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INVESTIGATION OF COMMERCIAL MOTOR VEHICLE DRIVER CUMULATIVE FATIGUE RECOVERY PERIODS: LITERATURE REVIEW

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by
Alison Smiley, Ph.D., CCPE
Diane B. Boivin, M.D., Ph.D.
Ron Heslegrave, Ph.D.
Dianne Davis, M.Eng., M.A.

Human Factors North Inc.

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Alison Smiley, Diane B. Boivin, Ron Heslegrave, and Dianne Davis

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118 Baldwin Street
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16. Abstract

Governments and the trucking industry would like to provide an optimal regulatory and operating framework within which Commercial Motor Vehicle (CMV) driver fatigue can be better managed to reduce its contribution to collisions. There is insufficient scientific information concerning the length of time required for drivers to recover from various types of work schedules, particularly night schedules.

This report covers Phase 1 of the project, Investigation of Commercial Motor Vehicle Driver Cumulative Fatigue Recovery. The goals of Phase 1 were two-fold: to review literature related to recovery, and to develop experimental protocols to examine driver recovery needs.

The literature on recovery in trucking and in other contexts, individual differences, sleep, and napping, was examined. Factors necessary to consider in the design of the experimental protocols were determined to include work-rest schedules, measures, screening criteria, and individual differences (age, tendency to nap, self-perceived vulnerability to fatigue).

Based on gaps identified in the literature review, eight experimental options, including field, laboratory and epidemiological studies, were formulated to address the specific question of recovery from fatigue. These protocols are further developed in Phase 2 of the project.

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Driver fatigue, commercial motor vehicle drivers, cumulative fatigue recovery, individual differences, hours of service, work schedules

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16. Résumé

Les gouvernements et l'industrie du camionnage souhaitent établir un cadre réglementaire et un cadre d'exploitation optimaux, qui mèneront à une meilleure gestion de la fatigue des conducteurs de véhicules utilitaires, et à une diminution des accidents. Ils constatent toutefois des lacunes dans les données scientifiques sur la durée des périodes hors service nécessaires pour récupérer à la suite de divers horaires de travail, en particulier les horaires de nuit.

Le présent rapport rend compte de la première phase du projet *Étude des périodes de récupération chez les conducteurs de véhicules utilitaires*, qui avait deux objectifs : recenser la littérature sur la récupération, et mettre au point des protocoles expérimentaux pour cerner les besoins de récupération des conducteurs.

La littérature recensée portait sur la récupération dans l'industrie du camionnage et dans d'autres contextes, et sur les différences individuelles, le sommeil et les sommes. Par ailleurs, il a été déterminé que les variables à inclure dans les protocoles expérimentaux comprennent les horaires de travail et de repos, diverses mesures, les critères de sélection et les différences individuelles (âge, tendance à faire des siestes, autoperception de sa vulnérabilité à la fatigue).

Selon les lacunes constatées au cours de la recherche documentaire, huit types d'expériences ont été proposées pour étudier la question de la récupération. Parmi celles-ci figurent des études sur le terrain, des études en laboratoire et des études épidémiologiques. La deuxième phase du projet consistera à élaborer les protocoles.

17. Mots clés
Fatigue des conducteurs, conducteurs de véhicules utilitaires, récupération à la suite d'une fatigue accumulée, différences individuelles, heures de service, horaires de travail

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EXECUTIVE SUMMARY

Governments and the trucking industry would like to provide an optimal regulatory and operating framework within which Commercial Motor Vehicle (CMV) driver fatigue can be better managed to reduce its contribution to collisions. There is insufficient scientific information concerning the length of time required for drivers to recover from various types of work schedules, particularly night schedules. The goal of Phase I, *Investigation of Commercial Motor Vehicle Driver Cumulative Fatigue Recovery Periods: Literature Review* is two-fold, first to review literature related to recovery and second, to develop experimental protocols to examine driver recovery needs. These protocols will be further developed in Phase II of this project, once information has been collected on typical CMV driver schedules through a questionnaire survey.

1. Literature Review Findings

Recovery in the Trucking Industry

A field study of recovery, involving a small number of drivers, showed that based on sleep and lane tracking data, 60 hours off are preferable to 36 hours, for both day and night drivers, but especially for the latter (Wylie, Shultz, Miller, Mitler, and Mackie, 1997). Two laboratory studies examined recovery after daytime driving. The first found that a time-off period which allowed two full nights and one full day off, i.e., 36 hours, allowed full recovery from daytime driving (O'Neill, Kruegar, Van Hemel and McGowan, 1999). The second found significant and dose-dependent performance deterioration for groups restricted to seven hours in bed or less during the work period (Balkin, Thome, Sing, Thomas, Redmond, Wesensten, Williams, Hall and Belenky, 2000). During a four day recovery period, there was minimal recovery for those who had been restricted to three hours in bed after each shift and incomplete recovery for the groups restricted to five or seven hours in bed, even after three nights of sleep.

Recovery in Other Contexts

A meta-analysis showed that for most schedules, day or night, weekly or rapid rotation, regular or irregular, when recovery was assessed with respect to subjective sleepiness, one recovery day that included a full night's sleep was sufficient. Exceptions included construction workers working seven consecutive 12 hour day shifts, who required three to four days off to reach normal sleepiness values, and oil platform workers working 14 consecutive 12 hour night shifts who were still not recovered after four to five days off. In a review of countermeasures against fatigue, Akerstedt stated that most shift workers reported that they needed at least two days with two normal sleep episodes to recover after three consecutive night shifts (Akerstedt, 1998). This study also demonstrated that the need for recovery increased by one day when working a succession of seven consecutive shifts.

A study of a variety of schedules worked by nurses suggest that a number of measures such as alertness, sleep duration, mood and social satisfaction tended to be worst on the first rest day and at least two days of recovery is required (Totterdell, Spelten, Smith, Barton and Folkard, 1995).

A study of the effect of chronic sleep restrictions showed the same amount of sleep restriction with respect to hours had a much stronger effect on performance when the sleep taken was during the day, as opposed to at night (Rogers, Van Dongen, Power IV, Carlin, Szuba, Maislin and Dinges, 2000). This study looked at recovery after schedules when sleep is taken during the day. For ten days, subjects were assigned to diurnal sleep restriction which was followed by two recovery days with a ten hour nocturnal sleep period. This indicates that it is important to consider the timing of sleep as well as the duration of off-duty time. A sleep deprivation study by Price, Rogers, Fox, Szuba, Van Dongen and Dinges (2000) indicated that providing a longer opportunity to spend time in bed and to sleep results in quicker recovery from acute sleep deprivation.

Individual Differences

In an on-road study of short-haul drivers on daytime schedules, Hanowski et al. (2000) found that drivers who showed evidence of fatigue and were involved in fatigue-related incidents had less sleep and of a poorer quality than drivers who did not show signs of fatigue (Hanowski, Wierwille, Gellatly, Early and Dingus, 2000). The majority of the incidents involved younger and less experienced drivers who also exhibited higher on-the-job drowsiness.

In studies of day and night nurses on permanent shifts, one study found that a minority of night nurses showed physiological adaptation to night work and had performance abilities similar to day nurses (Quera-Salva, Guilleminault, Claustrat, Defrance, Gajdos, Crowe McCann and De Lattre, 1997). Similarly when melatonin rhythms were studied, a minority of night workers were classified as adapters (Weibel, Spiegel, Gronfier, Follenius and Brandenberger, 1997). When adaptation was determined based on cortisol levels, another study found that the majority were adapters (Hennig, Moritz, Huwe and Netter, 1998).

In a study of nurses working regular night shifts, Boivin and James found that circadian rhythms can be realigned with work schedules through bright light treatment (Boivin and James, 2002). Another study demonstrated that daytime sleep following night shifts was significantly longer in nurses who participated in/benefited from the light treatment conditions (James, Chevrier and Boivin, 2002).

Sleep deprivation studies showed that increased age was associated with a decreased ability to recover from sleep deprivation (Gaudreau, Morettini, Lavoie and Carrier, 2001) and that there are significant differences between individuals in vulnerability to performance impairments from sleep loss (Van Dongen, Baynard, Nosker and Gingues, 2002). However, in a review of individual differences, including gender, age, psychological profile, chronotypes and circadian variation, Nachreiner concluded that none of them can consistently predict individual ability to adapt to shiftwork (Nachreiner, 1998).

In a review of various schedules, Knauth recommends that shift workers need two days to recover from three consecutive nights and three days to recover from seven consecutive night shifts (Knauth, 1997). This suggests that a 36-hour recovery period would be insufficient to repay the accumulated sleep debt.

Sleep

An actigraphic assessment of the sleep of 50 long- and short-haul CMV drivers over 20 consecutive days found that both groups averaged approximately 7.5 hours of sleep per 24-hour period (Balkin et al., 2000). Short-haul drivers obtained 3 percent, and long-haul drivers, 44 percent, of their sleep during their work shifts, suggesting that long-haul drivers spend a significant portion of their work shift in a state of partial sleep-deprivation. For each driver, sleep times varied greatly – up to 11.2 hours total per day across the 20 study days.

Napping

No studies were found on the relationship between napping and recovery in CMV drivers. However, the efficacy of naps on improving performance and reducing sleep debt was shown in a number of environments: for truck drivers during a simulated night shift following a three hour nap opportunity in the afternoon, for air traffic controllers during the night shift after a scheduled nap break, for emergency room personnel after a mid-nightshift 40 minute nap, and immediately following a ten minute afternoon nap. Night workers are more likely both to experience difficulty sleeping and to take naps.

2. Experimental Protocol Options

Eight experimental protocol options were developed. The studies and the hypotheses to be tested are outlined below:

1. Options 1, 2, and 3: The basic experimental design is a field study involving a sequence of four to five (day or night) driving shifts followed by one, two or three days of time off, followed by three to five (day or night) driving shifts. The first hypothesis is that the recovery period required to bring performance back to a baseline level after a period of night driving, followed by more night driving, will be longer than after a period of day driving followed by more day driving. Night driving followed by day driving will require an intermediate recovery period.

2. Option 4: Using the same experimental design, but for night driving only, the second hypothesis is that a mandatory two hour sleep opportunity (an element proposed for fatigue management plans), as compared to little or no napping between 00:00 and 06:00, will shorten the recovery period after night driving.

3. Option 5: The third hypothesis will be tested in a laboratory study involving night performance followed by four hours sleep and then daytime testing. It is predicted that drivers with self-perceived difficulty with night driving and recovery will require longer recovery periods.

4. Option 6: Using the same basic experimental design as for Options 1, 2 and 3, but varying sleep timing and sleep fragmentation, the fourth hypothesis predicts that drivers with consolidated sleep during a period of driving will require less recovery time than drivers with fragmented sleep, and that these effects will be stronger for night driving than for day driving.

5. Option 7: Using the same experimental design as for Option 6, but with a shorter sequence of work shifts, the fifth hypothesis predicts that shorter work periods (Option 7 vs. Option 6) will result in shorter required recovery periods

6. Option 8: Based on an epidemiological case-control study of drivers in crashes, the sixth hypothesis predicts that shorter recovery periods, a higher percentage of night driving, longer working times, and longer times since last sleep all increase crash risk.

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1 INTRODUCTION

Governments and the trucking industry would like to provide an optimal regulatory and operating framework within which Commercial Motor Vehicle (CMV) driver fatigue can be better managed to reduce its contribution to collisions. In Canada, the current hours-of-service regulations do not specifically include an extended off duty recovery period to reduce the "sleep debt" acquired by drivers after cumulative periods of sleep restriction or loss over multiple work shifts. This is only addressed indirectly by specification of maximum on duty hours over a cumulative period such as, for example, over seven days (Note: U.S. regulations, published April 28, 2003 increase the minimum off duty period from eight hours to ten hours between driving periods. They retain a prohibition against driving after 60 hours on duty in any seven consecutive days or 70 hours in any eight consecutive days. However, they include a "reset the clock" provision that requires a "recovery period" of at least 34 consecutive hours). There is little scientific information concerning the length of time required for drivers to recover from various types of work schedules. Developing a scientific basis for minimum recovery period is important from the safety perspective as well as for maximizing driver operational efficiency and quality of life.

The goal of Phase I, *Investigation of Commercial Motor Vehicle Driver Cumulative Fatigue Recovery Periods: Literature Review* is two-fold: to review literature related to recovery and to develop experimental protocols to examine driver recovery needs. These protocols will be further developed in Phase II of this project, once information has been collected on typical CMV driver schedules through a questionnaire survey.

1.1 Literature Search

The literature review was undertaken on the shiftwork and recovery aspects of CMV driving, including schedule rotation, nighttime driving, daytime sleeping, and daily and weekend recovery. Literature concerning shiftwork and recovery in occupations other than CMV driving was included. In addition, literature on individual differences related to adaptation to shiftwork, sleep and napping behaviour was reviewed. The literature review includes a critical analysis of methodologies to ensure a clear understanding of the strengths and limitations of each study, as well as results pertaining to recovery from cumulative fatigue.

The literature search was conducted on the library catalogue of the Transportation Development Centre of Transport Canada, MEDLINE, TRIS, and the DIALOG database using various key word combinations to identify literature relevant to the issue of the development of fatigue over several days, individual differences, and recovery from the cumulative fatigue. Keywords used included: fatigue, recovery, driving, accidents, sleep deprivation, alertness, performance and sleep deprivation, sleep debt and driving, performance recovery and fatigue, extended workdays, cumulative fatigue, acute and chronic fatigue.

1.2 Experimental Protocol Options

Based on the findings of the literature review, experimental protocol options were developed on the basis of the literature review. The intent of these protocols is to further our understanding of the minimum duration of off duty periods required for CMV drivers to recover, from a road safety perspective, from the effects of cumulative fatigue resulting from various shiftwork conditions involving multiple days and/or nights.

2 RECOVERY AND TRUCKING

There were three studies which explicitly addressed the issue of recovery of CMV drivers. Two of these studies (O'Neill et al., 1999; Balkin et al., 2000) were conducted in a laboratory and one in the field (Wylie et al., 1997).

U.S. – Canada On Road Schedule Comparison (Wylie, Shultz, Miller, Mitler and Mackie, 1997)

The goal of this study was to assess fatigue related to Canadian vs. U.S. driving schedules. The study focused on five groups of CMV drivers. One group of five drivers worked nights (i.e., 4 X 13 hour nights, followed by 36 hours off, and then worked 4 X 13 hour nights) and the remaining four groups worked days. Three of the groups worked 4 X 13 hour days and had varying recovery time (i.e., group 1: 10-11 hours, three drivers; group 2: 36 hours, six drivers; group 3: 60 hours, six drivers) before working an additional day. The final group of five drivers worked four 13 hour days, had 36 hours off and worked four additional days.

This study employed a number of measures to assess fatigue. In addition to collecting sleep and lane tracking data this study also administered subjective measures and other driving-performance-relevant assessments. These measures included a variant of the Psychomotor Vigilance Test (PVT) which has been shown in previous studies to be very sensitive to sleepiness. The PVT is a ten minute period of reaction time performance where drivers respond as fast as possible to brief visual stimuli. Reaction time and lapses (reaction times exceeding 500 ms) are recorded.

The sleep and lane tracking data from this study suggest that two work cycles (or shifts) (i.e. 60 hours) off are preferable to one work cycle (i.e., 36 hours) for both day and night driving, and in particular for night driving. The sleep patterns of day and night drivers who had 36 hours off during their first recovery, suggests incomplete recovery. Only sleep after the recovery period (not during) was measured. During their four 13 hour nights, drivers had an increase in sleep time suggesting an increasing need for sleep. After a 36 hour period off, the night drivers' first post-recovery sleep was markedly reduced to two hours, that may have been related to circadian factors associated with sleeping times. However, even with this reduced total sleep drivers had a 50 percent increase in slow wave sleep (SWS) compared to their first sleep of their prior work cycle. This increase in SWS is indicative of changes in sleep architecture associated with recovery from sleep loss, as it is well known that sleep deprivation results in deeper sleep (increased SWS) during the next sleep opportunity in order to enhance recovery.

After four 13 hour days, the first recovery night sleep was the longest sleep. It contained a greater percentage of rapid eye movement (REM) sleep (70 percent more REM) compared to the first sleep in the first work cycle but SWS was comparable. The total sleep during the first recovery night was also comparable to the first work cycle. After 36 hours off, the day drivers' first post-recovery sleep showed a 60 percent increase in SWS, and a 250 percent increase in SWS during the next post-work sleep period. In contrast, the day drivers who had 60 hours off (i.e., 2 work cycles) had no increase in SWS on their second post-work sleep. Together these data suggest that after 36 hours off, there remained a need for further recovery (resulting in increased

SWS) compared to the condition of 60 hours off (where no increase in SWS occurred relative to a normal sleep period).

The lane tracking variability of day drivers with none, one, or two work periods off appeared to be consistent with these expectations. The group with no extra time off experienced a large decline in lane tracking ability between the fourth and fifth work period (no work cycles off). In contrast, the decline in lane tracking ability for those with 36 hours off was somewhat smaller. Finally, those drivers who had two work cycles off showed no decline in performance from their range in their first work cycle. These data suggest that one work cycle (shift) off after four long day shifts results in only partial recovery in lane tracking performance.

Night drivers had a steady increase in the variability of lane tracking in the last three nights of driving during the first work cycle. During the second work cycle (shift) in the recovery period, they showed a similar pattern except the pattern was exaggerated, suggesting that 36 hours off was insufficient recovery time. Overall, the night drivers' lane tracking variability was worse than that of the day drivers regardless of the schedule. This suggests that if performance at daytime levels is the criterion for recovery, then night drivers will never meet the definition for recovery without prolonged recovery periods

It should be noted that the results from this study were based on data from a small number of drivers so that the replicability of these findings is of concern.

Simulator Study of Recovery from 14 hour Day Shifts (O'Neill, Kruegar, Van Hemel, and McGowan, 1999)

The goal of this study was to assess the effects of operating practices, namely schedule, loading and recovery, on alertness for drivers on daytime schedules. Ten male CMV drivers participated in one week of driving operations in a simulator followed by 58 hours of recovery time. This was followed by another week of driving, 58 hours of recovery time and a final driving day to verify performance after recovery. Half of the drivers performed three days of loading in the first week (i.e., 2 X 1.5 hour sessions) and had no loading in the second week. The remaining drivers did the reverse (i.e., loaded in week two). On loading days, drivers performed two 90 minute loading/unloading sessions during the driving day, one in the morning, and one in the afternoon. The drivers worked 14 hours on duty (i.e., 12 hours driving plus scheduled breaks) beginning at 07:00, followed by ten hours off duty.

Measures of sleepiness, sleep length, psychomotor performance and driving simulator performance were collected. The sleep measures included the Stanford sleepiness scale, self-alertness scales and wrist actigraphs (i.e., sleep length). Measures were collected using the Psychomotor Vigilance Task (PVT). Driving simulator performance measures included lane position, speed maintenance, and shifting performance. Response probes (e.g., tire blowout, merge squeeze, fog, etc.,) were used and driver response was evaluated by expert trainers on a three-point scale. Probes provided tests of driver vigilance, alertness, and response time.

Individual differences in performance in relation to age and height/weight were assessed. The age of the drivers was correlated with lane ($r = .508$, $p<.01$) and shifting performance ($r = -.287$, $p<.01$). Drivers height/weight ratio (a surrogate measure for general fitness) was correlated with poorer lane performance (r = -.358, p<.001) and shifting performance (r = -.428, p<.001).

Overall, there was a gradual decline in driver response quality, as measured by response probes, with hours of driving. There were improvements after each break, regardless of whether it was a rest, meal, or loading activity. After 6.5 hours of driving, drivers were returned to starting levels of safety (as measured by response to probes) by a 45 minute lunch break. The ability to maintain speed within posted limits and gear shifting performance deteriorated somewhat during the latter part of the driving day but there was no consistent linear relation to hours of driving.

There was an improvement in driver response to crash-likely simulated situations after the morning physical activity. However, gear shifting increased, indicating inefficiency in attention and co-ordination, and there was greater lane position variability after the morning loading session. The only effect of the afternoon loading session appeared to be an increase in cognitive errors, that is lapses in vigilance leading to missed turns.

Over the driving week, there was a slight but statistically significant deterioration in subjective sleepiness, reaction time response, and measures of driving performance over each working day. However, driver response in crash-likely situations did not show cumulative deterioration. The day-time oriented schedule of 14 hours on duty/10 hours off duty (12 hours driving) for a five day week did not appear to produce significant cumulative fatigue over the two week testing period.

The drivers returned to baseline levels of reaction time, driving simulator performance, and alertness within 24 hours recovery time after the end of a driving week as shown by sleep latency, reaction time testing, and driver rating of subjective sleepiness. However, it should be noted that drivers lived in an apartment during testing; therefore sleep may not have been typical of normal conditions during recovery, where drivers must deal with family and social obligations which may result in reduced sleep.

Laboratory Study of Recovery due to eight hours Sleep after Restricted Sleep (Balkin, Thome, Sing, Thomas, Redmond, Wesensten, Williams, Hall and Belenky, 2000)

The goal of this study was to examine the impact of a recovery period on performance after seven days of performance testing following varying levels of restricted sleep. Sixty-six CMV drivers had three days of orientation and baseline sleep in the laboratory before data collection commenced over seven days of performance testing with three, five, seven, or nine hours of sleep each night. The recovery period, that followed, lasted four days with eight hours in bed each night. Measures consisted of the psychomotor vigilance task (PVT), the cognitive performance assessment battery, driving simulator tasks (e.g., lane tracking) as well as sleep latency, EMG and sleepiness ratings.

On average, subjects slept 2.9, 4.7, 6.3, and 7.9 hours for the three-, five-, seven-, and nine-hour time in bed conditions respectively, and displayed dose-dependent performance impairment related to partial sleep loss. (As noted in the above sleep times, as sleep restriction was more pronounced, sleep latency periods declined, resulting in greater sleep efficiency or proportionally more sleep in the available period.) Performance in the three hour sleep group typically declined below baseline within two to three days of sleep restriction. Performance in the five hour sleep group was consistently lower than performance in the seven and nine hour sleep groups. In contrast, performance in the seven and nine hour sleep groups was often indistinguishable and improved throughout the study. Virtually no negative effects on performance were seen in the nine hour sleep group.

Sleep restriction effects were consistent across tasks for speed throughput (i.e. speed/accuracy trade-off) measures. All cognitive tasks were sensitive to differential sleep restriction. The PVT was the most sensitive measure. (It was also the performance measure which was the most resistant to changes in performance due to learning, an important issue when effects over many days are being examined.) Even the seven hour group with 6.3 hours of sleep showed decreased performance using this measure across the seven days. The majority of driving performance measures (e.g., increased lane-tracking variability, increased driving speed, increased speed variability and increased running-off-road accidents) also showed dose-dependent and/or cumulative sleep restriction effects.

Following chronic sleep restriction, the first eight hours in bed (6.5 hours of sleep) was insufficient for restoration of performance on the PVT task. During the four day recovery phase (eight hours in bed each night), five and seven hour sleep groups showed minimal or no recovery, remaining consistently below the nine hour sleep group and below their own baseline levels for the PVT. The three hour sleep group showed some recovery for the PVT on the first day and more on subsequent days but also remained well below their own baseline and below the performance of the other groups. Subjects' recovery to baseline or near baseline levels of performance on the PVT often required a second or third night of recovery sleep. These data suggest that after sleep debt has occurred (three, five, seven hours time in bed) a single bout of eight hours of night sleep leads to recovery but not full recovery. While further sleep is required for full recovery, the number of subsequent sleep periods to reach full recovery is unknown. For the three hour group, the data suggests that even three nights of normal sleep (eight hours spent in bed on each night) is not sufficient to restore performance to baseline levels (depending on the task). Balkin et al. (2000) conclude that "this suggests that full recovery from severe, extended sleep restriction may require more than three nights of normal-duration sleep" (p. 2-85).

In contrast to the findings concerning PVT performance, the simulator accident rate went back to baseline after one recovery day for all groups. In addition, lane position variability was near, but not quite back to baseline for all but the nine hour group. On recovery days lane position variability was slightly worse for the nine hour group who, after being allowed nine hours in bed each night during the work period, were restricted to eight hours of sleep.

This study provides important findings with respect to the effect of restricted sleep on performance, a common experience in modern life, and particularly for truck drivers. Two limitations of this study were that it only looked at daytime driving, and the recovery sleep was restricted to eight hours. These findings are unique and require further replication especially given that they suggest that three nights of full sleep is insufficient to promote full recovery from even minor sleep-deprivation induced performance impairment. However, the next set of studies also suggest that recovery from fatigue may be slower than previously expected after extended work periods.

3 RECOVERY IN OTHER CONTEXTS

Six studies looked at recovery in field and laboratory settings in relation to occupations or tasks other than driving. Three studies considered recovery in the field. The first examined a variety of schedules and jobs, and used subjective alertness as the main measure of recovery. The second examined a variety of schedules worked by nurses. Recovery was assessed using a number of measures, which were implemented on a hand-held computer, and completed on the job. The third study reviewed the type of schedule and the duration of successive shifts as countermeasures against operator fatigue in the field.

Three of the studies looked at recovery in laboratory settings. One study looked at the neurobehavioural effects of doses of sleep restriction. Another looked at the influence of recent sleep/wake history on the magnitude of neurobehavioral performance impairment during total sleep deprivation. The third study examined sleep physiology, following total sleep deprivation, across multiple recovery nights and with different durations of sleep opportunities.

Meta-Analysis of Recovery of Subjective Alertness for Various Shift Systems (Akerstedt, Kecklund, Gillberg, Lowden and Axelsson, 2000)

A meta-analysis compared the recovery process across different shift schedules. Shift schedules such as 12 hour day shifts, or 84 hour workweeks were examined in various industries (e.g., chemical, pulp and paper, or air/train transportation). Recovery was defined as subjectively assessed alertness during the day. Various measures were taken to assess fatigue and recovery, including the Karolinska Sleepiness Scale (KSS), the acti-watch and a six week daily sleep diary. In the KSS where “one” is very alert to “nine” which is very sleepy, values around five to seven are associated with driving off-the-road incidents in driving simulators (Horne and Reyner, 1995). Sleep recordings were taken once per week. According to the authors, a recovery day must be preceded by the opportunity of night rest between 24:00 and 08:00. Thus, the first recovery day after a night shift that ends in the morning does not start until the subsequent day.

There was significant time of day effect, in that there was increased sleepiness during the day for the traditional day week with weekends off. Recovery, as measured by subjective sleepiness, was complete on the first day off for those shift workers who worked the traditional day week (25 shift workers ages 25-64). This was also true for the traditional three eight hour shifts (i.e., shift change: 06:00, 14:00, 22:00), and the 12 hour day and night shifts (i.e., 06:00, 18:00 start times).

Recovery also seemed to be complete after one day off for 60 pulp and paper workers who worked an extremely rapid eight hour three shift schedule (i.e., a night shift (21:00-06:00), eight hours off, an afternoon shift (14:00-21:00), eight hours off, and a morning shift (06:00-14:00). This triad was followed by 56 hours off, including two normal night sleeps. Sleepiness was high during night shifts, intermediate during afternoon shifts and high again during morning shifts. There was no difference between the first and seventh shift in terms of sleepiness for 83 construction workers, working an 84 hour week (i.e., seven consecutive 12 hour day shifts between 07:00 to 19:00 followed by a week off). However they required three to four days of recovery to reach normal sleepiness values.

The sleepiness levels of seven oil production platform workers on the 2 X 84 hour night weeks (i.e., 14 consecutive nights between 19:00 and 07:00, followed by three weeks off) were extremely high during the first nights of work and progressively changed to become similar to day work patterns with intermediate sleepiness. Their bedtime gradually changed from 08:00 to 11:00 and their wake time from 17:00 to 18:00 with a sleep length close to eight hours. On days off they slept from 24:00 to 06:00 or 08:00. This suggests a progressive adjustment of the circadian system. Their sleepiness level remained high after four to five days off. It is unknown how much time was required for full recovery for these workers.

There were high levels of sleepiness from 04:00 on during early morning work for 45 train drivers working irregular schedules (i.e., early morning and night represented 42 percent of all shifts; usually two days off followed by four to five days of irregular work). Irregular schedules result in varying starting times and shift lengths, however the authors did not provide the actual shift times as they could not be described in any meaningful way as they involved all possible combinations of time of day. Their normal day of driving was characterized by intermediate sleepiness around 04:00 whereas afternoon driving and days off were characterized by low sleepiness. The recovery for these drivers appeared to be immediate. Recovery was complete on the first day off, however this was always preceded by a normal night's sleep.

Twenty-five cabin crew, flying across many time zones, equipped with sleep diaries and actigraphs, experienced high sleepiness levels at the end of an outbound flight. Similarly, while working on the day of return, they experienced high sleepiness levels towards the end of the flight, but moderate levels during the day. On their first recovery day the crew had slightly increased levels of sleepiness. Their recovery was not complete until their third recovery day.

While most of the irregular schedules seem to involve immediate recovery on the first day off, there were individual differences. The authors identified both fast and slow recovery groups within the pulp and paper workers on the unusual, very rapidly rotating system. While some of these workers returned to normal daytime levels on the first day off, others took three to four days to recover. The slow recovery group started sleep 0.8 hour later than the fast group.

Since night and early morning work is characterized by severe subjective sleepiness regardless of occupation, the authors concluded that the rest periods between shifts within a working week were sufficient. However, they recommended that more than one day of recovery is required for some individuals such as those individuals with less than optimal sleep behaviour or with schedules that involve a sequence of long work hours or circadian desynchronization.

The strength of the above study is the great variety of shift systems that were examined. The main weakness is that the only measure of recovery reported was subjective sleepiness: no objective measures of performance were reported. It is well known that subjective and objective measures are not necessarily correlated, and that workers may rate their rest as being adequate or good, even though their performance is affected. In addition, the work environments examined may or may not have been similar to that of CMV drivers with respect to the requirement for vigilance.

Study of Sleep, Performance and Recovery on Various Shift Systems (Totterdell, Spelten, Smith, Barton and Folkard, 1995)

The goal of this study was to examine sleep, mood, cognitive performance and recovery for 61 female nurses, ranging in age from 22 to 51 (mean age = 33.6) on a variety of schedules. Rotating and permanent night shift schedules were examined as well as flexible and non-flexible shift systems. Thirty-two nurses worked full time on shift systems with fast internal rotations between early, late and night shifts. Others worked full or part-time with permanent night shifts. (Day and evening shifts lasted approximately eight hours, and night shifts, and approximately 11 hours. Mean hours/week were 32-43 (range 8.25-84.25 hours) with longer hours for permanent night nurses.)

The subjects completed a set of self-rating scales before each main sleep period and a sleep diary following the sleep period. They also filled in additional rating scales and completed a short battery of performance tasks every two hours using a hand-held computer.

The findings of a number of the sleep, mood and social satisfaction ratings suggest that recovery from a shift did not occur by the end of the first rest day. These ratings tended to be more negative on the first rest day following work shifts as compared to the subsequent rest day. An effort to readapt to a day oriented schedule on a first rest day after a night shift could also have affected these results as, on the first rest day, nurses seemed to reduce their main sleep episodes in order to be able to fall asleep the following night. This also reflects the circadian influence with nurses having to adjust to their night shift schedule. There was a main effect of consecutive shifts on performance with a decrease in the subjects' reaction time and gaps over four consecutive night shifts. Reaction time decreased over consecutive night shifts and tended to increase over rest days following night shifts.

The results of this study suggest that a number of measures such as alertness and sleep duration, mood and social satisfaction tended to be worst on the first rest day and at least two days of recovery are required. Based on graphs of the results, after three days of recovery, alertness is even further improved, suggesting that sleep debt might persist beyond two days of recovery – a finding similar to the Balkin et al. (2000) study.

The strength of this study is that it assessed performance as well as sleep length and quality and subjective measures of alertness and mood, for a variety of different schedules. The main limitation of applying the findings of this research to a study of CMV drivers is that the work involved is much more active, unlike the vigilance type of task performed by many CMV drivers.

Countermeasures Against Operator Fatigue (Akerstedt, 1998)

The author reviewed countermeasures against operator fatigue. He observed that the type of schedule and the duration of successive shifts affect recovery. This was mainly discussed in terms of sleep loss. Thus recovery depends on the prior sleep-wake cycle and napping behaviour. Morning shifts with earlier starts can also be associated with sleepiness during the day. For pilots during long haul flights, as well as other workers, early shifts are associated with sleepiness and performance error and an increase in accident risks.

Most schedules included 16 hours of free time between consecutive shifts although some schedules with quick rotation had less off duty time. Sleep was clearly reduced in the latter case and a correlation was reported between the length of the free time and sleep duration. At least 16 hours of free time was considered to be necessary to allow a sleep duration of seven to eight hours. When a morning or day shift was followed by a night shift, with less than six hours of free time, the sleep duration was less than three hours. A night shift followed by an evening shift also resulted in a sleep deficit with sleep durations of less than five to six hours. The presence of social activities may also interfere with the sleep schedule.

Akerstedt's group observed that most shift workers reported that they needed at least two days with two normal sleep episodes to recover after three consecutive night shifts. (No indication was given whether this was in reference to eight or twelve hour shifts.) This study also demonstrated that the need for recovery increased by one day when working a succession of seven consecutive shifts. Evidence from jet lag indicates that it may take up to four days to recover after an acute shift of the sleep wake pattern.

According to Akerstedt, another important aspect of adaptation to night work is the succession of consecutive night shifts. For instance, the first night shift was associated with the greatest sleepiness but after seven shifts there was an indication of some adaptation. The sleepiness of the first night may be due to increased duration of prior wake time since most shift workers have been awake for at least 13 hours since the start of their first night shift. In comparison, they have only been awake for eight to nine hours before the following night shift. Nevertheless, even in the presence of some adjustment, sleepiness was higher on night shifts than that observed on day shifts. On rapidly rotating schedules with two to three days on night shifts it was not clear whether there was some adjustment occurring. Over successive night shifts, sleepiness gradually delays its timing of appearance in the shifts but the adjustment appears marginal and the sleep-wake cycle never seems to adjust completely to rotating night work.

The direction of the rotation was also important since forward rotation appears more physiologically appropriate than counter-clockwise rotation. However, there are relatively few studies that test this hypothesis. In fact a recent series of reports from the FAA suggests that the direction of rotation of shifts in air traffic controllers is not an important factor in fatigue and performance deterioration though time of day remains a significant fatigue factor (Boquet, Cruz, Nesthus, Detwiler, Knecht, and Holcomb, 2002; Cruz, Detwiler, Nesthus, and Boquet, 2002; Cruz, Boquet, Detwiler, and Nesthus, 2002).

The FAA reports summarize the details of a study designed to assess performance and physiological parameters with regard to operating on forward or backward shift rotations. The study consisted of a laboratory comparison of clockwise and counter-clockwise rapidly rotating shift schedules. Subjects were randomly assigned to a clockwise or counter clockwise rotating shift schedule. The first report (Cruz, Detwiler, Nesthus, and Boquet, 2002) looked at sleep. The findings of this report do not unequivocally support the hypothesis that a clockwise rotation will result in less sleep disruption. The second report (Cruz, Boquet, Detwiler, and Nesthus, 2002) looked at performance and vigilance assessed using measures of complex task performance from the Multiple Task Performance Battery (MTPB) and the Bakan Vigilance Task, respectively. While the counter-clockwise shift group appeared to perform consistently better than the clockwise group across all shifts, more specific analyses indicated that the difference was restricted to the first afternoon shift. These data do not support the hypothesis that a clockwise rotation will result in better outcomes on complex or vigilance task performance. In fact, performance in the two groups was generally equivalent, with a few exceptions in which the counter-clockwise group performed better. In the third report (Boquet, Cruz, Nesthus, Detwiler, Knecht, & Holcomb, 2002), cortisol, melatonin, and core body temperature were examined in participants randomly assigned to either a clockwise or counter-clockwise shift rotation. While some of the physiological measures were difficult to interpret, the results clearly did not support the assertion and commonly-held belief that counter clockwise rotations are inferior to clockwise rotations. The results reported in these FAA reports cast significant doubt on the importance of rotation direction with regard to fatigue and performance impairment; however, they support the importance that daily circadian rhythms have on performance impairment.

Influence of Recent Sleep/Wake History on Neurobehavioural Performance (Baynard, Nosker, Dinges and Van Dongen, 2000)

The aim of this study was to determine the influence of recent sleep/wake history on the magnitude of neurobehavioral performance impairment during total sleep deprivation. Nine healthy subjects (ages 29.4 ± 5.5; five males, four females) participated in three total sleep deprivation laboratory sessions, each lasting 36 hours, (10:00 until 22:00 the next day) at intervals of two weeks. Their sleep/wake history was manipulated in the week preceding each of the three total sleep deprivation sessions: six hours time in bed (04:00-10:00) or 12 hours time in bed (22:00-10:00) for seven days. One-third of the subjects were in the six hour-twelve hour-twelve hour condition, another third were in the twelve hour-six hour-twelve hour condition and the final third had the twelve hour-twelve hour-six hour condition.

Subjects completed a twenty-minute neurobehavioral battery including a PVT every two hours. Neurobehavioral performance impairment was assessed during the 36 hour total sleep deprivation. Impairment increased over subsequent exposures to total sleep deprivation. A relatively small non-linear influence from the sleep/wake history (six hour vs. 12 hour time in bed) was observed. There was a main effect of condition, suggesting that performance during total sleep deprivation was more impaired after the six hour than after the 12 hour sleep history condition.

This study indicates that 1) prior exposure to total sleep deprivation can sensitize subjects to subsequent total sleep deprivation 2) the influence of sleep/wake history (six hours vs. twelve hours time in bed for seven days) was smaller.

This study underlines the importance of the prior sleep-wake history. While it was not an experiment directly addressing recovery, it does suggest that more recovery would be needed if one were to be chronically sleep restricted.

Effects of Recovery Sleep Duration on Sleep Physiology Following Sleep Deprivation (Price, Rogers, Fox, Szuba, Van Dongen and Dinges, 2000)

The aim of this study was to examine sleep physiology, following total sleep deprivation, across multiple recovery nights and with different durations of sleep opportunity. The study examined the first seven hours of sleep physiology across three nights of recovery with seven hours vs. fourteen hours of time in bed following 88 hours of total sleep deprivation. Twenty-six healthy male subjects (age = 21-39 yrs) lived in the sleep laboratory for ten days. Following three baseline nights, with eight hours in bed each, subjects remained awake for 88 hours, followed by three recovery nights. Subjects were randomized to receive hourly caffeine or a placebo from the 22nd to the 88th hour of sleep deprivation. Subjects were also randomized to two seven hour recovery nights followed by one 14 hour recovery night or three 14 hour recovery nights.

A number of measures were taken during the study, including polysomnographic sleep recordings. There was no statistically significant effect of caffeine on any of the sleep variables. In contrast, the day of study and the type of recovery schedule influenced the sleep variables. Subjects fell asleep more rapidly and entered slow wave sleep more rapidly on the first recovery night compared to baseline. Sleep latency progressively lengthened from the first to the third recovery night as subjects slowly recuperated from their sleep debt. Providing 14 hours of time in bed for recovery versus seven hours resulted in an increase in slow wave sleep (SWS) during the first recovery night in the condition allowing 14 hours of time in bed and then a reduction in the following nights. This indicated reduced overall sleep deprivation and could be observed in the first seven hours of sleep on subsequent nights. The results of this study indicate that providing a longer opportunity to spend time in bed, and to sleep, results in a better recovery from acute sleep deprivation.

Neurobehavioural Effects of Doses of Chronic Sleep Restrictions (Rogers, Van Dongen, Power IV, Carlin, Szuba, Maislin and Dinges, 2000)

The aim of this study was to examine the neurobehavioural effects of three doses of chronic (ten days) sleep restrictions (four hours, 6 hours, 8 hours time in bed) with a sleep placed at an adverse circadian phase (i.e., diurnally). Following one night of baseline sleep (23:30-07:30) 44 healthy subjects (ages: 21-44; male = 29, female = 15) remained awake for 28 hours, followed by an eight hour diurnal sleep period (11:30-19:30). Subjects were randomly assigned to a diurnal sleep restriction condition (four hours: 15:30-19:30; six hours: 13:30-19:30; eight hours: 11:30-19:30) that was maintained for ten consecutive days, followed by two recovery days with a ten hour nocturnal sleep period (23:30-09:30).

Measures included a 35 minute neurobehavioural assessment battery every two hours during wakefulness. This battery consisted of a 35 minute neurobehavioural assessment including a PVT, digit symbol substitution task, and subjective measures of sleepiness (Karolinska sleepiness scale) and mood. In addition, polysomnographic recordings of sleep and wake periods were taken as well as measures of salivary melatonin and core body temperature.

Preliminary analyses suggested that a decrement in performance across days, as measured by the PVT, was the greatest when subjects were limited to four hours of sleep per day. Levels of neurobehavioural decrement were comparable between the six hour and eight hour sleep restriction conditions. The eight hour diurnal sleep condition demonstrated greater performance decrements relative to a previous study, where subjects were allowed a nocturnal eight hours sleep episode for 14 days. This last observation indicates that it is not only important to consider the total duration of off duty time available to sleep but its timing should also be considered. Thus an eight hour period of sleep opportunity is insufficient if it falls at an inappropriate time of day.

This study indicates the need to consider time of day and the sleep restriction effect (e.g., prior sleep-wake history) in any experimental protocols that are developed to study the conditions required to achieve driver recovery for fatigue-safe driving after the development of cumulative fatigue resulting from various work shift schedules.

4 INDIVIDUAL DIFFERENCES

Nine studies were found that considered individual differences. With the exception of a review of shiftwork schedules that made recommendations about recovery, none of these studies pertained directly to recovery. However one study involved truck drivers and examined the impact of the individual differences on the occurrence of driving incidents. Two studies examined individual differences and adjustment to shiftwork for day vs. night nurses, and a third for night workers. Two papers reviewed the literature on individual differences and adjustment to shiftwork. One study examined the impact of various schedules and made recommendations on the design of schedules and required recovery times. Two studies looked at recovery from 24 hour sleep deprivation.

Impact of Individual Differences on Driving Incidents (Hanowski, Wierwille, Gellatly, Early and Dingus, 2000)

The goal of this study, which examined the impact of the individual differences of truck drivers on the occurrence of driving incidents, was to study fatigue experienced by short haul truck drivers. Forty-two male short haul drivers (mean age = 31) participated in the study. Drivers completed two weeks of Monday-Friday daytime driving on normal delivery routes that were within 100 miles of home. Their distribution of work consisted of driving (28 percent), loading/unloading (35 percent), other assignments (26 percent), waiting to unload (7 percent), eating (2 percent), resting (0.5 percent) and other activities (1.5 percent).

A number of measures were used to assess the fatigue, inattention and drowsiness of the drivers, including analysis of a videotape of the three minute interval preceding the start of a critical incident, that is, a near-crash event. A critical incident involves an unexpected event resulting in a close call or requiring fast action on the part of a driver to avoid a crash. Incidents were detected by three methods: exceeding specified values in vehicle manoeuvres, via an incident pushbutton used by the driver and from analyst judgement. Analysts recorded eye transitions and the proportion of time that the driver's eyes were closed/nearly closed, or off the road, during these three-minute intervals.

The drivers' mean sleep was 6.43 hours per night (sleep log) and 5.31 hours based on the acti-watch (developed by Mini Mitter Co., Inc.). Drivers who showed evidence of fatigue and were involved in fatigue related incidents had less sleep and of a poorer quality than drivers who did not show signs of fatigue. Twenty-one per cent of the incidents implicated fatigue as a contributor based on observer assessments of drowsiness and the increase in proportion of time with eyes closed or nearly closed.

Over the two week period, there were 77 incidents (average 1.8 per driver) where the driver was judged to be at fault. With respect to individual differences, ten of the 42 drivers were involved in 86 percent of the incidents. The younger and less experienced drivers were significantly more likely to be involved in critical incidents and exhibited higher on the job drowsiness.

The strength of this study is that it focuses on individual differences and it has strong face validity with respect to traffic safety issues. The main weakness from the perspective of our study is that it does not address recovery directly.

Circadian Adaptation to Shiftwork (Boivin and James, 2002)

The authors enrolled 15 nurses working regular nights in a study including laboratory assessments of circadian phase both before and after the application of an intervention of judicious light exposure under field conditions. The treatment condition (n = 10, mean age ± S.D. 41.7 ± 8.8 years) included the administration of an intervention including six hours of intermittent bright light exposure in the workplace (~2000 lux) and shielding from bright morning light with tinted goggles on the commute home. Phototherapy during night shifts was administered via portable lamps installed in the workstations. Research assistants observed the nurses in their work environments on a nightly basis, and documented light levels with a concurrent timeline of the nurses' locations. Portable wrist activity monitors with mounted light sensors also documented levels of light exposure throughout the night. Control group subjects (n = 9, age 42.0 ± 7.2 years) were observed in their habitual work environments. Nurses in both groups maintained regular sleep/wake schedules including a single eight hour scheduled sleep/darkness episode beginning two hours after the end of the night shift.

In the presence of the intervention, the circadian rhythms of the core body temperature and salivary melatonin curves cycle were delayed by 9.32 (± 1.06) hours and 11.31 (± 1.13) hours, respectively. These were significantly greater than the phase delays of 4.09 ± 1.94 and 5.08 ± 2.32 hours displayed by the control group. Results of this study underline the importance of documenting the overall pattern of light to which humans are exposed throughout the 24 hour day. This can substantially affect circadian reentrainment to shifted work schedules and thus the quality of recovery sleep.

Circadian Adaptation to Shiftwork (Quera-Salva, Guilleminault, Claustrat, Defrance, Gajdos, Crowe McCann and De Lattre, 1997)

The authors compared the performance levels of 40 healthy nurses, aged 20-55, 20 on permanent night shifts and 20 on permanent day shifts. The groups did not use drugs that could affect melatonin production and had low anxiety and depression scores. Years of nursing experience were comparable: each nurse had two to twelve years on the same schedule with an average of six to seven years for both groups. All the nurses worked in the same department, were matched for age and gender and had similar social and family responsibilities. The day shift nurses worked eight hour shifts for five days on/two days off from 07:00 to 15:00. The night shift nurses worked ten hour shifts from 21:00 to 07:00 on a rotating three/two schedule. In the 15 days prior to the investigation, nurses worked three days on/two days off/two days on/three days off/two days on and three days off. All night shift personnel returned to daytime schedules on days off.

Subjects maintained a sleep-wake diary for 15 days prior to the study. Performance was evaluated by a memory test and a four-choice reaction time test, eight times per day for an eight day period prior to and throughout the experimental period. The experimental period lasted seven days for the day shift (five days on/two days off) and five days for the night shift (three nights on/two nights off). Each subject wore a wrist actigraph/photometer monitor on the non-dominant wrist. Light exposures were verified with the actigraph/photometer. Performance tests were carried out and on the last day of work and the first day off, urine samples were collected during the wake period. During two data collection nights, while the subjects slept in the lab, and light intensity was kept below 30 lux, urine samples were collected every two hours. Subjects completed two questionnaires: “Chronotypes” and the “European Standard Shiftwork Index”.

Sleep-wake logs indicated no difference in total sleep time between night and day shift nurses. However, as compared to day nurses, night nurses tended to significantly increase their sleep on days off. All night nurses reverted to daytime activities on their days off. Two sub-groups of night nurses were identified. The majority of nurses, 14 out of 20, did *not adapt* to night shift as they did not shift their rhythms on work nights and had their peak of 6-sulfatoxy-melatonin at 06:36 on average. The remaining group of six nurses did *adapt* to night shift showing a fast shift in their 6-sulfatoxy-melatonin rhythm with a peak around noon. Naps were not prohibited and nine out of the 20 night nurses took naps during their night shifts with an average of 114 ±45 minutes per shift. Only nurses who did *not* adapt to night shift fell asleep during working hours. There was no difference in total sleep time per day in nurses working dayshifts and those who *adapted* to working nights. A significant reduction of total sleep time was observed in *non adapted* nurses working nights compared to the other two groups.

All nurses performed equally well on days off. Daytime nurses and fast shifting night nurses had similar scores on workdays while non-night shifting nurses had lower scores at work. These results indicate that a minority of nurses had the physiological ability to adapt to a fast shifting sleep wake schedule of more than eight hours and were able to perform appropriately.

The sub-group of night nurses with adjusted rhythms (six out of twenty) had comparable amounts of sleep on workdays to the daytime control group. Total sleep time on workdays was significantly less for night, as compared to day, shifts. This was because the majority of night nurses (14/20) did not adjust and slept significantly less.

This study addressed the importance of circadian adaptation to explain individual differences in terms of adaptation to an atypical work schedule. We can assume that the difference in the need for recovery somehow depends on the sleep deprivation accumulated by individuals during their work schedule. Clearly, individuals who did not show an appropriate shift of their circadian system slept somewhat poorly and would also need greater recovery.

Circadian Adaptation and Shiftwork (Hennig, Moritz, Huwe and Netter, 1998)

The aim of this study was to determine the size of changes and the rapidity of adaptation of circadian rhythms during night shifts and whether they are associated with tolerance to shiftwork. Individual differences were considered in the rate of adaptation to night shifts.

The subjects were 24 night shift nurses (18 females and six males) aged 23-36, on a seven night schedule in a cardiac emergency unit. They were observed after two early day shifts, and then after seven consecutive night shifts. Saliva samples were collected four to five times per day for determination of cortisol levels with 28 measurements per subject

Large individual differences were observed. Six out of 24 subjects did not change their circadian rhythms. At the start of the study, the subjects had a normal circadian rhythm with peak values of cortisol levels in the early morning and a marked decrease in the evening with low variability. This variation of cortisol with time of day was maintained only during the first five nights of work and the pattern clearly changed after the fourth night and seemed to be reversed after the fifth night. The researcher identified 18 adapters (fifteen female, three male) and six non-adapters (three female, three male) based on their adaptation of cortisol value. They defined a worker as an adaptor if the cortisol concentration at 21:00 was greater than the one at 06:00 and remained higher for the rest of the night shift.

Large individual differences have been reported in the literature on factors predicting adjustment to shiftwork. There seem to be some adapters and non-adapters indicated by various biological correlates, although the predictive value of these biological markers before the start of shiftwork is difficult to assess. A question remains as to whether adapters were exposing themselves to light differently.

Circadian Adaptation to Shiftwork (Weibel, Spiegel, Gronfier, Follenius and Brandenberger, 1997)

The aim of this study was to measure the rate of adaptation of melatonin rhythms in 11 healthy male night workers, who had been working for at least two years on a four to six consecutive night shift per week schedule. These workers were studied immediately after their last night shift. Their results were compared to those of a group of eight healthy male day workers studied during two 24 hour cycles. The day workers were permitted to sleep from 07:00 to 15:00. Plasma melatonin was sampled every ten minutes and rectal temperature every minute. There was no documentation of performance and no documentation of exposure to light and darkness in the field.

The melatonin rhythm of the day workers did not really shift after an acute reversal of their sleep schedule. The night workers showed a great deal of variability in the onset of melatonin which could be observed between 21:45 and 05:05. There was a gradual shift of melatonin rhythm in seven of the eleven night workers with incomplete adaptation. Although it was not addressed directly in this paper the use of hormonal markers can give us some indication of the rate of adaptation of individual workers. This study addresses the biological basis for the variability observed in adaptation to night shiftwork. Some of this variability can be explained by the rate of circadian adaptation to shiftwork.

Impact of Individual Differences on Tolerance of Shiftwork (Härmä, 1992)

The goal of Härmä's study was to review individual differences in tolerance to shiftwork. Different strategies can be used by shift workers to schedule their lives, and especially their sleeping habits, in order to adapt to shiftwork.

A number of the variables examined in this study concern individual differences, such as individuals' circadian rhythms (i.e., adaptation and amplitude), that may play a role in adapting to shiftwork. It is possible that the degree of circadian adaptation affects tolerance to shiftwork. This is more frequently seen in rapidly rotating schedules or when the exposure to light and darkness is inappropriate. Some have raised the possibility that the amplitude of circadian rhythms could affect the degree of adaptation to atypical schedules. However, to date, in our opinion, there is no convincing evidence to support this statement. In most prior studies, circadian amplitude has been derived from ambulatory data and its assessment has been biased by disturbed rest-activity rhythms associated with irregular shifts

The commitment to shiftwork in terms of the willingness to work night shifts can affect an individual's attitude towards coping with shiftwork. Certain aspects of the personality, such as chronotype and introversion-extroversion, have also been associated with the degree of adaptation. For instance, it has been said that extroverts seem to adapt more rapidly. However this statement is questionable because personality could be negatively affected by maladaptation to shiftwork instead of the other way around. Morningness (i.e., chronotype) seems associated with more difficulty adjusting to night shift and an increase in the rigidity of sleeping habits. In addition, workers who are not healthy and who have medical problems might suffer more from shiftwork and should possibly be excluded from it.

The strength of this review is that it examined individual differences. The weaknesses are that, to our knowledge, some of the conclusions (e.g. the ones related to circadian amplitude) have not been properly tested, and, in reference to our study, there was no examination of recovery specifically.

Individual and Social Determinants of Shiftwork Tolerance (Nachreiner, 1998)

The author did a review on determinants of shiftwork tolerance from the literature published between 1993 and 1998. The review covered individual differences such as gender, age, psychological profile, chronotypes, and circadian variation. However, there was no clear definition of tolerance to shiftwork. The author concluded that none of the parameters evaluated have a predictive power to assess individual ability to adapt to shiftwork. Nevertheless, the study reported some interesting observations such as the fact that sleeping longer before a morning shift results in a more favourable attitude towards work. It also indicated that women show more symptoms of intolerance compared to men until the age of 50. However, family duties might confound these results as the double burden of raising a family and maintaining a job affects women more. Moreover, women show an earlier development in shiftwork related health complaints. The presence of a supportive spouse is a positive aspect of tolerance to shiftwork. The correlation between chronotypes and tolerance to shiftwork appears inconsistent. The author suggests a better adaptation for evening types and that slowly rotating systems would be preferred.

Design of Shift Schedules (Knauth, 1997)

The author reviewed different work schedules in order to make recommendations for the design of shift systems. He drew a number of conclusions that are summarized as follows. Shift workers need three days to recover from a series of seven consecutive night shifts. After three consecutive night shifts, the number of recovery days is reduced to two nights. The adjustment of circadian rhythms to night shifts, in general, is complete after one week. There is less disturbance of circadian rhythms after only one or two night shifts.

Recovery time while working day shifts, that follow night shifts, is generally shorter. Shift workers prefer quicker rotating shift systems because they can maintain a good level of social interaction. However, the long-term health effects of rotating schedules, or permanent night work, are unknown. Health problems will tend to develop on average after 7.4 years for permanent night workers, more than seven years for other shift workers, and more than 12 years for day workers.

Consecutive morning shifts may lead to cumulative sleep debt. Earlier starts lead to greater sleep debt. Shorter spells of morning and evening shifts are associated with reduced sleep debt and a reduction of sleep complaints. In forward rotations, at least two days off after the last night shift is recommended, otherwise there will only be 24 hours between the end of the night shift and the start of the next morning shift.

Recovery periods from work at regular intervals are highly recommended even though shift workers dislike splitting up days off by reducing the number of consecutive shifts. All of these recommendations should be adjusted to the level of stress within the working place. Experts recommend no more than five to seven consecutive working days. It is recommended that the duration of a shift with high physical strain does not exceed eight hours. However, comparative studies of physiological performance between eight, nine, ten or twelve hour shifts were not available at the time of this study (which was written in 1997).

Other factors should be considered. For instance, family duties, especially in female workers, can prevent a complete recovery from extended working hours. It is recommended that a rest period longer than 11 hours be scheduled between the end of one shift and the start of the following one. Shorter rest periods substantially reduce sleep duration to three to five hours per night. Commuting time and time for personal needs should be added to that minimal period in order to extend the time off.

In the three shift system, there are no clear recommendations as to the start and the end of morning shifts. These should take operational aspects into consideration such as public transportation, customer requests, etc. Early shifts reduce sleep before the morning start; however, a late end to the evening shift is also problematic. An early end of a night shift could allow sleep during the circadian nadir. Some authors recommend that the night shift ends at the latest at 05:00.

Weekends off are highly recommended since they will increase social interactions for the worker. These should include at least two consecutive days off. Some flexibility in working time is also recommended whenever feasible. However care must be taken to reduce the unpredictability in the work schedule with deviations from the set shift system.

The summary of the main recommendations pertinent to recovery are summarized as follows:

- At least two days off after the last night shift are recommended
- Avoid a succession of night shifts
- Avoid single working days between days off because it disrupts the blocks of leisure time
- Work for a maximum of a five to seven consecutive shifts
- Tolerate extended shifts only if the type of work or the work load is suitable and includes sufficient breaks and a good shift system to reduce the accumulation of fatigue

Recovery from 25 Hours Sleep Deprivation (Gaudreau, Morettini, Lavoie and Carrier, 2001)

This study looked at the recovery of 33 subjects (ages 20-60) from 25 hours sleep deprivation. The subjects were healthy individuals with no night work or trans-meridian travel in the three months prior to the study. Sixteen young subjects (eight females, eight males) and 17 middle-aged subjects participated in the study (eight females, nine males).

A number of fatigue measures were taken. Sleep was recorded for three nights before a 25 hour constant routine (procedure designed to unmask the endogenous circadian phase) and one night after the routine. The sleep recording taken following the constant routine was done in the early morning. A spectral analysis of the electroencephalogram (EEG) was done to document the slow wave activity), a reflection of the recuperative function of sleep. In addition to a vigilance and performance evaluation, saliva samples were collected in order to assay melatonin content, a reliable circadian marker, and subjects' rectal temperatures were taken.

With respect to individual differences, increased age was associated with a decreased ability to maintain sleep when subjects have to recuperate during an abnormal circadian phase. As expected, slow-wave sleep was increased in both the young and middle-aged groups following sleep deprivation. However, the rebound of SWS was significantly less pronounced in the middle-aged subjects.

The main strength of this study is that it provided information on recovery sleep scheduled in the early morning following a night of sleep deprivation. This scenario can occur in truckers who drive at night and must sleep during the day.

Recovery from Repeated Exposure to Total Sleep Deprivation (Van Dongen, Baynard, Nosker and Gingues, 2002)

The aim of this study was to quantify individual vulnerability to performance impairment from sleep loss. Ten healthy individuals (ages 23-28; six males, four females) participated in two laboratory-based total sleep deprivation sessions of 36 hours at intervals of two to four weeks. On the seven days preceding each of the two total sleep deprivation sessions, subjects were scheduled to sleep 12 hours. The last of the 12 hour sleep periods preceding each total sleep deprivation were spent in the laboratory. Each of the two total sleep deprivation sessions was followed by a 12 hour recovery sleep opportunity. Measurements were taken after the 12 hour recovery sleep. Fatigue was measured using a 20 minute PVT every two hours. Up to 70 percent of the variance in PVT performance deficits resulted from inter-individual differences in vulnerability to sleep deprivation. This study suggests that total sleep deprivation progressively exposed individual differences in vulnerability to sleep loss or that there was a circadian modulation of these inter-individual differences.

5 SLEEP

One of the major aspects of recovery is the return to “normal” sleep patterns. A recent study (Balkin, Thome, Sing, Thomas, Redmond, Wesensten, Williams, Hall, and Belenky, 2000) used actigraphs to measure sleep on CMV drivers with interesting results.

Assessment of the Sleep of CMV Drivers over 20 Days (Balkin, Thome, Sing, Thomas, Redmond, Wesensten, Williams, Hall, and Belenky, 2000)

The Balkin et al. (2000) study involved an actigraphic assessment of the sleep of 50 long and short haul CMV drivers ages 21 to 65 over 20 consecutive days. The drivers wore the Walter Reed wrist actigraphs at all times except when bathing or showering. In addition they completed sleep logs on driver’s daily log sheets to gather subjective information about sleep times, sleep latency, arousals during sleep, alertness upon awakening, naps (number and duration), and self-reported caffeine, alcohol and drug use. The data from each actigraph were downloaded to a personal computer, and each 24 hour actigraph recording period was examined for sleep in its entirety regardless of the duty status type or length indicated on the daily log sheet.

Both long- and short-haul drivers averaged approximately 7.5 hours of sleep per night, which is within normal limits for adults. However, in contrast to short-haul drivers who only obtained three percent of their sleep during on duty periods, long-haul drivers obtained 44 percent of their sleep during on duty periods. Short-haul drivers were more likely to consolidate their daily sleep into a single sleep period. As long-haul drivers obtained almost half of their daily sleep during work-shift hours (mainly sleep-berth time), it appears that they spend a significant portion of the work shift in a state of partial sleep deprivation, until the opportunity to obtain on duty recovery sleep presents itself.

There was no off duty duration that guaranteed adequate sleep for the long or short haul drivers. As drivers likely use a substantial portion of their off duty time to attend to personal business, off duty time must be of sufficient duration to allow drivers to accomplish these tasks and to obtain sufficient sleep. This may be particularly important for long-haul drivers, who often did not sleep at all during off duty periods.

The bulk of the first (main) daily sleep bouts for short-haul drivers were initiated between 20:00 and 02:00 hours. Sleep bouts initiated at these times lasted longer (i.e., clustered between six and ten hours) than sleep bouts initiated at other times of day. Several of the sleep bouts initiated between these times lasted longer than 12 hours.

Similar to the short-haul drivers, the majority of long-haul drivers’ first sleep bouts were initiated between 22:00 and 03:59 hours. However, long-haul drivers initiated their first sleep bouts more frequently during 00:00 and 03:59 hours. The duration of long-haul drivers’ first sleep bouts clustered between six and ten hours in duration. Sleep bouts exceeding 10 hours in duration were uncommon and none exceeded 12 hours. Some sleep bouts were initiated in the early and late afternoon hours (12:00 to 19:59) and, unlike short-haul drivers, almost half of the first sleep bouts initiated during this time frame were longer than four hours in duration.

There were large day-to-day variations in total sleep time for drivers in both groups. Sleep times varied for some long and short-haul individuals by up to 11.2 hours across the 20 study days for the long and short-haul drivers. Other drivers maintained more consistent sleep/wake schedules. Some individuals showed a pattern that suggested chronic sleep restriction with intermittent bouts of extended recovery sleep. The authors felt that this 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 and imaginative approaches.

The strength of this study is that all periods of sleep, not just those taken off duty, were recorded for a large group of CMV drivers over an extended period of time. The main limitation as far as our study is concerned is that the issue of recovery was not addressed specifically.

6 NAPPING

Strategic napping can be used to maintain performance over an extended period of work. It is a double-edged sword however, as individuals nap because they are tired but their next sleep will be reduced as a result. For instance, if a CMV driver or shift worker were to nap in the middle of the night shift for 30-60 minutes and the next available sleep period was a daytime sleep period, there may be more difficulty falling asleep and maintaining sleep during that daytime sleep period since the pressure to sleep (need for sleep) has been reduced by the nap. This could be a problem if one is trying to sleep at a time in their circadian cycle where sleep is difficult to achieve, such as a daytime sleep. However, recovery periods may be shorter if napping has occurred during the work period.

Eleven studies were found concerning napping. Three studies examined the napping behaviour of shift workers. Five studies examined the effectiveness of a nap in improving performance on night shift, and one of these five also looked at the impact of caffeine. One study looked at nap effects on afternoon shift performance. One looked at the use of naps during periods of extended operation. One study attempted to validate a computer model to predict the recovery effect of naps.

Napping Behaviour of Rotating Shift Workers (Akerstedt and Torsvall, 1985)

Nap and sleep behaviour for 282 male steel workers working on a rotating three shift system with shift changes at 04:45, 13:00 and 21:15 was recorded. Subjects spent between two and five days working on each shift. Half of the workers were habitual nappers but their napping behaviour depended on the type of shift.

The length of the main sleep period varied significantly across the various shifts with the shortest being associated with the night and morning shifts. Sleep duration was approximately six hours on the night and morning shifts and 9.15 hours on the afternoon shifts or days off. The proportion of nappers decreased with increasing length of the major sleep period. Thus, napping appears to be related to sleep loss. On days with morning or night shifts, 33 percent took naps whereas almost no workers took naps on the afternoon shifts or days off. Napping behaviour appears to significantly affect sleep debt and thus, the need for recovery.

Napping Behaviour (Akerstedt, Torsvall and Gillberg, 1989)

In this book chapter, the authors reviewed the napping behaviour of shift workers. They reported that there is a higher frequency of napping behaviour in shift workers, namely, those working three shifts, as opposed to the day workers. Napping clearly occurs during night shifts and sometimes in relation to morning shifts. The typical nap duration was less than two hours with an average of 1.1 hour. In rotating schedules, naps are rarely taken during afternoon shifts. The naps taken during the night shift were unauthorized and involuntarily. They occurred mainly during the second half of the night shift when sleepiness was at its peak. The naps included both REM sleep and SWS. REM sleep duration tended to increase with increasing sleep duration.

Sleep loss appeared to be the main reason for napping. Often the main sleep episode was reduced by two to three hours after the night shift so, as a result of circadian misalignment of the sleep period, most shift workers were reporting sleep debt and fatigue due to the need to sleep during the day and/or evening. SWS of the main sleep episode was seldom affected and REM sleep appeared evenly distributed throughout the sleep period instead of its normal temporal distribution at the end of the nocturnal sleep episode. There was a large variability among individuals and this seemed to be directly related to napping behaviour. Napping behaviour was also related to the duration of the main sleep episode. The composition of the main sleep episode can also affect the napping behaviour. More naps occurred when there was a deficit of stage two and REM sleep, which is surprising since it is the SWS that is associated with the recuperative or homeostatic aspect of sleep.

The authors note that one very important individual aspect of napping is age. The frequency of napping increases with age and napping may lead to a deterioration of the main sleep episode in older workers. The individuals who napped in the afternoon after a morning shift were evening types whereas those who napped in the afternoon after a night shift were morning types.

Shiftworker Nap Strategies (Tepas, Carvalhais and Popkin, 1990)

Napping strategies in 681 Permanent Day shiftworkers (PD) and 402 Permanent Night shiftworkers (PN) from U.S. plants in the rubber and plastics industry were examined. The shiftworkers were surveyed about their workday and days off behaviour. Respondents had a mean age of 34 years; 69 percent of them were male.

Five nap strategy groups were formed for both shifts. The napping strategies consisted of those workers who: often took naps during the work week; often took naps on their days off; often took naps during both the work week and on days off; did not often take naps during the work week or days off, and those who often take naps either during the work week or days off. The majority of PD and PN shiftworkers did not take naps during the work week or on days off. For both shifts, those who took naps both during the work week and on days off had the highest difficulty falling or staying asleep and those who did not nap at either time had the lowest or next to lowest percentage. Overall, the incidence of difficulty falling or staying asleep was 26.6 percent for PD and 41.7 percent for PN. ANOVAs of workday and days off sleep length data found no significant difference for nap strategy group, but a significant workday/days off sleep length difference and a significant day/night shift difference for workday sleep length (only). The authors conclude that the data suggest that PN worker napping is not a good strategy since nappers reported increased difficulty falling or staying asleep, but does not support the idea that PN workers who do not report such difficulties are naturally short sleepers. The data also confirms previous findings that PN decreases workday sleep length and increases napping.

Effects of an Afternoon Nap on Nighttime Alertness and Performance in Long-haul Drivers (Macchi, Boulos, Ranney, Simmons and Campbell, 2002)

The effects of an afternoon nap on alertness and psychomotor performance were assessed during a simulated night shift for eight professional long-haul drivers (one female, seven males, mean age: 40.0 years). The study used a counterbalanced crossover design with two conditions, one with a scheduled three hour nap on the afternoon preceding a night of simulated work (nap condition) and one without (no-nap condition). In the nap condition, the subjects were required to remain in bed, in darkness, from 14:00 to 17:00, whether or not they were able to sleep. In the no-nap condition, they spent that time engaged in sedentary activities.

Subjects had a restricted sleep period, in a lab, designed to increase sleep pressure in the following 24 hours, and to obtain sleep durations similar to those reported in a field study of truck drivers (Mitler et al., 1997). Alertness and performance testing sessions were conducted at 12:00 (pre-nap baseline), 24:00, 02:30, 05:00, and 07:30 , and followed two hour runs in a driving simulator. Testing consisted of the Walter Reed performance assessment battery, visual analog scales to assess subjective fatigue and sleepiness and a resting electroencephalographic (EEG) test.

Overall, nighttime sleep was similar in the two experimental conditions although REM sleep latency was significantly longer and stage two percent was significantly higher in the no-nap condition. The three hour afternoon napping opportunity alleviated the combined effects of increasing sleep pressure and of the circadian nadir in alertness and performance rhythms during a simulated night shift. Subjects in the nap condition showed reduced nighttime subjective sleepiness and fatigue, faster and less variable reaction times and higher electrocortical arousal levels during the simulated driving runs.

The results demonstrate that a three hour napping opportunity in the afternoon preceding a simulated night shift has beneficial effects on performance and on subjective and physiological measures of alertness measured up to 14 hours later. The authors believe that the long-lasting benefits observed in this study, and the fact that any sleep inertia effects of prophylactic naps would be expected to dissipate before the start of driving, indicate that such a napping strategy may be preferable to recuperative, on-the-job, naps. They recommend that this napping strategy be included in driver education programs aimed at counteracting fatigue in the trucking industry.

Psychomotor Performance Improvements with Nap on Nightshift (Signal and Gander, 2000)

Signal and Gander's study sought to determine whether a short workplace nap during a scheduled break on the night shift led to improvements in the psychomotor performance of operational air traffic controllers (ATC). Twenty-eight ATC (mean age = 35.5 years; nineteen males, nine females) worked four night shifts, each in a sequence of afternoon, day, and midnight shifts. Two of the night shifts started at 22:00, the remaining two shifts started at 23:30. The 40 minute nap opportunity occurred during a scheduled break two hours after the night shift started for the 22:00 shift start, and three hours after the night shift started for the 23:30 shift start. The controllers were to remain awake on the remaining night shifts. Polysomnographic data was collected during the nap opportunity.

During the shift, three ten minute PVT measures were taken: before beginning work, after the nap opportunity or at a similar time if no nap opportunity was provided, and at the end of the night shift. Despite the limited duration (mean = 17.7 min, due to long sleep latencies) and the fragmented nature of the sleep (including awakenings and other arousals), pre-planned naps in this operational setting produced significant improvements in psychomotor performance. The findings also indicate that even short naps of less than 20 minutes can significantly affect a shift worker's performance.

Effectiveness of Night Shift Nap on Performance in Emergency Department (Smith-Coggins, Howard, Kawn, Wang, Rosekind, Sowb, Balise and Gaba, 2000)

The aim of this study was to investigate the effectiveness of a mid-shift nap intervention as a countermeasure to fatigue encountered by physicians and nurses during emergency department night shifts. Seventeen subjects were studied during two consecutive 12 hour night shifts: a baseline and an intervention shift. Subjects were randomized into nap or no nap groups. Nap subjects took a 40 minute mid-shift nap (between 03:00 and 04:00). Subjects in the no nap group had the same schedule as nap subjects but no nap between 03:00 and 04:00.

A number of measures were used to measure subjects' fatigue: Probe Recall Memory Test (PRM), CathSim intravenous insertion virtual reality simulation, PVT, Profile of Mood States Questionnaire, and the Stanford Sleepiness Scale. These measures were taken three times a night during the baseline and interventions shifts (pre-shift = 18:30-19:30; mid-shift = 04:00-05:00; post-shift = 08:00-09:30).

The nap subjects performed better on the CathSim simulation, PRM, and PVT tests than the non-nap group, but showed no statistically significant effects for the mood or subjective self-reported sleepiness scale. The total time required to successfully perform a CathSim intravenous insertion was faster among the nap group. Their mean pre-shift and post shift insertion time improved by 2.2 percent while the no nap group showed an increase of 18.2 percent in total time. The nap subjects had a 23 percent improvement in their mean pre-shift to post-shift PRM score as compared to a mean score decrease of 29 percent for the no nap subjects. The nap subjects had reduced PVT mean of their slowest 10th percentile reaction times, and lapses at the post-shift testing period as compared to no nap subjects.

Introduction of One Short Nap during the Night Shift (Bonnefond, Muzet, Winter-Dill, Bailloeuil, Bitouze and Bonneau, 2001)

A study was conducted to test the possible long-term effects of implementing short naps during night shifts. The experiment was conducted over a period of one year with 12 male (volunteer) shiftworkers operating in an industrial plant (age range: 30 to 46 years). Shiftworkers were authorized under certain conditions to use sleeping areas, for a maximum of one hour, between 23:30 and 03:30. Prior to the study participants were given precise rules on how to deal with taking a short rest period. For example, specialists gave participants relaxation training in order to teach them how to relax and thus facilitate their ability to fall asleep. Participants completed daily and bi-monthly questionnaires to record their schedule of main sleep, and evaluate their mood, quality of work, as well as changes to their lives.

Results showed that these opportunities for short rest periods introduced a general satisfaction about the quality and the ease of the work at night (e.g., less fatigue, less sleepiness, gain of energy). For example, vigilance level was considered to be higher during the hours following the nap. In addition, the general quality of life improved for most subjects. The efficacy of the nap-time progressively increased for most subjects. In addition, perceived sleep quality within short rest periods increased over time for all subjects. While a few participants felt falling asleep was less easy on the following morning at home, the statistical analysis did not show any detrimental effect of the short rest period on the length of the immediately consecutive main sleep period. However, statistical analyses did reveal significant differences between the main sleep durations following the night shift compared with those following both the afternoon shift and the resting period (i.e., the former was shorter). The main sleep duration following the night shift was *not* statistically different from that of the morning shift. The authors conclude that a short nap during the night shift can be considered a positive way to counteract the low level of vigilance that normally occurs during the late part of the night.

Napping and Caffeine as Countermeasures during Night Shifts (Schweitzer, Randazzo, Stone and Walsh, 2000)

This study systematically examined the effects of napping and caffeine before night shifts. Fifty-two subjects (mean age = 32.5±12.8; 26 males, 31 females) participated in one of four conditions: nap before the first two of four consecutive simulated night shifts (NAP); 4mg/kg caffeine before all four simulated night shifts (CAF); the combination of the NAP and CAF conditions (NAP+CAF); placebo before all four simulated night shifts (PBO). All subjects participated during four consecutive nights and the following four days. The simulated night shift began at 23:00 and ended at 07:00.

Various measures were used to measure fatigue: Maintenance of Wakefulness Test (23:45, 01:45, 03:45, 06:30); Neurobehavioural Assessment Battery (23:00, 01:00, 03:00, 05:45); various cognitive tests (02:15, 04:40) and length of daytime sleep (08:30 with minimum of six hours time in bed). The authors found that caffeine and/or napping improved both alertness and performance during the four simulated night shifts. The improvements in alertness were maximal on the first night shift with slight differences among the three active treatments. The NAP+CAF combination appeared to be a slightly more alerting manipulation as its effect persisted into the second night.

Recuperative Value of Brief Afternoon Naps (Tietzel and Lack, 2000)

In this study, 16 adult healthy sleepers (mean age = 22.5 years, SD = 3.86 participated in one of four conditions: no nap; ultra-brief naps of 30 seconds; ultra-brief naps of 90 seconds; brief ten minute nap. Naps were scheduled to terminate at approximately 15:00. On the evening preceding each laboratory session, participants limited their nocturnal sleep to between 24:00 and 05:00 (mean = 4.70 hours, SD = 0.13)

Subjects' fatigue was assessed through the Stanford Sleepiness Scale (subjective alertness), Symbol-Digit Substitution Task, and the Letter Cancellation Task. The fatigue measures were assessed pre-nap, five minutes post-nap and 35 minutes post-nap.

Following mild nocturnal sleep restriction, a ten minute afternoon nap reduced subjective fatigue (Stanford Sleepiness Scale) and improved cognitive performance for at least 35 minutes and improved alertness for at least one hour. In contrast, ultra-brief naps of 30 and 90 seconds produced no measurable benefits within one hour of napping.

Strategic Naps in Operational Settings (Rosekind, Smith and Miller, 1995)

The authors reviewed several studies that document the beneficial effect of naps in order to maintain performance or improve it during periods of extended waking. These beneficial effects are expressed as improved performance on performance measurements and decreased measures of sleepiness on MSLT. Naps of durations varying from 20 minutes to eight hours were examined and there appears to be a dose-dependent effect with a greater improvement associated with longer naps. The negative effects of naps are the sleep inertia which varies from a few minutes to 35 minutes although most of these effects seem to disappear after ten to fifteen minutes. Naps taken in flight appear as a useful strategy to promote performance and alertness during critical phases of the flight, namely during take-off and landing. The naps are taken outside of these critical times and thus their planning is dictated by operational setting instead of physiology. The authors note that it is known that the circadian nadir occurring at the end of the night is a time prone to involuntary naps and associated with an increased ability to fall asleep. Therefore it appears reasonable to suggest strategic napping at that time. This is possible for CMV drivers but not always possible for aircrew since it may correspond to the time of landing.

Prediction of Recovery Effect of Naps (Fletcher and Dawson, 2001)

The aim of this study was to validate a computer model design to predict alertness levels based on the schedule of sleep and work. Data were analyzed for 193 volunteer train drivers within the Australian railway industry. They were 189 males and four females with an average age of 39.6. These subjects were chosen because they covered the range of possible conditions and among them some operated 24 hours per day. The number of hours worked per week varied between 40 and 80. The study schedule was determined several months in advance in certain groups and only one or two days prior to work in other groups. The input for the work related fatigue module was the start and end times of shifts with a minimum of seven days. Subjects completed a daily work diary. Visual analogue scales were used to measure self-rated alertness. A computerized test called “OSPAT” was administered. This test requires hand-eye coordination and measures reaction time and vigilance. It requires the subjects to return a randomly moving cursor to the centre of a circular target.

This test revealed a stronger relationship between predicted fatigue and self-rated alertness than between predicted fatigue and objectively measured performance. The fatigue model predicted self-rated alertness better in the afternoon and evening hours after having worked four consecutive shifts.

7 DISCUSSION AND CONCLUSIONS

7.1 Recovery and Trucking

A field study of recovery, based on a very limited sample of drivers, showed that, based on sleep and lane tracking data, 60 hours off are preferable to 36 hours, for both day and night drivers, but especially for the latter (Wylie, Shultz, Miller, Mitler and Mackie, 1997). Three daytime drivers, who had two work cycles off, showed no decline in performance, while those with 36 hours off showed some decline in performance when they started their second week of driving. In general, performance of night drivers was worse than that of day drivers. The night drivers who had 36 hours off had worse performance during the second week as compared to the first week of driving. Unfortunately the impact of 60 hours off on night drivers' recovery was not investigated in this study.

Under ideal conditions, no family or social commitments, unrestricted time for sleep on recovery days (O'Neill et al., 1999), a time-off period which allowed two full nights and one full day off, i.e. 36 hours, allowed full recovery from daytime driving. The main limitation of this study was that it was a laboratory study, restricted to daytime driving and there were no demands on the subjects competing for sleep time. As a result their sleep times were longer (on average 6.5 hrs during work periods) than those found in other studies. For example, Mitler et al. (1997) found subjects on the daytime schedule of ten hours driving starting at 09:00 slept an average of 5.4 hrs (time in bed 5.8 hrs) (Mitler, Miller, Lipsitz, Walsh and Wylie, 1997). This is 1.1 hrs less than the sleep obtained by the laboratory subjects.

Another laboratory study (Balkin et al., 2000), which also required subjects to carry out simulated driving during the day time, restricted sleep to three, five, seven or nine hours. Recovery was measured over a four day, three night period. Recovery sleep was restricted to that obtainable for eight hours in bed (on average 6.5 hrs). The main finding of this study was that, following significant and dose-dependent performance deterioration in the three, five and seven hour groups, there was minimal recovery for the group restricted to three hours in bed per night, and incomplete recovery for the groups restricted to five or seven hours in bed, in that not all tasks recovered baseline performance, even after three nights of sleep. Thus, in an environment in which subjects obtained less sleep, more typical of real world driving, even with a daytime schedule, and sleep taken at night, subjects did not fully recover in the 84 hour recovery period.

The three hour sleep group represents an extreme, as in this time period, subjects were able to obtain 2.9 hours of sleep on average. In the Mitler et al. (1997) study, which involved real-world driving, even in the worst condition of steady night driving, and with the interference of measuring equipment and study demands on the subjects, average sleep obtained was 3.8 hours.

An additional concern with the validity of the test conditions is that the restriction of sleep in the recovery period to 6.5 hours may be somewhat low. The O'Neill (1999) study, for example, allowed unrestricted sleep on recovery days, after daytime driving, and drivers slept 7.1 hrs on average on recovery days.

Neither the Balkin et al. (2000) nor the O'Neill et al. (1999) studies examined schedules in which drivers drove at night. In such circumstances, drivers must perform at night, when circadian rhythms result in sub-optimal performance, and sleep during the day, when the quality of sleep is poorer. For nighttime schedules, recovery would be expected to take longer than is the case for daytime schedules.

7.2 Recovery in Other Contexts

A meta-analysis showed that recovery, for most schedules, as measured by subjective sleepiness, was complete after one recovery day that included a full night's sleep, day or night, weekly or rapid rotation, regular or irregular. The exceptions were cabin crew flying across many time zones who required three days for full recovery, construction workers working seven consecutive 12 hour day shifts, who required three to four days off to reach normal sleepiness values, and oil platform workers working 14 consecutive 12 hour night shifts who were still not recovered after four to five days off. There were individual differences, in that, within 60 pulp and paper workers on the very rapidly rotating schedule, some recovered within the first recovery day, whereas others took three or four days to recover. The main weakness of this study is that only a subjective measure was used, and it is well known that workers can assess themselves as well rested, even though there are objective signs of impairment.

A study of a variety of schedules worked by nurses suggest that a number of measures such as alertness, sleep duration, mood and social satisfaction tended to be worst on the first rest day and at least two days of recovery is required (Totterdell, Spelten, Smith, Barton and Folkard, 1995). Alertness is still improving on the third day of recovery, suggesting that sleep debt might persist beyond two days of recovery. While night work appeared to require additional recovery time, too much recovery time may negatively affect adaptation to a nocturnal routine. Reaction time decreased over consecutive night shifts and tended to increase on rest days following night shifts.

In a review of countermeasures against fatigue, Akerstedt (1998) stated that most shift workers reported that they needed at least two days with two normal sleep episodes to recover after three consecutive night shifts. This study also demonstrated that the need for recovery increased by one day when working a succession of seven consecutive shifts. Evidence from studies involving jet lag indicates that it may take up to four days to recover after an acute shift of the sleep wake pattern.

A study of the effect of chronic sleep restrictions showed the same amount of sleep restriction with respect to hours had a much stronger effect on performance when the sleep taken was during the day, as opposed to at night (Rogers et al., 2000). This indicates that it is important to consider the timing of sleep as well as the duration of off duty time.

In a study by Price et al. (2000), subjects underwent 88 hours of sleep deprivation, followed either by two seven hour recovery nights followed by one 14 hour recovery night or three 14 hour recovery nights (Price, Rogers, Fox, Szuba, Van Dongen and Dinges, 2000). The results of this study indicate that providing a longer opportunity to spend time in bed, and to sleep, results in quicker recovery from acute sleep deprivation.

7.3 Individual Differences

In an on-road study of short-haul drivers on daytime schedules, Hanowski et al. (2000) found that drivers who showed evidence of fatigue and were involved in fatigue-related incidents had less sleep and of a poorer quality than drivers who did not show signs of fatigue. With respect to individual differences, ten of the 42 drivers were involved in 86 percent of the incidents. The younger and less experienced drivers were significantly more likely to be involved in critical incidents and exhibited higher on the job drowsiness. Since all drivers were on the same schedule, this study suggests that individual differences in amount of sleep taken affect performance. Whether these differences are as a result of drivers deliberately cutting sleep in order to participate in family, social or other obligations, or are a result of difficulty sleeping, remains to be determined.

In a comparison of permanent day and permanent night nurses, no differences were found in total sleep time (Quera-Salva, Guilleminault, Claustrat, Defrance, Gajdos, Crowe McCann and De Lattre, 1997). However, as compared to day nurses, night nurses tended to significantly increase their sleep on days off and to curtail their sleep on work nights. All night nurses reverted to daytime activities on their days off. Performance testing indicated that a minority of night nurses showed physiological adaptation to night work and had performance abilities similar to day nurses. Since these comparisons only involved six adapting night shift workers, this finding should be tested in future studies.

In a second study of nurses, Hennig et al. (1998) found that, among 24 nurses who worked seven consecutive night shifts, eighteen could be considered adapters, and six non-adapters, based on adaptation of cortisol levels. In contrast to the previous study then, the majority were adapters.

When melatonin rhythms were studied, a gradual shift of melatonin rhythm in seven of eleven night workers showed incomplete adaptation (Weibel, Spiegel, Gronfier, Follenius and Brandenberger, 1997). Day workers did not adapt when asked to sleep during the day.

In a field study of 15 nurses working regular night shifts, Boivin and James (2002) found that circadian rhythms can be realigned with the work schedule by a judicious schedule of light and darkness. The benefit of the approach was maintained even though all night nurses reverted to daytime activities on their days off. In another study, the authors demonstrated that daytime sleep following night shifts was significantly longer in nurses in the treatment conditions (James, Chevrier and Boivin, 2002). This observation indicates that the degree of circadian adaptation to shifted schedule can significantly affect the duration of recovery sleep.

In a review of individual differences in tolerance to shiftwork, Härmä discusses the impact of individual circadian rhythms (adaptation and phase), willingness to work nights, introversion-extroversion, chronotype, and gender issues (Härmä, 1992). Some of his findings are now considered questionable, although the negative impact of age has received continued support. For instance, many of the same factors were reviewed more recently by Nachreiner (1998), who concluded that none of them have a consistent predictive power to assess individual ability to adapt to shiftwork.

Nonetheless the author suggests that evening types adapt better and that slowly rotating systems are preferable.

In a review of various shiftwork schedules, Knauth (1997) makes recommendations on the design of shift systems. Of particular relevance to truck drivers, who work nights, and on rotating schedules, he recommends that shift workers need two days to recover from three consecutive nights and three days to recover from a series of seven consecutive night shifts. This suggests that a 36 hour recovery period would be insufficient to pay off the accumulated sleep debt. He recommends 1) that morning starts should not be too early, if feasible not before 06:30, and 2) that night shifts should start early in the night and allow the driver to sleep during the circadian nadir. This solution would substantially reduce micro-sleep episodes and fatigue.

A group of healthy individuals had three nights of normal sleep, followed by 24 hours of sleep deprivation after which they were allowed to sleep, starting in the morning (Gaudreau, Morettini, Lavoie and Carrier, 2001). Increased age was associated with a decreased ability to recover from sleep deprivation. As expected, slow-wave sleep was increased in both the young and middle-age groups following sleep deprivation. However, the rebound of slow wave sleep was significantly less pronounced in the middle-aged subjects. In another study of sleep deprivation in healthy individuals, Van Dongen et al. (2002) found that there are significant differences between individuals in vulnerability to performance impairments from sleep loss.

7.4 Sleep

The Balkin et al. (2000) study involved an actigraphic assessment of the sleep of 50 long and short haul CMV drivers over 20 consecutive days. Both groups averaged approximately 7.5 hours of sleep per night. While short-haul drivers obtained 3 percent of their sleep during on duty periods, long-haul drivers obtained 44 percent of their sleep during on duty periods. As long-haul drivers obtained almost half of their daily sleep during work-shift hours (mainly sleep-berth time), it appears that they spend a significant portion of the work shift in a state of partial sleep deprivation, until the opportunity to obtain on duty recovery sleep presents itself. There was no off duty duration that guaranteed adequate sleep for the long or short haul drivers. The authors note that as drivers likely use a substantial portion of their off duty time to attend to personal business, off duty time must be of sufficient duration to allow drivers to accomplish these tasks and to obtain sufficient sleep. This may be particularly important for long-haul drivers, who often did not sleep at all during off duty periods.

There were large day-to-day variations in total sleep time for drivers in both groups. Sleep times varied for some long and short-haul individuals by up to 11.2 hours across the 20 study days for the long and short-haul drivers. Other drivers maintained more consistent sleep/wake schedules. Some individuals showed a pattern that suggested chronic sleep restriction with intermittent bouts of extended recovery sleep.

7.5 Napping

Napping reduces sleep debt and for this reason may reduce recovery time. No studies were found on the relationship between napping and recovery in CMV drivers. However a number of studies showed the efficacy of naps in improving performance and reducing sleep debt.

In an examination of the napping behaviour of shift workers, Akerstedt and Torsvall (1985) found that the proportion of nappers decreased with increasing length of the major sleep period. In addition, while half of the workers normally took naps when on night shifts, almost no workers took naps on the afternoon shifts or days off. This suggests that napping is related to sleep debt. In a review Akerstedt et al. (1989) report a higher frequency of napping amongst shift workers as compared to day workers. Naps taken during the night shift were unauthorized and involuntarily, and occurred mainly during the second half of the night shift when sleepiness was as its peak. Napping was associated with a reduction of approximately two hours in the following main sleep episode.

Napping strategy was examined in permanent day and permanent night shift workers (Tepas, Carvalhais and Popkin, 1990). Five different napping strategies were defined, in relation to whether or not workers napped during the workweek or only on weekends or both, and the frequency with which they napped. The authors found that permanent night workers who napped were more likely to report difficulty sleeping. No evidence was found to suggest that permanent night workers who did not nap did not do so because they were naturally short sleepers. As has been found in previous studies, permanent night workers were more likely to nap and to experience difficulty sleeping than were permanent day workers.

A study involving long-haul truck drivers found that a three hour nap opportunity in the afternoon preceding a simulated night shift had beneficial effects on driving simulator performance and on subjective and physiological measures of alertness measured up to 14 hours later (Macchi, Boulos, Ranney, Simmons and Campbell, 2002).

A study involving air traffic controllers showed that a short workplace nap during a scheduled break on the night shift led to improvements in performance, despite its limited duration (about 18 minutes) and the fragmented nature of the sleep obtained (Signal and Gander, 2000). Similarly, the job-related performance of emergency room personnel was improved by a mid-nightshift 40 minute nap (Smith-Coggins et al., 2000). Caffeine and/or napping improved both alertness and performance during four simulated night shifts, with the greatest impact being on the first night shift, and for the combination of caffeine and napping (Schweitzer, Randazzo, Stone and Walsh, 2000).

A ten minute afternoon nap, following mild nocturnal sleep restriction, reduced subjective fatigue and improved performance for at least 35 minutes and improved alertness for at least one hour (Tietzel and Lack, 2000).

The effects of a one hour maximum nap on sleep length, perceived sleepiness and quality of life, were examined for night shift workers (Bonnefond, Muzet, Winter-Dill, Bailloeuil, Bitouze and Bonneau, 2001). The nap opportunity was found to lead to a general satisfaction about the ease of work at night, and an improvement in the general quality of life.

In a review of several studies, Rosekind et al. (1995) found that naps were effective in maintaining performance or in improving it during periods of extended wakefulness. Based on studies involving naps of durations varying from 20 minutes to eight hours, there appears to be a dose-dependent effect with a greater improvement associated with longer naps. Although sleep inertia can be a negative effect, its effects seem to disappear after ten to fifteen minutes.

A study which aimed to validate a computer model design to predict alertness levels based on the schedule of sleep and work test revealed a stronger relationship between predicted fatigue and self-rated alertness than between predicted fatigue and objectively measured performance (Fletcher and Dawson, 2001). The fatigue model predicted self-rated alertness better in the afternoon and evening hours after 4 consecutive shifts had been worked.

8 FACTORS TO BE CONSIDERED IN EXPERIMENTAL PROTOCOLS

One of the aims of the literature review was to identify factors that should be considered in the development of experimental protocols to determine recovery periods for commercial drivers which will result in a return to "normal performance levels" at the beginning of the next work week. Table 1 shows the factors that were identified with respect to schedules that should be examined, measures which could be used, subject selection criteria and restrictions, individual differences that might be examined, as well as other considerations.

With respect to the schedules which should be studied, while there have been laboratory and on road studies of day time driving in relation to recovery, there is minimal information on nighttime driving and recovery. Given the difficulty of obtaining good quality sleep during the day, and the sleep debt associated with night driving, studies of recovery from nighttime driving are particularly critical. Based on the study of nurses on a variety of schedules, two recovery days were required based on measures of alertness, sleep duration, mood and social satisfaction. Alertness was still improving on the third day. In a study by Kecklund and Akerstedt, most shift workers reported that they needed two days with two normal sleep episodes to recover after three consecutive nights, and an additional recovery day after seven consecutive nights (Kecklund and Akerstedt, 1995). Using a small sample of drivers who completed four 13 hour night shifts, Wylie et al. (1997) found that, after a 36 hour recovery period, performance was worse than it had been at the start of the previous week. Based on these studies, recovery periods examined in experimental protocols should include, at a minimum, no recovery, one night, two nights, and three nights.

With respect to measures, most studies involve subjective, physiological and performance measures. Subjective measures are relevant when doing studies on fatigue because it is essentially a subjective concept. However, subjective measures by their very nature are subject to individual interpretation and bias. Such measures can also be manipulated by respondents to reflect other environmental biases. However, careful, within subject comparisons of valid instruments that have been assessed for reliability and internal bias can be helpful in assessing fatigue, performance and sleep especially if they are assessed along with other more objective measures.

Physiological measures are good objective measures, but when used as psychophysiological measures, i.e., physiological measures that are intended to reflect psychological concepts such as fatigue, can be subject to difficulties in interpretation. For instance, EEG measures can serve as good measures of alertness and fatigue since there is a wide body of literature relating EEG frequencies to drowsiness potential. Eyelid closures can also be useful since it is difficult to respond to stimuli in the environment if the eyes are not sufficiently open to acquire the stimuli. On the other hand, the interpretation of measures such as heart rate are more difficult to assess since heart rate can vary because of many parameters and without sufficient control over the environment, such measures are difficult to interpret.

Performance measures can be used as effective probes to assess performance and change in performance associated with fatigue. Such measures, that have been used successfully, include the PVT, a cognitive test that is very sensitive to sleep deprivation and circadian rhythm, and was used in many of the studies we reviewed. In addition, performance measures should include driving measures, particularly lane tracking variability, which has been shown to be sensitive to drowsiness and fatigue. Driving performance may not be as sensitive as PVT, for example, but they have strong face validity. Measures involving the identification of driving incidents are of particular interest.

With respect to subject screening criteria, age has been clearly associated with sleep quality and length especially for shift workers. Drivers with untreated sleep disorders should be screened out. Currently, there are effective screening tools to assess, in a self-administered fashion, the most common sleep disorder of concern, that is, sleep apnea. Instruments such as the Edentrace and the Sleep Strip can be used at home by participants. Simple instructions are given and the results are stored for later interpretation. Full polysomnographic screening is no longer necessary. In order to understand individual differences in recovery many variables should be recorded, whether or not they are used as screening criteria. These include chronotype, napping behaviour, caffeine, alcohol and drug use, family circumstances, and commuting distance.

The impact of napping on the length of recovery should be examined, as should the effect of age and other individual differences such as being a circadian adapter, a napper, having a particular chronotype, and lifestyle issues.

Table 1. Potential Factors to Be Considered in Experimental Protocols

SCHEDULES

- Daytime, nighttime, regular, irregular
- Length of recovery period
- Length and timing of sleep allowed during work
- Length of sleep allowed during recovery
- Loading/unloading activity – length and timing
- Naps allowed during work

MEASURES

- Desirable characteristics of measures: naturalistic or short learning curve
- Sensitivity to circadian phase, sleepiness
- Subjective measures
  - Stanford sleepiness
  - Sleep diaries (length and quality and alertness after main sleeps and naps)
  - Driver assessment of whether recovery sleep was as long as was needed and if not, what prevented them from obtaining adequate sleep – difficulty sleeping or social/family/other engagements
  - Job satisfaction
- Physiological measures
  - EEG
  - Polysomnographic sleep recordings
  - Wrist actigraph
  - Urine melatonin levels
- Test battery measures
  - PVT (lapses, fastest 10 percent)
  - Cognitive test battery (e.g., Walter Reed Test Battery)
  - Driving performance measures – simulator/on-road
    - Lane position variability
    - Speed maintenance
    - Shifting performance
    - Response probes (e.g. fog)
    - Critical incidents assessed by video/instructors
- To be recorded
  - Caffeine consumption
  - Exposure to light
  - Drug use
  - Prior sleep-wake schedule

Table 1 (continued)

SUBJECT SCREENING CRITERIA

- Smoking
- Caffeine use
- Alcohol use
- License type
- Age
- Sleep disorders
- Chronotype
- Toxicological screening for illicit drugs

INDIVIDUAL DIFFERENCES

- Age
- Gender
- Height/weight ratio as indicator of physical health
- Traits predictive of vulnerability to performance impairment due to sleep loss (health status, sleep disorders, family situation, chronotype)
- Habitual napper or non-napper
- Psycho-social factors (young children at home, commuting distance)

RESTRICTIONS

- Rest time
- Location of rest
- Caffeine
- Alcohol

OTHER CONSIDERATIONS

- Impact of study demands on subjects' ability to sleep
- Unexpected delays (customs, traffic, etc.)

9 EXPERIMENTAL PROTOCOL OPTIONS

The ultimate aim of Phase I of this project is to provide a range of experimental protocols that are designed to address the specific question of recovery from fatigue. In this section we develop 8 scientifically sound experimental options. These options will be expanded in Phase 2, at a second scenario development workshop involving the team members, and then debated by key experts and stakeholders.. This debate is expected to yield the most appropriate scientific and pragmatic experimental options to provide more definitive guidance to regulate recovery periods for commercial motor vehicle drivers. In addition, this debate is expected to identify the limitations of specific approaches so that it will be clear what questions the experiments can answer and what questions the experiments will not be able to address. Over-the-road field assessments, and laboratory and epidemiological studies were considered as well as options to investigate the impact of individual differences and circadian factors on recovery.

9.1 Goals and Assumptions of the Proposed Study Options

The fundamental goal of the study options is to determine how long a period of time off is required for drivers to recover to their rested state after a sustained period of work. Studies will be carried out within the current applicable laws and hours of service regulations. A driver will be considered recovered when the following are equivalent to (or at least not significantly different from) that obtained when the driver has been off work for several days:

- Quality and length of sleep
- Driving performance
- Subjective alertness

Because performance and alertness vary by time of day, a driver will be considered recovered when performance and alertness are equivalent to rested performance and alertness measured at the same time of day.

In the literature review it was determined that 1) circadian factors and consecutive driving days/nights are the primary factors that affect fatigue, and, 2) age is the primary individual difference variable that may influence fatigue and subsequent recovery. Clearly all test conditions must induce some degree of fatigue and then establish the effectiveness of recovery options based on the degree of fatigue. Both fatigue and recovery are influenced by circadian rhythms so this factor is key to the design of studies. Since age is a critical individual variable, each study should include sufficient numbers of subjects to make comparisons on the basis of age.

A number of experimental protocols are outlined below. The experimental protocols include laboratory, field and epidemiological studies. Having noted that a variety of approaches to assessing recovery are possible, it is clear from the literature review and our own knowledge concerning the acceptability of research findings by the industry and by regulators that field assessments of drivers must be the primary focus of the assessment. The most influential studies in the past have been field studies. While laboratory studies have the advantage of rigor and control over a wide variety of factors that can confound or otherwise influence the outcomes, they are necessarily artificial with regard to stressors that exist in the commercial motor carrier environment – notably the hazards associated with the real task of driving and controlling a tractor-trailer for long periods over many days and attempting to recover from that task, in the face of family and social obligations. Nevertheless, laboratory experiments that clarify field-oriented questions are scientifically valuable and can positively impact the design of key field experiments. Therefore, our approach has been to consider the laboratory studies as either answering specific questions that need more rigorous control or establishing individual differences in individuals that may be predictors of recovery in field settings. The importance of those factors would then be validated in field studies. For this reason the core study is a field study, and this is described first. Options involving variations on parameters within this core field study are addressed following an understanding of this fundamental study.

9.2 Hypotheses to be Tested

The hypotheses to be tested in the 8 options outlined below are as follows.

1. Options 1, 2, and 3: A period of night driving followed by another period of night driving will require a longer recovery period than a period of day driving followed by more day driving. Night to day driving will require an intermediate recovery period.

2. Option 4: A mandatory two hour sleep opportunity (an element proposed for fatigue management plans) as compared to little or no napping between midnight and 6 am will shorten the recovery period after a period of night driving.

3. Option 5: Drivers with self-perceived difficulty with night driving and recovery will require longer recovery periods.

4. Option 6: Drivers with consolidated sleep during a period of driving will require less recovery time than drivers with fragmented sleep. This effect will be more pronounced for recovery after night driving than for recovery after day driving.

5. Option 7: Shorter work periods will result in shorter required recovery periods

6. Option 8: Shorter recovery periods, a higher percentage of night driving, longer working times, and longer times since last sleep increase crash risk.

We propose to test Hypotheses 1 and 2 in field studies, Hypotheses 3, 4 and 5 in laboratory studies, and Hypotheses 6 in an epidemiological study of crashes and controls.

9.3 Option 1: Core Field Study for Night Drivers

The assumption behind this core field study is that the impact of different recovery time periods should be assessed following a common, yet challenging, work schedule of drivers. While the specific work schedule and recovery periods will be refined at a later time based on the responses to our Driver Workload and Recovery Questionnaire as well as input from industry stakeholders, the parameters defined here are our best estimates of industry standards and our knowledge of the literature.

9.3.1 Experimental Design

The basic experimental design will be a three-group repeated measures design where three groups of drivers are monitored for fatigue over consecutive shifts of night driving followed by three different recovery opportunities. A work period will follow the recovery period.

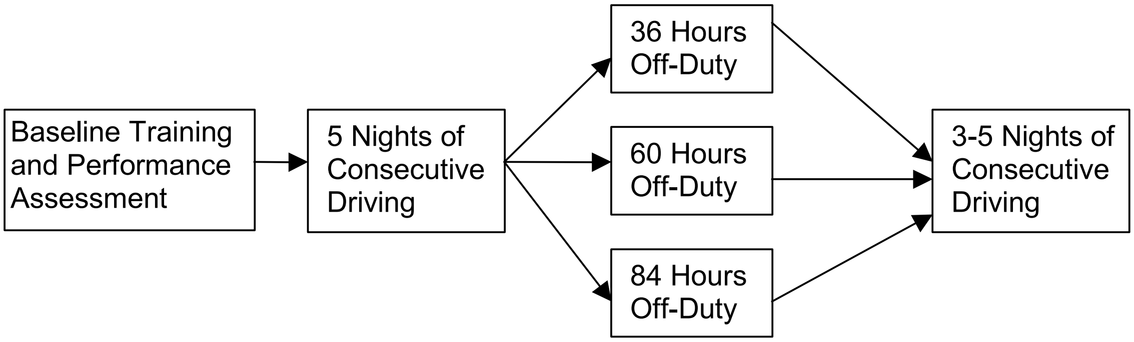

Figure 1. Option 1: Core Field Study for Night Drivers

9.3.2 Design and Parameter Rationale

The recovery time available to drivers is systematically manipulated. This variable recovery period is followed by a subsequent work period to assess adequacy of the recovery period. For recovery periods where full recovery occurs, the decline in performance seen over the second period of work should be similar to that seen over the initial period of work. If recovery is incomplete following the recovery opportunity, it would be expected that performance across consecutive driving periods would decline earlier than in the first set of night driving periods and that the decline would likely be of greater magnitude.

The basic design above begins with a baseline training period to familiarize drivers with and develop skill on the performance assessment tools (described later). To ensure that drivers begin the study in a well-rested condition, they will be required to have been living on a day-oriented schedule for at least one week and meeting their daily sleep requirements, and to have had at least three days off immediately before the described work period.

During the three days of non-driving, drivers would be trained on the performance measures and other assessments (on-route subjective measures). Also the quantity of sleep (using actigraphy) in the period immediately before driving would be recorded.

The five nights (defined as driving at least four hours during the 22:00 to 06:00 period) of driving was chosen because it is a relatively common occurrence yet is likely to maximize the fatigue that would develop under normal operational conditions. In addition five nights of driving (assuming some 10-12 hours per night) would be consistent with the current Canadian Hours of Service regulations. If typical hours of work reflect maximum hours allowable, the five nights of driving may have to be reduced to four nights of driving. Any such change to four nights should be decided before the study commences to maintain consistency across all conditions.

The recovery periods were intended to cover a normal range of off duty time. The 36 hours off duty after the finish of a final night of driving would allow drivers to obtain both some day sleep as well as some night sleep in that 36 hour period and then return to the same night driving schedule as they worked earlier. This 36 hour recovery period was also chosen because this is the minimum recovery period recommended under the proposed Hours of Service regulations. The 60 and 84 hours of time off would allow an additional one and two nights for sleep before returning to night driving. (It should be noted that a standard weekend for nine to five work allows 64 hours off and three night sleep opportunities) Thus, drivers in this study would obtain one, two, or three night sleep opportunities. Prior to the Balkin et al. (2000) study, the recovery manipulation would have been restricted to 36 and 60 hours. The Balkin et al. study examined recovery following day driving after time in bed periods of three, five, seven and nine hours and suggested that full recovery may not occur after 2 nights of sleep following periods of partial sleep deprivation. Since shiftworkers and commercial drivers typically report only five to six hours of sleep in a 24 hour period when they are working primarily night shifts, the Balkin et al. study would suggest that recovery may not be complete even after 60 hours. Therefore it is recommended that an 84 hour condition be included.

The subsequent work period is suggested to be a minimum of three nights and a maximum of five nights. For recovery periods where full recovery occurs, the decline in performance seen over the second set of five night shifts should be similar to that seen over the initial five nights. When full recovery occurs, a shorter period of three nights may be sufficient to document similar declines in function in the first and second set of night shifts. Similarly, if full recovery is not evident, less subsequent driving will be required to demonstrate that only partial recovery has occurred. Ideally, the subsequent driving period should be five nights but it is recognized that if recovery is incomplete then driving may be hazardous if prolonged and this three to five night window allows and encourages drivers to withdraw from the study if fatigue becomes a safety issue.

In this and in all other study options, safety of drivers is paramount. From an ethical perspective, the informed consent process will make it clear to drivers that they are free to deviate or withdraw from the study at any time. Their safety must be the paramount factor in making driving/resting decisions.

9.3.3 Drivers

In this study, driver demographic characteristics (types of driving, years of experience, experience with night driving, self-perception of adaptability to night driving, etc) will be used as covariates in order to determine their relationship to recovery. Since age is an important individual difference variable, study groups will be balanced or stratified according to age category. Ideally the driver populations volunteering for this study would be stratified by age into four groups: under 30, 30-39, 40-49 and 50 years of age and over. If this is not possible, age will be used as a covariate as well.

9.3.4 Measures

Subjective, objective behavioural probe measures, and driving measures are possible in this study. At a minimum, subjective and objective measures of fatigue and sleep are required.

Subjective assessments of fatigue, drowsiness and the quantity and quality of sleep will be carried out using logbooks. All sleep periods will be recorded. Both fatigue (disinclination to continue working) as well as drowsiness (potential for falling asleep) will be measured. Since the drivers will be night driving, fatigue and drowsiness will be assessed at the beginning, middle and end of each shift. To ensure that time of day is taken into account, two hour time windows will likely be defined where the beginning of night driving should ideally be rated. These two hour windows will be separated from each other by two to three hours. This separation ensures that measurements taken one minute apart are not allocated to different circadian periods, but are clearly separated. The time periods will the same for all options, to allow comparability, and measurements will be made only in those time periods when drivers are awake. The time periods used will be 03:00-05:00 (early morning and circadian nadir), 09:00-11:00 (mid-morning), 13:00-15:00 (post-lunch dip), 18:00-20:00 (circadian peak) and 22:00-24:00 (late evening). For night drivers, measurements will not likely be collected in the 09:00-11:00 and 13:00-15:00 periods.

Objective measures should minimally include an actigraphy assessment to assess sleep/wake patterns. Actigraphy could be collected over the entire protocol duration. Behavioural assessments should include the psychomotor vigilance task (PVT) as this test has been used in numerous previous studies and will be used in the study “Evaluation of a North-American Fatigue Management Program for Commercial Motor Carriers”. In addition, a computerized test called “OSPAT” should be considered. This test was used in an Australian train driver study of napping and is a simple random visual-motor tracking task that requires hand-eye coordination and measures reaction time and vigilance. It requires the subjects to return a randomly moving cursor to the centre of a circular target. Both of these behavioural tasks should be administered at the same time on each shift as the fatigue and drowsiness assessments.

This study should also incorporate driving performance measures. The objective performance measure that has been most reliably shown to be affected by drowsiness is the standard deviation of lane position. The main concern with this measure is that it is affected by road geometry and vehicle type. In the U.S. /Canada study by Wylie et al. (1997), the comparisons of U.S. and Canadian shift lengths (ten vs. thirteen hours) were confounded by differences in routes and in vehicle types, which were likely responsible for unexpected findings associated with lane tracking. In the study being proposed, this would not be a concern, as long as drivers were on the same routes, and within subject comparisons can be made with regard to whether or not full recovery has occurred, after a specific recovery period.

Other driver performance measures which have high face validity and have been used in previous on-road studies (Hanowski, Wierwille, Gellatly, Early and Dingus, 2000) involve analysis of videotapes of the three minute intervals preceding the start of critical incidents. An incident was defined as a control movement exceeding a threshold, based on driver or analyst input. Analysts recorded eye transitions and the proportion of time that the driver’s eyes were closed/nearly closed, or off the road, during these three minute intervals. Since critical incidents in which the drivers were at fault averaged 1.8 per driver over two weeks of driving, more continuous measures of driving performance, such as lane position variability, will be required.

The subjective and objective behavioural probes should also be measured during the recovery periods at the same time of day as was the case during the driving days, with the exception of the 02:00-05:00 test time where drivers will be sleeping on their recovery days.

Physiological measures are more cumbersome and do not appear recommendable though the expert panel may debate this issue and stakeholders may prefer such objective physiological measures. The primary reason for not recommending physiological measures is that the "gold standard" measure of circadian rhythm is core body temperature. The "gold standard" measures for sleepiness are EEG/eye closure. None of these measures are easily collected during a field study. Moreover, accurate body temperature measures are intrusive and EEG and eye closure (PERCLOS) measures are extremely resource intensive with respect to analysis.

9.4 Option 2: Field Study Variant – Night Drivers Moving to Day Driving

The basic assumptions behind this study are essentially the same as those of Option 1. The main difference is that the second set of shifts will be day driving instead of night driving. The move for drivers to day driving is based on the assumption that driving duties will be shared equitably in companies between day and night assignments and/or that drivers will likely move from a period of night driving to a period of day driving. From a circadian perspective, which has been shown in the past to be the predominant factor affecting fatigue, it can be reasonably assumed that the adaptation back to day driving will be easier given that the night driver initially will revert to days on their time off at home and thus will be better acclimatized to adapt to day driving. Moreover, despite the occurrence of night shifts, drivers will still be sensitive to the influence of environmental synchronizers, and most of them will not revert their circadian system to a night-oriented schedule. The same basic study design is proposed but, due to the switch from night to day driving, the proposed recovery periods are shorter. Of course the specific parameters may be altered based on results from the Driver Fatigue and Recovery Questionnaire and influenced by the consultation workshop.

9.4.1 Experimental Design

The basic experimental design will be a three-group repeated measures design where three groups of drivers are monitored for fatigue over consecutive shifts of night driving followed by three different recovery opportunities. A work period will follow the recovery period.

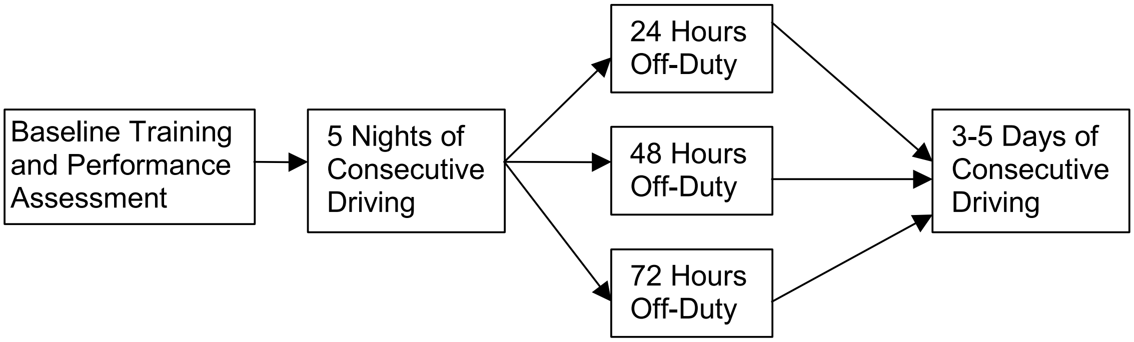

Figure 2. **Option 2: Field Study Variant – Night Drivers Moving to Day Driving**

9.4.2 Design and Parameter Rationale

The only manipulation is the amount of recovery time available to drivers. This variable recovery period is followed by a subsequent work period to assess the adequacy of the recovery period. Because of concerns about the adequacy of a 24 hour recovery period after five nights of driving, we propose that such a recovery period be included only if the results of the Driver Fatigue and Recovery Questionnaire indicate that this is something drivers typically do. Furthermore if the 24 hour recovery period condition is included, the schedule must conform to the hours of service regulations. It may not be practical to find drivers on a schedule that allows five nights of driving, followed by 24 hours off, and then more driving, which fits the regulations.

As in Option 1, we propose a baseline training period for familiarization and skill development on the performance assessment tools. The initial five nights (defined as driving at least 4 hours during the 22:00 to 06:00 period) of driving was chosen because it is a relatively common occurrence yet is likely to maximize the fatigue that would develop under normal operational conditions. In addition five nights of driving (assuming some10-12 hours per night) would be within the current Canadian hours of service regulations. The results of the Driver Fatigue and Recovery Questionnaire will be used to determine typical lengths for night driving shifts. If experimental conditions are to reflect typical hours of work, the five nights of driving may have to be reduced to four nights of driving, to stay within the regulations.

The recovery periods were intended to cover a normal range of off duty time. The 24 hours off duty after the finish of a final night of driving would allow drivers to obtain both some day sleep as well as some, though perhaps more limited, night sleep based on their start time the next morning. This 24 hour recovery period was also chosen because this is the minimum time period that should be expected given that there is an opportunity for two recovery sleep periods as well as one of those recovery sleep periods being a night sleep period. Such a sleep schedule might promote recovery to normal daytime circadian rhythms. The 48 and 72 hours of time off would allow an additional one and two nights for sleep before returning to day driving. This design assumes that night drivers naturally return to day driving and therefore might be able to make the adjustment faster, than night drivers returning to night driving after recovery, thus requiring less recovery time.

The subsequent day driving work period should be a minimum of three days and a maximum of five days. As drivers will tend to resynchronize to normal circadian rhythms on this schedule, it is expected that fewer days of driving (vs. nights) would be necessary to demonstrate that full recovery has occurred. Of course, such evidence is more convincing if longer driving periods (e.g. five days) can be measured.

9.4.3 Drivers

Driver characteristics will be as described for Option 1.

9.4.4 Measures

Subjective, objective behavioural probe measures, and driving measures will be similar to those described in Option 1 with the following exceptions. As the drivers will be initially driving nights, subjective and behavioural measures will be collected in a manner similar to Option 1, i.e., at the beginning, middle and end of the night driving at windows 18:00-20:00, 22:00-24:00 and end 03:00-05:00, where possible. On recovery days, similar measures should be taken with windows of measurement including 18:00-20:00, 22:00-24:00 where possible. For day driving subsequent to recovery, beginning, middle and end of shift times should be used and possibly an additional measurement period in the evening. Thus, morning, afternoon and evening periods of measurement should be used which should include, where possible, the 09:00-11:00, 13:00-15:00. and 18:00-20:00 windows of assessment.

9.5 Option 3: Field Study Variant – Day Drivers Continuing with Day Driving

The basic assumptions behind this study are essentially the same as those of Options 1 and 2 but for day driving only. Currently there is no distinction in the hours of service regulations between day and night driving but the literature indicates that night driving is more problematic. To consider the maximum exposure allowed under the current hours of service regulations, yet with the minimum disruption of circadian rhythms, Option 3 allows for maximum daily exposure of working but eliminates the circadian impact by only considering day driving.

The same basic study design is described but only two recovery periods for assessment – 36 and 60 hours – are proposed, and only day driving.

9.5.1 Experimental Design

The basic experimental design will be a two-group repeated measures design where two groups of drivers are monitored for fatigue over consecutive shifts of day driving followed by two different recovery opportunities. A work period will follow the recovery period.

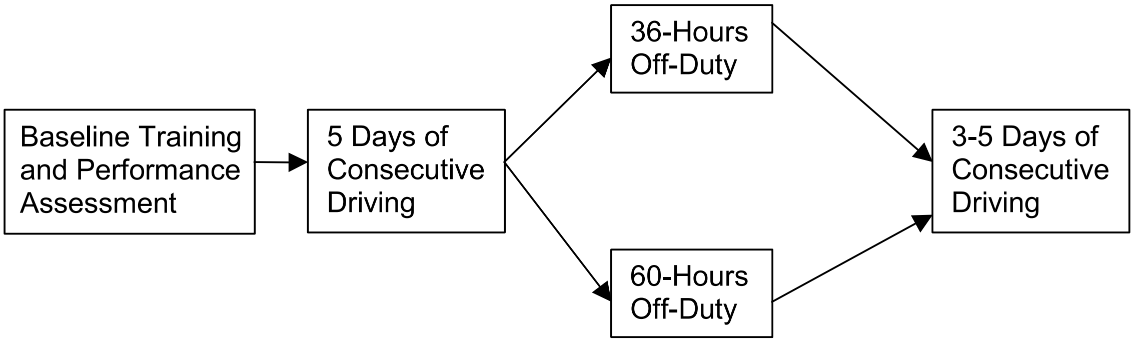

Figure 3. Option 3: Field Study Variant – Day Drivers Continuing with Day Driving

9.5.2 Design and Parameter Rationale

The recovery periods were intended to cover a normal range of off duty time. The 36 hours off duty after the finish of a final day of driving would allow drivers to obtain two normal nights sleep and additional naps if needed. The 60 hours of time off would allow an additional night for sleep before returning to day driving.

As drivers will be synchronized to normal circadian rhythms on this schedule, it is expected that fewer days of driving would be necessary to demonstrate full recovery that is sustainable. Of course, such evidence is more convincing if longer driving periods (e.g. five days) can be measured.

9.5.3 Drivers

Driver characteristics will be as described for Option 1.

9.5.4 Measures

Subjective, objective behavioural probe measures, and driving measures will be similar to those described in Option 1 with the following exceptions. As the drivers will be initially driving days, subjective and behavioural measures will be collected at times which overlap some of the times proposed in Option 1. Measures will be taken at the beginning, middle and end of the day driving where assessments are performed, where possible, during the following two hour windows: 07:00-09:00, 13:00-15:00, and 18:00-20:00. On recovery days, measures will be collected during the same two hour windows. If any of the earlier options are studied, these time windows will allow a comparison with the night driving time window of 18:00-20:00.

9.6 Option 4: Night Driving Field Study with and without 2 Hour Nap

The focus of this study is an intervention condition, which is proposed as an element of Fatigue Management Plans. This intervention is a two hour nap opportunity between 24:00 and 06:00. The purpose of this option is to determine whether such a nap reduces the required recovery period. The assumptions behind this study are essentially the same as those of Options 1-3.

9.6.1 Experimental Design

The basic experimental design will be a mixed two (two hour nap or not) X three (recovery period) groups repeated measures design where three groups of drivers are monitored for fatigue over consecutive shifts of driving followed by three different recovery opportunities. Half of the each group will have a two hour nap opportunity while the other half will not be asked to do this. Those not asked to take a two hour period for napping, will not be prevented from napping if that is what they normally do. This is critical from an ethical and safety perspective. To ensure that the drivers in the "no nap" condition have much less or no nap time as compared to the drivers in the "nap" condition, it will be important to select drivers who normally drive at night without napping. In all other respects, the same driver selection criteria and measures are proposed as in Option 1.

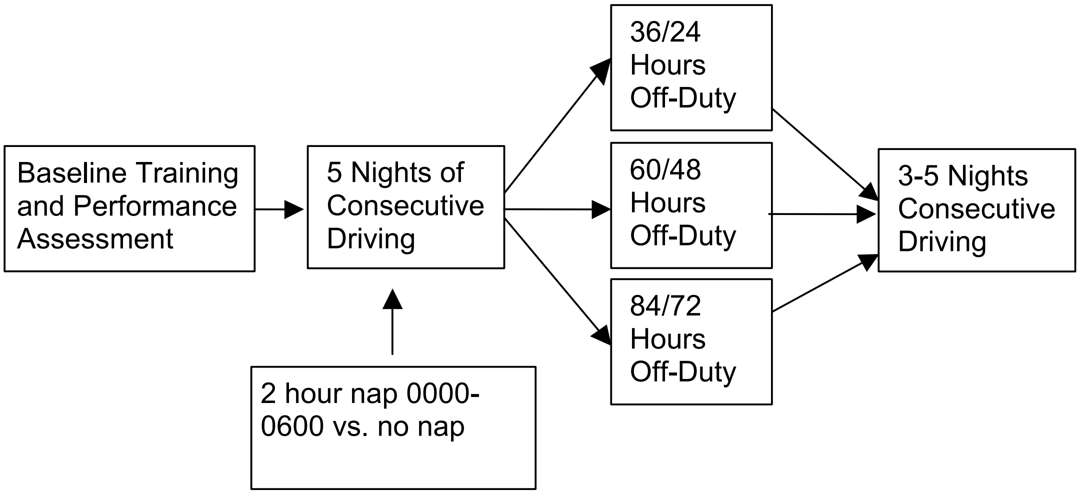

Figure 4. Option 4: Field Study Variant – Plus or Minus 2 Hour Nap

9.6.2 Drivers

Driver characteristics will be as described for Option 1, with the exception noted above, that drivers not accustomed to regular napping during the night shift will be selected.

9.6.3 Measures

Subjective, objective behavioural probe measures, and driving measures will be similar to those described in Option 1.

9.7 Option 5: Laboratory Study of the Relation Between Self-Perceived Difficulty with Night Driving and Recovery

While we know that fatigue and recovery are experienced very differently from one individual to another, we do not have evidence that this self-perception is accurate with respect to performance deterioration or subjective sleepiness. This option first involves assessing the self-perceived susceptibility to fatigue and drowsiness driving by developing a questionnaire, then using that questionnaire to select and/or classify subjects according to their degree of susceptibility, and then testing the validity of the self-perception in a laboratory study. Using night driving as an example, the questionnaire might use the following criteria:

Self-perception of night driving:

- Little problem with night driving
- A lot of problems with night driving

Self-perception of recovery:

- Little problem with recovery after night driving
- A lot of problems with recovery after night driving

Self-perception can also be assessed with respect to problems associated with long driving or recovery need after designated work periods.

The previous options can serve as a basis for assessing self-perception of fatigue in specific circumstances. In all options self-perception of fatigue and recovery should be assessed so that groups can be appropriately balanced. This variable can also serve as a covariate in the examination of the impact of the various recovery periods.

If the laboratory study were conducted prior to any of the field studies, then it would serve as an objective measure of susceptibility to circadian rhythm impairment and degree of recovery from sleep, and subjects could be screened or classified according to this susceptibility, using screening criteria shown to be predictive of performance.

9.7.1 Experimental Design

In the laboratory study depicted below, drivers would be brought into the laboratory for a single night of sleep deprivation. Subjects would arrive after a normal day of activity on a day off and be trained on the tasks that will be used in the subsequent laboratory study. They would then be kept awake for a single night of sleep deprivation where their fatigue and performance levels would be recorded on an hourly basis to assess the impact of sleep deprivation on fatigue and performance levels during the circadian low points.

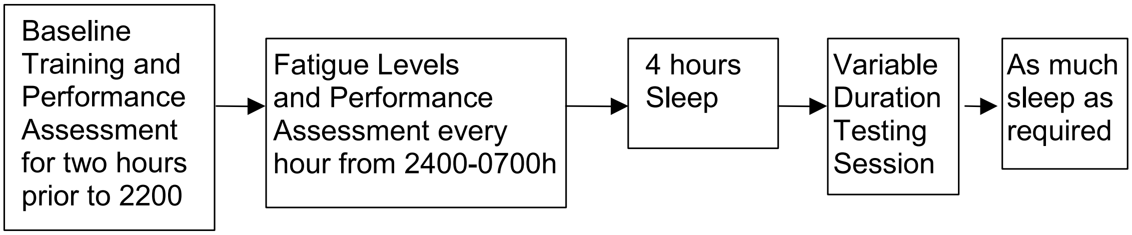

Figure 5. **Option 5: Laboratory Study Variant, Determining Predictive Validity of Self-Perceived Susceptibility to Fatigue**

To assess individual differences in the recuperative power of sleep, it is proposed that drivers be given an opportunity to sleep after the night of sleep deprivation and then enter a continuous assessment period where the degree of recovery in performance is assessed as well as the sustainability of that performance.

9.7.2 Design and Parameter Rationale

Given that previous trucking studies have indicated that truckers obtain only about four to five hours sleep during night driving, it is proposed that an initial assessment of the propensity for recovery is made by waking drivers after four hours of sleep. It is further proposed that this sleep period be followed by a continuous assessment period to assess fatigue and performance (similar to the hourly testing during the first night of sleep deprivation). This second assessment period of fatigue and performance could last for perhaps as long as another 24 hours.

It is proposed that this testing session be variable in duration and be terminated based on the degree of performance impairment on standardized measures. It is proposed that the recovery portion of the study be terminated when a 20 percent decline in performance occurs compared to the performance at the beginning of the study. Thereafter, drivers will be sent home by an appropriate method to obtain as much sleep as needed.

To account for learning effects which may well be present even after extensive training, performance after sleep will be compared to the best performance before sleep, even if that best performance is not the initial performance. Furthermore, the threshold used for optimum performance should be sustained across more than one measurement period, to avoid an artificially high statistical “blip” in performance.

Such a study would serve to characterize the drivers by way of the impact of circadian rhythms on their performance as well as the ability of drivers to recover quickly from periods of sleep deprivation. Such data would be very useful in terms of more objectively defining the susceptibility of drivers to circadian and recovery factors prior to entering into the field options listed earlier.

9.7.3 Drivers

Driver characteristics will be as described for Option 1. However, drivers may be selected according to extremes of self-perceived susceptibility to fatigue during driving.

9.7.4 Measures

Performance measures would include those objective measures to be used in field studies as well as standardized laboratory tests assessing cognition and attention. Driving simulator performance measures could also be included, and possibly used as a continuous task to better assess performance over time. In this manner susceptibility to circadian variation would be objectively defined.

9.8 Option 6: Laboratory Study of Impact of Consolidated vs. Fragmented Sleep on Recovery

The focus of this study is advice proposed as an element of Fatigue Management Plans. This advice is to encourage consolidated as opposed to fragmented sleep. While studies have suggested that consolidating sleep is beneficial, no studies have examined this issue with respect to recovery. The purpose of this option is to determine whether consolidated sleep reduces the required recovery period.

The basic assumptions behind this study are essentially the same as those of Options 1-3. Specifically, this study will help determine whether one consolidated sleep opportunity of eight hours, at an inappropriate time (falls at wrong circadian phase), gives less recovery than two four hour recovery sleep opportunities falling at a good circadian phase. In addition, it will help determine whether one consolidated sleep opportunity of eight hours, falling at a good circadian phase, gives more recovery than two periods of four hour recovery sleep also falling at a good circadian phase.

9.8.1 Experimental Design

The experimental design will be a mixed two (sleep conditions: fragmented or consolidated) x two (sleep times: good or bad) x three (recovery period) groups repeated measures design where three groups of drivers are monitored over five days/nights of driving followed by three different recovery opportunities (i.e., 36, 60 or 84 hours off duty). A driving period of three to five days/nights will follow the recovery period.

Comparisons that can be made are the impact of consolidated sleep vs. fragmented sleep on recovery from night driving, and the impact of consolidated sleep vs. fragmented sleep on recovery from day driving.

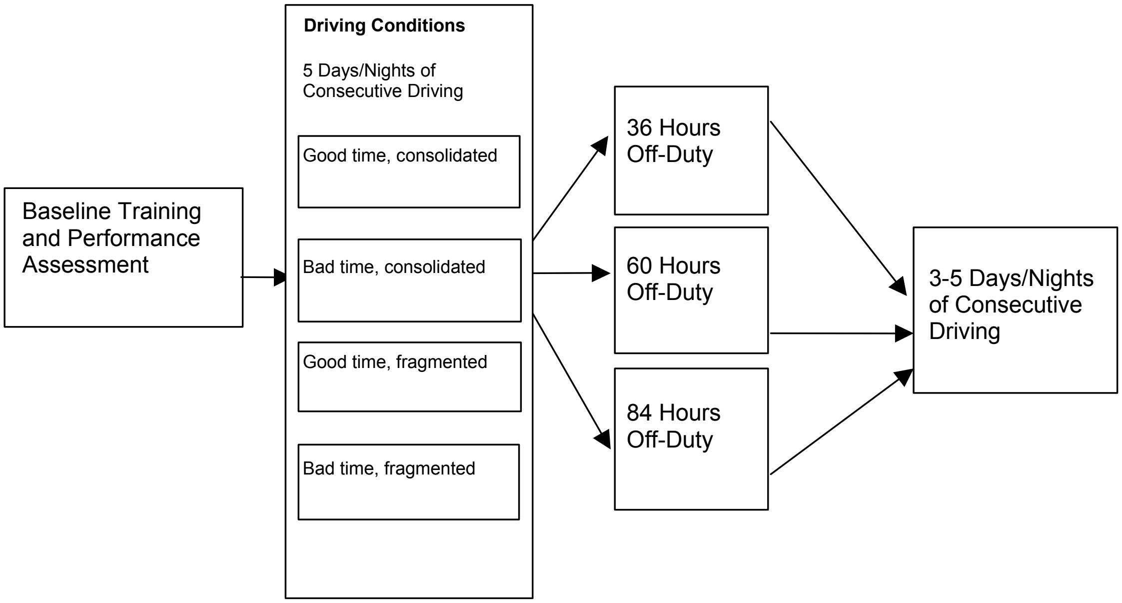

Figure 6. **Option 6: Laboratory Study of Impact of Consolidated vs. Fragmented Sleep on Recovery**

9.8.2 Design and Parameter Rationale

The design is a mixed repeated measure design. Sleep time and type (i.e., adequate or inappropriate scheduling), and driving times will be manipulated as well as the amount of recovery time available to drivers. The four sleep conditions will include combinations of good and bad sleep times and good and bad sleep types (consolidated vs. fragmented). Condition 1 is an optimal sleep time and a consolidated sleep. Condition 2 has an optimal sleep time but sleep is fragmented. Condition 3 is a “bad” sleep time but is consolidated. Finally, Condition 4 is at a bad sleep time and is also fragmented. Whenever feasible, the same methods to measure performance as those proposed for field studies will be used.

Drivers will participate in twelve hours of “driving time” (a mix of time in a driving simulator as well as participation in subjective and objective measures of fatigue) for each of the five days. To ensure that the study is not confounded by differential sleep times, each of the four conditions will receive the same amount of time in bed (maximum of eight hours) for each of the five days of the driving conditions. The drivers will have a *total* of 12 hours off (including eight hours in bed) each of the five days. The drivers’ total rest times as well as their sleep and drive times can be seen in Table 2 below.

Table 2. Sleep, Drive and Rest Times for Option 6

	Condition 1: Good sleep time – Consolidated	**Condition 2: Good sleep time – Fragmented**	**Condition 3: Bad sleep time – Consolidated**	**Condition 4: Bad sleep time – Fragmented**
Total Rest Times (includes sleep times)	1000 – 2200	0100 – 0700 1300 – 1900	0900 – 2100	1000 – 1600 2100 – 0300
Sleep Times *(max. 8 hours)*	0000 – 0800	0200 – 0600 1400 – 1800	1100 – 1900	1100 – 1500 2200 – 0200
Drive Times *(12 hours)*	1000 – 2200	0700 – 1300 1900 – 0200	2100 – 0900	1600 – 2100 0300 – 1000

It is important to note that the times in Table 2 apply to subjects who typically sleep from midnight to 08:00. These times can be modified for subjects who are morning (”larks”) and evening type individuals (”owls”). For example, a subject who typically sleeps from 22:00 to 06:00 could have a sleep schedule that starts two hours earlier than the one in Table 2. Similarly, a subject who typically sleeps from 02:00 to 10:00 could have a schedule that starts two hours later.

The drivers in each condition will be given a 36 hour, 60 hour, or an 84 hour recovery time. This will be followed by a subsequent work period of a minimum of three days/nights and a maximum of five days/nights.

9.8.3 Drivers

Driver characteristics will be as described for Option 1.

9.8.4 Measures

The subjective and objective behavioural probe measures used in Options 1-3 will also be used for this study. This study will also incorporate driving simulator performance measures. These measures will be determined in part by the measures available in the chosen driving simulator. Ideally, the performance measure used in Options 1-3, which has been shown most reliably to be affected by drowsiness, standard deviation of lane position, should be used. In addition, as in Options 1-3, the analysis of video of the three minute interval preceding the start of a critical incident may also be used.

In addition, to the above subjective, objective behavioural probe, and driving performance measures used in Options 1-3, physiological measures are recommended. As this study will be conducted in a laboratory, the “gold standard” measures of circadian rhythm and sleep: core body temperature, hormone collection and polysomnographic recordings, can be collected. The phase of the endogenous circadian pacemaker can be assessed with hormone collection by withdrawing blood. While subjects are asleep, blood can be collected using an in-dwelling catheter to assess hormone levels such as Plasma Melatonin or Plasma Cortisol. In addition, urine can also be used to measure the content in 6–sulphatoxymelatonin. Core body temperature can be taken with a rectal sensor every minute throughout the protocol.

9.9 Option 7: Laboratory Study of Impact of Consolidated vs. Fragmented Sleep on Recovery for Shorter Driving Periods

This study is identical to Option 6, with the exception that subjects will drive for a shorter term of three days to determine if shorter periods of driving allow shorter recovery periods. There is evidence in literature on performance that frequent short breaks are preferable to infrequent long breaks. If both Options 6 and 7 are selected, the combination will help determine whether subjects need more recovery time the longer they are on a particular schedule.

9.9.1 Experimental Design

The experimental design will be a mixed two (sleep conditions: fragmented or consolidated) x two (sleep times: good or bad) x three (recovery period) groups repeated measures design where three groups of drivers are monitored over three days/nights of driving followed by three different recovery opportunities (i.e., 36, 60 or 84 hours off duty). A driving period of three days/nights will follow the recovery period.

Comparisons that can be made are the impact of consolidated sleep vs. fragmented sleep on recovery from short periods of night driving, and the impact of consolidated sleep vs. fragmented sleep on recovery from short periods (three days) of day/night driving, as contrasted, in both cases, with longer periods (five days) of day/night driving. The size of this study may be reduced by considering only the fragmented sleep condition, and making the comparison of recovery time after five days/nights as compared to that required after three days/nights.

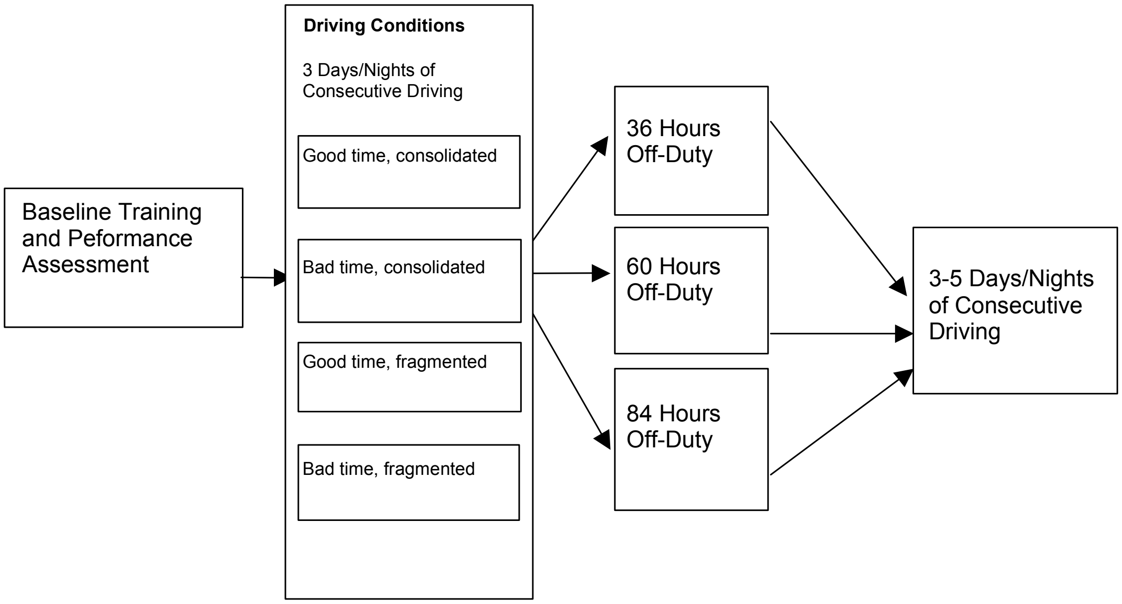

Figure 7. **Option 7: Laboratory Study of Impact of Consolidated vs. Fragmented Sleep on Recovery After Short Periods of Driving**

9.9.2 Drivers

Driver characteristics will be as described for Option 1.

9.9.3 Measures

Measures will be as described for Option 6.

9.10 Option 8: Epidemiological Study of Impact of Schedule and Recovery Period on Crash Risk

The final study proposed is a case-control epidemiological study similar to that of Jones and Stein (1987). Data on schedules will be collected for 200 drivers of trucks involved in crashes, as well as for a control sample of equal size. The schedule data will include:

- Work hours since last period of 24 hours off
- Work hours since last period of 8 hours of sleep
- Total hours since last period of 24 hours off
- Total hours since last period of 8 hours of sleep
- Percent of work hours since last period of 24 hours off that were worked between midnight and 6 am
- Length of most recent recovery period (minimum 24 hours)

A control driver will be selected for each crash-involved driver. Controls will be drivers of trucks of a similar type (e.g. tractor-trailer, single unit), on the same section of roadway, on the same day of the week and during the same two hour time period as the time of the crash. Multiple regression analysis will be used to determine the relationship between work hours since last 24 hour off period, between percent night hours and between the length of the most recent recovery period and crash risk.

In addition, the schedules used in crashes will be input into several of the fatigue models to determine whether the schedule would have predicted a fatigue-related accident. Specifically, the models proposed by Akerstedt (1998), Balkin et al. (2000), and Fletcher and Dawson (2001) will be evaluated to determine the predictive value of these models. With good predictive value, schedules susceptible to fatigue will be validated by crash data.

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