EFFECTS OF SLEEP SCHEDULES ON COMMERCIAL MOTOR VEHICLE DRIVER PERFORMANCE:

EXECUTIVE SUMMARY

INTRODUCTION

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

PROJECT PARTICIPANTS

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

BACKGROUND

Under current U.S. Federal Hours of Service (HOS) regulations, CMV drivers are restricted to a maximum of 10 hours of driving (and/or 15 hours on-duty time) after 8 consecutive hours off-duty; and a maximum of 60 hours on-duty time over 7 consecutive days (or a maximum of 70 hours over 8 consecutive days for those who operate 7 days per week). However, the HOS regulations do not necessarily prevent significant sleep debt and sleepiness-related performance deficits in CMV operators. This is because: (a) under HOS regulations, driving may occur in the early morning hours; (b) the HOS regulations do not prohibit backwardBrotating or highly irregular work/rest schedules; and (c) a minimum off-duty period of 8 hours may not be long enough to ensure adequate sleep (since drivers would also be expected to eat, shower, etc., during this period). The field study was designed to assess, using wrist actigraphy, the relative amounts of sleep obtained by short- and long-haul CMV drivers over 20 consecutive days continuously, both on-duty and off-duty.

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

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

METHOD

Subjects

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

Design

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

Measures

Wrist actigraphy was used to objectively measure the timing and duration of sleep periods over a 20-day period. Drivers were also given sleep logs to fill out on each of the 20 consecutive study days. These sleep logs were used to gather subjective information on sleep times, sleep latency, arousals during sleep, alertness upon awakening, napping (number and duration), and self-reported caffeine, alcohol, and drug use. Initially, long-haul drivers were asked to provide copies of their daily logs corresponding to study dates, and short-haul drivers were asked to keep track of their on-duty and off-duty times across the 20 days of the study. Because of noncompliance in the short-haul group (mainly attributed to drivers forgetting to keep track of duty times), all drivers were then given Driver=s Daily Log sheets (identical to those normally used by drivers as part of Department of Transportation requirements). These were filled out on each of the 20 consecutive study days.

Data Analysis

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

Strengths and Limitations of the Methodology

<u>Strengths</u>:

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

<u>Limitations</u>:

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

RESULTS AND DISCUSSION C CMV DRIVERS FIELD STUDY

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

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

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

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

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

METHOD

Subjects

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

Design

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

Measures

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

Data Analysis

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

Strengths and Limitations of the Methodology

<u>Strengths</u>:

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

Limitations:

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

RESULTS AND DISCUSSIONCTHE SDR LABORATORY STUDY

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

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

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

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

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

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