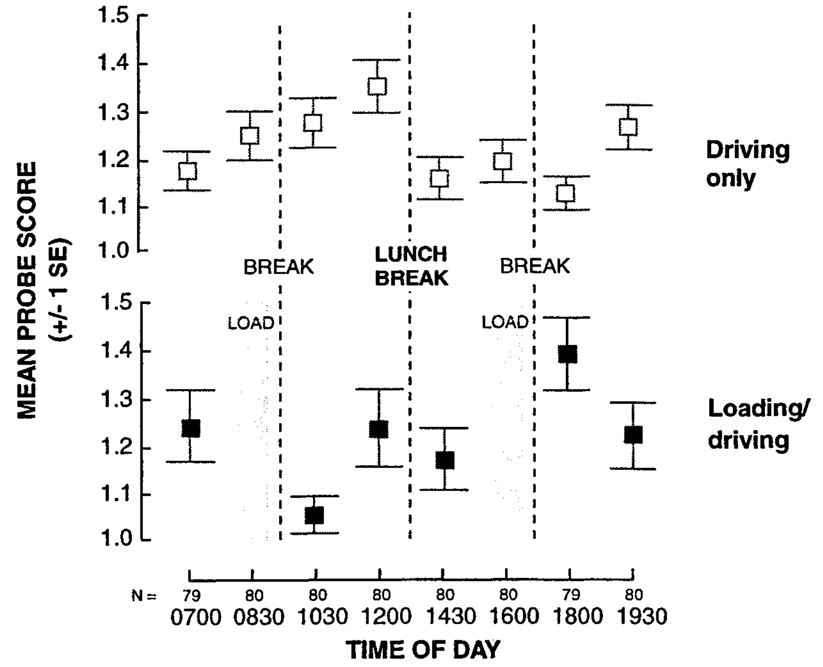

Figure 2: Effects of loading and unloading on mean probe score. These graphs show the distributions and variability of mean probe score by time-of-day for all drivers. (Error bars on all graphs represent +/- 1 Mean Standard Error.) The results are complex. Each condition (loading/driving or driving only) is statistically significant (F[5,174] = 2.492, $p < .05$ for loading/unloading days and F[7,630] = 2.496, $p < .05$) for nonloading, but the combined scores are not; however, the loading/time-of-day interaction is significant (F[5,802] = 3.622, $p < .01$), and this is the question of practical significance. During the period after the first loading session, probe score drops (performance improves) significantly, but increases nonsignificantly over the comparable time period on non-loading days. In the afternoon loading period, probe score increases (that is, driver's responses are less appropriate) in the first subsequent driving hour.

The principal contrast between loading and driving days occurred in the third driving scenario – that is, immediately following the morning loading session and the 30-minute break that followed it. (The loading sessions were deliberately scheduled to precede short rest breaks because this conforms to common industry practice.) During interviews and focus groups in Phase 1 of this program, drivers who routinely load or unload report a short-term invigoration. Whether this is due to the physical activity "pumping up" the driver's energy and attention levels, or due simply to the imposition of a change in activity, or both, cannot be determined from these data. However, the effect seemed to be demonstrated in the first driving period following loading/unloading in the morning. On Loading/unloading days, probe score actually improved after physical activity and a short break. On all-driving days, there is a monotone trend upward in probe score (that is, response quality deteriorated when confronted by mechanical failure or a crash-likely situation) that is interrupted by the lunch break. (See Section 4.4.2.)

In the afternoon loading/unloading period, however, this invigoration effect does not appear to have occurred or is eclipsed by other factors such as time-of-day. The mean probe score during driving period 7 is at its highest point (poorest responses) for the day on loading/unloading days, and its *lowest* (best responses) point for all-driving days. This may represent a combination of cumulative physical/general fatigue that is sufficient to overpower the short-term effects of a change in activity.

Although the exact causes are uncertain, this is a finding of practical significance to operating practices. The mixed subjective assessments of drivers suggested a simple, short-term physiological/psychological "lift" followed by more complex interactions involving cumulative fatigue, age, time-of-day, physical fitness, and other factors – observations that appear to be supported by these results. Significantly, many drivers interviewed in Phase I appear to count on this short-term invigoration; based on what is known of human responses and the results of this study, it may be unwise to depend on a post-exercise effect to improve driving performance and safety.

4.1.3 Physical fatigue and cognitive errors. A second variable extracted from logbook data is the rate of errors made by the driver. These incidents are independent of the probes, and are noted in the test logbook – most involve lapses in vigilance (missed turns and similar errors). The contrast between loading and driving-only days is quite different from that displayed in probes. The only striking difference is a marked increase in errors in the first hour following the afternoon loading session. The apparent invigoration effect shown with probe score is not as evident. The reason for this apparent contradiction cannot be derived from the existing method and data. It has been suggested that "errors" in the sense used here are principally lapses in vigilance and cognitive choices, while probe performance is more strongly influenced by attention and visual-motor response time. If so, this result is unexpected. Cognitive errors are generally expected to show sensitivity to fatigue earlier than attention/response time performance. Here the sequence seems to be reversed.

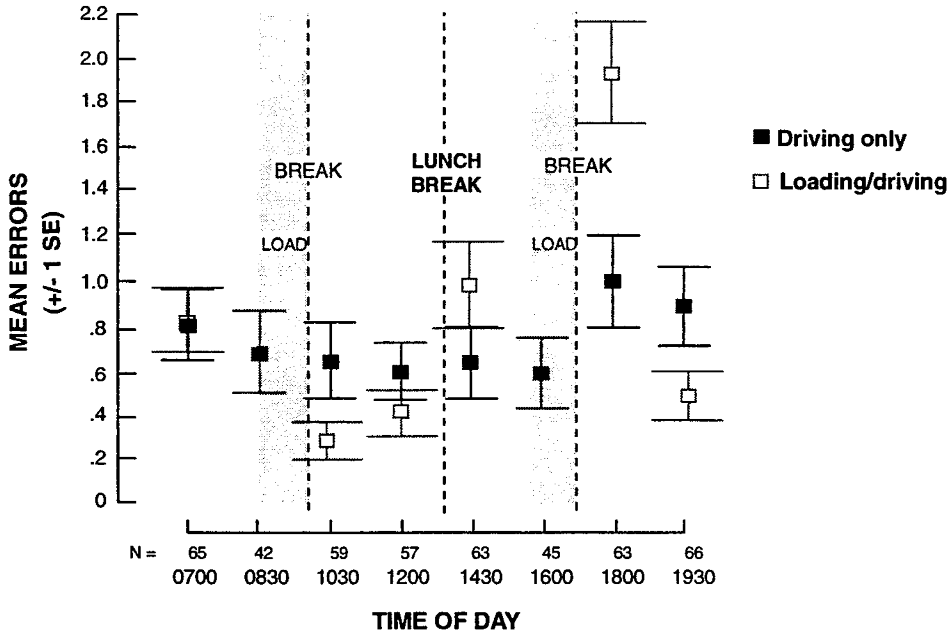

Figure 3: Errors by time-of-day and loading/unloading. Errors are drawn from incidental observations in the logbooks maintained by the Experimenters, and comprise incidents in which the driver made an invalid response or failed to make a valid response under circumstances not captured by probes or by other simulator variables. The majority of these are events in which the driver failed to make a turn or became lost while executing the scenario. The morning loading/unloading session appears to cause very little change, though there is a slight but nonsignificant observed improvement after the morning loading session. After the afternoon session, however, there is an abrupt observed increase on loading days which does not occur on nonloading days; the increase is short-lived. (Time-of-day and loading main effects are nonsignificant ($\alpha = .05$); again, load by time-of-day interaction is significant (F[5,444] = 2.946, $p < .05$.)

4.1.4 Physical fatigue and lane performance.

A third variable that showed a shift on loading/unloading days was lane performance, a measure of the degree to which drivers weave out of the center lane zone. This measure showed an effect quite different from that in probes and errors.

On driving-only days, the amount of time outside center zone rises very gently from the start time at 0700, drops slightly (like probe score) after the lunch break, then resumes its rise, levelling out in the last two driving scenarios. This effect is significant within Subjects (F[7,63] = 6.94, $p < .001$, GLM repeated measures model).

On loading days, we would hypothesize changes between driving sessions[2] 1-2 and 4-5, corresponding to the two periods before and after loading. This clearly occurs in the morning (1-2) period but not in the afternoon.

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[2] We use the term "session" to specify a driving period, without respect to which scenario is driven in that period. There are eight daily sessions, with 12 scenarios balanced across these sessions across the 11 test driving days.

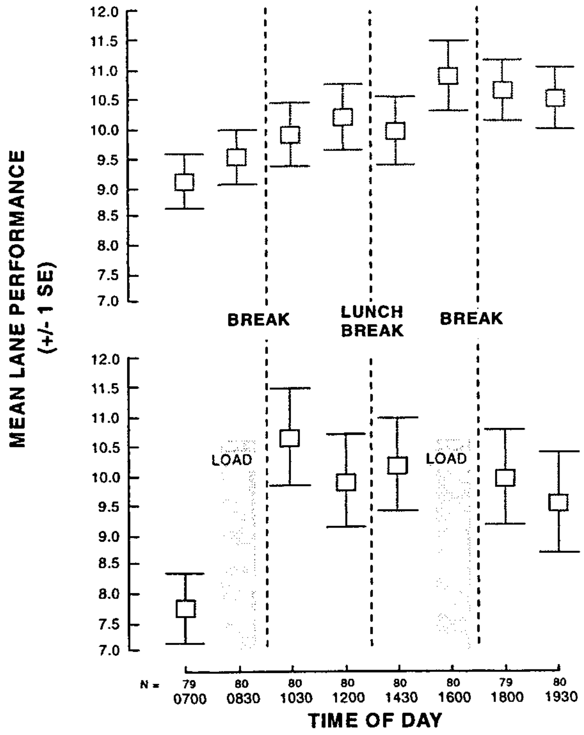

Figure 4: Lane performance by time-of-day and loading/unloading. The normal pattern of lane performance across a driving day is shown in the upper graph – a mild and gradual increase in lane excursions briefly interrupted (as with probe score) by the lunch break (F[7,803] = 2.604, $p < .05$). On loading/unloading days, there is an abrupt discontinuity after the first loading session (T[174] = 2.669, $p < .01$) which does not appear on driving-only days. The afternoon loading session, as was the case with probe score, does not show this effect.

An interesting observation from these results is what appears to be a difference in effects of physical exercise between types of activity. Attention and reaction time appear to improve, while the principal visuomotor task (steering) declines in efficiency. It is possible that lane performance deteriorates because of upper-body muscular fatigue following rather than from general fatigue; however, this hypothesis was not testable in this experiment.

4.1.5 Physical fatigue and gear shifting performance. One possible threat to safety associated with physical labor is muscular fatigue, which may affect motor activities associated with driving tasks. For example, the number of shifts recorded varies significantly across time-of-day between loading and nonloading days. Number of shifts is generally associated with inefficient attention and coordination.

This result indicates that strenuous physical activity of the kind associated with loading and unloading a truck by hand causes enough physical fatigue to influence driving performance. Note that this result addresses physical fatigue only, and not the general/mental fatigue that is addressed directly by this study. This example is included only to show that physical factors as well as general/mental performance are affected by loading/unloading.

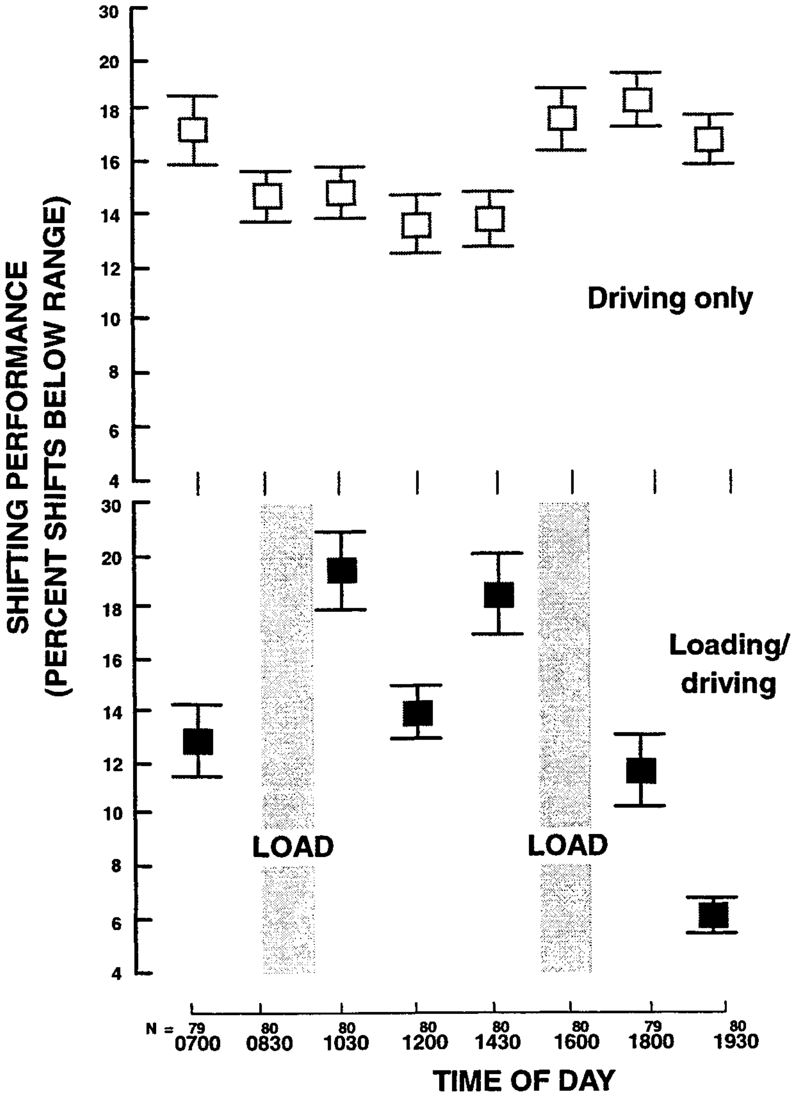

Figure 5: Gear shifts by time-of-day and loading/nonloading. On nonloading days, percent of shifts appears to vary consistent with time of day and circadian effects. On loading/unloading days, however, performance varies widely, including a significant increase immediately following the morning loading period. Time-of-day effect is significant (F[7,802) = 5.912, $p < .001$), as is time-of-day/load interaction (F[5,802] = 15.041, $p < .001$). Shifts above nominal rpm range were similarly distributed; overall time-of-day effect was significant (F[7,802] = 2.047, $p < .05$), as was time-of-day/loading interaction (F[5,802] = 5.413, $p < .001$). (See also Section 4.3.3.)

4.1.6 Discussion. The physical activity of loading and unloading appears to have mixed effects. There appears to have been a short-term tendency to *increase* alertness and response latency, followed by a longer-term decline in performance. These results are consistent with widespread driver beliefs about physical exercise. Conversely, there was a mild deterioration of lanekeeping performance immediately after the loading/unloading task (but not the afternoon session), probably due to upper-body muscle fatigue.

4.1.7 Conclusion.

Loading and unloading activities appeared to exert a mixed effect on driving performance. The initial effect was an improvement in driver response to crash-likely situations, probably resulting from a short-term invigorating effect on vigilance and response time associated with physical exercise and a break in driving routine. This effect faded with the passage of a driving day. These results are consistent with subjective reports of drivers whose operating practices include loading and unloading.

4.2 Objective 2: Nonduty time (rest and recovery) required to reestablish baseline alertness and fitness for duty.

4.2.1 General.

Multiple measures were employed to gauge recovery, including sleep patterns, sleep latency, subjective sleepiness, and performance on the psychomotor vigilance task (PVT). These measures were repeated regularly four times each day during the 58-hour rest and recovery periods.

4.2.2 Sleep patterns.

The amount of sleep each 24-hour period was assessed by wrist activity monitor, a device attached to the driver's wrist to measure level of activity over time. These wrist monitors have an extensive record of successful use in sleep measurement, and data can be downloaded periodically for analysis using an algorithm for detection of valid sleep periods.

During the first two months of the experiment, there were scattered instances of data loss due to unknown technical problems. Data lost to the wrist activity monitor were backed up by sleep logs maintained by the drivers. Comparison of actigrams and subjective amounts of sleep showed a comfortable concordance, and the few losses of electronic data are adequately supported by subjective estimates.

Drivers wore wrist activity monitors for 48 hours before the formal start of training/testing to allow development of a sleep history immediately before the measurement period for other performance data. For analysis purposes, measurement began at midnight of the first day of testing, and it is these data that are reported here. The mean sleep time per 24-hour period for all drivers followed an unsurprising pattern. Sleep was relatively uniform during the driving week, followed by a brief increase on the first recovery day.

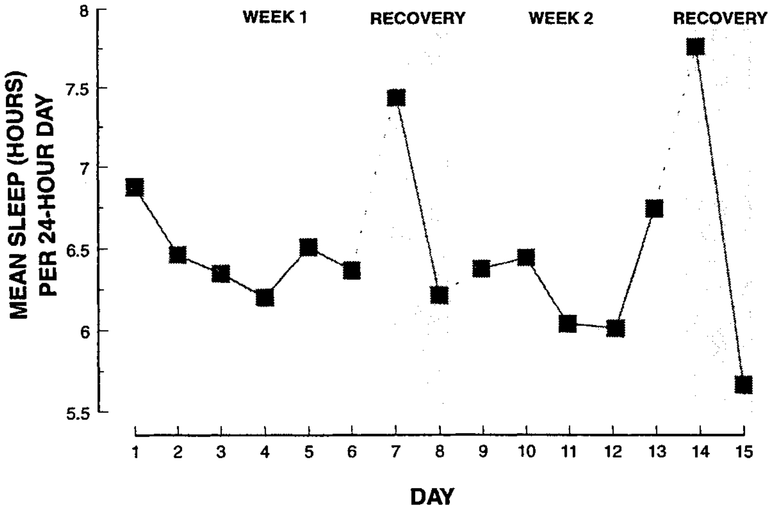

Figure 6: Mean sleep recorded for the test period. The peaks represent an increase in sleep time (including daytime naps) per 24-hour period, 0000-2400) during the first full recovery days after a driving week (that is, on "Saturday"). (F[14,126] = 3.18, $p < .001$, repeated measures GLM)

This pattern was not unexpected. Nominal sleep loss during the work week was relatively small compared to drivers' assessments of their "normal" sleep time. After the first recovery day, the amount of sleep in a 24-hour period returned to baseline.

4.2.3 Sleep latency. The amount of time required to reach Stage 2 sleep has long been a standard measure of sleep deprivation. Sleep latency in this study was measured by EEG scoring, with Stage 2 established by the period required for appearance of a valid K-complex, test truncated at 20 minutes. We would expect sleep latency to follow the total sleep time indicated by wrist activity monitor. In fact, this is what happened.

These results are consistent with a priori expectations. The first MSLT was conducted between 2200 and 2230 on the last driving day (nominal Friday night), after administration of a final PVT and Stanford Sleepiness Scale, transportation to the participant residence, and application of electrodes and test equipment. Most drivers preferred to take time for a shower and shampoo [prior to electrode attachment. At this point, drivers were not ready to sleep, however tired they might feel, since they had just been released from a 14-hour driving day. The second MSLT was conducted between 0900 and 0930 the next morning (nominal Saturday), shortly after the drivers had awakened from a night's sleep. The third (1300) test was thus the crucial first measure of recovery; this proved to be dramatically the shortest sleep latency, and occurred as anticipated at the beginning of the daily circadian lull.

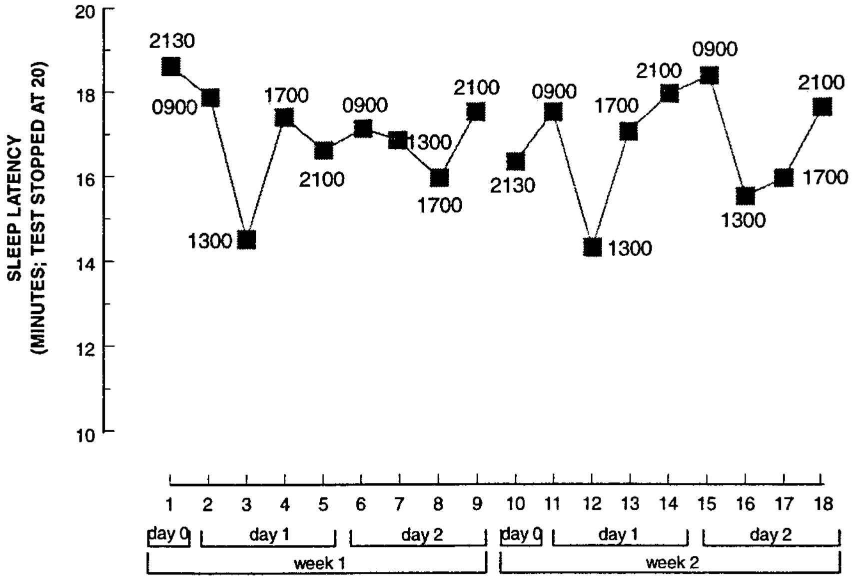

Figure 7: Sleep latency for the test period. "Sleep latency" is the time in minutes required to enter Stage 2 sleep, marked by EEG events (K-complexes). The two visually obvious low points represent the second (1300) test on the first full recovery day, the same period during which wrist activity monitor data indicated maximum total sleep time. The tests were stopped after 20 minutes whether the driver had entered Stage 2 sleep or not.

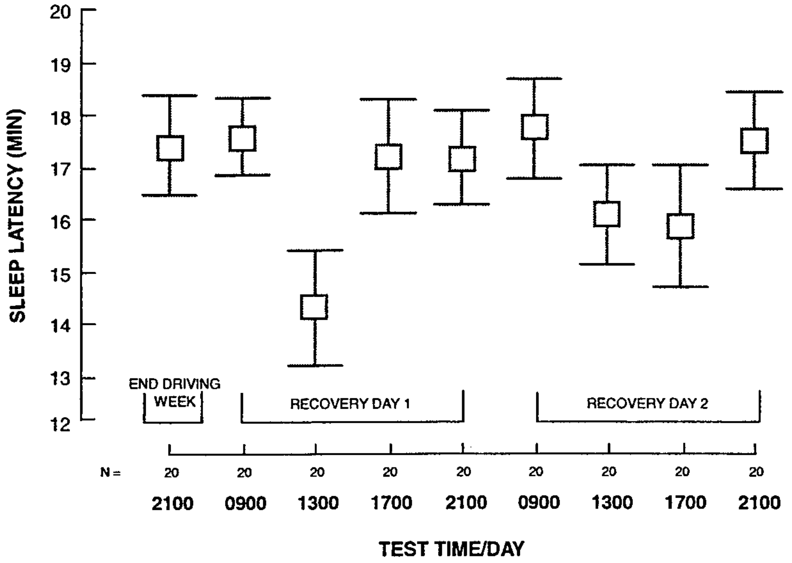

Figure 8: Mean sleep latencies for off-duty rest periods. This figure shows the consolidated latencies for both off-duty rest periods combined. The 1300 test period, expected to be the shortest latency, differed significantly in mean latency from the other test times (T[171] = 2.645, $p < .01$).

4.2.4 Subjective sleepiness. Driver subjective rating of tiredness provides some context for these observations. Mean Stanford Sleepiness Scale ratings across the five driving days (collapsed across two weeks) show an increase in self-reported tiredness, followed by a brief decrease in the last driving session (Figure 9). The mean self-ratings across all 15 days of the study (11 driving days and 4 recovery days) shown in Figure 10 is likewise informative, though the effect is inconsistent in the second week: subjective tiredness increases, followed by a final decrease on the last day, the reasons for which are unclear. Subjective tiredness is lower during the off-duty rest periods.

The diminished cumulative effect in driving week 2 may be attributable to driver familiarity with the task.

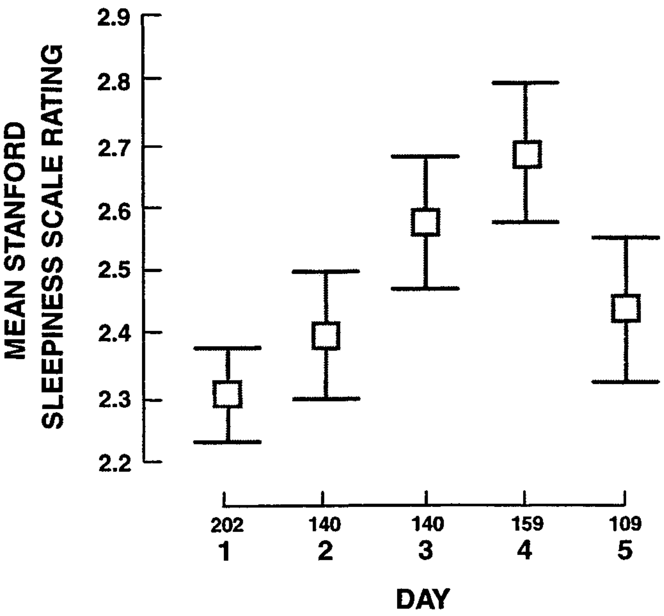

Figure 9: Mean Stanford Sleepiness ratings across driving days. Both driving weeks are consolidated for this figure. Ratings differ significantly across the driving week (F[4,805] = 2.501, $p < .05$).

Stanford Sleepiness Scale ratings also showed an obvious decline across the first off-duty rest day. Note that the subjective sleepiness at the end of the last driving period was not higher than the first such score on the following morning (first recovery day). Drivers reported feeling less sleepy after the completion of day 5 in the driving week due to the relief at the end of the long driving schedule and the prospect of free time.

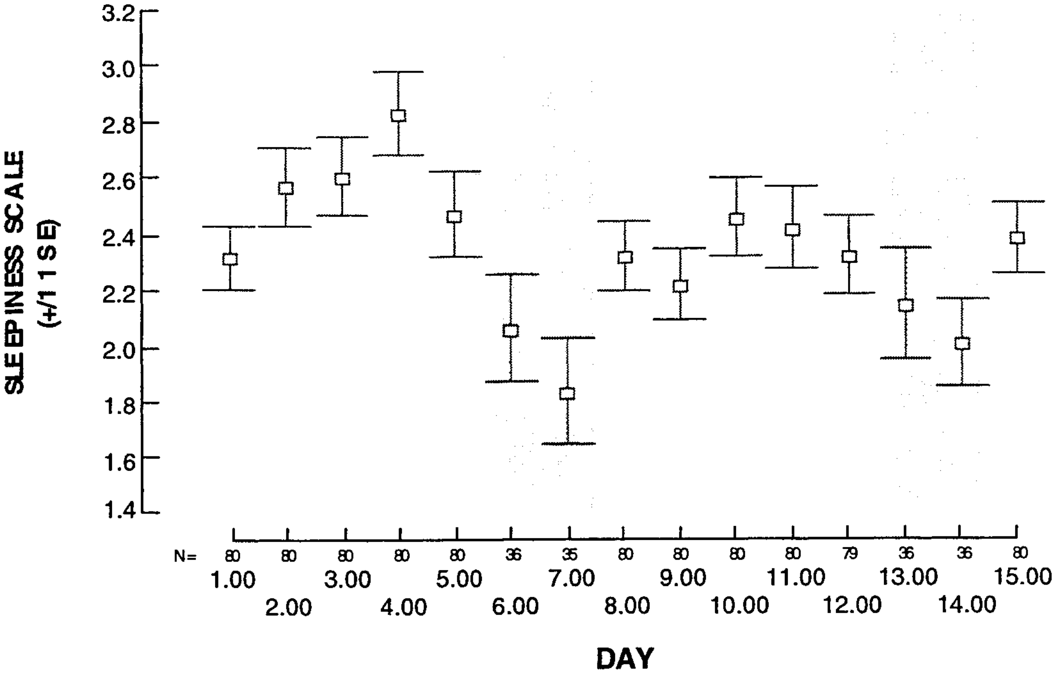

Figure 10: Mean Stanford Sleepiness Scale ratings across test period. Shaded areas show off-duty rest days. The day effect is significant across the test period (F[14,1023] = 2.161, $p < .01$); contrast between recovery days and driving days is significant (T[1023] = -3.073, $p < .01$).

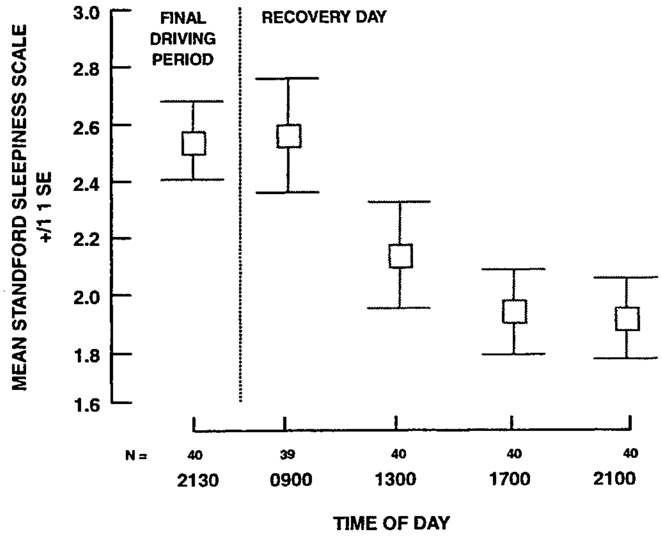

Figure 11: Mean Stanford Sleepiness Scale ratings for off-duty rest day. This includes the mean score for the last rating on the final driving day of the week. The decline is significant (F[1,155] = 2.969, $p < .05$).

4.2.5 Psychomotor Vigilance Task (PVT). PVT median reciprocal response time and number of lapses in the PVT were tested at 0645, 1330, and 2100 on driving days and at approximately 0850, 1250, 1650, and 2050, or immediately before sleep latency testing, on recovery days. The PVT score used here, median reciprocal response time, is selected to reduce the exaggerated effect of outliers associated with use of the mean score and to produce a measure of effectiveness in which a high score is associated with high performance. Figure 12 shows the mean scores for all drivers across a full week (first and second weeks are here aggregated).

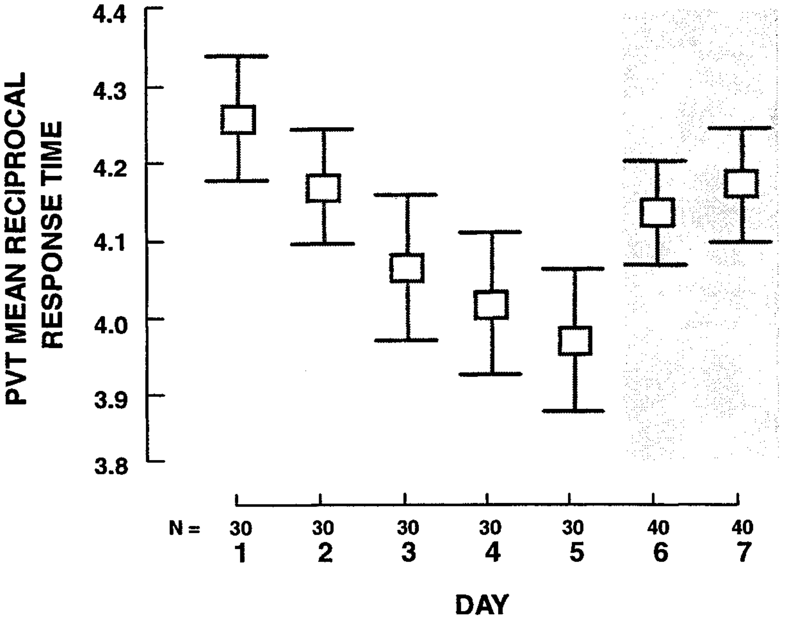

Figure 12: Psychomotor Vigilance Task performance.

The recovery of psychomotor vigilance and response time was during the off-duty rest period (shaded area) is visually compelling, and parallels the effects shown by other measures. Despite the graphical elegance, however, variations between drivers render the differences statistically nonsignificant.

4.2.6 Discussion. Driver recovery following the five driving days appeared to be complete by the end of the first full off-duty day. This effect is generally consistent across drivers. The typical recovery pattern involved extra sleep during the first rest day (verified by wrist activity monitor), and an increased level of sleepiness during the afternoon of the first day (indicated by shorter sleep latency).

The environment imposed during the testing regime can be said to be unrealistic in some respects. Drivers occupied an apartment, and did not have guests during the driving week, hence may have experienced fewer distractions than would have been the case at home or on the road. In addition, hours were very regular compared to those typical of revenue runs. Ample time was afforded for sleep; some drivers took more advantage of sleep opportunity than did others, but on the whole most tried to get adequate sleep. We do not believe the peak sleep periods during the "weekend" days were due principally to sleep deprivation.

As shown in Table 1, drivers varied significantly in number of hours of sleep per night. However, by-case examination of driver sleep patterns did *not* show a higher rebound for those who slept less during the driving week, indicating that the variation observed did not represent deprivation.

SUBJECT	MEAN SLEEP (HOURS)
101	6.36
102	5.51
103	6.56
104	6.32
105	7.03
106	6.32
107	7.42
108	7.01
109	6.30
110	6.15

Table 3: Mean hours sleep per 24-hour day for all drivers.

Most drivers managed between 6 and 7 hours of sleep per night on average, with one significant outlier (Subject #102), who slept slightly less than 6 hours per night on average. Figure 13 shows the individual sleep patterns for all drivers, illustrating the relative consistency of patterns across the 15 test days.

Experimenters observed certain common characteristics in recovery sleep patterns. Most drivers did not go to sleep readily during the first recovery ("Friday") night. Many reported being too tense after days of confined driving, and put off additional sleep until the first full recovery day. Since the morning MSLT was scheduled for 0900, there was no opportunity to sleep in; and in any case, 0900 is a time of rising circadian trends. By the 1300 test on the first day, drivers were finally free to enjoy additional sleep, and did so with surprising uniformity across individuals.

This observation was supported by sleep latency. Idiosyncratic sleep habits and individual tolerance for the test procedure created some variation in results, but latency paralleled quite closely the general sleep patterns. If the 14/10 schedule contributed to cumulative fatigue or sleep loss across five driving days, the effect appears to have been erased within 24 hours.

However, this line of reasoning does not allow direct comparison to other schedules, including the present hours of service criteria. Across five days, the daily schedule effect is confounded by any cumulative effect. There is only one direct comparison that can be made: results of the first week day (days 1, 8, and 15), since recovery appears to be complete prior to the start of each week, and performance can be expected to be free of confounding cumulative effects. Since the 14-hour driving day includes effects of shorter schedules (e.g., 10 hours, 12 hours) some comparisons can be made.

4.2.7 Conclusion. Based on these results, it seems reasonable to conclude that the 58-hour nonduty periods were more than sufficient to provide restoration from the five-day duty week. Most recovery occurred within 24 hours of the final driving day for each week.

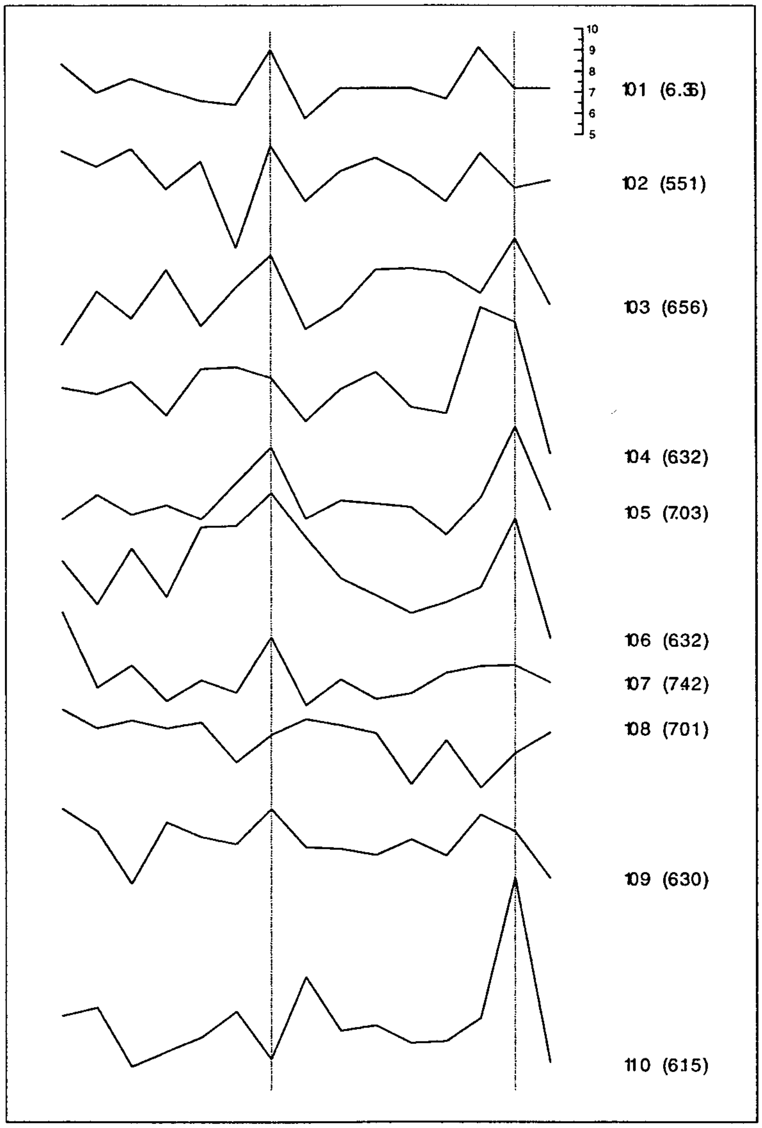

Figure 13: Sleep patterns by driver. Ten drivers (coded 101-110) and their sleep patterns. Sleep measurement is as of midnight for the preceding day; hence, the first value represents the day *prior* to the first day of testing, and the last point represents the day prior to the last driving day. The low values for the final "weekend" day reflect drivers packing and making other preparations for departure. This small multiple graph is designed to show parallel trends for visual inspection; all use the same vertical scale (shown for Driver 101).

4.3 Objective 3: Effects of 14/10 driving schedule.

4.3.1 General. Examination of the suitability of the 14/10 schedule relies on two arguments. The first is that, if such a schedule is too stressful in terms of time on task over an extended period, cumulative deterioration will occur over the course of the five driving days in each week. As noted elsewhere, such effects were mixed and of very low magnitude. However, there is no useful way to compare the cumulative effects of the 14/10 schedule with other possible schedules (including those logically subsumed, such as 10- hour and 12-hour duty periods) because the cumulative effects for each are confounded. The most that can be said about cumulative effects is that they appear to be nil for practical measures (e.g., probe scores), and mild for parallel subjective measures such as subjective sleepiness.

However, a direct comparison is possible on the relative effects of schedules within a day if we examine only the first days of each driving week (days 1, 8, and 15). Since, as noted earlier, full recovery of alertness seems to be obtained during the two-day break, cumulative effects should be removed in these cases, and it is possible to compare the 14-hour duty day schedule against shorter included schedules.

4.3.2 Probe (driving challenge) performance. The principal measure of safety, mean probe score, shows a distribution across time for first driving days of each week that is typical of the entire period: a gradual increase in score (i.e., decline in response quality) over time, with a discontinuity following the mid-day break. By inspection, there is an increase in probe score between the driving periods corresponding to a 10-hour schedule and a 14-hour schedule, but the difference is not quite significant. Note that this difference is of dramatically lower magnitude than the change before and after mid-day break. It is fair to speculate that, had drivers not taken a lunch break, the trend in probe score would have continued upward, and a significant difference between 10 hours and 14 hours would have appeared; however, this presumes that drivers on a 14-hour duty day will take no breaks; this is not a reasonable case. (The implications of the break are discussed later.)

Lane performance on the first driving days shows a distribution similar to the aggregate score, and is probably influenced most powerfully by circadian factors. Lane variation increases almost linearly from the session beginning at 0700 and reaches a peak at the 1600 session, a result predictable from known time-of-day effects. The change is not dramatic, and is confused by unaccounted differences in driver circadian phase (one in particular appeared to have an atypical circadian cycle); though significant for the entire driving period, the smaller sample for day 1 cases does not permit an overall significant F statistic.

In short, it appears that if there is any deterioration in lanekeeping between the 10 hour schedule and the 14-hour (and, by inclusion, the 12-hour), it is overpowered by the general time-of-day effect.

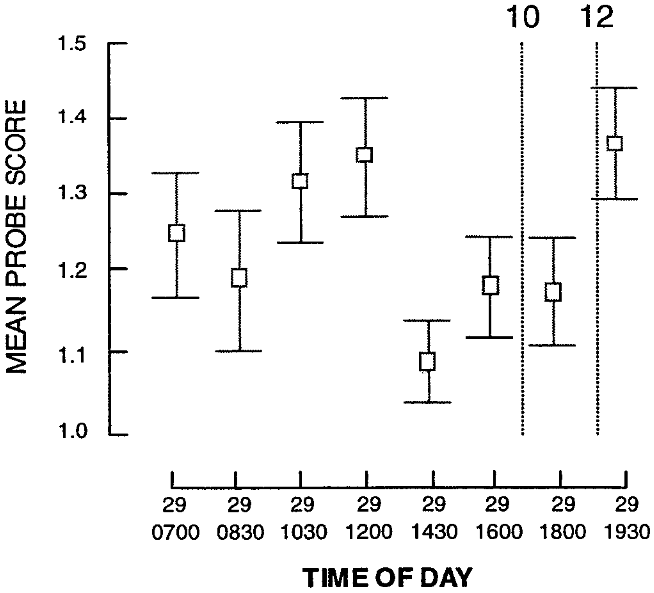

Figure 14: Mean probe score by time for first driving days. For this sample (aggregate results for all drivers on days 1, 8, and 15) there is no significant main effect (F[7,232] = 1.737, *ns* $\alpha = .05$). The hypothesis of interest (does probe score differ at 10 hours and 14 hours duty time) also yields a nonsignificant contrast (T[232] = -1.78, *ns* $\alpha = .05$). Note also that the probe score at the end of the driving day is virtually the same as the score immediately before the mid-day "lunch" break of 60 minutes.

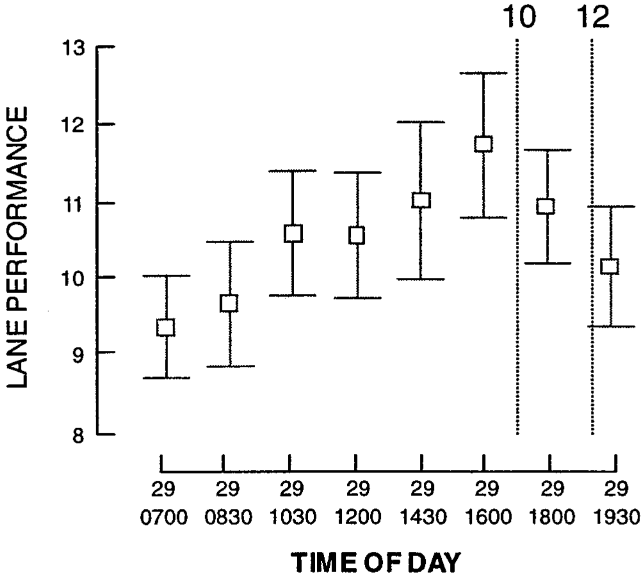

Figure 15: Mean lane performance for first driving days. Day 1 cases, which are unconfounded by cumulative effects over a driving week, are here selected to the exclusion of other days. The result is a pattern similar to that for all driving days (cf. Figure 4), and consistent with expected results related to circadian factors. Note that, by inspection, performance actually appears to improve between the 10- and 14-hour scenarios (however, this shift is nonsignificant (T[232] = 1.337, *ns* $\alpha = .05$). A related contrast of theoretical interest is the difference between lowest and highest points during the day (showing the difference between a fresh, rested driver and one with significant time on task combined with the circadian postprandial period); this contrast is significant for day 1 cases (T[232] = -2.008, $p < .05$).

4.3.3 Speed maintenance and shifting performance. Two variables showed a significant change across the 14-hour driving day not predicted by theory: the ability to maintain speed within posted limits and the number of gear shifts. Both deteriorated significantly in the last three sessions of the day.

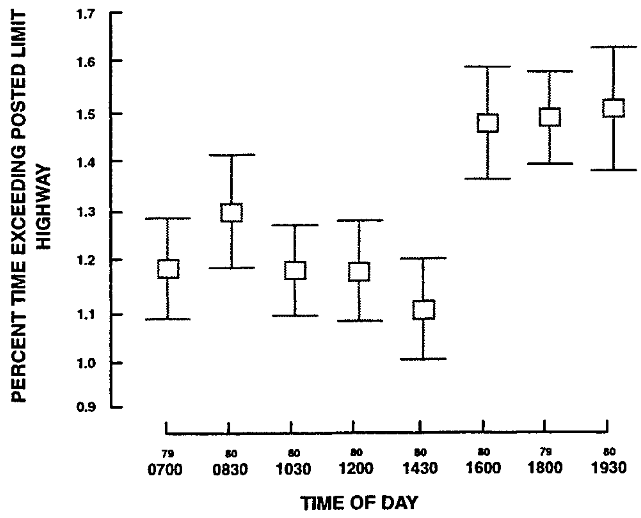

Figure 16: Speed maintenance by time of day (driving days only). Drivers tended to exceed the speed limit more frequently and for longer duration in the last three driving sessions (F[7,630] = 2.428, $p < .05$). However, this spans the time zone from 10 to 14 hours of duty/driving, and does not increase during that period.

During the same period that speed increased, the total number of shifts also increased. The simultaneous occurrence of these two events suggests a deterioration of physical coordination and vigilance late in the day, which is not in itself surprising. Again, these data are from driving days only, and do not reflect effects of loading and unloading.

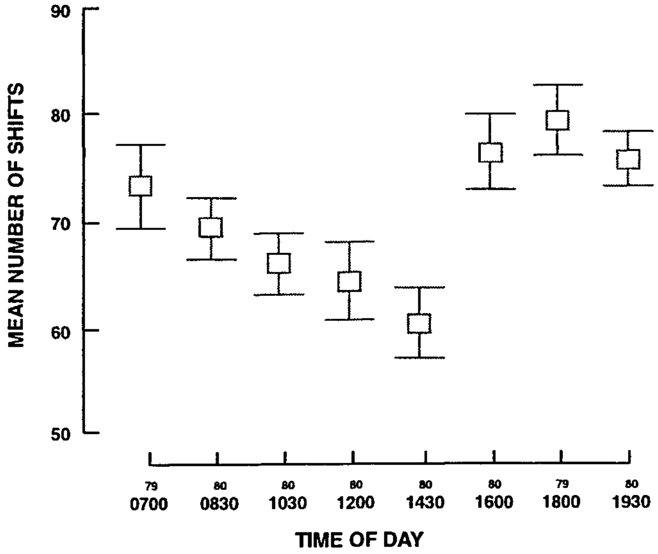

Figure 17: Number of gear shifts by time of day (driving days only). Total number of shifts increases significantly in the last three driving sessions of the day (F[7,630] = 4.05, $p < .001$).

4.3.4 Subjective sleepiness. Across day 1 cases, subjective feelings of tiredness measured by the Stanford Sleepiness Scale followed an elegant sinusoidal distribution similar to the results for probe score, but with a less dramatic discontinuity following the mid-day break. This effect is largely attributable to time on task and time-of-day, since even if some hidden sleep loss occurred across the five-day driving weeks, it would not have appeared in the case of a single day immediately following verified recovery.

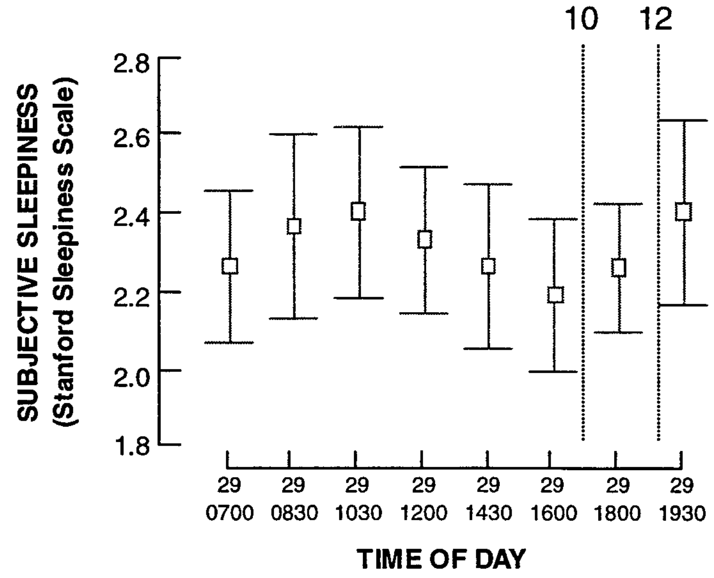

Figure 18: Subjective sleepiness by time-of-day for first driving days. Drivers' subjective assessment of their relative sleepiness varied with time-of-day (F[7,49] = 2.527, $p < .05$, using GLM repeated measures design).

Levels of sleepiness for 10- and 12-hour periods did not differ significantly from those at 14 hours, though the curve appears to rise. It is interesting to note that, although drivers felt sleepier as the day ended, their lane performance appeared to improve just as they report feeling sleepiest.

4.3.5 Discussion. The most important point to be appreciated in this analysis is that simple time on task is not a uniformly effective determiner of performance. Factors such as time-of-day (and its relation to circadian cycle) and rest break schedule are so influential that other factors customarily associated with performance deterioration over time are often dwarfed. In this case, it is a reasonable observation that, in a typical day (morning to eventing) shift, the difference between a 10- or 12-hour duty day and a 14-hour day is negligible.

We caution, however, that this observation cuts both ways with respect to the suitability of a 14-hour duty schedule. We cannot say with certainty that this result would be observed with other than a day shift, since the powerful effects of circadian factors could interact with time on task and length of duty day to produce very different results for different shift schedules.

In addition, the rest break schedule (discussed in more detail in the next section had a consistent effect on performance that once again cuts across the simple variable of duty schedule/time on task.

4.3.6 Conclusions. From the results of this study, we find no reason to believe that a schedule of 14 hours on duty, 12 hours driving, followed by 10 hours off duty, is likely to cause noticeable performance decrement on drivers, and it has the advantage of allowing five days of continuous work at such a schedule without the complication of offsetting the 24-hour circadian rhythm. That is, such a regularized 14/10 schedule permits drivers to maintain their work schedules in parallel to expected circadian body rhythm changes in physiology and performance. This conclusion is limited to conditions in which the driver is (1) conditioned or accustomed to the schedule being followed (that is, a change in shift that upsets the circadian rhythm would in all likelihood negate the 14/10 schedule much as it would an 16/8 or 12/12 or any other notional schedule); (2) the driver is allowed a reasonable break schedule; (3) the driving is accomplished on a typical day shift pattern (since night driving was not tested in this study); and (4) the off-duty time is actual off-duty time during which a driver may obtain sleep.

4.4 Incidental findings

4.4.1 General. In addition to the principal objectives of this study, there were related findings that may be of significant interest to the industry and to the government. These include the unexpectedly powerful effect of rest breaks in the driving schedule and the apparent relationship between age, physical fitness, and performance.

4.4.2 Rest break schedule. One obvious factor in the rate of driver performance deterioration in this study was the effect of rest breaks. In some respects, this variable was the most powerful influence on critical safety measures. Figure 19 illustrates this finding.

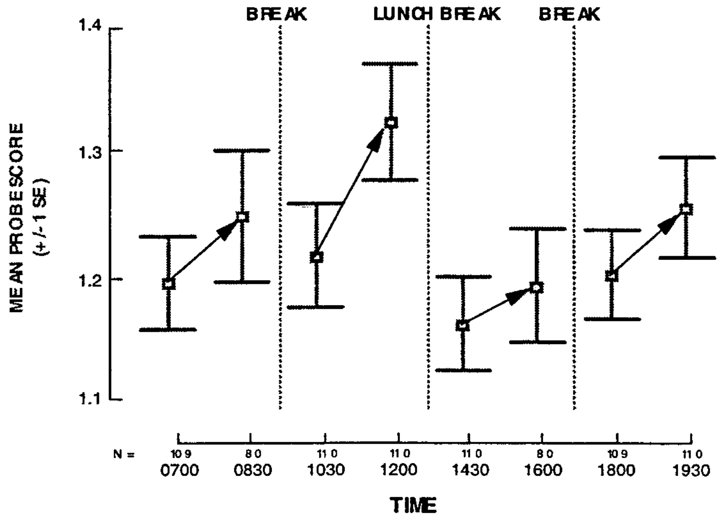

Figure 19: Effects of breaks on mean probe score. Note that there is an increase in probe score (indicating lower performance) between scenarios in each of the periods between breaks. The contrast of interest (shift in performance before and after the 45-minute lunch break) is significant (T[810] = 2.841, $p < .01$).

We remind the reader that the breaks were scheduled by the experiment, not taken *ad libitum*, as would more likely be the case in an actual long haul operation. The three rest breaks included 30-minute periods in the morning and evening and a 60-minute lunch break at mid-day. The daily schedule was so arranged that two 90-minute driving scenarios were conducted between each break period.

However, as noted earlier, the loading/unloading variable contributed to a significant interaction. It is of use to examine the days when no such activity occurred, since these are more typical of the industry as a whole, and are free of the loading/unloading variance. These results are at Figure 20.

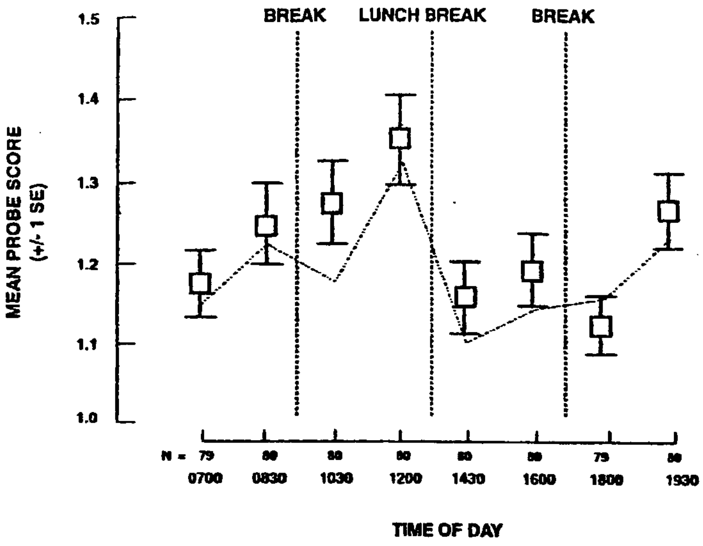

Figure 20: Effects of breaks on mean probe score for non-loading days. In this graphic, error bars show the means and mean standard errors for non-loading days only; the dashed line shows the results when loading/unloading days are included (see Figure 15). Recall that higher probe score = poorer performance. Again, there is an apparent break effect, particularly for the mid-day (lunch) break The overall time-of-day effect is significant (F[7,630] = 2.496, $p<.05$), as is the 3rd order (cubic) polynomial contrast (F[1,630] = 9.893, $p<.01$). (This means that the visually evident effect of rise in mean probe score before lunch, followed by a decline, then another rise, is significant.)

While the recovery effect of a rest break in driving is not surprising, the magnitude of the effect is striking. In essence, the effects of 6.5 hours of driving are reduced to starting levels by the 45-minute break; in fact, the final performance level for response to probes does not differ significantly between the scenario running from 1930-2100, the last scenario before the mid-day break.

Discussion. While it is risky simply to extrapolate the rate of deterioration for the first four simulator scenarios through the end of the 14-hour driving day (both because drivers are unlikely to continue 14 hours without a break and because such an extrapolation does not account for circadian factors), it is nonetheless evident that the break was needed. In fact, for reasons of experimental design it came rather later (1330) than many drivers would have preferred. It is worthwhile to ask whether an ad libitum [3] schedule would have yielded a flatter distribution of probe performance, on the presumption that an experienced driver would, given a choice, have taken a longer break prior to the probe performance decrement peak in the fourth scenario. This observation suggests that factors that affect a driver's ability to take a break at the appropriate time (e.g., lack of rest areas, scheduling pressures) may have an influence even more dramatic than supposed. Recall that these data were obtained *in the absence of significant sleep loss*; deterioration resulted from time on task and time-of-day effects. With sleep loss added into the equation, the effect might be expected to be even more evident.

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[3] The term *ad libitum* (or commonly *ad lib.*) means literally "at pleasure." A driver who takes breaks from driving activity whenever he or she feels the need is on an ad libitum break schedule.

4.4.3 Age and physical fitness. A reasonable presumption from the outset of this program has been that loading/unloading activities will have differential effects on performance related to driver age and physical fitness. It was not practical to determine objective levels of aerobic and anaerobic fitness for drivers, as this effort exceeded the resources available; however, we selected height/weight ratio as a surrogate for general fitness, and age was recorded for each driver.

To obtain a rough estimate of age and height/weight effects, we employed a multiple linear regression model for two variables considered likely to be related to physical fitness and coordination: lane performance and shifting performance. Both showed significant interactions with loading/unloading, and might reasonably be expected to show differential effects for drivers with different levels of fitness.

The combination of age and height/weight was strongly correlated with lane performance for the ten drivers measured ($R = .511$, $R^2 = .262$; $F[1,816] = 283.84$, $p < .0001$). The result for shifting performance was similar ($R = .428$, $R^2 = .183$; $F[1,816] = 182.80$, $p < .0001$). Individually, age was correlated with lane performance ($r = .508$, $p < .01$) and shifting performance ($r = .287$, $p < .01$); height/weight ratio was correlated with lane performance ($r = -.358$, $p < .001$) and shifting performance ($r = -.428$, $p < .001$). Age and height/weight ratio were strongly correlated ($r = 1.614$, $p < .001$).[4]

Discussion. These results are not surprising, but we caution that the sample used here is very small, and may not be representative of the industry as a whole. In addition, while strong correlations with age and height/weight appear with largely physical tasks, they are absent or negligible in other variables such as mean probe score.

4.4.4 Circadian patterns. The influence of circadian cycles on driving performance is well documented; however, much emphasis in previous studies seems based on the presumption that cycles are uniform for drivers.

The use of the Psychomotor Vigilance Task (PVT) in this study allowed an examination of this presumption. The results were unexpected. Of the ten drivers used in the study, seven had "normal" predicted patterns, while three were atypical. PVT (see Section 4.2.5) was measured on driving days at 0645 immediately before the first scenario; at 1330 at the beginning of the mid-day break; and at 2100 following the last driving scenario of each day.

A typical pattern showed high performance in the morning and evening measurement points, with a deterioration in the mid-afternoon, observations consistent with known circadian effects. This "chevron" shape was very consistent within drivers; but the appearance of consistent variations indicative of circadian abnormalities in three of ten drivers was surprising.

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[4] The negative coefficients for height/weight ratio occur because the figure used is literally height (cm) divided by weight (kg); therefore, a heavy build scores low, a more athletic body type scores high.

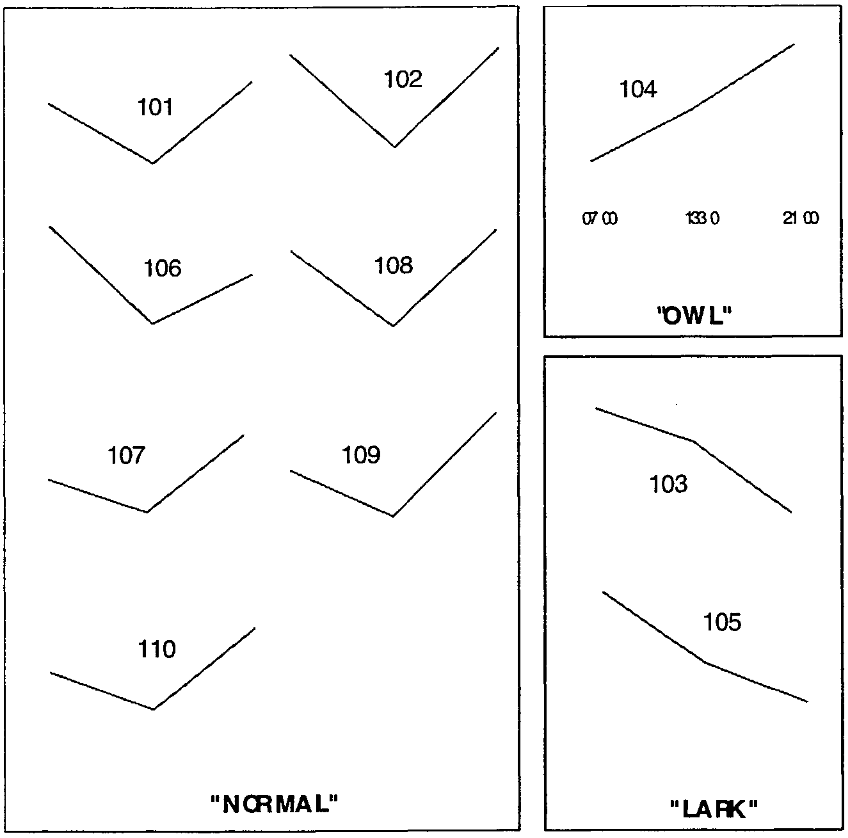


Figure 21: Circadian variation indicated by PVT (median reciprocal response time). The normal "chevron" form appeared in seven of ten drivers. The remaining three included one whose response time improved linearly throughout the day (consistent with subjective circadian "owls"), and two whose response times deteriorated linearly ("larks"). These patterns were generally supported by subjective sleepiness ratings.

It is extremely risky to generalize from so small a sample, but the discovery that nearly one third of a random sample of 10 drivers do not fit the expected circadian profile is of interest, and suggests new hypotheses. By way of illustration, Figure 19 shows the mean probe score patterns for the three categories.

Discussion. Key assumptions guiding driver fatigue countermeasures are based on the influence of time-of-day circadian factors. These assumptions are explicit or implicit in many areas of training, procedure, and policy. However, they are all based on the idea of uniform circadian cycles for drivers, even though exceptions are known to exist, and even though cycles are known to change along with such factors as shift schedules. If exceptions to the expected circadian cycle are common, some countermeasure approaches may prove to be counterproductive.

However, circadian cycle at a given time can be measured without extraordinary effort, even by use of simple subjective scales. Such a precaution would allow managers and individual drivers to tailor work conditions and habits to the actual circadian cycle. Determining how to bring this about, however, is a more complex task, requiring a more reliable census of the driver population's circadian patterns in combination with evaluation of possible tailored countermeasures.

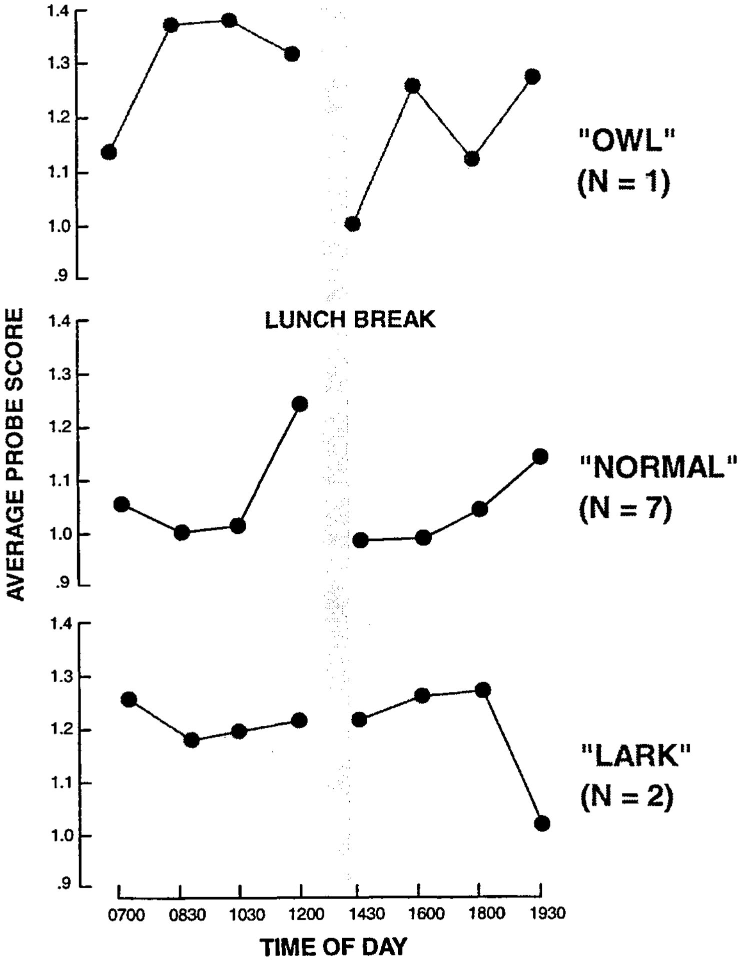


Figure 22: Mean probe score performance for identified circadian categories. This chart shows the pattern of response to planned and unplanned probes. The sample is very small, and no sound conclusions can be drawn from these results; however, the data are suggestive. "Normal" circadian cycle drivers show the increase of probe score (deterioration of performance) over time on task, punctuated by the dramatic effect of the mid-day break. The two "larks" and the single "owl" show performance changes consistent with their PVT scores.

5. Conclusions

The authors propose the following principal conclusions:

5.1 The effects of loading and unloading are mixed.

Immediately after a morning loading/unloading session, drivers' performance in crash-likely circumstances improved, a finding consistent with interviews and focus groups that suggested a transient invigorating effect of physical exercise. Later loading/unloading sessions are less clear, but may show an amplification of the effects of time-of-day and time on task.

The principal implication of this result is that drivers who routinely load and/or unload their trucks appear to recognize the short-term effect of physical exercise, which in some respects acts more like a rest break, in that performance is actually improved for a short time. Less clearly recognized is the evidence that this effect is of short duration and, unlike traditional breaks, loading activity may have long-term effects. In this study, the invigorating effect of a loading activity appeared only in the first session of the day, and did not recur when repeated in the afternoon. Drivers should be aware of their limitations, and should rely on the physiological/psychological "lift" of loading only under conditions in which it does not interact with time on task and time-of-day.

5.2 Drivers recovered baseline performance within 24 hours of the end of a driving week, and should be fit to resume duty after 36 hours.

Though drivers do not appear to have accumulated significant sleep loss in the course of the study, there was an increase in measured sleep and a decrease in sleep latency on the first off-duty rest day following the end of a driving week. This observation is supported by a variety of objective and subjective measures.

This does not necessarily mean that all drivers will recover alertness fully within a day. The limitations of this experiment did not allow for conditions in which the driver is significantly sleep-deprived, or suffering from significant cumulative effects of other types. It does mean that a driver who has completed a fairly typical five-day work week, and who obtains regular sleep, is unlikely to need more than 24 hours to recover baseline function.

We also caution against attempting to apply a "24-hour" rule (that is, restart the weekly clock hours), since this suggests a driver is prepared to begin driving again 24 hours after the end of the last work day. In fact, a 24-hour restart would necessitate a significant disruption of the circadian cycle, a condition likely to lead to significant safety-related problems.

The typical driver in this study – and there was little variation – went to sleep on the night following the final duty day, awakened in the morning in response to circadian forces and/or necessity to prepare for the first sleep latency test, then napped during the day, an event recorded on sleep logs and by wrist monitor). Complete recovery of alertness could not be obtained under these conditions until late in the first recovery day, by which time the driver was outside the circadian pattern for continued work. In essence, these findings suggest the effectiveness of a full two nights and one day off (that is, "Friday night" to "Sunday morning" as a minimum safe restart period – about 32 hours off duty) under the conditions tested.

5.3 A schedule of 14 hours on duty/10 hours off duty for a 5-day week did not appear to produce significant cumulative driver fatigue.

Subjective sleepiness, psychomotor vigilance response, and some other measures showed a slight but statistically significant deterioration over the 5-day driving weeks, but performance on planned and unplanned probes did not show cumulative deterioration. Since only the 14/10 schedule was used in the study, cumulative fatigue for this schedule could not be compared to that associated with shorter alternatives because the cumulative effects were confounded.

Comparison of results on the three first-day schedules following recovery allowed a limited comparison before cumulative effects confounded them. Here again, differences are both mixed and very mild; probe score and subjective sleepiness, for example, appear to increase slightly between 10 and 12 hours on duty and 14 hours; lane performance, on the other hand, improves slightly. These effects are minor compared to that of the mid-day break.

It is also prudent to note that these results reflect a test environment. Different results might be obtained in operating practice under the following conditions:

(1) The driver is not conditioned or accustomed to the schedule being followed (that is, a change in shift that upsets the circadian rhythm would in all likelihood negate the 14/10 schedule much as it would an 16/8 or 12/12 or any other notional schedule).

(2) The driver is not allowed a reasonable rest break schedule.

(3) The driving is not accomplished on a typical day shift pattern (since night driving was not tested in this study). The results here are valid only for a day schedule like that tested (0700-2100).

(4) The off-duty time is not actual off-duty time during which a driver may obtain sleep.

5.4 Some incidental results are worthy of further study.

(1) The schedule of rest breaks was critical to performance in this study. Critical performance variables (particularly the critical task of responding to probes) showed a dramatic discontinuity before and after the 45-minute lunch break. It has been

suggested that this resulted because the break was scheduled later in the duty day than most drivers preferred (1345), and performance decline prior to that break was somewhat exaggerated. It is probably true, however, that undesirable break times are a fact of the trucking industry, because of schedules, opportunities, and other factors. The unexpectedly strong effect of rest breaks suggests that more attention should be paid to this issue. For example, further delay in the scheduled 1345 test break might have resulted in a singularly unsafe condition if the probe score line is simply extrapolated. *This effect was of great practical significance.*

(2) Age and physical fitness were correlated with driving performance. In most GLM models used in this analysis, age and height/weight ratio were used as covariates, and were generally significant.

(3) Examination of objective and subjective measures of fatigue indicate that the circadian cycles of the sample were not uniform; several drivers had atypical rhythms, loosely associated with the "owl" and "lark" categories used to describe persons whose subjective level or performance is best late in the day or early in the day, respectively. While the sample used here is far too small to draw conclusions, this result suggests that the "one size fits all" approach used in fatigue countermeasure training on circadian factors may be risky.

6. Recommendations

The authors recommend the following studies and actions:

6.1 **Examine the effects of a night driving schedule to balance the information gained in the present study.** This is of particular importance in view of the strong time-of-day effects demonstrated in this and in previous programs. Any attempt to effect universal hours of service regulation must reasonably include consideration of night conditions.

6.2 **Examine the effects of rest break scheduling on performance deterioration.** This manipulation was not possible in the present experiment, but could be included in later studies. The benefits of such an inquiry are evident from the dramatic effect associated with the lunch break in this program, and could contribute significantly to a broader understanding of the factors that interact to influence driving performance.

6.3 **Survey the driver population to determine the incidence and range of circadian variance.** The observation that there may be a variety of circadian cycles represented in the driver population may be a significant finding, and could influence the nature of fatigue countermeasure programs. It is also a relatively low cost research option.

Appendices

A Description of FAAC DTS-2000 driving simulator

The FAAC, Inc. DTS-2000 driving simulator is a high-fidelity system with computer-generated display and accurate vehicle dynamics for a wide range of vehicular configurations. This device has been used successfully in other driving studies.

The device used in this test was owned and operated by North American Van Lines, Inc., under subcontract to Star Mountain, Inc. The simulator was mounted as an integral part of a system used for several years as a training device installed in a converted 40-foot semitrailer. The simulator was manned by two expert trainers employed by North American; these technicians operated the simulator, trained the driver/participants, and scored driver challenge probes.

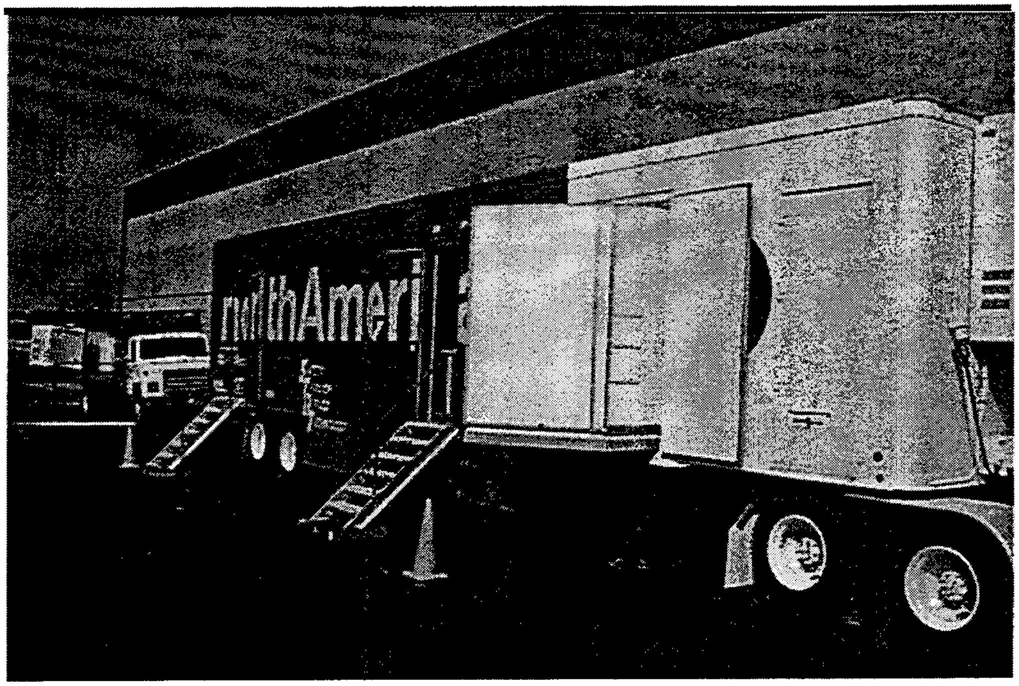


Figure A-1: North American simulator lab (external view).

The training configuration provided by North American Van Lines was modified for this experiment. Software routines were changed to allow more efficient recording of driver performance data in a column format, rather than in the summary report format used in the training role. In addition, two video cameras were mounted in the simulator cab, one to record the scene from a point of view behind the driver, the other to provide continuous monitoring of the driver's face.

The final system configuration is shown below:

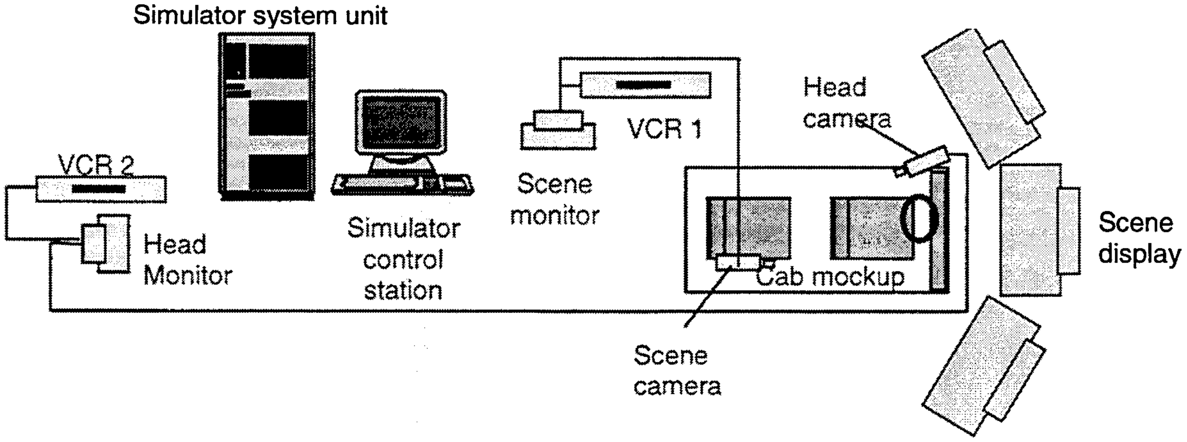


Figure A-2: Simulator integrated system – schematic.

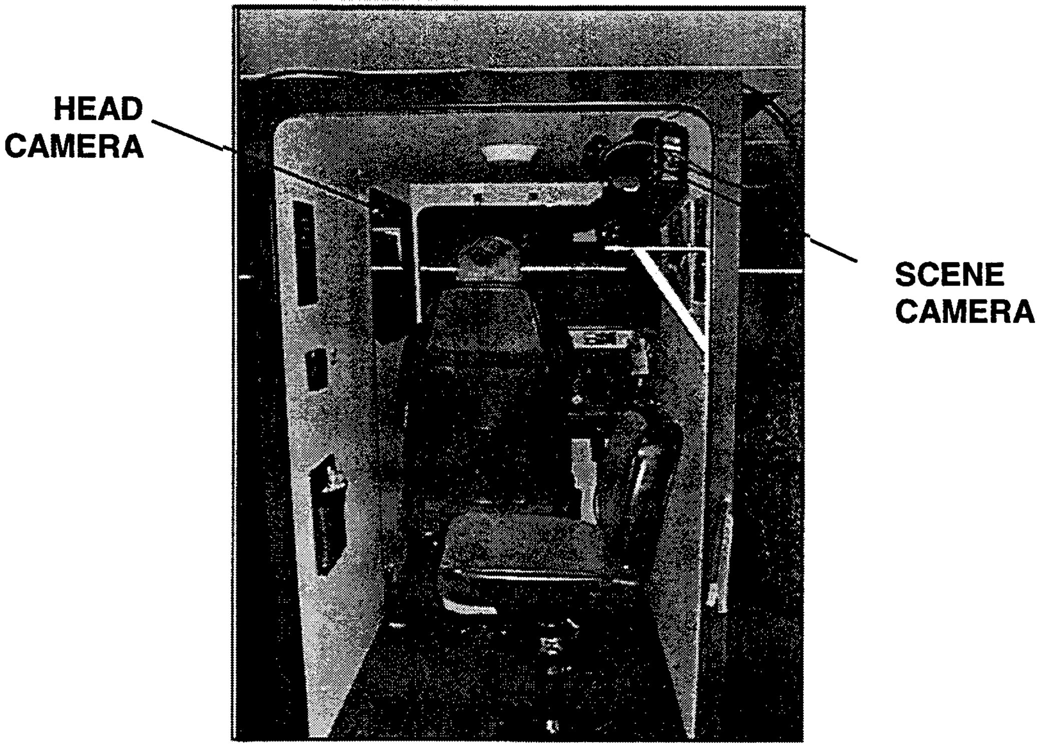
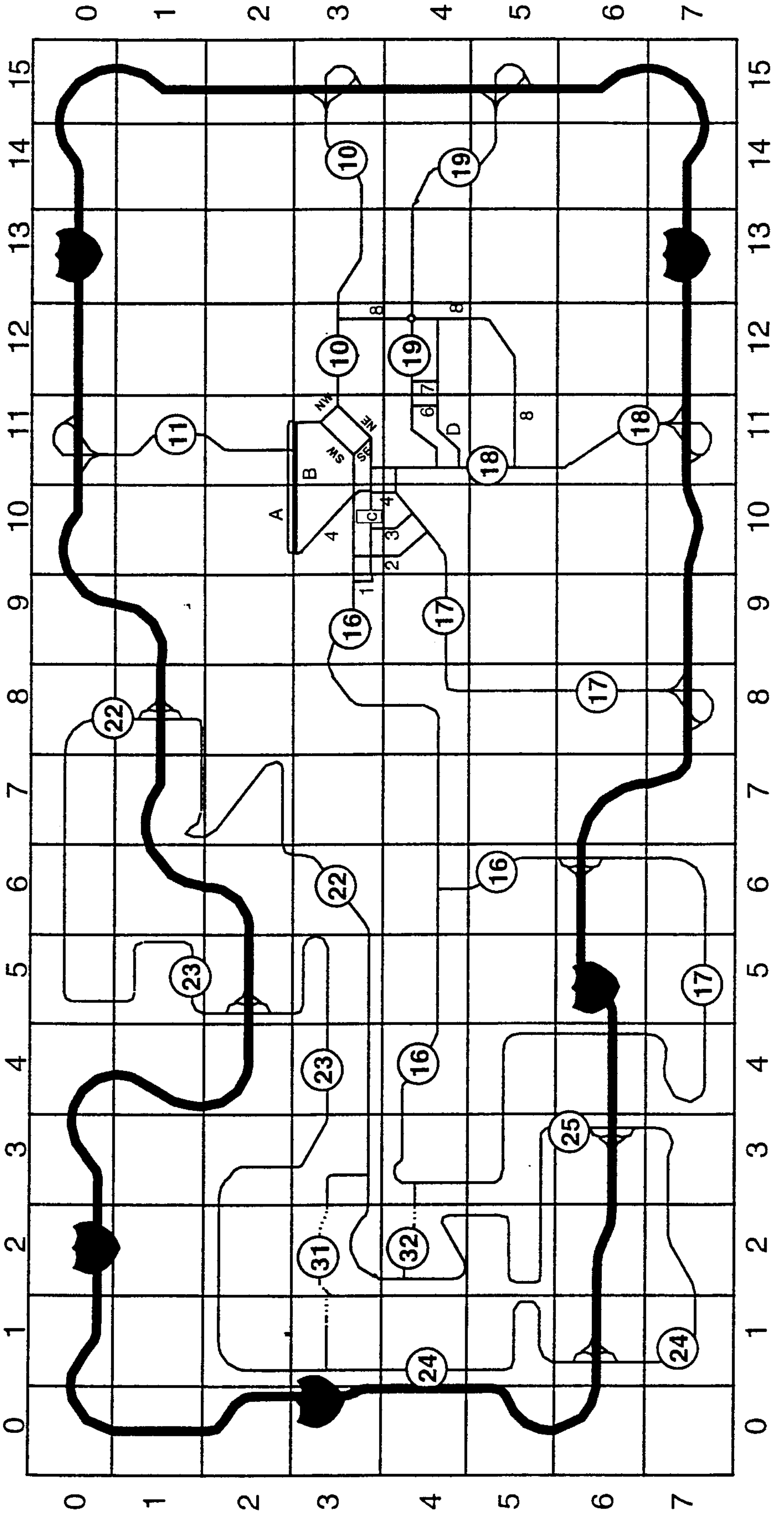


Figure A-3: Simulator cab

B Highway data base map

The simulator data base includes 87 miles of varied highway, including urban and rural roads, divided highway, and primary and secondary road. Urban areas include buildings.

Driving runs were conducted using 12 preset scenarios, each consisting of a fixed route designed to take approximately 90 minutes to complete at the posted speed limits. Drivers were provided a marked map and written instructions at the beginning of each of eight driving sessions per day; scenarios were balanced across time periods for the full testing period.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C Telephone screening form

The attached form was used as a prompt for telephone pre-screening interviews.

Telephone Pre-Screening Form - Operating Practices Study

Date screened: ____/____/_____ Screened by:____________

Volunteer's name: ______________________________________

SSN: ________-______-__________

Phone Numbers: Work:______________________ Cell:________________________
Home:______________________ Pager:________________________

Home address: ____

____

Date of birth: ____/____/_____

Age: _____

Current CDL? YES NO (must have current CDL through participation)

How long have you continuously held your current CDL? ______________yr ._________mo.

Do you smoke? YES NO (must be no)

Have you smoked within last 3 years? YES NO If yes, last date smoked?____________
must be "clean" 6 mos.

Do you chew tobacco? YES NO (must be no)

Do you use any tobacco or nicotine products at all? YES NO
(include dip, snuff, nicotine patch or gum) (must be no)

How many cups of caffeinated coffee, tea, or cans of soda do you drink a day, average?________

Are you willing to restrict your caffeine intake to 3 or 4 servings a day? YES NO

How much alcohol do you normally drink in a week? ________________

Have you ever had a problem with alcohol? YES NO
If yes, get details____

What is your height?____________________ Weight?_______________

Do you have any current illness or condition that requires medical care? YES NO

If yes, what?____

Do you now have, or have your recently had hemorrhoids or back trouble that would affect your ability to spend long periods driving? YES NO

If yes, details ____

Do you take any prescription drugs of any type? YES NO

If yes, what?____
For what?____

Do you take over-the-counter drugs of any type? YES NO

If yes, what?____
For what?____

Do you wear prescription glasses or contact lenses? YES NO
Do you normally wear them while driving? YES NO
Do you have any night vision problems? YES NO

When was your last DOT physical? (approximate date OK)________________________

If w/in 90 days, can you provide the results of that physical? YES NO

This study will run on a 7-day per week basis. Do you have any religious or other objections to working through the entire week? (We will not run during holiday periods.)
YES NO (must be no)

Have you ever driven a truck simulator before? YES NO
If yes, did you experience any queasiness or discomfort in the simulator? YES NO
Do you experience queasiness or nausea on amusement park rides or in similar situations?
YES NO

Do you typically drive long-haul (away from home overnight) or short-haul (return to home each day or night)? Long-haul Short-haul Some of each.
Details?____

What kind of truck do you typically drive?
Straight Tractor-trailer. If tractor-trailer: Conventional Cab-over?

Do you perform loading and/or unloading as part of your work? YES NO
If yes, how frequently?________________ Primarily: Load? Unload?
If no, do you have any problem performing physical labor like lifting and moving cartons for an hour or hour and a half at a time (20-30 lb. cartons). (Back problems, etc?)
YES NO

Sleep questions:

Have you ever had a serious sleep disorder or frequent difficulty sleeping? YES NO
If yes, what and when?________________________________

Have you had, or do you now have, difficulty staying awake during normal waking hours?
YES NO
If yes, details____________________________________

At what time do you normally go to bed at night on:
Weeknights (Sun.-Thur)? __________AM PM
Weekends (Fri.-Sat.)? __________AM PM

At what time do you normally awaken on:
Weekdays (Mon.-Fri.)? __________AM PM
Weekends (Sat.-Sun.)? __________AM PM

How long does it typically take you to fall asleep at night?
Weeknights (Sun.-Thur)? __________Min. Hr.
Weekends (Fri.-Sat.)? __________Min. Hr.

Do you often feel sleepy during the day? YES NO
At what time do you feel sleepiest? ________AM PM
At what time do you feel most alert? ________AM PM

Is daytime sleepiness currently a problem for you? Yes No
If yes, explain how daytime sleepiness affects your life.

____

____

What is your typical work shift, or normal working hours?
_______AM PM to _____AM PM VARIABLE

Do you often change your working hours or work rotating shifts? YES NO
If yes, explain shift rotation or varying hours.

____

____

Do you often have difficulty falling asleep? YES NO
If yes, how often? __________ per week ___________ per month

To the best of your knowledge, do you often do any of the following during sleep? If others have told you that you do any of these, please answer yes.

Talk	YES	NO
Walk	YES	NO
Kick your legs	YES	NO
Snore	YES	NO
Make unusual motions	YES	NO
Grind your teeth	YES	NO

If yes to any, get details:

Have you ever been tested for sleep apnea? YES NO. If yes, what were the results?

What is the longest time that you have ever gone without sleep: ____________hours
Get details

Do you typically take more than two naps a month? YES NO (nap ≤2hrs at a time)
If yes, approximately how many times a month do you nap?________
At what time of day do you typically like to nap? From ___________ to ___________

Do you consider yourself a "morning person" or an "evening person"? That is, do you feel most energetic and productive in the morning or the evening? MORNING EVENING

Do you consider yourself a light, normal, or heavy sleeper?
LIGHT NORMAL HEAVY

Do you typically need a very quiet environment in order to fall asleep? YES NO

Do you typically fall asleep (without intending to) while listening to radio/stereo or watching TV? YES NO

Have you ever taken sleeping pills? YES NO

If yes, when?_______________ For how long?_________________

Name of sleeping pill, if remembered: _________________________

Do you normally have a snack during the two hours before you go to sleep at night?

YES NO

If yes, what do you typically eat?_________________________________

Then:

If no obvious disqualifiers:

"Thank you. We will review your answers and get back to you as soon as possible to let you know whether you are qualified for the study. You should hear from us within a week or two.

If you are chosen to participate, we are looking for a participant for early April, and alternates for late March and Late April. Which of these would you be available for? "

____

If clearly disqualified:

"Thank you. We will not be able to have you participate because of _______________, but we appreciate your interest in the study. If you know anyone else who may be interested in participating, please have them call us at 703-960-0779, ext. 440."

Notes:

____

____

____

____

____

____

____

D Volunteer agreement affidavit

Driver participants were required to sign the attached affidavit prior to participating in the study.

VOLUNTEER AGREEMENT AFFIDAVIT

Privacy Act of 1974. Authority: 10 USC 3013, 44 USC 3101, and 10 USC 1071-1087

Principal Purpose: To document voluntary participation in the Federal Highway Administration Office of Motor Carriers Research Program.

Disclosure: The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates your health may be adversely affected. Failure to provide the SSN and home address information may preclude your voluntary participation in this investigational study.

Routine Uses: The Social Security Number (SSN) and home address will be used for identification and locating purposes. Information derived from the study will be used primarily to document the results of the research project. That is usually in the form of grouped data appearing in reports. Information may be furnished to Federal agencies.

Volunteer Affidavit

I, ______________________________, SSN ______________________________, having full capacity to consent and having attained my _______th birthday, do hereby volunteer to participate in a research experiment entitled: **Effects of Operating Practices on Driver Alertness,** under the joint direction of Gerald P. Krueger, Ph.D., Timothy R. O'Neill, Ph.D., and Susan B. Van Hemel, Ph.D., all of Star Mountain, Inc., 3601 Eisenhower Ave. Alexandria, VA 22304; phone: (703) 960-7000.

The implications of my voluntary participation, duration and purpose of the research study, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected, have been explained to me by one or more of the three investigators whose names are listed above.

I have been given an opportunity to ask questions concerning this investigational study. Any such questions were answered to my full and complete satisfaction.

I understand that at any time during the course of the study I may revoke my consent and withdraw from the study without penalty or loss of participant pay to that point; however, I may be required or requested to undergo certain examinations if, in the opinion of the experiment's physician, such examinations are necessary for my health and well-being.

My refusal to participate will involve no penalty, and I will be paid for work accomplished to that time at the reduced pay scale agreed upon in this documentation.

Subject Initials/Date____________________
Witness Initials/Date ____________________

Participant Instructions Containing Elements of Informed Consent to Participate

DESCRIPTION of the STUDY:
EFFECTS of OPERATING PRACTICES on DRIVER ALERTNESS

You are asked to volunteer for a 17-day research study examining driver alertness and performance as they are affected by different amounts of truck simulator driving and by varying amounts of physical activity involved in loading/unloading or re-stacking of boxes on pallets. After you read the following description of what will happen, we will discuss the entire procedure. You should ask questions about anything that is unclear. It is important that you understand that:

a. **Your participation is completely voluntary**, and that you may withdraw from the study at any time without penalty or loss of benefits to which you are otherwise entitled.

b. The results of your simulator driving in this experiment are to be held confidentially by the research staff. Your performance data will not be shared with your employer, or with a prospective employer, and thus will not be used to impact your employment. The results of this study therefore may be of no direct benefit to you. The knowledge gained by your participation in this study may help others in the trucking community.

Expectations of Research Participants and Procedures to be Followed

Age, vision, fitness. You must be over 21 years of age to be considered for participation. You must hold a valid Commercial Driver's License (CDL), and you must have normal vision corrected via lenses to 20/40 or better. You must have normal color vision. We must ensure that you are in good health, and in particular that during this experiment you can satisfactorily lift, carry, or otherwise load and unload 40 lb. boxes onto and off of standard warehouse or shipping pallets.

You will fill out some forms to gather background information; then you will have a physical examination during which you will be required to provide a urine sample, and a small sample of blood will be drawn. A routine panel of blood tests will be accomplished (e.g. determinations of cholesterol etc.). You will be given a treadmill test monitored by a cardiologist to determine your aerobic fitness. Every effort will be made to keep the results of your medical examination as confidential as possible, within the limits of the law.

Chemical substances. You may not drink anything with alcohol in it during the course of the 17-day experiment. You are requested to refrain from consuming more than four (4) servings of caffeine each day for the two days (48 hrs) before you arrive for the study. During the 17-day experiment you will be restricted to four or less servings of caffeine per 24-hr day. (A serving is considered to be the equivalent of the amount of caffeine normally found in a single cup of caffeinated coffee or a 12 ounce soft drink).

If you are taking prescription or non-prescription drugs or medications at the time of your physical exam, you are to tell the person doing your physical exam what drugs you have taken within the last month, whether legal or illegal, over-the-counter or prescription. Use of drugs will not necessarily exclude you from the study, but the information will help determine whether these substances would affect your level of alertness in the study.

You are asked to consult with the experimenters before taking any drugs (prescription or over the counter non-prescription medications) during the 17-day experiment as these may affect your level of driving alertness being studied. If you require prescription medications, or should the necessity for taking medications arise during the experiment (e.g. head cold or allergies) you are asked not to take such medications without informing the experimenter staff and discussing alternatives with them. You will recall for example that some cold medications and antihistamines used for allergies affect alertness, while some alternatives that do not.

You may not use tobacco or nicotine products (cigarettes, cigars, pipes, chewing tobacco, etc.) before or during the study.

Wrist activity monitor. So that we can verify your sleep schedule, we will ship you (via overnight express) an activity recorder (wrist activity monitor) to be placed on your non-dominant wrist three days before you begin the experiment with us. The recorder is about the size of a wrist watch. You are to wear the recorder for **three** days and nights prior to the start of the study. When you report on the first day for participation in the experiment, your wrist activity monitor will be removed and you will be given another one to wear for the next 17 days. You are expected to wear the wrist recorder at all times except when taking a shower or bath during the entire 17-day experiment.

Study location at the truck driving simulator. If you comply with wearing the wrist activity monitor and drug/alcohol, caffeine restrictions, you will be eligible to participate in the study. You will be expected to report to the North American Van Lines truck simulator (positioned at Von Paris North American Van Lines offices on Beulah Street in south Alexandria, VA) no later than 8:00 AM on the first day (Day 1) of the study. On Day 1 you will begin familiarization with the truck driving simulator, other instrumentation for use in the experiment, some data collection equipment, and the procedures for use with the truck simulator and all experimental equipment that will be used in the study.

Length of work days. Your two training work days (Day 1 and 2) will be about 9 hours in length. The 11 experimental test days (two 5-day work weeks, and one final day after resting: Day 17) will involve about 14+ hr work schedules beginning at the test site about 6:45 AM and ending approximately 9:15 to 9:30 PM each evening. During the "work weeks" you will be allowed to live and sleep at an apartment (see pg. 4) from about 10:00 PM each night until approximately 6:30 AM each morning before reporting again to the simulator.

Subject Initials/Date____________________

Witness Initials/Date ____________________

The truck driving simulator. Over a 2-day training period, you will be trained extensively on the truck driving simulator by a qualified, certified North American Van Lines simulator training instructor. The simulator display of the roadway involves pretty realistic computer generated imagery (CGI), and truck sounds are included within a mock-up truck driving cab. The simulator does not include a motion base. The simulator will be used for your driving task portions of the study and will involve as many as 12 hours of simulator driving plus two rest breaks and a lunch period on most of your 14+ hour work days (driving periods) over the seventeen day experiment.

Simulator sickness assessment. During the two days of simulator training we will determine if you are one of those individuals who seem to be subject to bouts of simulator sickness (motion sickness induced by the CGI, and usually experienced in the form of dizziness, wobbliness of gait, and or a sense of light nausea). If you are subject to such simulator sickness, we may be forced to discharge you from the study, and in that instance you will be compensated for your time according to our agreement.

Periodic administration of other tests and subjective rating scales. Several times per day, during periods when you are not driving the simulator, you will be expected to perform on a short set of reaction-time visual tests (we call it the PVT test), and also to complete a subjective rating scale to estimate your own driving performance and your level of alertness after each simulator scenario is complete.

Loading and unloading physical tasks. On as many as three days during one of your two "work weeks" with us, you will perform simulated "loading and unloading" tasks in the adjoining warehouse. These physical work periods will last 1.5 hours each, up to two times per day, and will entail continuous lifting and carrying of standard size moving boxes, weighing 40 lbs each, from one pallet to another in a simulation of re-palletizing a load. This set of physical tasks constitutes a portion of the required study, and will be monitored by the experimenters for data collection purposes.

Meals and snacks. Throughout the study, meals and snacks will be permitted at scheduled times during the simulator portions of the work week. You will have a 30-minute break each morning and each afternoon, and a one-hour lunch period each day. During your two days rest periods (non-driving days) you will have more freedom to eat when you please at the apartment, or even at a restaurant at the shopping center within a short walking distance of the apartment.

Apartment housing. During the seventeen (17) days of the experiment, you will be housed and sleep in a rented apartment about a mile from the simulator site. The apartment will be your living quarters for 17 days, and it will include bedding, cooking, bath and shower facilities etc. You will either drive your own automobile to the simulator site each morning for a 6:45 AM reporting time, and return at night (about 9:30 PM), or if you prefer, we will provide that transportation each morning and evening.

Subject Initials/Date____________________

Witness Initials/Date ___________________

Wearing scalp and facial electrodes. On the three nights and two days "off work" (non-driving days) at the end of a five-day driving period (work week) some sensors or "electrodes" (probably 6 to 8 of them) will be placed on your scalp and facial areas using adhesive patches. From time to time during your "off duty" hours, at the apartment we will obtain electrical recordings from those electrodes. The electrodes will help us determine whether you are awake or asleep while we examine how long it takes you to fall asleep in your assigned apartment bedroom. The electrodes are not painful in any way, but they may feel uncomfortable at times. You are likely to be required to wear these electrodes 24-hours per day during your entire "off-duty" time -- essentially at the apartment at the end of each of two "work weeks." Periodically during your off duty time, when you retire to your bed, wires from the electrodes will be connected to a computerized recorder to permit us to collect measures of you falling asleep.

Periodic PVT testing during off-duty periods. Several times per day or evening during your "off duty" periods, at the apartment we will administer the PVT reaction time test, usually before you go to bed, or shortly after you awaken.

Activities during apartment stay. During your stay at the apartment, you will be permitted to engage in most ordinary activities around the apartment, including watching TV, letter writing, reading, telephoning, walking about the complex, to the shopping center etc. We simply ask that you not engage in additional strenuous activities such as physical exercising, which should be limited, as such activity may impact your state of alertness during the experiment. Using good judgment here is requested and the experimenter staff should be consulted if there is any doubt about whether activities are permitted.

POSSIBLE RISKS, INCONVENIENCES, and SIDE EFFECTS

The risks to you in participating in this experiment are considered to be minimal. You will be expected to work 14+ hour work days, five days per week. About 80% of that time will be spent in driving a "non-threatening" truck driving simulator. You will be expected to perform sustained bouts of somewhat rigorous physical activity for 1.5 hours at a time (twice per day) in the loading and unloading portions of the experiment on each of about 3 days in one of your two work weeks. If you are in reasonably good physical shape, such exercise should not pose a threat to your physical health, and no hazards will be present. If at any time you feel this exercise is too much for you to continue, you can voluntarily withdraw from the experiment without penalty.

If you experience motion sickness, called simulator sickness, during the 17-day experiment, you may stop participating in the experiment at that time. Together with the experimenters a decision will be made whether or not you should continue participating.

There are no health or safety hazards or risks associated with wearing the scalp and facial electrodes to be used for sleep recordings; nor are there any safety hazards or risks with any of the other equipment used in the experiment.

PAYMENT

Upon successful completion of your 17 days of participation in the experiment you will be paid $4,000. If you do not complete the full experiment, you will be paid $7.00 per hour on a 24-hours basis for those days that you do participate.

You will be provided a food allowance of $250. with which your are expected to purchase your own food for the 17-day period you stay with us.

CONFIDENTIALITY

All data are considered private and confidential, and observations, responses, and other personal data are coded so that personal identification is not possible. Representatives of the Office of Motor Carriers, Federal Highway Administration, and the Trucking Research Institute (TRI) of the American Trucking Associations Foundation may inspect records of this research.

You will receive a copy of this volunteer consent form for your own records.

Typed Name of Volunteer: ________________________________

Typed Name of Witness: ________________________________

I do ______________, do not ___________ (*mark one & initial*) consent to inclusion of this form in my medical treatment records.

Signature of Volunteer: ________________________________

Date: ________________________

Permanent Address of Volunteer:

____

____

____

Signature of Witness: ________________________________

Date: ________________________

Signature of Experimenter Staff Member: ______________________

DATE: ______________________

E Participant personal and payment information form

The attached was filled out by each driver prior to participation in the study, and includes emergency notification instructions and verification of personal medical insurance.

Operating Practices Study
Participant Personal and Payment Information

Name ____ Participant No. _______

Home Address ____

____

Social Security No. ____

Phone: Home _______________________ Other __________________________

In emergency notify:

Name____

Address ____

Phone: ____

Participation Dates:

Begin 8:00 AM _________/________/_____________

End 9:30 PM __________/________/_____________

Medical Insurance:

Insurer: ______________________________

Group No:______________________________

Insured Name:__________________________

Account or ID No.: ______________________

(or attach copy of insurance card)

F Participant agreement to terms of participation

Participants were required to read and sign the attached form describing the terms of participation in the study.

Operating Practices Study
Agreement to Terms of Participation

I, ______________________________________, have agreed to participate in the study of Operating Practices sponsored by the U.S. Department of Transportation, and conducted by Star Mountain, Inc. and the Trucking Research Institute. I understand the risks of this study, and have given my informed consent for participation.

If I am excluded from participating in the study on the basis of my physical and fitness examination results, I will be paid $50 for my time taking the physical.

If I pass the physical and complete the entire 17 days of the study, I will be paid $4000 for participating. Payment will be by check and will be mailed to the address I have provided on my Form W-9. Additionally, I will be paid a food allowance of $14.70 per day, while I am participating, to be paid $100 at the beginning of each of the first two weeks and $50 at the beginning of the last (partial) week.

If for any reason I begin the study and cannot complete the full 17 days, I will be paid at the rate of $7 per hour, 24 hrs per day, for the time I have completed. Payment will be by check and will be mailed to the address I have provided on my Form W-9.

I understand that I am participating in this study in an "independent contractor" capacity, and that neither the project sponsors nor the contractors conducting the study will take responsibility for any insurance coverage for participants, and that no taxes will be withheld from the participant payment. A 1099 form will accompany the final payment.

I understand that, as an independent contractor, I am responsible for:

1) providing my own medical and disability insurance coverage;

2) paying the applicable income and Social Security taxes on the payment I receive for my participation.

I also understand that Star Mountain will be providing me with lodging in an apartment leased by Star Mountain, Inc. I agree to use the apartment for my own lodging only, and to have no overnight visitors, and no more than one daytime visitor at a time (on off-duty days only) unless I clear additional visitors in advance with the project staff. I will be responsible for leaving the apartment in essentially the same condition in which I find it. (Maid service will be provided twice monthly.) If I cause any significant damage to the apartment other than normal wear and tear, I will be held responsible for the cost of repairing such damage.

My signature below signifies my understanding of and agreement to this arrangement.

Signed:____________________________________

Date: ____________________________________

Witness: ____________________________________

G Participant instructions and information

The attached form was mailed of sent by facsimile to each participant after agreement to participate, and explained procedures to follow before and immediately after arrival in Alexandria, Virginia. In most cases the wrist activity monitor was provided to the participant at the same time.

Operating Practices Study
Participant Instructions and Information

Subject Name: ____________________________

Study Date: ________________

Enclosed is the actigraph for you to wear for three days prior to your participation in the Operating Practices Study. Please read the following instructions carefully and follow them.

Overview:

1. Begin wearing the actigraph when you get up in the morning on __________________.

2. Continue to wear the actigraph on your non-dominant wrist until you report for the study at 8:00 AM on _____________________, except as noted below.

3. Call us if you have any questions about how to use the actigraph, or if you suspect it is not working.

4. Please call to arrange with us when you will be arriving and what your transportation needs are, at least 3 or 4 days before you plan to arrive. If you plan to arrive the night before your participation begins, we will need to meet you and give you apartment keys, etc. Star Mountain's phone number is (703) 960-7000. Ask for Susan Van Hemel or Adam McGowan.

Instructions for use of Actigraph:

The actigraph should be worn day and night during the period indicated above.

Wear the actigraph on your non-dominant wrist (left wrist if you are right-handed; right wrist if you are left-handed). You may wear a wrist band or other light padding under the actigraph, or fasten it outside your shirt sleeve, if it is more comfortable that way. Just do not have it sliding around; it should stay in one place on your wrist as you move.

The actigraph may be considered an oversized watch, worn on the wrist and forgotten about during normal day-to-day activities. Carry on with your activities as you normally do.

REMOVE THE ACTIGRAPH WHEN TAKING A SHOWER OR BATH, swimming, or doing an activity that would expose it to large amounts of water (like washing dishes by hand, washing a car), and PUT IT BACK ON IMMEDIATELY AFTERWARD. DO NOT PUT IT IN WATER OR ANY OTHER LIQUID.

The small button on one side of the actigraph is an "event marker." It puts a mark on the activity record each time it is pressed. It also produces a series of very quiet "chirps" when pressed, if the actigraph is working properly. If you can remember to, **please press the button once each time you go to bed, and once each time you get up**, so we know where to look on the record for sleep times. Do not press the button at other times.

Although the actigraph is not an extraordinarily delicate instrument, it must still be handled with some care. Do not strike it against anything rigid, and do not drop it.

You will sign for the particular actigraph issued to you. It is a valuable instrument, and you will be responsible for its safe return to the project staff when you report for the study. (Another actigraph will be issued for you to wear during the study.)

Sleep Log:

As a backup to the actigraph, "Sleep Log" forms are enclosed for you to record your sleep for the three days before you begin participating in the study. You will be completing these each day while you participate, as well. It will take you just a minute each morning to fill one out, and they will help us to evaluate your work and rest cycles. Complete the form soon after you get up in the morning, while you still remember the information it calls for.

General Instructions and Information

It may be helpful for your family to read these, too, so they will understand what you are and are not able to do while you are in this study.

We need you to arrive by 8:00 AM on the first day of participation. It may be easier for you to arrive the evening before. When you decide when and how you will be arriving, please call the study team at (703) 960-7000. Ask for Susan Van Hemel or Adam McGowan. We will provide you with directions, if you need them, and we will make plans to meet you at the apartment to give you keys, etc. if you arrive the day or night before the study begins. If you are arriving by public transportation or being dropped off, we can provide transportation between the study site and the apartment while you are here.

Apartment and food:

The apartment we have rented for participants is furnished and provided with a fully-equipped kitchen, dishes, pots and pans, linens, etc. It has a TV with cable service, clock-radio, phones, coffeepot, microwave, and washer and dryer. We will provide basic household supplies such as paper goods, detergent, etc.; but if you have a favorite brand or special needs, it will be up to you to bring your own. Bring your favorite pillow and/or blanket, if you are particular about such things.

We will also provide some "staples," like basic spices, to allow you to cook your own meals. You will provide whatever else you wish with your food allowance (or bring it with you, if you like). There are two grocery stores and assorted carryouts and restaurants within a mile of the apartment and study site. These include a bagel/sandwich shop, two pizza/sub shops, a Chinese carryout, a Roy Rogers (while it lasts) and a "basic American" restaurant. The grocery stores have good salad bars and ready-to-eat deli stuff, too.

You will be expected to keep the apartment reasonably neat and clean. Maid service will be provided after each participant leaves, but you are expected to clean up your dishes, and generally keep the place orderly. Smoking is not allowed in the apartment. Please be sure your visitors comply.

The apartment is provided with basic phone service, but long distance calling is "blocked." To make long distance calls you must use a phone card such as AT&T, Sprint, MCI or other long distance service you may have. **Remember to bring your card/access numbers with you.**

The apartment address is:
6003L Rock Cliff Lane
Alexandria, VA 22315

The apartment phone no. is:
(703) 921-1152

Clothing:

You should bring comfortable casual clothes; there is no need to dress up for anything you will be doing. The simulator trailer is air conditioned/heated, but sometimes gets chilly; a sweater or sweatshirt might be a good thing to have. Loading will be performed in a warehouse that can be cold in winter. On your off-duty days, you will have electrodes with wires on your head and face; on these days, shirts that button are easier to manage than ones that go over the head; don't bring all turtle-necks! You may find it helpful to bring a baseball cap or other hat, to wear when you have electrode leads on and want to go out.

A washer and dryer are in the apartment, so you don't need to bring an awful lot of clothes, if you are willing to do laundry.

Restrictions on your activities:

On your two off-duty days each week, you will be able to bathe or shower (wearing a shower cap to keep the electrodes and wires dry) but not to shampoo. On other days, there are no restrictions on shampooing.

You may have one daytime visitor at a time in the apartment **on off-duty days only**, as long as they do not interfere with your availability for testing at scheduled times. Visitors will be asked to leave the apartment during testing. **No overnight guests are permitted.** If you want to have more than one visitor, discuss it with the staff before inviting them, and we'll consider it on a case-by-case basis.

Similarly, you may leave the apartment for short periods, but must return for scheduled testing. This means short neighborhood trips are OK; sightseeing trips to Washington are **not** appropriate.

You will be busy 14 or 15 hours a day while you are participating in this study. You will not have time to keep up with a lot of outside interests or activities. You will not be able to make frequent phone calls, check messages, or carry on business during the workday, and we want you to get good rest in your off-duty hours. **If you are not able to devote your full time and attention to the study, please do not commit to participate.**

Miscellaneous:

Feel free to bring books, etc., for your off-duty time. It is possible to use a laptop with modem in the apartment if you have a phone number that allows you to reach your internet/e-mail provider with a local call in the DC-Northern VA area.

If you normally use a special seat cushion or back support when driving, bring it along. We want you to be as comfortable as possible in the driving simulator. The simulator has a comfortable but not luxurious driver's seat. Similarly, if you normally use a lumbar support belt while lifting, you may bring your own. We will provide a belt for those who do not bring one. You may bring a radio to use while "driving." It should have the type of earphones that allow you to hear outside sounds, so you will be able to hear and respond to engine noise, staff instructions, etc.

Thank you, and we look forward to working with you.

-- The Operating Practices Study staff.

- - - - - - - - - - - - - - - - - - -

Directions to Star Mountain Apartment from I-95/495 (Capital Beltway):

Exit 95/495 at Virginia Exit 3, Van Dorn Street.

At end of off ramp, turn Right (South) on Van Dorn. Continue on Van Dorn through major intersection at Franconia Road (center two lanes go through), and follow on as two right lanes of road take a hard right and become Kingstowne Blvd.

Continue on Kingstowne/ Manchester Blvd. to light at Hayfield Road (4th light after Franconia intersection. Total distance from I-495 is about 2½ mi.).

Turn left onto Hayfield.

Take first right, Rock Cliff Lane, into Windsor Gable apartment complex.

Turn right at top of hill, and go to second building on right, 6003 Rock Cliff Lane. Walk into breezeway by "6003" sign and go to second door on left, apartment 6003L.

H Fitness testing information and check list

Participants were provided the attached instructions prior to arriving for the physical examination and treadmill (cardiac stress) test.

The Experimenter's check list is included in this appendix.

Visit for Physical and Fitness Testing
Participant Information

Name:________________________________

Appointment time:______________________

When you come in for the physical exam and treadmill test, you will be scheduled for the exam around 7:30 or 8:00 AM. If you are from out of town, you will need to arrive the night before. You will be able to stay at a local motel at our expense (you pay and we reimburse you), if you arrange it with us when we schedule your physical.

The night before and morning of the physical, you are to **fast (eat or drink nothing but water) from midnight until after the testing**. That means no orange juice, no food, no coffee, no soft drinks! There will be time for breakfast or a snack after the testing is done.

If you are staying at the motel, one of the study staff will pick you up at the motel at 7:00 AM on your testing day, take you to the testing site (a local clinic associated with a hospital), and return you afterward to the motel. **Please be ready promptly at 7:00 AM.**

If you are local, you can come to the Star Mountain offices at 7:00 and we will take you to the testing site. Let us know, and we'll give you directions to the office.

You should bring with you some athletic shoes (whatever kind you find comfortable for running/walking) and shorts and T-shirt or sweats for the treadmill test.

You will be asked to sign some releases before the treadmill test, and may be asked to show proof of medical insurance. **Please bring your insurance card and your CDL with you.**

After the testing, we may ask you to return to the Star Mountain office for some paperwork, and may also introduce you to the driving simulator, if it is available. This will allow us and you to check that you are not prone to "simulator sickness." After that (around noon), you will be free to leave.

Contact point:

Dr. Susan Van Hemel
Star Mountain, Inc.
3601 Eisenhower Ave.
Alexandria, VA 22304
(703) 960-7000

Visit for Physical and Fitness Testing
Checklist

1. ____ Have candidate read informed consent. Answer any questions and have him initial and sign form. Sign as witness.

2. ____ Take candidate to physical. If results are OK (or seem to be) continue.

3. ____ Have candidate sign other forms, as appropriate. If he won't be starting for a while, save forms for when he arrives to participate.

4. ____ Actigraph receipt: give actigraph and instructions if within one week of participation date. Otherwise get address to Fedex it to. Discuss how Actigraph works. Give instructions with actigraph

5. ____ Participation and payment information form

6. ____ Agreement to terms of participation

7. ____ Give participant information on when to arrive, what to bring, schedule for study. Arrange reminder call date and time.

I Information for prospective participants

This form provides general information on the study, and was mailed of sent by facsimile to each prospective participant to explain the overall objectives and terms of the study.

Operating Practices Study
Information for Prospective Participants

The Operating Practices Study will examine the effects of various factors on fatigue in truck drivers. We will ask participants to remain in the study for 17 days, staying in an apartment provided near Alexandria, and working most of the time in a trailer-mounted truck driving simulator near the apartment. The 17-day study schedule consists of two days of familiarization and pre-testing; two five-day workweeks, each followed by a two day off-duty period; and a final workday. One person at a time will participate. Starting dates will range from October, 1997 to April or May, 1998.

Participants will spend their working hours "driving" the simulator, performing physical work similar to loading or unloading cargo (lifting and moving cartons weighing about 20-30 pounds), completing some short questionnaires, and performing some game-like tasks on a hand-held device. Duty days will be 14 hours long, (including breaks). After work, participants will be free to relax in the apartment, and will be expected to make an effort to get a good night's sleep each night.

On off-duty days, participants will be given some physiological tests that require having recording electrodes attached to the scalp and face. (The electrodes are not painful and do not penetrate the skin. They are attached with a sticky substance or adhesive patches.) They also may be asked to complete some short questionnaires. These tests will take about ½ hour three or four times a day. Otherwise, on off-duty days participants will be free to watch TV or videos, read, etc. in the apartment, or to take short trips outside. (There are shopping malls, restaurants, grocery stores, etc. within walking distance or a short drive from the apartment.) They will be permitted to have daytime visitors in the apartment only on off-duty days, and only if they do not conflict with the test schedule. (No overnight visits.) The apartment will have a TV and VCR, and a fully equipped kitchen with microwave. Cleaning service will be provided at the end of each participant's stay.

At all times during the study, and for two days before beginning it, participants will wear an activity recording device, which is similar to a wristwatch and causes no discomfort.

Participants will be asked to restrict caffeine-containing foods or beverages to a maximum of 3-4 servings a day, and not to consume any alcohol, during the study.

Participants will be required to sign an informed consent form before beginning the study, to ensure that they understand what will be required of them and agree to abide by the requirements and restrictions of the study. There will also be forms to sign agreeing to the "business" terms of participation, including that participants will be expected to carry their own health insurance, will be responsible for paying any income or other taxes on their payment for participation, will take reasonably good care of the apartment provided, etc.

Participants who complete the study will be paid $4000 for their participation, upon completion. Any participant who leaves the study before completion, whether because he chooses to, or because he is unwilling or unable to fulfill the conditions of the study, will be paid for the time he has put in at a reduced rate of $7.00 per hour (on a 24-hour basis). A $100 per week food allowance will be provided, also.

Candidates will be selected for the study based on a preliminary questionnaire screening, followed by a physical exam and a treadmill "stress test" for those who pass the first screening, to ensure that they are physically able to perform in the study. Prospective participants will be expected to provide their own transportation to the physical in the Alexandria/Arlington area, arriving the night before (unless they are local residents) for an early morning exam. We will provide lodging and pay for the exam. Anyone who comes in for the final screening and is not selected to participate will be paid $50 for his time.

The results of the study will be reported to the US Department of Transportation, Office of Motor Carriers, (the project sponsors) and will be among many sources of information considered by OMC in their policy making processes. No personal information will be reported. Individual participants will not be identified in any reports, and all personal information, including the results of the physical exams, will be kept confidential.

J Instructions and record form for Psychomotor Vigilance Task (PVT)

Procedure for giving PVT

First time on Training Day 1: Be sure PVT is set up for participant. Select Demo for first instruction to participant.

Read "formal" instructions (next page) to participant, then talk/walk through demo (1 min. test) to be sure participant understands what to do.

Stress these points:

- Try to respond as quickly as possible without "jumping the gun." False starts (presses before any numbers appear) are to be avoided.
- In first few trials, experiment with how to sit, hold box, press key, etc.. Once you find a comfortable, efficient way, stick to it.

Then have participant do a full 10-min. trial. Watch to see that he is not doing anything seriously wrong. Correct any major problems you see. Tell him what he is doing right.

After training days, give the following instructions at least once each day:

> Remember to do the PVT test the same way you have been doing it. Don't make major changes in how you sit, hold the box, or press the button.

Beginning with S103, we will try to follow the following procedures for PVT:

> Have participant sit at back of trailer on workdays, on sofa or at dining room table (pick one and stick with it) in apartment. Try to have lighting as consistent as possible.
>
> Workdays: Keep all staff in forward part of trailer while participant takes PVT in rear. Close doors between front and back areas. Do not let anyone enter back and distract participant during test. Keep phone with staff.
>
> Off-duty days: Observe at first to check that participant is in usual position, etc. Do not do anything to distract participant while he takes PVT. Be sure TV and other noise-making appliances are off before giving him the box.

STAR MOUNTAIN, INC.

Data Recording Form
Operating Practices Study

PVT

Subject Name________________________ Subject No.______________ Sheet No. ______

Date/Time (start)______________________ Date/Time (end)________________________

Date	Exptl. Period/Day	Time	Filename/ Trial No.	Notes

K Instructions and record form for Sleep Latency Test

STAR MOUNTAIN, INC.

Data Recording Form
Operating Practices Study

SLT

Subject Name________________________ Subject No.______________ Sheet No. ______

DateTime (start)______________________ Date/Time (end)________________________

Date	Exptl. Period/Day	Start Time	Elapsed Time Min./sec.	Observations e.g. K complex, sleep spindles, other waveforms noted, end of test

L Daily data record form – loading/unloading

STAR MOUNTAIN, INC.

Data Recording Form
Operating Practices Study

Load/
Unload

Subject Name________________________ Subject No.______________ Sheet No. ______

DateTime (start)____________________ Date/Time (end)________________________

Date	Exptl. Period/Day	Time	No. of full transfers/ add. boxes	Notes

M Daily record form -- driving

Operating Practices Study - Daily Log

Subject No.______
Date_______
Page______

Time	Exptl. period/ day	Scen- ario No., Location	Event/ conditions	Response	Outcome/Notes
	Wk Day				

N Summary data for driver loading/unloading activities

Appendix N

Driver Loading and Unloading Data

a. Methodology

During one of their two scheduled workweeks, drivers mixed simulator driving with the physical activity of loading and unloading cargo. Drivers spent two 90-minute sessions per day, on Days 2, 3 and 5, of that week manipulating freight in an adjacent warehouse. The drivers' task was to move manually a stack of book boxes, each box with an approximate mass of 20 kg (~44 lbs.) from one cargo pallet to another; then, using a non-motorized hydraulic pallet-jack, move the pallet a distance of about 7.62 m (simulating movement within a truck trailer) and then unload the pallet and re-stack the boxes on another adjacent pallet. This task was done repeatedly and at the driver's own pace for each 90-minute session.

The drivers were not coached on what technique to use in moving, carrying or stacking the boxes themselves. They were simply encouraged to keep working continuously for 90-minutes each session. They were told the goal was to establish a constant flow of work for the entire session, and that there was no set number of boxes that needed to be moved. The drivers were aware that an experimenter was recording and timing their activities.

b. Drivers' Loading and Unloading Technique and Performance

The techniques the drivers used in moving the boxes from one pallet to the other differed substantially, as did their performance measured by the amount of freight actually moved per 90-minute session. The table below lists performance data in summary form across all sessions.

	Boxes Moved by Session						Mean Boxes Moved	Mean Pallets Moved	Mean Mass Moved (kg)
Subject	1	2	3	4	5	6			
101	405	393	384	368	372	402	387.33	12.1	7746.67
102	513	423	521	492	525	402	479.33	14.98	9586.67
103	360	288	439	416	517	382	400.33	12.51	8006.67
104	510	435	434	430	451	454	452.33	14.14	9046.67
105	416	395	460	416	457	439	430.50	13.45	8610.00
106	316	316	304	205	228	215	264.00	8.25	5280.00
107	448	312	449	384	425	384	400.33	12.51	8006.67
108	359	364	409	373	389	384	379.67	11.86	7593.33
109	429	478	397	484	464	439	448.50	14.02	8970.00
110	384	424	416	352	354	384	385.67	12.05	7713.33
Mean	414	382.8	421.3	392	418.2	388.5	402.80	12.587	8056

The boxes presented to the driver were arrayed with eight boxes on a level, stacked four levels high, for a total of 32 boxes on the pallet (~ 640 kg or ~1408 lbs.). Several drivers systematically reconstructed each level of eight boxes before putting the next layer of boxes atop the previous one. Other drivers were more creative, stacking the boxes in what looked initially like a haphazard array until the stack was complete.

One driver (#2 on the table), who moved the most boxes of all drivers, used a technique of essentially building a jagged-looking pyramid out of the boxes until the whole array of 32 boxes was reconstructed on the next pallet. When queried about his technique, this driver indicated that a warehouse worker taught him to minimize the biomechanical stresses on his back by moving boxes at the same level, and to minimize the lifting of the boxes from lower levels (the bottom row) up to the higher levels (top rows). This appeared to be a very efficient loading technique. We made no systematic attempt to categorize the variety of box moving techniques (about 4-5 different ones) we witnessed.

All drivers occasionally took short rest breaks (on the order of 90 to 120 seconds) during which they rested, often while carrying on a conversation with the experimenter. Several drivers inquired about how their performance compared to that of other drivers who had preceded them in the loading freight task. The experimenters gave noncommittal responses and simply encouraged them to work at their own pace. No doubt some drivers were motivated to match other drivers in their task performance.

No attempts were made to correlate driver age or physical fitness level with performance. Judging by their physical appearance, by the amount of work they accomplished, and by the amount of "huffing and puffing," and resting they did, it is our general impression that the few drivers who were less physically fit had a more difficult time in maintaining the task level effort for 90 minutes. Since no specific measures of aerobic and anaerobic fitness were collected we prefer not to make too much of this observation.)

The amount of physical work performance accomplished in a single 90-minute session of almost continuous work (see the table) ranged from a **minimum** of 4100 kg (205 boxes of 20 kg each, ~9,020 lbs.) to a **maximum** of 10,500 kg (525 boxes, 23,100 lbs.). The range of **average** amount of physical work accomplished by individual drivers over their complete set of six loading sessions over three work days was from 5280 kg (264 boxes, ~11,616 lbs.) to 9580 kg (479 boxes, ~21,076 lbs.).

We did not have direct measures of physical energy expended by the drivers during the loading activities. However, from the work output over time it can be estimated. Generally, the drivers in the loading/unloading portions of this study put forth metabolic rates of energy expenditure in the **moderate work level** (1.0 to 1.5 liters of Oxygen per minute, and from 325 to 500 watts of energy expended) to **heavy work level** (1.5 to 2.0 liters of Oxygen per minute, and generally in excess of 500 watts of energy expended) categories as described by McArdle et al. (1991) and by Astrand and Rodahl (1997). For further discussion, see the report for this project on Phase I, Task 1 by Krueger and Van Hemel, (May, 1997).

We believe the physical work expenditure put forth by the drivers in this study is representative of many of the driver loading and unloading tasks we learned about from our driver focus group interviews and questionnaires administered throughout the long haul trucking industry in the United States. We also observed similar task performance in our trucker loading and unloading task analyses accomplished in Phase I. See reports for Phase I, Task 2 by Van Hemel and Krueger, (May, 1997), and Phase 1, Task 3, by Krueger and Van Hemel, (December, 1997).

References

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Krueger, G.P. & Van Hemel, S. B. Behavioral task analysis of truck drivers loading and unloading trucks: Relationship to driver fatigue, alertness, and driving safety. December, 1997. Final Report, Phase I, Task 3: Commercial Driver Loading and Unloading Study for American Trucking Associations' Foundation's Trucking Research Institute, and Federal Highway Administration, Office of Motor Carriers. Alexandria, VA: Star Mountain, Inc. (Project #4301-1).

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Van Hemel, S.B. & Krueger, G.P. Characterization of non-driving on-duty activities: Relationship to driver fatigue, alertness, and driving safety. May, 1997. Final Report, Phase I, Task 2: Commercial Driver Loading and Unloading Study for American Trucking Associations' Foundation's Trucking Research Institute, and Federal Highway Administration, Office of Motor Carriers. Alexandria, VA: Star Mountain, Inc. (Project #4301-001)

O Record form for end-of-session rating

End-of-Session Self-Rating

Subject No._________
Date_______________
Week/Day_____/_____
Driving period_______
Time _______:_______

1. How would you rate your performance in the session just completed?

Driving scenario ☐
Loading session ☐

Circle the number representing your self-rating.

Excellent	Very good	Good	Fair	Poor
1	2	3	4	5

2. How alert were you during the session you just completed? Circle the number corresponding to your alertness level as described below.

1 2 3 4 5 6 7

1. Feeling active, vital, alert, wide awake.
2. Functioning at a high level but not at peak, able to concentrate.
3. Relaxed, awake but not fully alert, responsive.
4. A little foggy, let down.
5. Foggy, beginning to lose track, difficulty in staying awake.
6. Sleepy, prefer to lie down, woozy.
7. Almost in reverie, cannot stay awake, sleep onset appears imminent.

P Sleepiness self-rating form – recovery days

Sleepiness Self-Rating
Recovery days

Subject No.________

Date______________

Week/Day_____/_____

Time _______:_______

2. What is your current level of alertness? Circle the number corresponding to your current alertness level as described below.

1	2	3	4	5	6	7

1. Feeling active, vital, alert, wide awake.
2. Functioning at a high level but not at peak, able to concentrate.
3. Relaxed, awake but not fully alert, responsive.
4. A little foggy, let down.
5. Foggy, beginning to lose track, difficulty in staying awake.
6. Sleepy, prefer to lie down, woozy.
7. Almost in reverie, cannot stay awake, sleep onset appears imminent.

Q Daily sleep log

The attached form was filled out by each driver at the beginning of the driving day (0645) as a backup for the wrist activity monitor data.

Sleep Log

Subject # ___108__
Date___________
Time__________
Week ____Day___

Please indicate, as best you can, the time at which you went to bed _______________

Please indicate, as best you can, the time at which you fell asleep ________________

Circle the number which best describes how you slept.

Excellent ----- 1 2 3 4 5 ----- Poor

At what time did you awake for good this morning?_____________

Did you take any naps during the day yesterday? Y N

If you did nap during the day, what time period(s) were you asleep?_________________

R Data tables

The attached tables show summary data and details of statistical tests for all figures for which analyses were accomplished.

All analyses were performed using SPSS Version 6.1.

Figure 2 **Mean probe score by time-of-day and loading/unloading**

		TIME OF DAY								
		0700	0830	1030	1200	1430	1600	1800	1930	Overall
Loading	Mean	1.256	▨	1.067	1.250	1.183	▨	1.406	1.233	1.232
	N	30		30	30	30		30	30	180
	SD	0.415		0.222	0.450	0.359		0.417	0.388	0.390
Nonloading	Mean	1.179	1.252	1.279	1.354	1.162	1.198	1.131	1.269	1.228
	N	79	80	80	80	80	80	79	80	638
	SD	0.362	0.459	0.464	0.487	0.397	0.393	0.305	0.420	0.418
Overall	Mean	1.200	1.252	1.221	1.326	1.168	1.198	1.206	1.259	1.229
	N	109	80	110	110	110	80	109	110	818
	SD	0.366	0.459	0.422	0.477	0.385	0.393	0.359	0.410	0.412

GLM General Factorial Model

Source	Sum Squares	DF	Mean Squares	F	P
Time	1.320	7	0.189	1.129	0.343
Time x load	3.026	5	0.605	3.622	0.003
Error	133.911	802	0.167		
Total	1374.000	818			

Figure 3 **Errors by time-of-day and loading/unloading**

		TIME OF DAY								
		0700	0830	1030	1200	1430	1600	1800	1930	Overall
Loading	Mean	0.889		0.250	0.400	0.941		1.765	0.588	0.820
	N	18		16	15	17		17	17	100
	SD	1.231		0.683	0.828	1.600		1.985	0.939	1.366
Nonloading	Mean	0.809	0.837	0.837	0.714	0.565	0.622	0.739	1.020	0.756
	N	47	42	43	42	46	45	46	49	360
	SD	1.227	1.154	1.400	0.970	1.088	1.029	1.290	1.479	1.216
Overall	Mean	0.831	0.714	0.678	0.632	0.667	0.622	1.016	0.909	0.770
	N	65	42	59	57	63	45	63	66	460
	SD	1.219	1.154	1.266	0.938	1.244	1.029	1.560	1.367	1.249

GLM General Factorial Model

Source	Sum Squares	DF	Mean Squares	F	P
Time x load	21.496	5.000	4.299	2.945	0.013
Error	648.232	444.000	1.460		

(Age and height/weight ratio used as covariates)

Figure 4 **Lane performance by time-of-day and loading/unloading**

		TIME OF DAY							
		0700	0830	1030	1200	1430	1600	1800	1930	Overall
Loading	Mean	8.051		10.732	10.036	10.292		10.082	9.689	9.814
	N	30		30	30	30		30	30	180
	SD	2.974		4.218	4.001	4.002		4.108	4.321	3.998
Nonloading	Mean	9.164	9.572	9.946	10.238	10.006	10.929	10.688	10.548	10.137
	N	79	80	80	80	80	80	79	80	638
	SD	4.040	4.124	4.777	4.969	5.118	5.255	4.561	4.636	4.710
Overall	Mean	8.858	9.572	10.160	10.183	10.084	10.929	10.521	10.313	10.066
	N	109	80	110	110	110	80	109	110	818
	SD	3.797	4.124	4.625	4.708	4.823	5.255	4.430	4.549	4.563

GLM General Factorial Model

Source	Sum Squares	DF	Mean Squares	F	P
Time x load	21.496	5.000	4.299	2.945	0.013
Error	648.232	444.000	1.460		

Contrast before-after morning loading sessions

Source	SE	DF	T	P
Time	1.023	174	-2.62	0.01

Figure 5 **Low-rpm shifts by time of day and loading/unloading**

		TIME OF DAY								
		0700	0830	1030	1200	1430	1600	1800	1930	Overall
Loading	Mean	15.400	▨	24.430	16.870	23.100	▨	13.700	6.000	16.600
	N	30		30	30	30		30	30	180
	SD	10.600		11.570	8.180	12.370		10.350	5.560	11.660
Nonloading	Mean	17.160	14.640	14.790	13.590	13.740	17.540	18.320	16.740	15.810
	N	79	80	80	80	80	80	79	80	638
	SD	12.120	8.440	8.720	9.880	9.450	11.030	9.260	8.690	9.860
Overall	Mean	16.680	14.640	17.420	14.480	16.320	17.540	17.050	13.810	15.980
	N	109	80	110	110	110	80	109	110	818
	SD	11.700	8.440	10.460	9.520	11.110	11.030	9.740	9.270	10.280

GLM General Factorial Model

Source	Sum Squares	DF	Mean Squares	F	P
Time	3939.8	7	562.839	5.912	0.000
Time x load	7159.7	5	1431	15.041	0.000
Error	76351	802	95.201		

(Age and height/weight ratio used as covariates)

Figure 6 **Mean sleep recorded for test period**

		TEST DAY														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Mean sleep (Hours)	Mean	6.870	6.454	6.351	6.215	6.516	6.364	7.438	6.201	6.383	6.447	6.038	6.026	6.745	7.778	5.666	6.499
	N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	150
	SD	1.286	0.685	1.055	0.921	0.823	1.315	1.251	1.104	0.636	0.619	0.806	0.954	1.061	1.708	1.228	0.539

Repeated measures General Linear Model (GLM)

Source	Sum Squares	DF	Mean Squares	F	P
Day	4.760	14.000	2.911	3.182	0.000
Error	115.261	126.000	0.915		

Figure 8

Mean sleep latencies for off-duty rest periods

Test	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mean	18.625	17.85	14.48	17.45	16.575	17.12	16.83	15.93	17.57	16.4	17.38	13.775	17.125	17.95	18.475	15.95
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SD	2.94687	2.98189	4.84006	4.90153	4.55224	4.79926	3.76388	5.10339	4.44773	5.24696	3.79028	4.93633	5.08163	3.46771	3.75731	5.02466

Test	17	18	Total
Mean	16	17.625	16.8394
N	10	10	180
SD	5.57275	4.016027	1.84554

Contrast: Expected maximum sleep perion (1300) of first off-duty rest day to overall

Source	SE	DF	T	P
Time	1.023	171	-2.645	0.01

Figure 9

Mean Stanford Sleepiness ratings across driving days

Day	1	2	3	4	5	Total
Mean	2.323	2.414	2.586	2.692	2.453	2.479
N	232	140	140	139	139	790
SD	140	1.187	1.223	1.359	1.325	1.233

Oneway analysis of variance

Source	Sum Squares	DF	Mean Squares	F	P
Between G	15.101	4	3.775	2.501	0.041
Within G	1215.043	805	2		
Total	1230.143	809			

Figure 10 **Mean Stanford Sleepiness ratings across test period**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Mean	2.275	2.588	2.625	2.900	2.512	2.200	2.000	2.337	2.237	2.500	2.475	2.342	2.250	2.125	2.400	2.422
N	80	80	80	80	80	40	39	80	80	80	80	79	40	40	80	1038
SD	1.006	1.270	1.236	1.356	1.387	1.159	1.147	1.113	1.128	1.263	1.331	1.218	1.149	0.939	1.154	1.22
						off-duty							off-duty			

Oneway analysis of variance

Source	Sum Squares	DF	Mean Squares	F	P
Between G	44.332	14	3.167	2.161	0.008
Within G	1498.85	1023	1		
Total	1543.18	1037			

Contrast off-duty days to duty days

Source	SE	DF	T	P
Day	2.11	1023	-3.073	0.01

Figure 11 **Mean Stanford Sleepiness ratings for off-duty rest days**

Time	2130	900	1300	1700	2100	Total
Mean	2.323	2.564	2.150	1.950	1.925	2.145
N	232	39	40	40	40	159
SD	140.000	1.231	1.189	0.959	0.888	1.096

Oneway analysis of variance

Source	Sum Squares	DF	Mean Squares	F	P
Between G	10.308	3	3.436	2.969	0.034
Within G	179.365	155	1.157		
Total	189.673	158			

Figure 12 Mean PVT performance (median reciprocal response time) by day of week

	DAY						
Driver ID	1	2	3	4	5	6	7
101	4.915	4.795	4.640	4.660	4.690	4.830	4.745
102	4.225	4.310	4.175	4.265	4.285	4.295	4.185
103	4.340	3.915	3.805	3.815	3.705	4.070	4.675
104	3.655	3.690	3.265	3.285	3.285	3.335	3.345
105	4.230	4.360	4.220	4.120	4.250	4.065	4.140
106	3.695	3.635	3.430	3.445	3.430	3.510	3.315
107	4.285	4.380	4.330	4.220	3.775	4.140	4.175
108	4.200	4.155	4.085	4.000	4.030	4.280	4.170
109	4.300	4.365	4.435	4.485	4.445	4.500	4.545
110	4.140	4.340	4.155	4.260	4.220	4.245	3.965
Mean	4.199	4.195	4.054	4.056	4.012	4.127	4.126

Figure 13: **Sleep patterns by driver**

	DAY														
Driver ID	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
101	7.13	6.2	6.65	6.27	5.93	5.8	7.58	5.37	6.35	6.35	6.35	6.35	6.35	6.35	6.35
102	6.35	5.83	6.42	5.08	6	3.05	6.53	4.67	5.68	6.12	5.52	4.65	6.28	5.12	5.37
103	4.75	6.58	5.65	7.33	5.38	6.72	7.83	5.28	6.00	7.32	7.37	7.23	6.52	8.40	6.12
104	6.23	6.02	6.43	5.3	6.88	6.95	6.58	5.10	6.18	6.77	5.57	5.35	9.00	8.50	4.00
105	6.33	7.17	6.5	6.83	6.33	7.58	8.78	6.35	6.98	6.87	6.75	5.80	7.08	9.47	6.67
106	6.58	5.1	7	5.35	7.75	7.78	8.92	7.40	5.98	5.40	4.78	5.15	5.67	8.03	3.93
107	9.6	7.02	7.78	6.57	7.28	6.85	8.75	6.42	7.3	6.63	6.82	7.52	7.75	7.78	7.2
108	8	7.37	7.63	7.37	7.57	6.23	7.15	7.68	7.47	7.2	5.47	6.95	5.35	6.53	7.23
109	7.38	6.62	4.83	6.92	6.42	6.18	7.38	6.07	6.02	5.8	6.33	5.77	7.17	6.6	5.02
110	6.35	6.63	4.62	5.13	5.62	6.5	4.88	7.67	5.85	6.02	5.42	5.48	6.28	11	4.77
Mean	6.870	6.454	6.351	6.215	6.516	6.364	7.438	6.201	6.383	6.447	6.038	6.026	6.745	7.778	5.666
SD	1.286	0.685	1.055	0.921	0.823	1.315	1.251	1.104	0.636	0.619	0.806	0.954	1.061	1.708	1.228
							1st off-duty day							1st off-duty day	

Figure 14: **Mean probe score by time for first driving days**

	TIME OF DAY								
	0700	0830	1030	1200	1430	1600	1800	1930	Overall
Mean	1.250	1944.000	1.317	1.350	1.094	1.183	1.178	1.367	1.242
N	30	30	30	30	30	30	30	30	240
SD	0.430	0.463	0.445	0.438	0.269	0.334	0.355	0.414	0.403

GLM General Factorial Model

Source	Sum Squares	DF	Mean Squares	F	P
*					
Between G	1.933	7	0.276	1.737	0.101
Within G	36.883	232	0.159		
Total	38.817	239			

Contrast: 10- hour and 14-hour

Source	SE	DF	T	P
Time	0.1029	232	-0.1835	0.068

Figure 15: **Mean lane performance for first driving days**

	TIME OF DAY								
	0700	0830	1030	1200	1430	1600	1800	1930	Overall
Mean	9.482	9.776	10.665	10.625	11.054	11.751	10.984	10.235	10.572
N	30	30	30	30	30	30	30	30	240
SD	3.495	4.277	4.265	4.380	5.436	4.936	3.892	4.156	4.380

GLM General Factorial Model

Source	Sum Squares	DF	Mean Squares	F	P
Between G	112.210	7	16.030	0.832	0.562
Within G	4472.543	232	19.278		
Total	4584.753	239			

Contrast: 10- hour and 14-hour

Source	SE	DF	T	P
Time	1.3367	232	0.661	0.509

Contrast: lowest (session 1) and highest (session 6)

Source	SE	DF	T	P
Time	1.3367	232	-2.002	0.046

Figure 16: **Speed maintenance by time of day (driving days only)**

	TIME OF DAY							
	0700	0830	1030	1200	1430	1600	1800	1930	Overall
Mean	1.188	1.301	1.184	1.180	1.104	1.476	1.486	1.504	1.303
N	79	80	80	80	80	80	79	80	638
SD	0.869	0.999	0.794	0.906	0.917	1.017	0.811	1.109	0.942

Source	Sum Squares	DF	Mean Squares	F	P
Between G	14.810	7	2.116	2.428	0.018
Within G	549.090	630	0.872		
Total	563.910	637			

Figure 17: **Number of gear shifts by time of day (driving days only)**

	TIME OF DAY								
	0700	0830	1030	1200	1430	1600	1800	1930	Overall
Mean	73.62	69.69	66.50	64.93	61.00	76.64	79.51	75.96	70.96
N	79	80	80	80	80	80	79	80	638
SD	34.09	25.49	24.57	32.32	29.35	30.76	29.11	22.71	29.26

Source	Sum Squares	DF	Mean Squares	F	P
Between G	23481	7	3355.37	4.050	0.000
Within G	521838	630	828.32		
Total	545391	637			

Figure 18: **Subjective sleepiness by time-of-day for first driving days**

Driver	TIME OF DAY								
ID	0700	0830	1030	1200	1430	1600	1800	1930	Overall
101	1.000	1.000	1.000	1.000	1.000	1.330	2.000	2.000	1.291
102	2.000	2.670	2.670	2.670	3.330	2.670	2.670	2.670	2.669
103	2.670	3.000	3.000	3.330	3.000	3.330	3.330	5.000	3.333
104	3.670	4.330	3.670	2.670	3.330	2.330	1.670	1.330	2.875
105	2.000	2.000	2.000	2.330	2.000	2.000	2.000	2.000	2.041
106	2.330	2.670	3.000	3.670	2.670	2.670	2.670	2.670	2.794
107	2.000	2.000	3.500	2.500	2.500	2.500	2.500	2.500	2.500
108	2.330	2.000	1.670	1.330	1.000	1.000	1.000	1.460	1.474
109	2.000	1.330	1.330	1.330	1.330	1.330	2.000	1.670	1.540
110	2.670	2.670	2.670	2.670	2.670	3.000	3.000	3.000	2.794
Mean	2.267	2.367	2.451	2.350	2.283	2.216	2.284	2.430	2.331
SD	0.68245	0.935569	0.91046	0.87789	0.90269	0.77866	0.68468	1.06187	0.69884

Repeated measures General Linear Model (GLM)

Source	Sum Squares	DF	Mean Squares	F	P
Time	4.525	7	0.645	2.527	0.027
Error	12.532	49	0.256		

(Age and height/weight ratio used as covariates)

Figure 19: **Effects of breaks on mean probe score**

	TIME OF DAY								
	0700	0830	1030	1200	1430	1600	1800	1930	Overall
Mean	1.200	1.252	1.221	1.326	1.168	1.198	1.206	1.206	1.229
N	109	80	110	110	110	80	109	109	818
SD	0.377	0.459	0.422	0.478	0.385	0.393	0.359	0.359	0.412

GLM General Factorial Model

Source	Sum Squares	DF	Mean Squares	F	P
Between G	1.808	7	0.258	1.527	0.155
Within G	137.019	810	0.169		
Total	138.827	817			

Contrast: Before and after mid-day break

Source	SE	DF	T	P
Time	0.055	810	2.841	0.005

Figure 20: **Effect of breaks on mean probe score for non-loading days**

	TIME OF DAY								
	0700	0830	1030	1200	1430	1600	1800	1930	Overall
Mean	1.179	1.252	1.279	1.354	1.162	1.198	1.131	1.269	1.228
N	79	80	80	80	80	80	79	80	638
SD	0.362	0.459	0.464	0.487	0.397	0.393	0.305	0.420	0.418
				Before break	After break				

GLM General Factorial Model

Source	Sum Squares	DF	Mean Squares	F	P
Between G	3.011	7	0.430	2.496	0.016
Within G	108.564	630	0.172		
Total	111.575	637			

Contrast: Before and after mid-day break

Source	SE	DF	T	P
Time	0.0656	630	2.92	0.004

Glossary of Terms

The terms defined here occur in course materials to be presented to learners, and do not include all technical words and phrases from the Instructor References. Words are defined elsewhere in the glossary are rendered in boldface.

alertness The relative readiness of a person to receive, recognize, and act on information; the general level of **attention**. One of the effects of **fatigue** is to reduce alertness; a fatigued driver may, for example, miss an exit due to loss of alertness.

apnea (Greek: "without breathing") A more or less severe disorder of sleep in which the sufferer experiences episodes during which the airway closes and breathing stops. This results in an increase in carbon dioxide in the blood, and causes the sufferer to awaken, gasping for air. This may occur hundreds of times in a night, and remain unknown to the sufferer. The destruction of quality sleep causes health and safety problems. Apnea can be diagnosed and treated.

attention The general allocation of sensory and perceptual functions to a limited range of inputs. A driver may be paying **attention** to exit signs and other roadway information. **Alertness**, as the term is used here, is a more broad-range readiness to receive any important inputs; we may pay **attention** to exit signs, but be **alert** to possible traffic problems.

caffeine A naturally-occurring mild stimulant that affects duration of some nerve transmissions. Caffeine is found in coffee, tea, chocolate, and other commonly available natural food sources and artificial sources like soft drinks and food additives. Caffeine is commonly found in diet pills and other medications, and can be purchased in pill form (e.g., No Doz). Caffeine also influences resetting of the biological clock.

CDL Commercial Drivers License.

circadian rhythm A **biological rhythm** of approximately 24 hours (Latin *circa die*, "about a day") that governs elements of sleep and waking, mood, alertness, secretion of stomach acid, key hormonal cycles (including growth hormone and **melatonin**), and other biological events. The cycle includes a low point in the early morning hours during which many functions are depressed and the body is adjusted for sleep, and a mid-afternoon lull (**postprandial dip**) during which the rise in rhythm briefly levels off. The phase and frequency of the cycle are governed by a **circadian clock.**

cognitive Of or pertaining to the higher mental or intellectual functions, e.g., thinking, reasoning, remembering.

Hours of service (HOS) Regulated maximum schedules of duty/nonduty time applicable to commercial vehicle carriers and drivers.

drowsiness The subjective experience of gradually increasing tiredness associated with a condition of sleep loss, low points in the circadian cycle, effects of drugs such as sleeping pills and antihistamines, or other causes. Drowsiness is characterized by subjective desire for sleep, loss of **attention**, high rates of eye blinks and long eye closures, and other events.

electroencephalograph A device used to measure brain waves by placing electrodes on the scalp to measure small, rhythmic changes in DC potential, the result of algebraic summation of millions of nerve impulses on the surface of the brain. The output of an electroencephalograph (EEG) is called an *electroencephalogram*, and may be recorded as line traces on moving paper using ink styluses, recorded digitally, or displayed on a high-persistence phosphor oscilloscope. The sleep stages are recognizable principally by characteristic EEG brain wave electrical patterns of given frequencies and amplitudes.

fatigue [1]An internal state produced by repetitive mental or physical activity, sleep loss, boredom and monotony, excessive task demands, and other factors, characterized by loss of strength, diminished **alertness** and **vigilance**, depression of mood and motivation.

[2]A set of observable changes in behavior such as slowed response times, decreased alertness, and increased likelihood of errors, brought about by sustained performance, lack of sleep, and other causes.

These two definitions are related, but differ in a subtle but important way: The first is a *construct*: a concept invented for scientific purposes to explain changes in behavior, while the second is the behavioral changes themselves. This is important because the definition we choose has effects on how we study fatigue.

general fatigue General or mental fatigue describes the effects of sustained performance on mental activity — **alertness**, **vigilance**, response speed and accuracy — associated with diminished **cognitive** and perceptual performance. General fatigue is distinct from **physical fatigue**, which results from overstressing muscles and tendons through sustained physical effort.

K-complex A short burst of very high amplitude in the EEG record of a person entering sleep. The K-complex was used in this and other studies as a marker indicating the onset of Stage 2 sleep.

lapse [1]A pause, usually brief, in **attention**, **alertness**, or **vigilance** caused by **fatigue**, **drowsiness**, or sustained performance. [2]An error of omission — failure through inattention or other performance loss to detect a condition and take appropriate action.

lark A general term for persons who report higher performance early in the daily **circadian cycle**; a "morning person" (from the bird which sings early in the morning). See **owl.**

mental fatigue See **general fatigue.**

nap A brief sleep period, usually during the day, to supplement or replace sleep normally obtained at night. For purposes of this program, a short night's sleep is *not* a nap. Naps are short sleep periods in addition to the normal (even if briefer than usual) night's sleep.

owl A general term for persons who report higher performance late in the daily **circadian cycle**; an "evening person." See **lark**.

postprandial dip (Latin *post prandium*, "after lunch") A leveling in the general performance increase associated with the rising part of the daily **circadian rhythm**. This occurs in mid-afternoon, includes a feeling of **drowsiness**, and is often incorrectly attributed to the effects of digesting lunch.

probe An event triggered purposefully in an experimental setting to trigger a measurable response. In this study, a probe was any of a series of conditions, including changes in mechanical state of the truck, visibility, or traffic conditions requiring the driver to make a correct and timely response.

psychomotor vigilance task (PVT) A self-administered test using an electronic apparatus that measures reaction time following the display of a visual stimulus. The PVT is extremely sensitive to fatigue and other impaired conditions.

rest A period of relaxation or change of activity during a sustained period of work during which sleep does *not* occur — rest simply gives the mind and body a break from some sustained activity. Rest alone cannot restore lost sleep.

scenario In this study, a scenario is a prescribed driving route in the highway data base that a driver must follow for a set period of 90 minutes.

sleep debt A condition caused by loss of sleep, most particularly cumulative. If an individual's nominal healthy or preferred daily sleep requirement is 8 hours, two consecutive days with only six hours of sleep will produce a 4-hour sleep debt.

sleep inertia A period of grogginess and low performance immediately after awakening from a period of sleep, particularly after awakening from a nap longer than 45 minutes to an hour.

sleep latency The time required for a Subject to enter sleep (usually Stage 2 sleep). A tired person will generally have a shorter latency than a rested person.

sleep spindle Groups of spikes often observed in the EEG during Stage 2 sleep.

sleep stages Human sleep proceeds in stages that vary in depth from lightest sleep (stage 1) to deepest sleep (stage 4). These stages are defined by characteristic brain wave patterns.

Stanford Sleepiness Scale A 7-point subjective scale of how drowsy a Subject feels.

vigilance A state in which a person maintains a high level of sensory **attention** (usually visual or auditory) in order to detect a change, as when a driver watches for a particular exit sign. Vigilance differs from **attention** in that it is directed at a more specific range of events.

wrist activity monitor A wrist-mounted device sensitive to physical displacement that allows recording of Subject activity from which accurate estimates of sleeping and waking times may be calculated.

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