TP 12850E

Commercial Motor Vehicle

Driver Rest Periods and Recovery of Performance

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TP 12850E

COMMERCIAL MOTOR VEHICLE DRIVER REST PERIODS AND RECOVERY OF PERFORMANCE

Prepared for

Transportation Development Centre
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Canadian Trucking Research Institute
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16. Abstract

The purpose of this study was to assess the "recovery" effect of zero, one and two workdays off on driver fatigue and alertness. It was hypothesized that there would be some level of improvement in dependent measures of driver performance on trips following the time off.

The study involved 25 of the 40 drivers who participated in the two Canadian observational Conditions of the joint study by Canada and the U.S. known as the Commercial Motor Vehicle Driver Fatigue and Alertness Study (DFAS). Field data were collected from 55 trips, in addition to those of the DFAS, and resulted in five new observational Conditions that spanned a maximum of eight workdays, nominally with 12 hours, 36 hours and 48 hours of time off after the fourth workday. Three conditions included the 36-hour off-duty period, of which two had drivers do four more workdays following time off while the third had drivers do one more workday. Two conditions included twelve and 48 hours of time off and these had one more workday follow the time off.

The data collection equipment and procedures were similar to those of the DFAS study and were described in detail in the final report issued on that project. Measures, which were identical to those used in the DFAS, included EEG, face video recordings, vehicle lane tracking, and computerized surrogate performance tests. Because of the smaller number of drivers who participated in this "recovery" study by comparison with the DFAS, the statistical tests did not have the same power to detect effects.

For one workday off (i.e., 36 hours), there was: 1) no objective evidence of driver recovery; 2) some improvement in driver subjective feeling reflected by self-rating, although this could be a reflection of driver expectation of recovery; 3) for day-start drivers, some increase in the amount of sleep obtained during time off; and 4) for night-start drivers, interference with work-rest patterns and less sleep during time off.

For two workdays off (i.e., 48 hours), there was no objective evidence of driver recovery although the statistical power of the tests to detect recovery effects was not high because of random variation associated with the smaller number of drivers.

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16. Résumé

La présente recherche avait pour objet de vérifier l'effet éventuel d'une récupération au bout d'une période de repos d'un ou de deux jours, ou sans repos du tout, sur la fatigue et la vigilance des conducteurs. L'hypothèse retenue au départ était qu'on pourrait observer une certaine récupération se manifestant dans les variables dépendantes mesurées lors de la reprise du travail.

Elle a fait appel à 25 des 40 conducteurs canadiens ayant participé aux deux protocoles canadiens faisant partie de l'Étude canado-américaine sur la fatigue et la vigilance au volant chez les conducteurs de véhicules utilitaires. Les données correspondantes avaient été recueillies lors des 55 voyages complémentaires effectués à l'issue de l'étude principale. Cinq autres protocoles ont été mis en oeuvre, comportant un maximum de huit jours de travail, se caractérisant par 12 heures, 36 heures et 48 heures de repos après la quatrième journée travaillée. De ces cinq protocoles, trois comportaient une période de repos de 36 heures, au bout de laquelle les conducteurs selon deux protocoles devaient travailler quatre autres journées consécutives, et ceux selon le troisième n'en travaillaient qu'une seule. Quant aux deux protocoles restant, ils comprenaient une période de repos de 12 heures et de 48 heures, respectivement, au bout de laquelle les conducteurs effectuaient une autre journée de travail.

Pour cette étude complémentaire, les procédures et le matériel de saisie de données ont été les mêmes que pour l'étude principale et leur description est donnée dans le rapport final publié à l'issue de cette dernière. Diagrammes électroencéphalographiques, enregistrements des expressions faciales, mesures des déviations de trajectoires et résultats des tests auto-administrés, aidés par ordinateurs, ont été parmi les données analysées. À cause du plus petit nombre de conducteurs ayant participé à l'étude complémentaire, les analyses statistiques n'ont pas réussi à cerner les symptômes de récupération avec autant de précision que durant l'étude principale.

Dans le cas des conducteurs ayant eu une période de repos de 36 heures (équivalant à un jour de travail) : 1) aucun symptôme de récupération n'a pu être objectivement observé; 2) une certaine amélioration dans les auto-diagnostics a été constatée sans que l'on puisse déterminer si cette amélioration ne serait pas une simple impression de récupération ressentie par les conducteurs; 3) pour les conducteurs commençant leur quart au milieu de la journée, une légère augmentation dans le nombre d'heures de sommeil durant la période de repos a été observée; 4) pour ceux qui commençaient la nuit, il a été constaté que la période de repos gênait le déroulement normal du cycle travail-repos, les conducteurs finissant par avoir moins d'heures de sommeil durant la période de repos.

Dans le cas des conducteurs ayant eu une période de repos de 48 heures (équivalant à 2 jours de travail), aucun symptôme de récupération n'a pu être objectivement observé, les analyses statistiques n'ayant pas réussi non plus à cerner les symptômes de récupération à cause des variations aléatoires résultant du trop petit nombre de participants.

17. Mots clés: Camionneur, fatigue, vigilance, conducteurs de véhicules utilitaires, travail par roulement, performance des camionneurs, récupération, repos, heures de service
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SUMMARY

The purpose of this study was to assess the "recovery" effect of zero, one and two workdays off, after having accumulated the maximum number of hours permitted in a seven-day period by the Canadian hours-of-service regulations (e.g., 60 hours), on driver fatigue and alertness. It was hypothesized that there would be some level of improvement in dependent measures of driver performance on trips following the time off.

The study involved 25 of the 40 drivers who participated in the two Canadian observational conditions (C3-13nightstart and C4-13daystart) of the joint study by Canada and the U.S. known as the Commercial Motor Vehicle Driver Fatigue and Alertness Study (DFAS). Field data was collected during 55 trips made following those of the DFAS, and resulted in five new observational conditions that spanned a maximum of eight workdays, nominally with 12 hours, 36 hours and 48 hours of time off after the fourth workday. Three conditions included the 36-hour off-duty period, of which two had drivers do four more workdays following the time off while the third had drivers do one more workday. Two conditions included 12 and 48 hours of time off and these had one more workday follow the time off.

The data collection equipment and procedures were similar to those of the DFAS and were described in detail in the final report issued on that project. Data collected included EEG, face video recordings, vehicle lane tracking, and computerized surrogate performance tests. The data was examined for evidence of fatigue and any recovery effects due to days off-duty. No evidence of recovery due to time off was seen in any of the measures used in this study, although the drivers' self-reports improved and drivers working shifts that started during the day got more sleep with time off. Because of the smaller number of drivers who participated in this "recovery" study by comparison with the DFAS, the statistical tests did not have the same power to detect effects. The statistical reliability of results varied by observational condition due to differences in the number of drivers and workdays.

For three drivers taking no workday off, lane tracking standard deviation trended upward (indicating worsening performance) across the five workdays. There were no statistically significant surrogate performance test score changes between Trips 4 and 5. The results from this Condition are the most subject to random variation due to the small number of drivers involved.

For sixteen drivers taking one workday off (e.g., 36 hours off), there was no objective evidence of driver recovery of performance. One measure of driving performance Lane Tracking Standard Deviation (LTSD) and one surrogate performance test (Simple Response Vigilance Test) showed deteriorating performance across trips, with no recovery from the 36-hour off-duty period. Some improvement in driver subjective feeling was observed from their self-rating on the Stanford Sleepiness Scale although it is not known whether this was a reflection of driver expectation of recovery. For drivers working shifts that started during the day (e.g., about noon), there was some increase in the amount of sleep obtained during time off. For drivers working shifts that started during the night (e.g., about midnight), the time off seemed to interfere with work-rest patterns and they appeared to obtain less sleep during the time off. In all likelihood, drivers working the night-starting

shifts resumed day shift sleep-wake patterns on their time off even though the amount of time off was insufficient for accommodation.

For six drivers taking two workdays off (e.g., 48 hours off), there was no objective evidence of driver recovery although the statistical power of the tests to detect recovery effects was not high because of random variation associated with the small number of drivers involved.

It was recommended that the test methodology used in this study be repeated with a larger number of subjects to improve the sensitivity of the tests. The effects of longer off-duty periods should also be investigated, with the objective of establishing the duration required for “full” driver recovery, for day, night, rotating and irregular schedules.

SOMMAIRE

La présente recherche avait pour objet de vérifier l'effet éventuel d'une récupération au bout d'une période de repos d'un ou de deux jours, ou sans repos du tout, sur la fatigue et la vigilance des conducteurs de véhicules utilitaires faisant le nombre maximal d'heures de conduite par semaine selon la loi canadienne, c'est-à-dire 60 heures. L'hypothèse retenue au départ était qu'on pourrait observer une certaine récupération se manifestant dans les variables dépendantes mesurées lors de la reprise du travail.

Elle a fait appel à 25 des 40 conducteurs canadiens ayant participé aux deux protocoles canadiens C3-13débutnuit et C4-13débutjour faisant partie de l'Étude canado-américaine sur la fatigue et la vigilance au volant chez les conducteurs de véhicules utilitaires. Les données correspondantes avaient été recueillies lors des 55 voyages complémentaires effectués à l'issue de l'étude principale. Cinq autres protocoles ont été mis en oeuvre, comportant un maximum de huit jours de travail, se caractérisant par 12 heures, 36 heures et 48 heures de repos après la quatrième journée travaillée. De ces cinq protocoles, trois comportaient une période de repos de 36 heures, au bout de laquelle les conducteurs selon deux protocoles devaient travailler quatre autres journées consécutives, et ceux selon le troisième n'en travaillaient qu'une seule. Quant aux deux protocoles restant, ils comprenaient une période de repos de 12 heures et de 48 heures, respectivement, au bout de laquelle les conducteurs effectuaient une autre journée de travail.

Pour cette étude complémentaire, les procédures et le matériel de saisie de données ont été les mêmes que pour l'étude principale et leur description a été donnée dans le rapport final publié à l'issue de cette dernière. Diagrammes électroencéphalographiques, enregistrements des expressions faciales, mesures des déviations de trajectoires et résultats des tests auto-administrés, aidés par ordinateurs, ont été parmi les données analysées à la recherche de symptômes de fatigue et de symptômes de récupération se manifestant après la période de repos. Aucune récupération n'a pu être observée, quelle que soit la variable analysée, bien que les auto-diagnostics aient indiqué une certaine amélioration et que les conducteurs commençant leur quart au milieu d'une journée aient déclaré avoir eu plus d'heures de sommeil grâce à la période de repos. À cause du plus petit nombre de conducteurs ayant participé à l'étude complémentaire, les analyses statistiques n'ont pas réussi à cerner les symptômes de récupération avec autant de précision que durant l'étude principale. Il a été constaté que la fiabilité statistique des résultats variait selon le protocole analysé, c'est-à-dire selon l'écart dans le nombre de participants et de journées travaillées.

Dans le cas des trois conducteurs n'ayant eu aucune période de repos séparant les cinq jours travaillés, l'écart type dans les déviations de trajectoires a évolué vers des valeurs supérieures. Entre les quatrième et cinquième jours de travail, aucune différence significative n'a été observée dans les tests auto-administrés. Les données tirées de ce protocole ont été celles les plus susceptibles de variations aléatoires en raison du trop petit nombre de participants.

Dans le cas des 16 conducteurs ayant eu une période de repos de 36 heures (équivalant à un jour de travail), aucun symptôme de récupération n'a pu être objectivement observé : l'écart type dans les déviations de trajectoires et un test auto-administré (Test de vigilance simple) ont indiqué une

détérioration progressive de la vigilance, sans aucune récupération après la période de repos de 36 heures. Une certaine amélioration dans les auto-diagnostics a été constatée des tests d'appréciation de l'état de somnolence selon l'échelle Standford, sans que l'on puisse déterminer si cette amélioration ne serait pas une simple impression de récupération ressentie par les conducteurs. Pour les conducteurs commençant leur quart au milieu de la journée (vers midi), une légère augmentation dans le nombre d'heures de sommeil durant la période de repos a été observée. Pour ceux qui commençaient la nuit (vers minuit), il a été constaté que la période de repos gênait le déroulement normal du cycle travail-repos, les conducteurs finissant par avoir moins d'heures de sommeil durant la période de repos. Les conducteurs selon le protocole débutnuit semblaient retrouver le cycle veille-sommeil du protocole débutjour durant leur période de repos, malgré le peu de temps à leur disposition pour effectuer une transition complète.

Dans le cas des six conducteurs ayant eu une période de repos de 48 heures (équivalant à 2 jours de travail), aucun symptôme de récupération n'a pu être objectivement observé, les analyses statistiques n'ayant pas réussi non plus à cerner les symptômes de récupération à cause des variations aléatoires résultant du trop petit nombre de participants.

Il a été recommandé de reprendre les mêmes méthodes dans le cadre d'une nouvelle étude faisant appel à un nombre plus élevé de participants, de façon à accroître la sensibilité des tests. Et d'en profiter pour étudier l'effet de périodes de repos plus étendues, dans le but de déterminer celle qui permettrait une pleine récupération de la part des conducteurs travaillant selon des protocoles différents : de jour, de nuit, tournants ou irréguliers.

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COMMERCIAL MOTOR VEHICLE DRIVER
REST PERIODS AND RECOVERY OF PERFORMANCE

This technical report presents the research conducted under Transport Canada's study of Commercial Motor Vehicle Driver Rest Periods and Recovery of Performance (e.g., the "recovery" study). Data collection for this research was undertaken in conjunction with that for the joint study by Canada and the U.S. known as the Commercial Motor Vehicle Driver Fatigue and Alertness Study (DFAS) [1].

This report is divided into four sections. In the Introduction (Section 1), the reader is provided with the study's objectives, the background, as well as an overall view of the study design and approach to data analysis. Section 2 presents a description of the work/rest schedules used as study observational conditions. Section 3 presents the results, examining first the changes in EEG and related measures during sleep, then driver drowsiness assessed from video recordings of the drivers' faces, vehicle lane-tracking, and finally the results of computerized surrogate performance tests of driver abilities. Section 4 presents conclusions and recommendations.

SECTION 1. INTRODUCTION

STUDY OBJECTIVES

The purpose of this study was to assess the "recovery" effect of zero, one and two workdays off, after having accumulated the maximum number of on-duty hours permitted in a seven-day period by the Canadian hours-of-service regulations (e.g., 60 hours), on driver fatigue and alertness. It was hypothesized that there would be some level of improvement in dependent measures of driver performance on trips following the time off.

BACKGROUND

In 1993, Transport Canada's Transportation Development Centre (TDC) contracted with Essex Corporation to collect data from additional trips to be made by some of the Canadian drivers who were participating in the two Canadian observational Conditions of the DFAS. Transport Canada wished to obtain objective scientific data on the duration of off-duty time required for driver recovery from cumulative fatigue with a view to reviewing related aspects in the hours-of-service rules. This

1 The final report on the main U.S./Canadian study is titled "Commercial Motor Vehicle Driver Fatigue and Alertness Study", by Wylie, Shultz, Miller, Mitler, and Mackie, dated October 1996. The report is available from Transport Canada as report number TP 12875E as well as from the U.S. Federal Highway Administration as report number FHWA-MC-97-002.

additional data collection made efficient use of the considerable scientific and logistical equipment and procedures already in place for the main study. It was a particularly opportune moment to undertake this recovery study because of a Canadian industry proposal to provincial and federal governments to establish a "reset" rule as a primary feature of revised hours-of-service regulations. The proposal would institute a rest period of 36 hours to "reset the clock" once drivers reach the cumulative on-duty maximum of 60 hours.

DRIVER FATIGUE AND ALERTNESS STUDY (DFAS)

The DFAS study data collection involved 20 drivers in each of four observational Conditions, two in Canada and two in the U.S. (i.e. a total of 80 drivers), who were monitored over a period of 16 weeks. The overall DFAS data collection program and study design are presented in Figure 1. A number of work-related factors thought to influence the development of fatigue, loss of alertness, and degraded driving performance in commercial motor vehicle drivers were studied within an operational setting of revenue-generating trips. Factors studied included: the amount of time spent driving during a work period; the number of consecutive days of driving; the time of day when driving took place; and schedule regularity.

RECOVERY STUDY DESIGN AND DATA ANALYSIS

For this recovery study, field data was collected from 25 of the 40 drivers in the DFAS, who drove a total of 55 additional trips after completing their scheduled DFAS trips. This resulted in five new observational conditions (see Table 1) that spanned a maximum of eight workdays, nominally with 12 hours, 36 hours and 48 hours of time off after the fourth workday. Three conditions included the 36-hour off-duty period, of which two had four more workdays follow the time off while the third had one more workday. Two conditions included 12 and 48 hours of time off and these both had one more workday follow the time off. The data collection equipment and procedures were similar to those of the DFAS and were described in detail in the final report issued on that project.

The work/rest schedules implemented for this recovery study were developed by Transport Canada and provided to Essex. The schedules were designed to take advantage of the fact that each group of five drivers participating in the DFAS would normally reach the on-duty limit specified in the Canadian hours-of-service regulations (60 hours in seven days) by the end of the fourth workday, after which the drivers would have to leave the study and the five instrumented trucks would be idle for the following three workdays until the subsequent set of five drivers arrived. By taking advantage of the 14-day cycle provisions in the Canadian hours-of-service rules (which allow 120 hours of on-duty time during a period of 14 consecutive days, but require a 24-hour off-duty period before completing 75 hours), it was possible to continue the drivers' participation during the remaining three

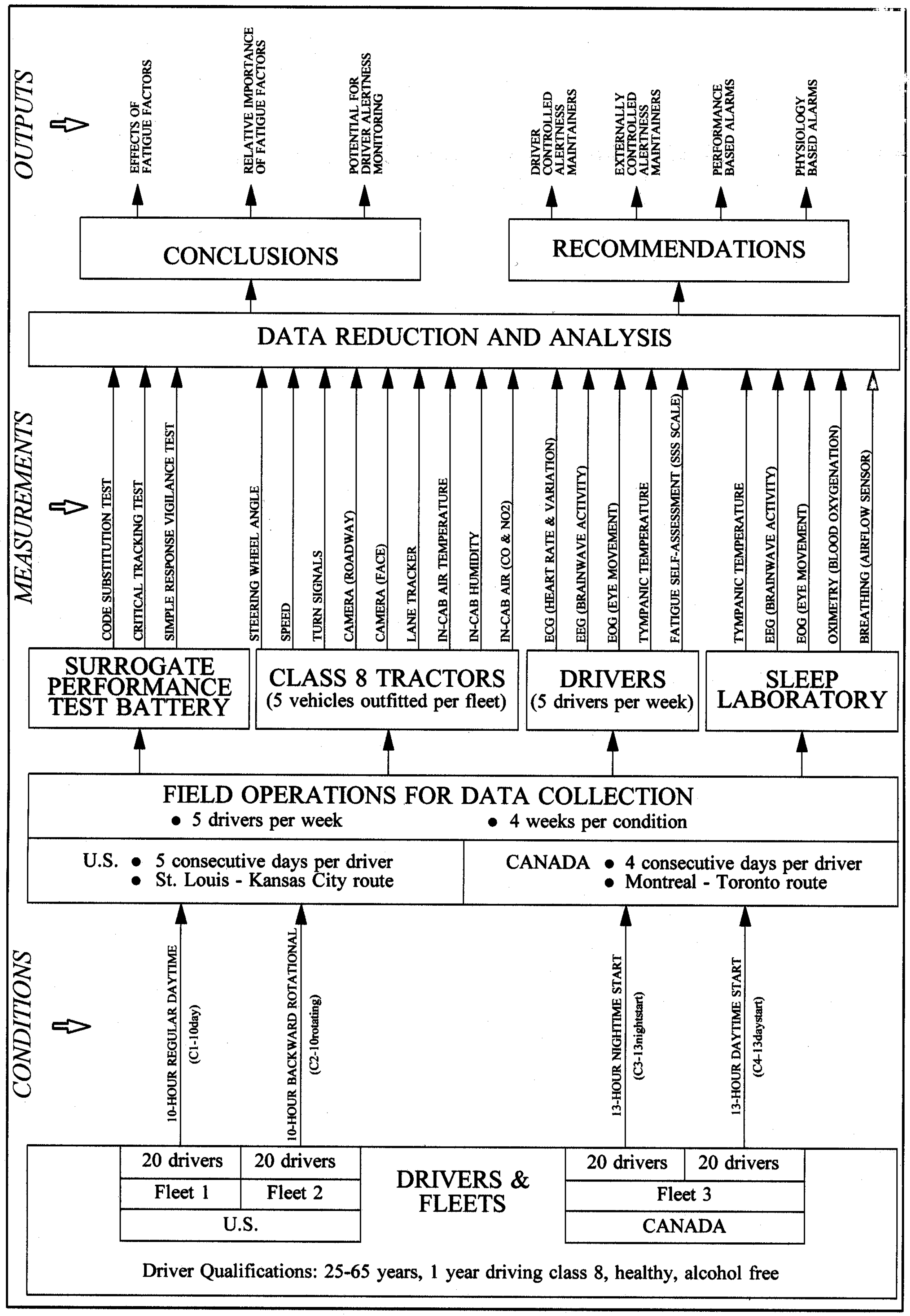

Figure 1. Overall data collection program and design of Driver Fatigue and Alertness Study (DFAS).

workdays of each week. Additionally, at the completion of data collection at the end of the fourth week of each of the two Canadian conditions, the participation of each set of five drivers was extended by an additional four workdays by delaying the start of data collection for the subsequent DFAS observational condition. Because the decision to undertake this recovery study was taken while the DFAS work was underway and due to the lead time required to institute the study protocol and purchase additional equipment, the first fifteen drivers of observational Condition C3 (C3-13nightstart) could not be monitored.

Although the data collected for this recovery study was similar to that of the DFAS, the analysis undertaken for this study focussed principally on identifying changes in dependant measures of driver performance between workdays before and after the various off-duty periods. In addition, this analysis took advantage of the knowledge gained from the DFAS such that emphasis was placed on those measures that were shown to be the most valuable in assessing driver performance. Consequently, polysomnography (PSG) analysis of EEG data collected during driving was not conducted for this recovery study. The results of the DFAS showed that few episodes of "PSG-Drowsy Driving" could be expected to be included in the database. The expected low incidence of PSG Drowsy Driving would not have allowed meaningful comparisons of level of driver recovery after varying lengths of time off-duty.

SECTION 2. WORK/REST SCHEDULES AND OBSERVATIONAL CONDITIONS

Data was collected from five drivers in DFAS Condition 3 (C3-13nightstart) during four more 24-hour periods after the drivers had one 36-hour period off-duty. These follow-up recordings on Condition 3 drivers are coded as Condition 5 throughout this report. We also collected data from five drivers in DFAS Condition 4 (C4-13daystart) during four more 24-hour periods after they had one 36-hour period off-duty. These follow-up recordings on Condition 4 drivers are coded as Condition 9 throughout this report. Combining the data collected under Conditions 3 and 4 with that of Conditions 5 and 9, respectively, results in the recovery study Condition 3-5 (nightstart) and Condition 4-9 (daystart).

Additional data was collected from other DFAS Condition 4 drivers as follows: for three drivers, during one more workday following the fourth workday - without an intervening workday off (Condition 6); for six drivers, during one more workday following one workday off-duty (Condition 7); for six drivers, during one more workday, following two workdays off-duty (Condition 8). Combining the data collected for these drivers under Condition 4 with that of Conditions 6, 7, and 8 provides the recovery study Conditions 4-6, 4-7, and 4-8, all daystart conditions.

Table 1 shows the driving schedules for which the data reported here was collected. The first column, Condition, shows the Conditions (3-5, 4-6, 4-7, 4-8, and 4-9) into which data used for this study is grouped. Each condition is associated with either zero, one, or two workdays off following the fourth trip. One workday off nominally spanned 36 hours of time off between the fourth and fifth trip. Two workdays off was nominally 48 hours. No workday off was nominally 12 hours. For operational reasons, the observed amount of time off varied somewhat from that of the specified nominal. Figures 2a and 2b show the driving schedules actually observed, with average times calculated from recorded trip durations.

Table 1. Observational conditions and driving schedules, for both the "recovery" study and the DFAS.

Condition	**Number of drivers**	**Workdays**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	20	X	X	X	X	X	U.S. drivers of DFAS Conditions 1 and 2 drove five turnaround trips each.			
2	20	X	X	X	X	X				
3	20	X	X	X	X		Canadian drivers of DFAS Conditions 3 and 4 drove four turaround trips each.			
4	20	X	X	X	X					
3-5	5	X	X	X	X		X	X	X	X
4-6	3	X	X	X	X	X				
4-7	6	X	X	X	X		X			
4-8	6	X	X	X	X			X		
4-9	5	X	X	X	X		X	X	X	X

DFAS OBSERVATIONAL CONDITIONS	
Condition 1 (C1-10day)	10-hrs driving nominally starting at same time each morning.
Condition 2 (C2-10rotating)	10-hrs driving starting 3 hrs earlier each day.
Condition 3 (C3-13nightstart)	13-hrs driving nominally starting at midnight in Toronto.
Condition 4 (C4-13daystart)	13-hrs driving nominally starting at noon in Montreal.

RECOVERY STUDY OBSERVATIONAL CONDITIONS	
Condition 3-5 (nightstart)	Condition 3 drivers who had one workday (e.g., 36 hours) off after the fourth workday, and then did 4 added workdays on the same schedule.
Condition 4-6 (daystart)	Condition 4 drivers who drove a fifth workday, without a workday off following the fourth workday.
Condition 4-7 (daystart)	Condition 4 drivers who drove a fifth workday, following one workday (e.g., 36 hours) off.
Condition 4-8 (daystart)	Condition 4 drivers who drove a fifth workday, following two workdays (e.g., 48 hours) off.
Condition 4-9 (daystart)	Condition 4 drivers who had one workday (e.g., 36 hours) off after the fourth workday, and then did 4 added workdays on the same schedule.

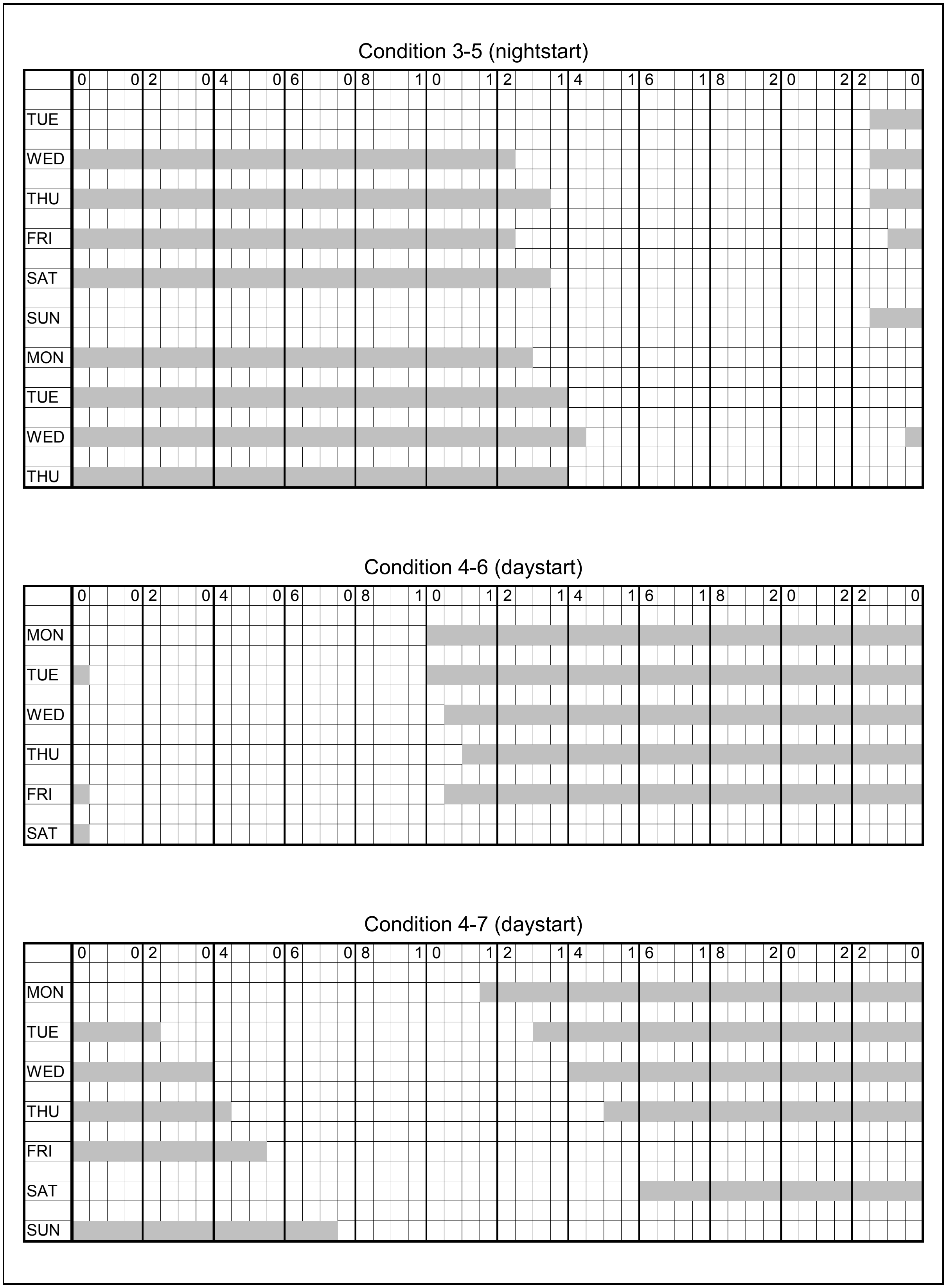

Figure 2a. Observed driving schedules for Conditions 3-5 (nightstart), 4-6 (daystart), and 4-7 (daystart). Shaded bars indicate intervals between average departure and arrival times.

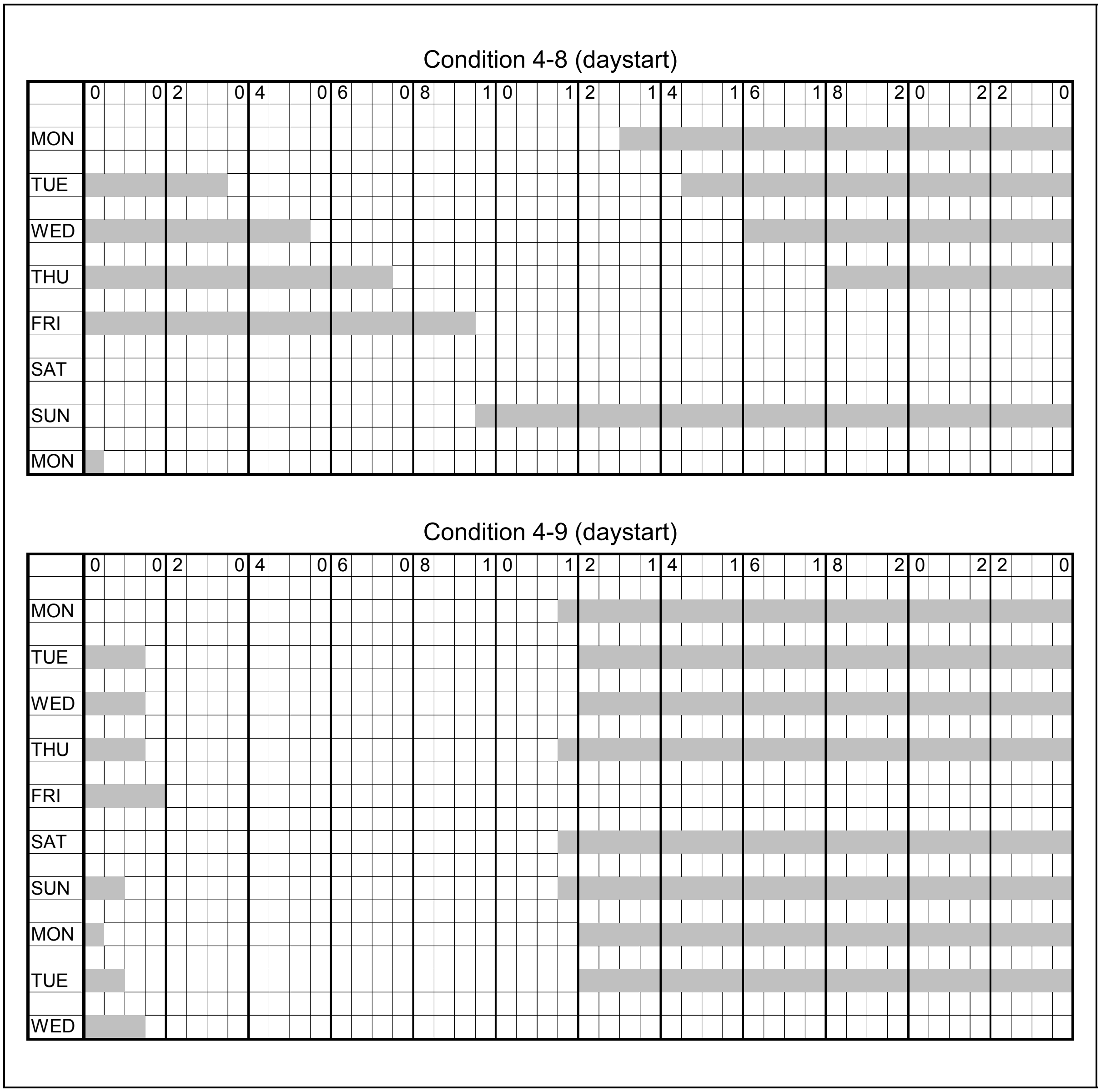

Figure 2b. Observed driving schedules for Conditions 4-8 (daystart) and 4-9 (daystart). Shaded bars indicate intervals between average departure and arrival times.

SECTION 3. RESULTS OF DATA ANALYSIS

EEG AND RELATED MEASURES DURING SLEEP

During the one workday (36 hours) and two workdays (48 hours) of time off at the end of Trip 4 of Conditions 3-5, 4-9, 4-7 and 4-8, drivers were instructed to return home and conduct themselves as they would normally. Since driver sleep was not monitored during time at home on off-duty workdays, they were also instructed to return to the sleep centre at any and whatever times they chose to take their principal sleep periods. At the sleep centre they were then prepared for the usual monitoring during sleep. The sleep times reported in this study are for those sleeps taken at the sleep centre and are based on EEG data.

Detailed tabulations of sleep related data from resting drivers of Conditions 3-5, 4-6, 4-7, 4-8, and 4-9 are included in Appendix 1. There were too few subjects to warrant detailed statistical analysis beyond what is presented for total sleep time.

SLEEP DURATION AND ONE WORKDAY (36 HOURS) OFF FOR DRIVERS IN CONDITIONS 3-5 (NIGHTSTART) AND 4-9 (DAYSTART)

Figure 3 presents average total sleep time for all principal sleep periods for the two groups of five drivers of Conditions 3-5 (nightstart) and 4-9 (daystart). The first 5 sleeps are those sleeps these drivers took during their participation in DFAS Condition 3 and Condition 4 respectively. Then, there are five more sleeps for Condition 3-5 drivers, and four more sleeps for Condition 4-9 drivers. These drivers had a nominal 36-hour period off (e.g., one workday) between sleeps 5 and 6 with no work-related duties. Sleep 1 was taken prior to the first drive. Drivers drove Trip 1 between Sleeps 1 and 2, Trip 2 between Sleeps 2 and 3, and so on, for the duration of their participation. There are only 9 principal sleep periods for the Condition 4-9 drivers because they ended their participation in the study after the drive following the ninth principal sleep period.

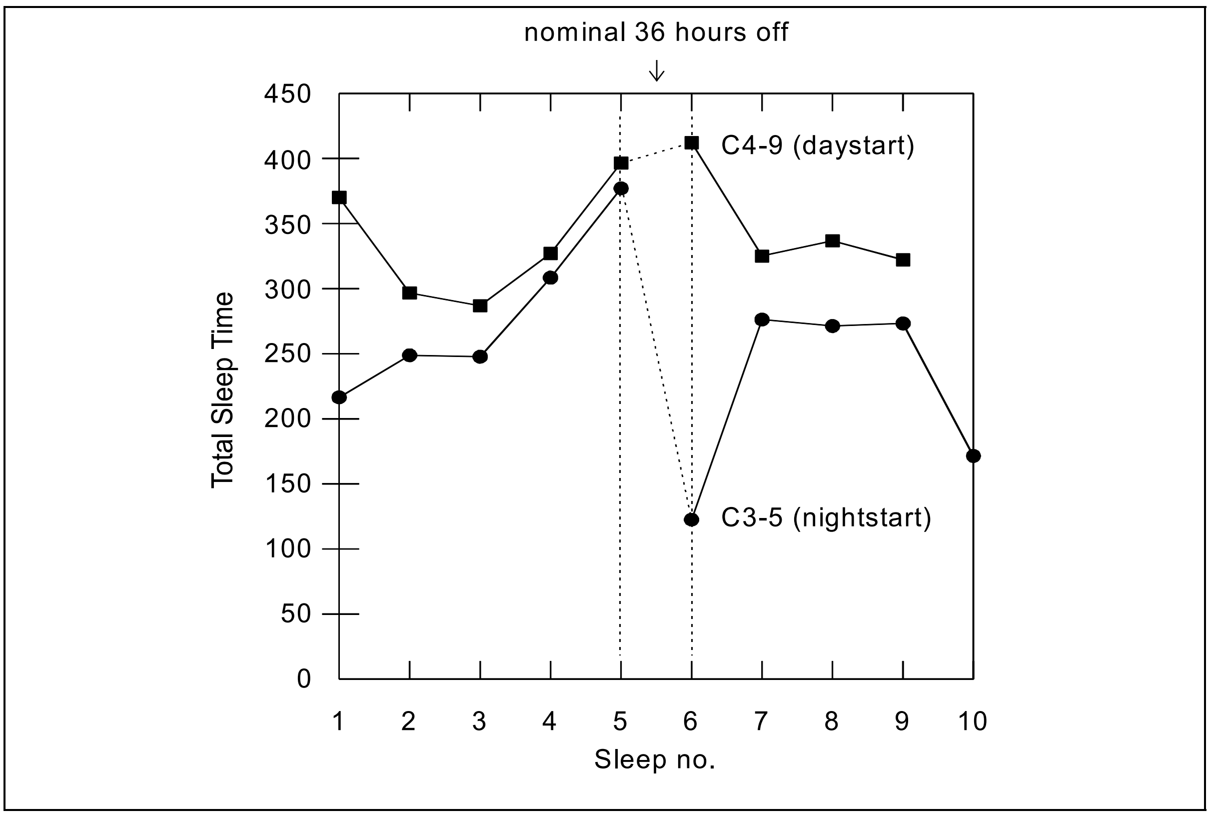

Figure 3. Sleep duration in Conditions 3-5 (nightstart) and 4-9 (daystart), both before and after the 36 hours off-duty.

Drivers in Condition 4-9 (daystart) obtained significantly more sleep than did drivers in Condition 3-5 (nightstart). This pattern continued throughout the drivers' participation in the study. The marked drop in sleep time for Condition 3-5 (nightstart) drivers after the 36-hour period off was statistically significant and reflects a truncation of recovery. A less truncated pattern of recovery sleep is seen for Condition 4-9 (daystart) drivers, who show increased sleep during Sleep 6. Summary sleep data and detailed outcomes of statistical procedures used are in Appendix 1.

Inspection of the sleep parameters relevant to sleep continuity and structure did not reveal systematic differences from the data of DFAS Conditions 1 to 4.

SLEEP DURATION AND ZERO, ONE, OR TWO WORKDAYS OFF FOR DRIVERS IN CONDITIONS 4-6, 4-7 AND 4-8

Figure 4 presents average sleep duration during principal sleep periods for the 15 drivers in Conditions 4-6, 4-7 and 4-8, all daystart Conditions.

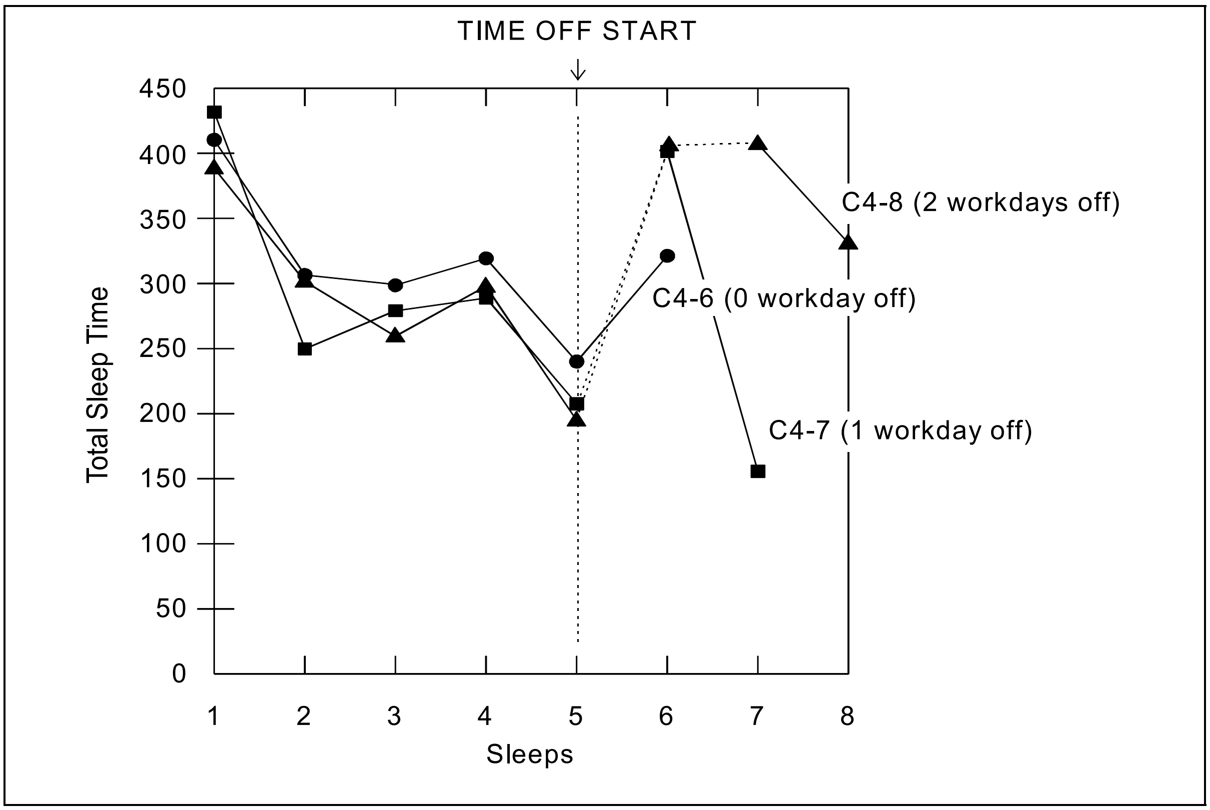

Figure 4. Sleep duration in daystart Conditions 4-6, 4-7, and 4-8, (e.g., nominally 12, 36 or 48 hours off), respectively.

There was no overall statistically significant difference between the three groups. However, the extended recovery sleep on sleep 6 relative to sleeps 1 - 5 is obvious for the group with one workday off, Condition 4-7. Likewise, the extended recovery sleep on sleeps 6 and 7 relative to sleeps 1 - 5 is obvious for the group with two workdays off, Condition 4-8.

Inspection of the sleep parameters relevant to sleep continuity and structure did not disclose systematic differences from the data of DFAS Conditions 1 - 4.

VIDEO RECORDING OF DRIVER'S FACE

The Mann-Whitney U-test was used to compare the average proportion of analysis epochs judged "drowsy" for all the recovery study Conditions (i.e., 3-5, 4-6, 4-7, 4-8, 4-9) aggregated by Condition and half trip. The test failed to reveal statistically significant differences in prevalence of drowsiness between the first four trips completed by each driver and subsequent trips taken after the prescribed recovery periods.

In the symmetrical Conditions 3-5 (nightstart) and 4-9 (daystart), drivers completed four trips, then took 36 hours off, then completed an additional four trips. The repeated-measures analysis of covariance of the arcsine transform of the proportion of analysis epochs judged "drowsy," with between-subjects factors "Condition" (= 3-5, 4-9) and "Age" (covariate) and within-subjects factors "Trip" (= 1st, 2nd, 3rd, 4th) and "Set" (= first set of four trips, second set of four trips) showed no significant effect of Condition or Set, but a significant interaction of Set by Trip by Condition, $F(3,21)=5.0$, $p<.009$. The means are shown in Figures 5a and 5b. It can be seen that there was a relatively high proportion of drowsiness during Trips 2 and 3 of the first 4 trips of Condition 4-9 (daystart), although this does not seem to bear on the issue of recovery. Contrasting the trip preceding the 36-hour time-off period with the trip following it revealed no difference in both conditions 3-5 and 4-9.

In summary, recovery effects of the 36 hours off-duty were not apparent for the prevalence of drowsiness measure.

LANE TRACKING

Lane tracking standard deviation (LTSD) by trip for Conditions 3-5, 4-9, 4-6, 4-7 and 4-8 are shown in Figures 6, 7, 8, 9 and 10, respectively.

Each mean in these figures is accompanied by error bars showing standard error of the mean. It can be seen from these figures that on the fifth trip, mean LTSD is at or above its highest preceding value. In the case of the Conditions with the two driving cycles of 4 days with an intervening workday off, Conditions 3-5 (nightstart) and 4-9 (daytstart), LTSD during the second set of 4 days, when compared with the first set, shows no evidence of recovery.

In summary, there was no evidence of recovery of lane tracking performance following 0, 1, or 2 workdays off.

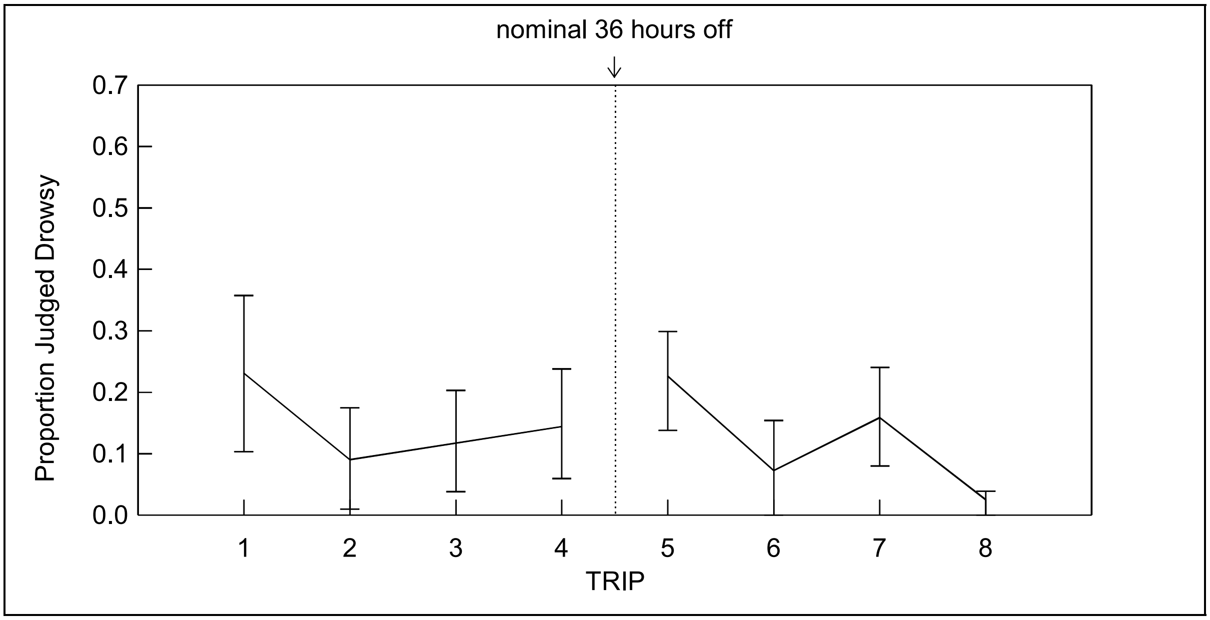

Figure 5a. Proportion of analysis epochs judged "drowsy", Condition 3-5 (nightstart); Set 1 (Trips 1-4), Set 2 (Trips 5-8).

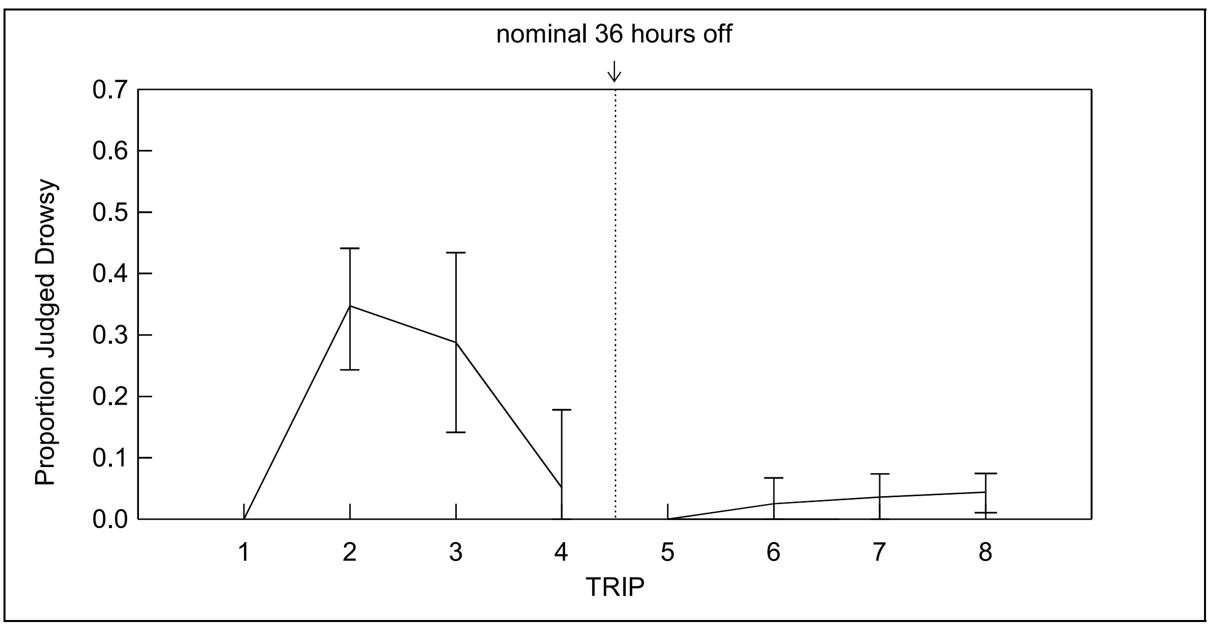

Figure 5b. Proportion of analysis epochs judged "drowsy", Condition 4-9 (daystart); Set 1 (Trips 1-4), Set 2 (Trips 5-8).

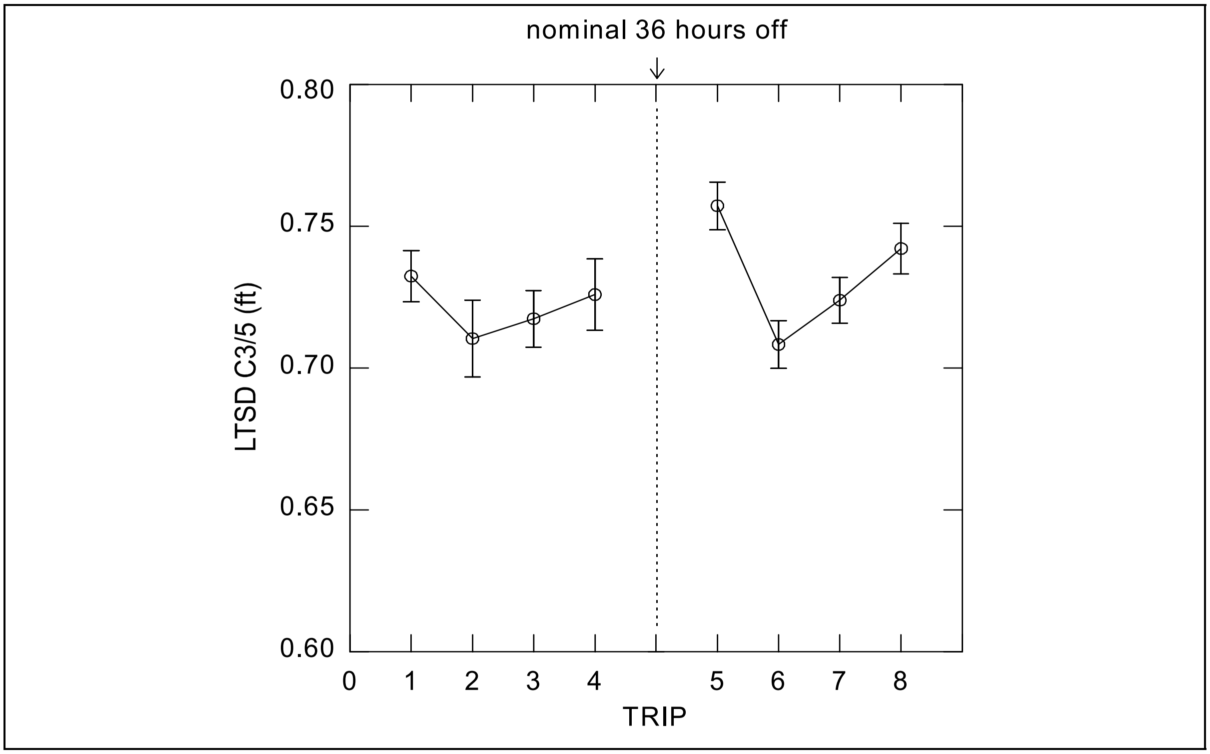

Figure 6. Lane tracking standard deviation, Condition 3-5 (nightstart); with one workday (36 hours) off after Trip 4.

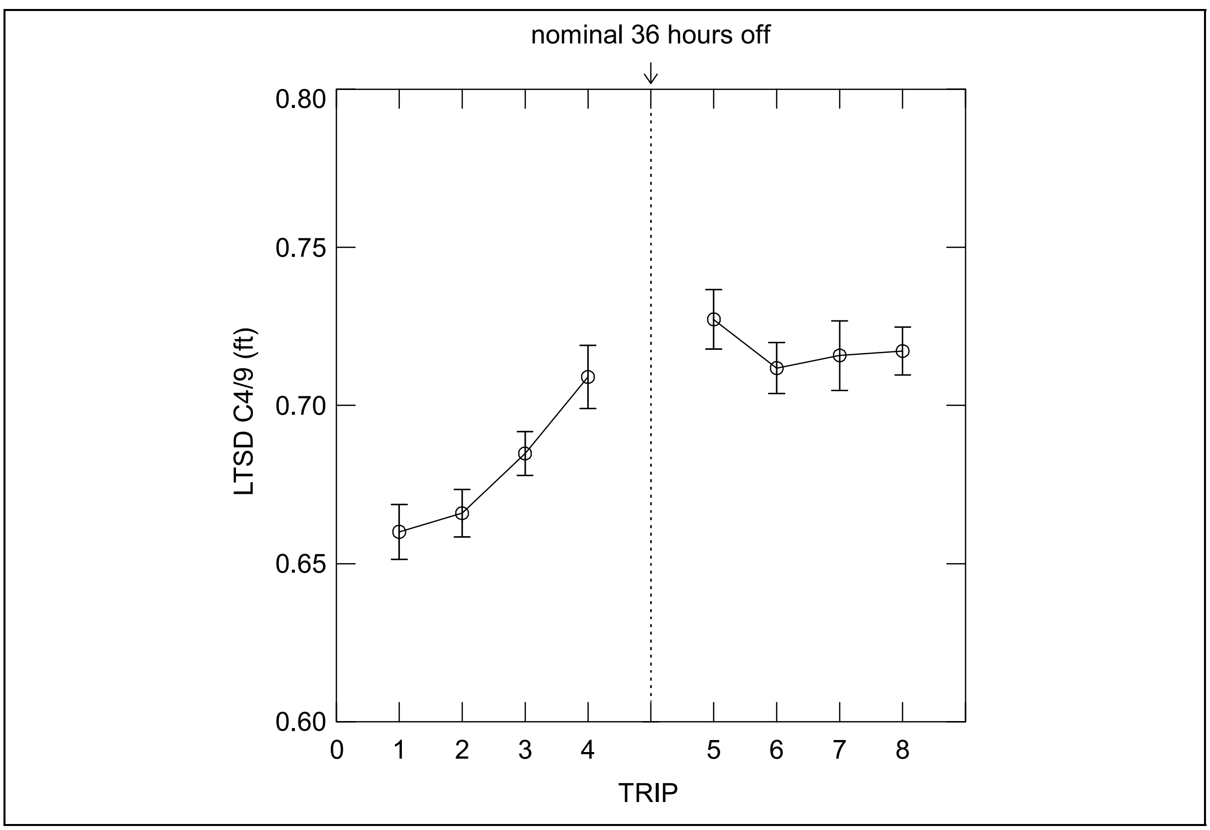

Figure 7. Lane tracking standard deviation, Condition 4-9 (daystart); with one workday (36 hours) off after Trip 4.

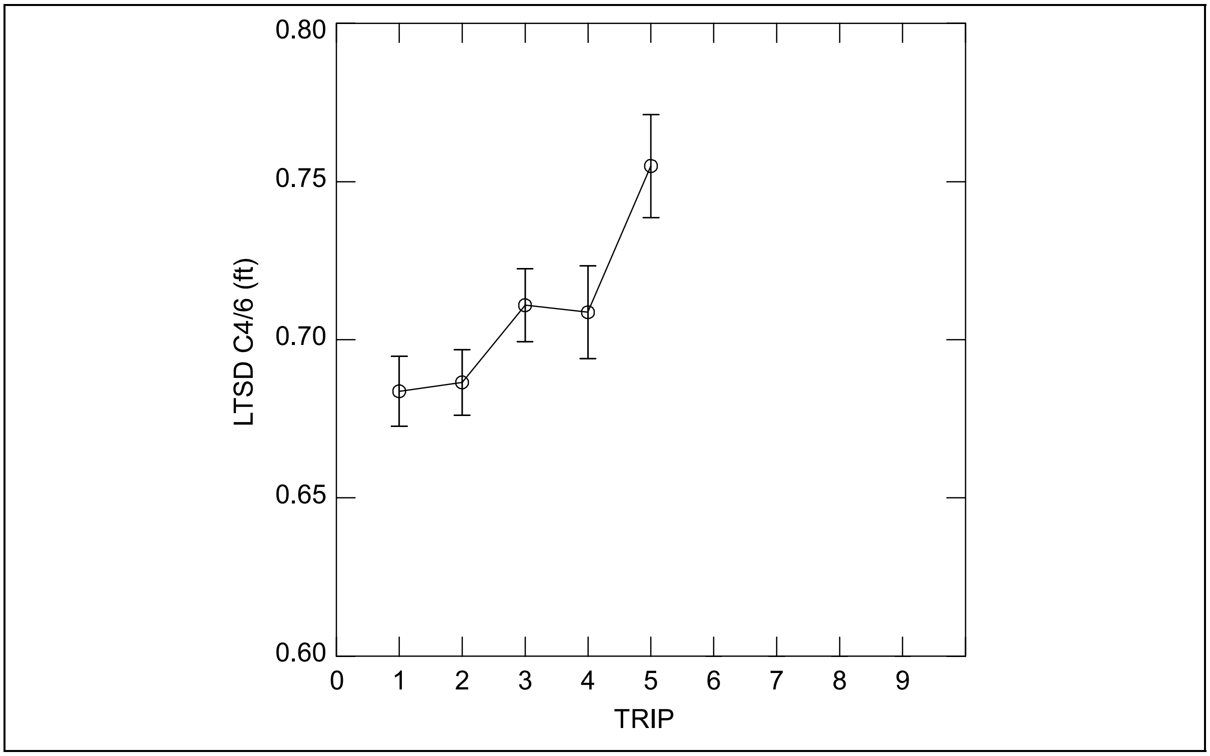

Figure 8. Lane tracking standard deviation, Condition 4-6 (daystart); with no workdays off after Trip 4.

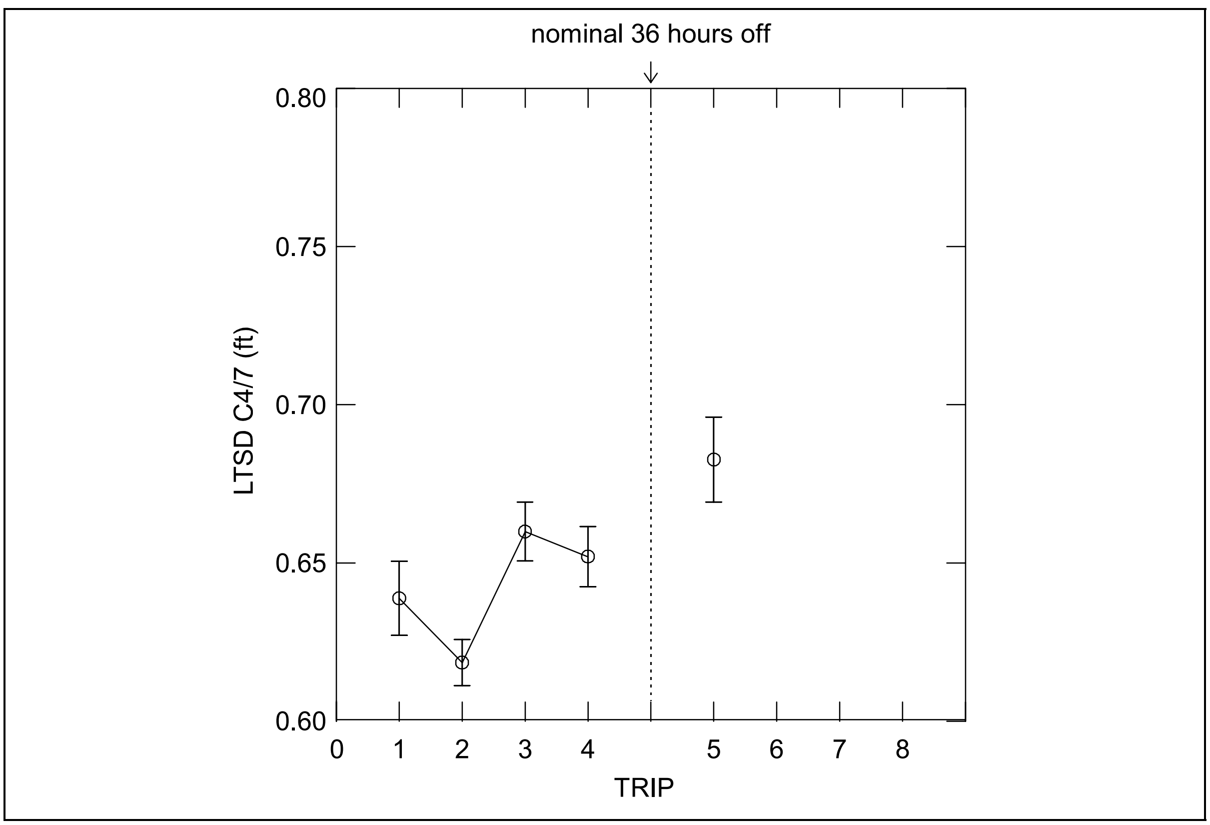

Figure 9. Lane tracking standard deviation, Condition 4-7 (daystart); with one workday (36 hours) off after Trip 4.

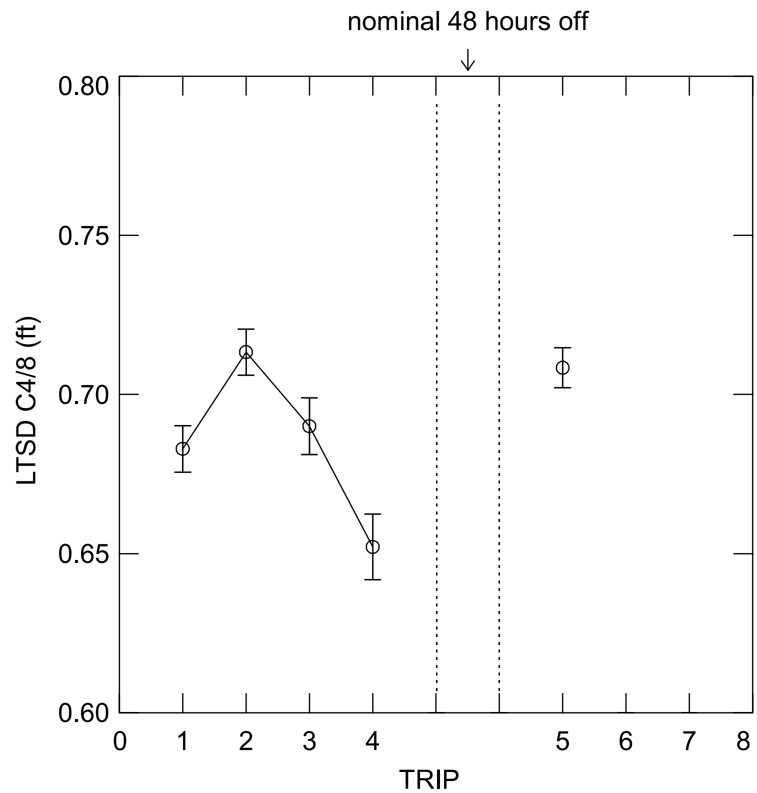

Figure 10. Lane tracking standard deviation, Condition 4-8 (daystart); with two workdays (48 hours) off after Trip 4.

SURROGATE PERFORMANCE TESTS

This section describes results of analyses of surrogate performance test scores on trips following the four base trips of the 13-hour Conditions 3 and 4. Scores on the additional trips were compared with scores on the first four trips. The direction of change in scores (degradation versus improvement) was not specified in advance, and therefore two-tailed tests of significance were used throughout. (The definition of each measure, the shape of its distribution, and its correlation with independent variables, other than length of time between the fourth and subsequent trips, are discussed in the DFAS report.) The focus of this section is the change in driver performance between the fourth trip, after which the prescribed off-duty period is taken, and subsequent trips. The ANOVAs performed can be divided into two main groups:

- those that compared a second set of four trips with the first set of four trips, with one intervening workday (36 hours) off (Conditions 3-5 and 4-9; N = 10), and
- those that contrast the fifth trip with the fourth trip,
  - with no intervening workday off (Condition 4-6; N = 3),
  - after one workday off (Conditions 3-5,4-7,4-9; N = 16), and
  - after two workdays off (Condition 4-8; N = 6).

The results presented in this subsection are based on three administrations of the performance test battery. Whereas Conditions C1 and C2 of the DFAS had four administrations per trip, Conditions C3 and C4 drivers had only three administrations per trip. A fourth administration (administration number three which was taken just prior to inbound departure at the mid-trip turnaround point in Conditions C1 and C2) had to be eliminated because it would have caused these drivers to exceed allowable on-duty time limits specified by Canadian hours-of-service regulations.

PERFORMANCE OVER EIGHT TRIPS AND THE EFFECTS OF ONE WORKDAY (36 HOURS) OFF AFTER FOUR TRIPS

Five nightstart (Condition 3-5) and five daystart (Condition 4-9) drivers took a workday (36 hours) off following their fourth trip, then drove a second set of four trips. Their performance test scores did not differ markedly from those of the other drivers in Conditions 3 and 4. In the discussion that follows, the two-level variable "Set" distinguishes the first set of four trips (Set 1) from the second set of for trips (Set 2). Repeated measures ANOVAs were performed for each of the four performance test measures (e.g., CS, CTT, Lapses, RVS), structured as Condition (two levels), by Set (two levels), by Trip (four levels), and by Administration (three levels). Set, Trip, and Administration are within-subject repeated measures.

Code Substitution (CS) Test

The results of the ANOVA of Code Substitution (CS) Test score results are shown in Table 2. There was a statistically significant Administration by Condition interaction, as one would expect from the sizeable impact of time-of-day on performance. Drivers performed more poorly on CS at night than during the day. Figure 11 shows driver CS means on each of the 24 test sessions (3 sessions on each of 8 trips). T1 through T4 are the first set of four trips, and T5 through T8 are the second set. It would be difficult to describe the improvement between Trips 4 and 5 as recovery of function, since recovery implies a prior degradation of performance, and clearly there was none. The statistically significant Set and Trip effects appear to be the result of ongoing skill acquisition with practice. The nature of the Administration and Administration by Condition interactions is illustrated in Figures 12 and 13. Both figures show better scoring during the day.

Table 2. Results of ANOVA of CS test for Conditions 3-5 (nightstart) and 4-9 (daystart), contrasting the first and second sets of four trips.

Factor	F-ratio	df1	df2	Probability
Condition	0.968	1	8	0.354
Set	21.641	1	8	0.002
Trip	4.419	3	24	0.013
Administration	4.459	2	16	0.029
Administration * Condition	6.552	2	16	0.008

The median time of day at the start of each test administration in Conditions 3-5 through 4-9 is shown in Table 3. Median times better characterize the general case, rather than means, since means were strongly influenced by a few drivers who did not keep to schedule.

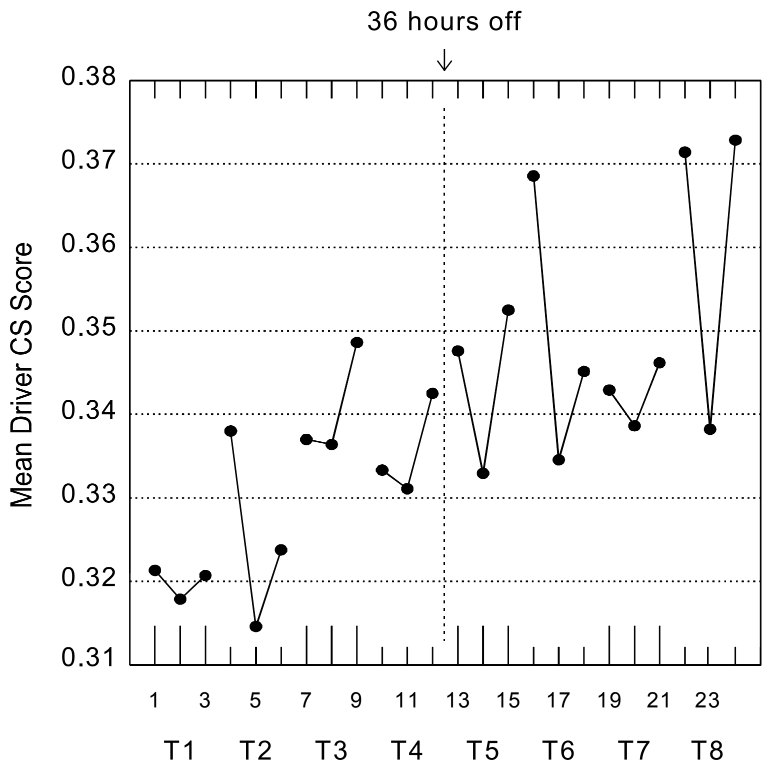

Figure 11. Combined CS scores from Conditions 3-5 (nightstart) and 4-9 (daystart) showing improvement with each successive trip.

The nightstart drivers (Condition 3-5) performed better during Administration 4, which occurred in the early afternoon (Figure 12). The daystart drivers performed better during Administration 1, which occurred around noon of each day (Figure 13).

Table 3. Median start times of surrogate performance test administrations. (N.B. Administration no. 3 was not performed in these Conditions.)

Condition	Administration		
	1	2	4
3-5	22:51	6:09	13:27
4-6	10:24	17:48	1:06
4-7	13:00	20:06	4:09
4-8	13:27	21:06	5:03
4-9	11:18	18:27	1:36

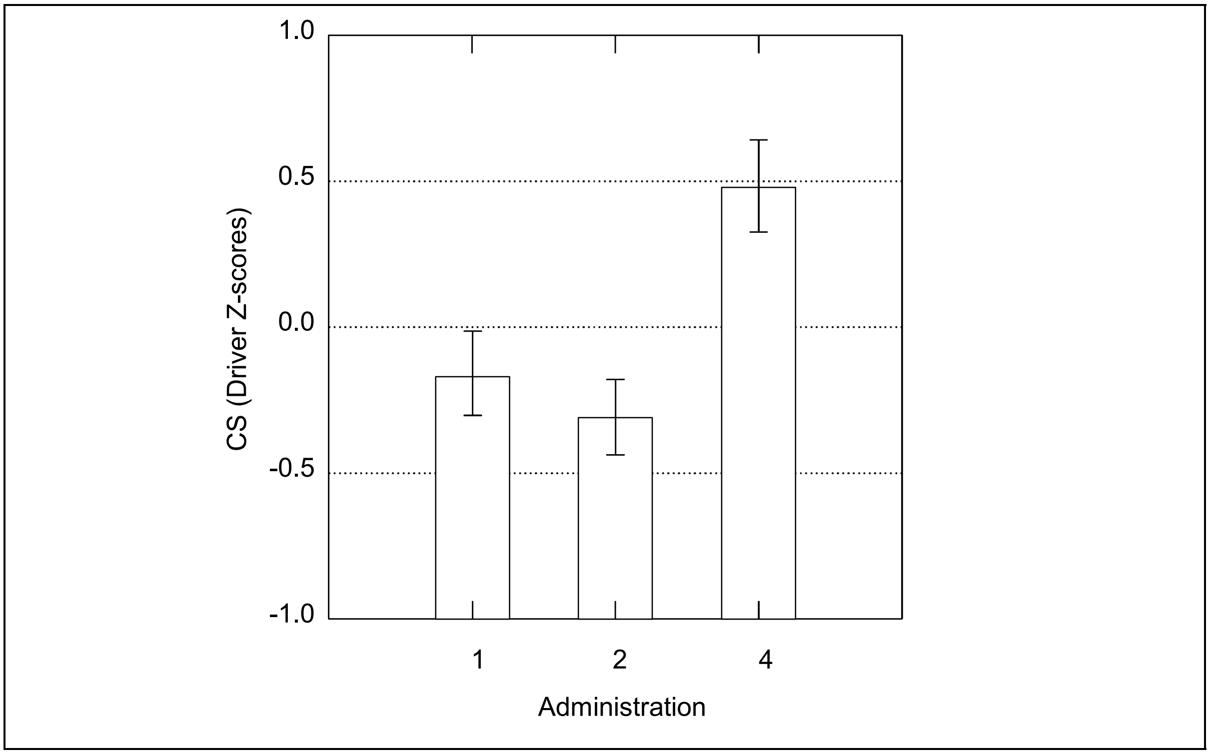

Figure 12. Mean CS Z-scores of Condition 3-5 (nightstart) drivers, illustrating daytime score improvement on Administration 4. (N.B. Administration no. 3 was not performed in these conditions.)

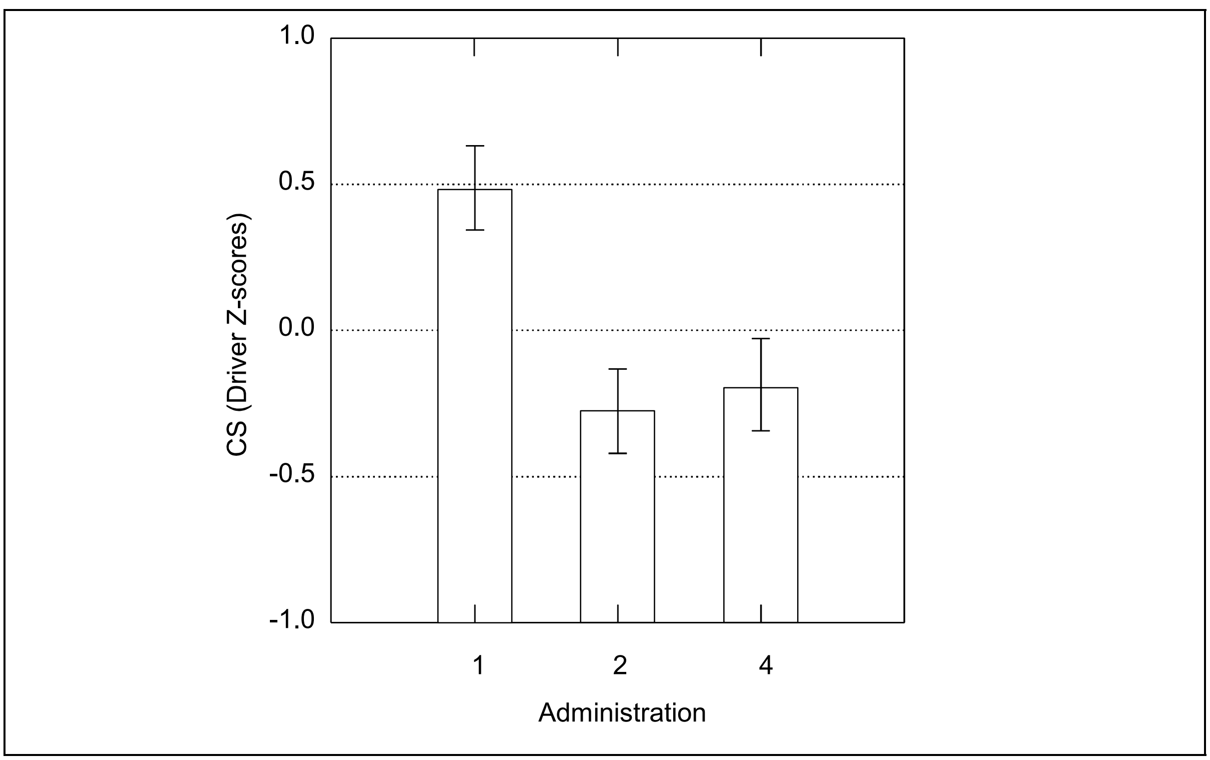

Figure 13. Mean CS Z-scores of Condition 4-9 (daystart) drivers, showing lower scores on Administration 2 and 4, which occurred at night. (N.B. Administration no. 3 was not performed in these conditions.)

Critical Tracking Test (CTT)

The univariate repeated measures ANOVA of Critical Tracking Test (CTT) scores failed to reveal statistically significant main or interaction effects. Minor differences in CTT between the nightstart and daystart 13-hour trips lack statistical significance. Figure 14 shows the drivers' CTT performance by trip for Conditions 3-5 and 4-9, with 36 hours off between Trips 4 and 5. There was a slight tendency for improvement on the first three trips of both 4-trip sets, and a performance decrement on the last trip of each set. The slight improvement in CTT over the 36 hours between Trip 4 and Trip 5 is not statistically significant.

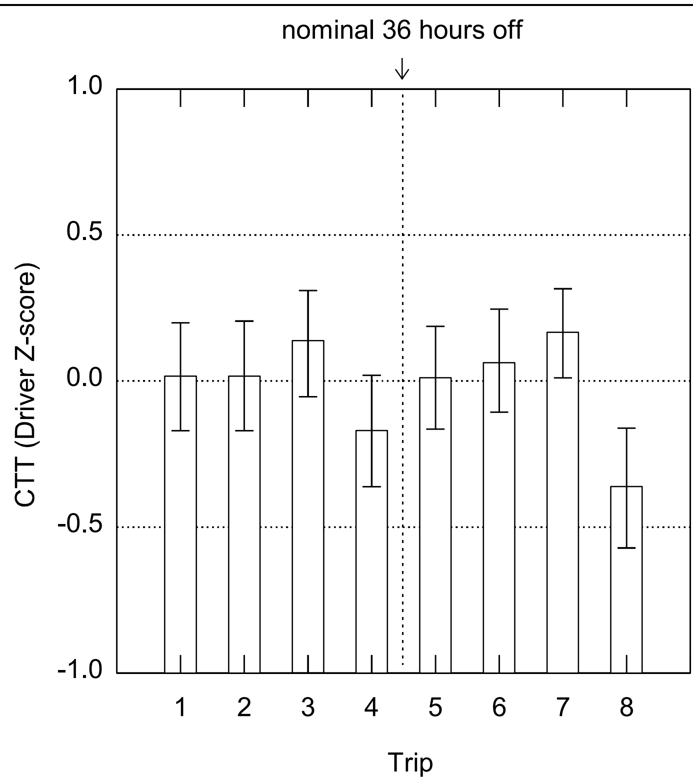

Figure 14. Conditions 3-5 (nightstart) and 4-9 (daystart) driver CTT performance by trip.

Number of Lapses during Simple Response Vigilance Test (SRVT)

The ANOVA of Normalized Lapses failed to slow any statistically significant differences between Conditions 3-5 and 4-9, the two sets of four trips, or the four trips of each set. The only statistically significant effect revealed was one of decreasing performance (greater number of Lapses) by Administration, $F(2,14) = 9.452$, $p = 0.003$. The effect is visible in both the daystart (Condition 4-9) and nightstart (Condition 3-5) data. Figures 15 and 16 illustrate the trend of increasing numbers of Lapses during each trip. Figure 15 shows performance on the nightstart trips (Condition 3-5), and Figure 16 shows performance on the daytstart trips (Condition 4-9). The reader is reminded that the scores derived from the Simple Response Vigilance Test (Lapses, number of response latencies greater than 500 milliseconds; and RVS, reciprocal of median response latency) appeared to vary with ambient light levels, which would have influenced stimulus intensity on the CRT display used for the SRVT. Ambient light level during test administration was not controlled, but appeared to have less effect on the 13-hour conditions than in the 10-hour conditions. The effect of ambient light levels is discussed more fully in the results section of the main DFAS report.

The structure of the ANOVA obscured a trend of increasing numbers of Lapses with each successive trip after Trip 3. This effect, which was not statistically significant, can be seen in Figure 17, which also shows driver self-ratings of sleepiness on the Stanford Sleepiness Scale. It is particularly interesting that driver self-ratings tended toward recovery after the 36-hour break between Trips 4 and 5, despite no reduction in the numbers of Lapses experienced. Drivers tended toward greater numbers of Lapses on the first day of the second cycle.

Response Vigilance Score (RVS) from the Simple Response Vigilance Test (SRVT)

The ANOVA of RVS data failed to show any statistically significant differences between the two Conditions, the two sets of four trips, or the four trips of each set. Although there was a tendency toward decrement in performance at the end of both daystart and nightstart trips this change fell short of statistical significance. The only statistically significant effect revealed by the ANOVA of RVS data was an Administration by Trip interaction, $F(6,42) = 2.607$, $p = 0.031$ (see Figures 18 and 19). The degradation within each trip became less with each added trip, but this effect was only of marginal statistical reliability given the number of ANOVAs performed on this data.

The structure and results of this ANOVA obscured RVS degradation that occurred across all eight trips of Conditions 3-5 (nightstart) and 4-9 (daystart) - see Figures 18 and 19. Figure 18 shows the combined Conditions 3-5 and 4-9 RVS data for each test session, grouped by trip number. The decrease in RVS (indicating increasing reaction time) across the eight trips of Conditions 3-5/4-9 was statistically significant, $F(7,49) = 3.57$, $p = 0.003$. The 36-hour off-duty period occurs between trips T4 and T5. It is particularly remarkable that drivers had worse RVS scores following their 36 hours off. This is seen in the poor performance of the night start drivers on T5 and T6, visible in Figure 19. The extreme low points were on the second test sessions (Administration 2) of the first two trips following 36 hours off. These test sessions occurred at 05:50 (T5) and 06:43 (T6) after approximately seven hours on duty.

The RVS changes closely mapped driver self-ratings on the Stanford Sleepiness Scale. The correlation of this data with driver self-ratings is -0.29 ($p < .0005$), suggesting that these drivers were to a certain extent aware of impairment of abilities measured by the SRVT.

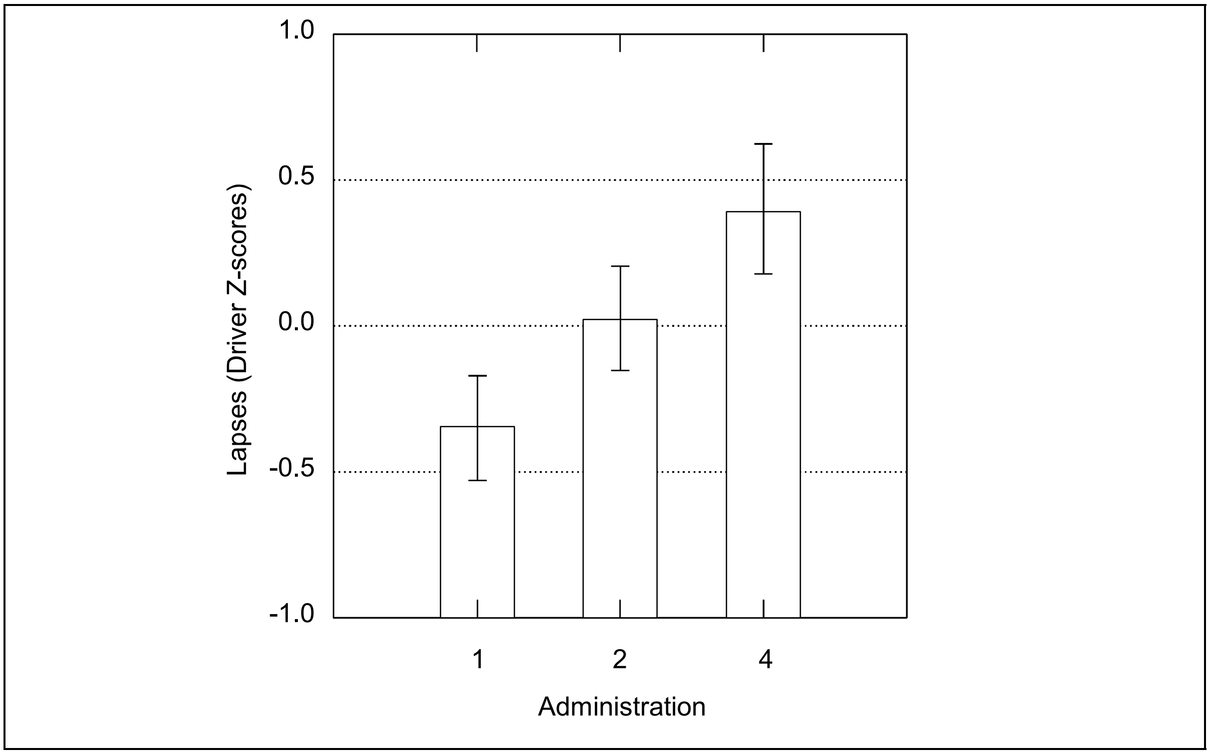

Figure 15. Lapses on Condition 3-5 (nightstart) trips by Administration. (N.B. Administration no. 3 was not performed in these conditions.)

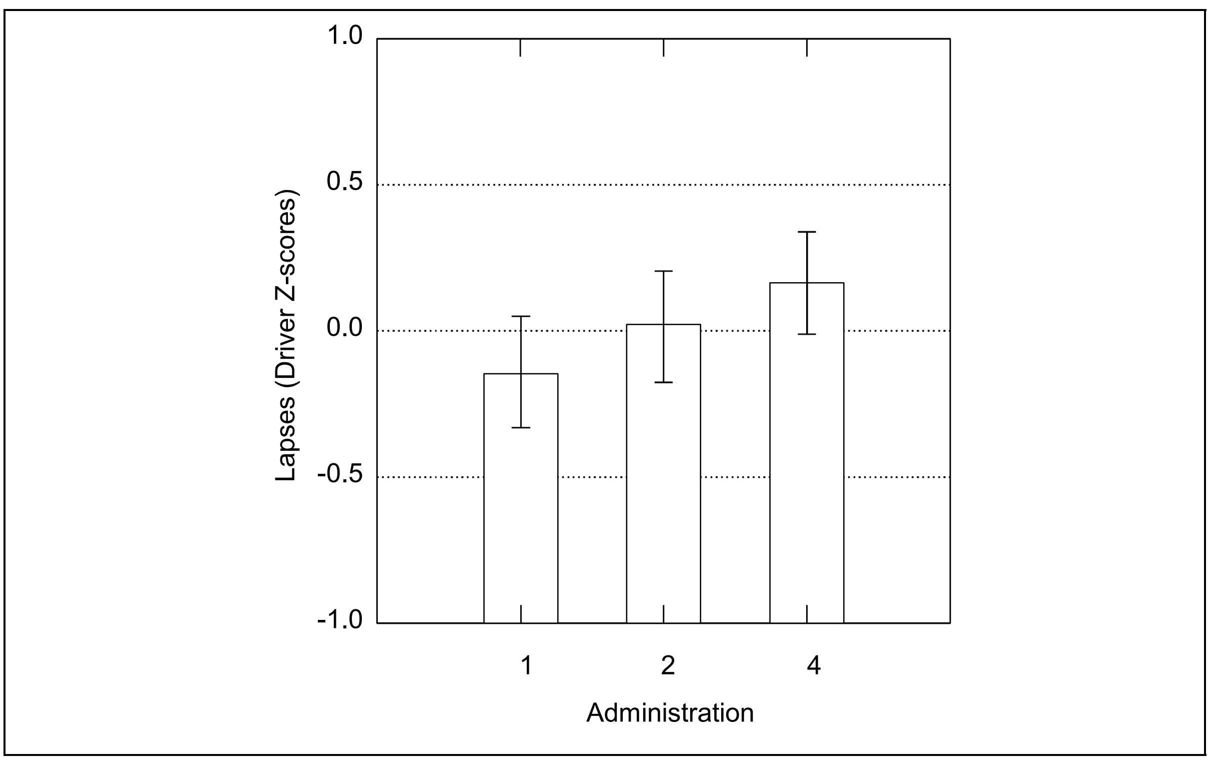

Figure 16. Lapses on Condition 4-9 (daystart) trips by Administration. (N.B. Administration no. 3 was not performed in these conditions.)

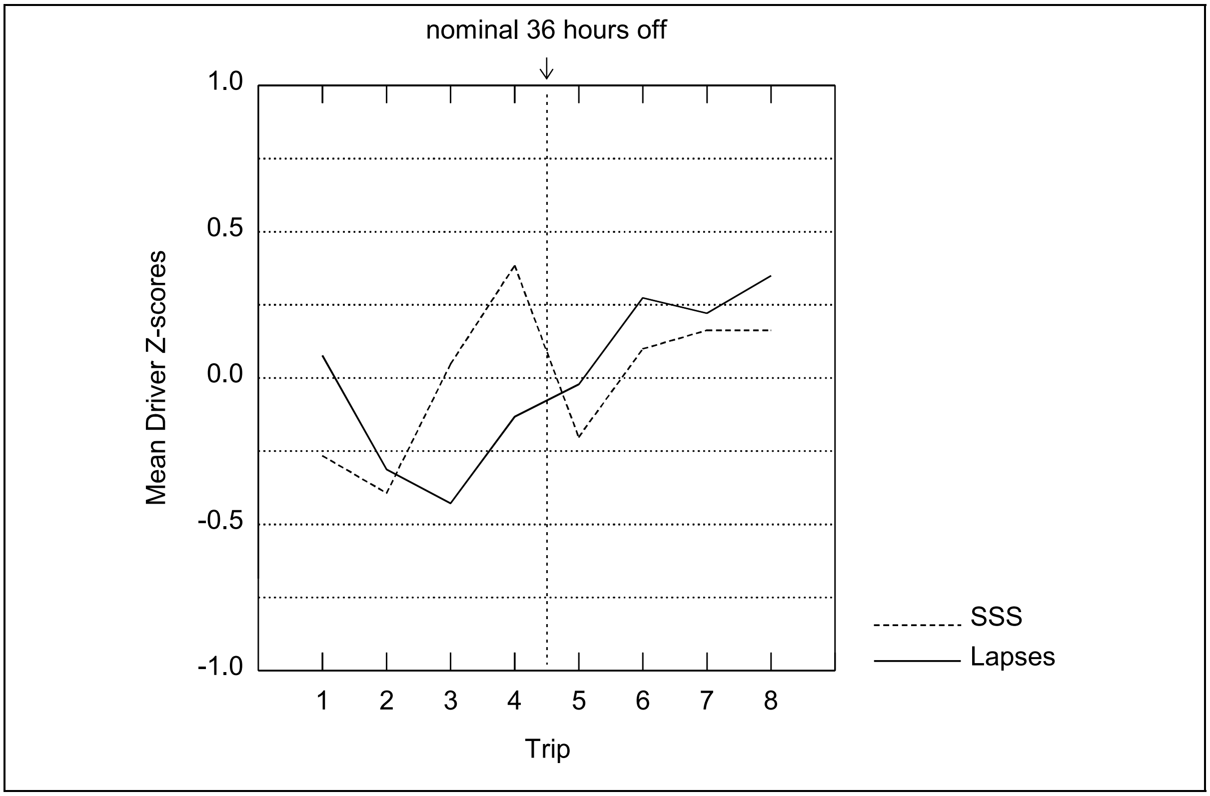

Figure 17. Number of Lapses and Stanford Sleepiness Scale (SSS) self-rating by trip in Conditions 3-5 (nightstart) and 4-9 (daystart).

THE EFFECT OF TIME OFF ON PERFORMANCE THE FOLLOWING TRIP

Another series of ANOVAs was performed on the data with the goal of quantifying changes associated with the amount of time off between the fourth and fifth trips. Three drivers drove a fifth trip without taking a workday off between the fourth and fifth trips (Condition 4-6), sixteen drove a fifth trip after one workday (36 hours) off (Conditions 3-5, 4-7, and 4-9), and six drivers drove a fifth trip after two workdays off (Condition 4-8).

No workday off, Condition 4-6

Repeated measures ANOVAs were performed with five levels of Trip and three levels of Administration using the data of the three drivers participating in Condition 4-6 (daystart). Trip 5 data was then contrasted with Trip 4 data. The small subject sample severely limited the ability to make reliable estimates of observed effects. No statistically significant performance test score differences were observed between the fourth and fifth trips. The results of contrasting these two trips on each measure are shown in Table 4.

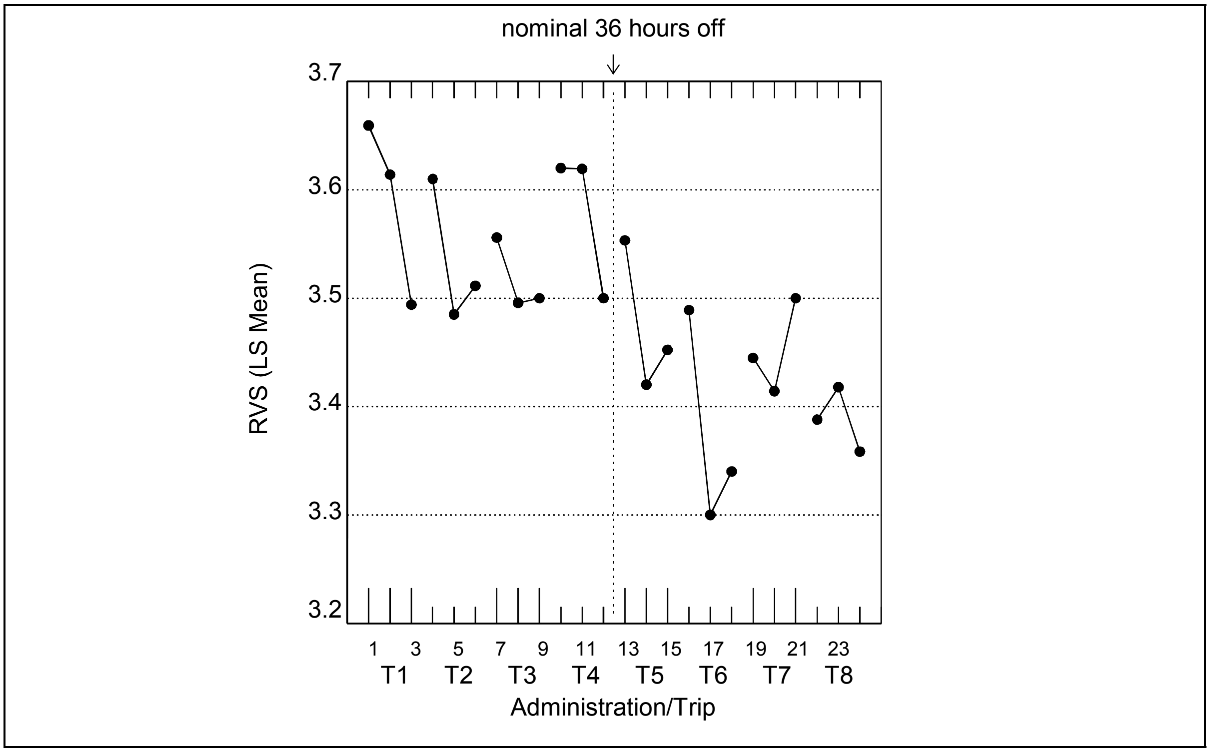

Figure 18. RVS scores on each test administration in Conditions 3-5 (nightstart) and 4-9 (daystart) trips, grouped by trip number.

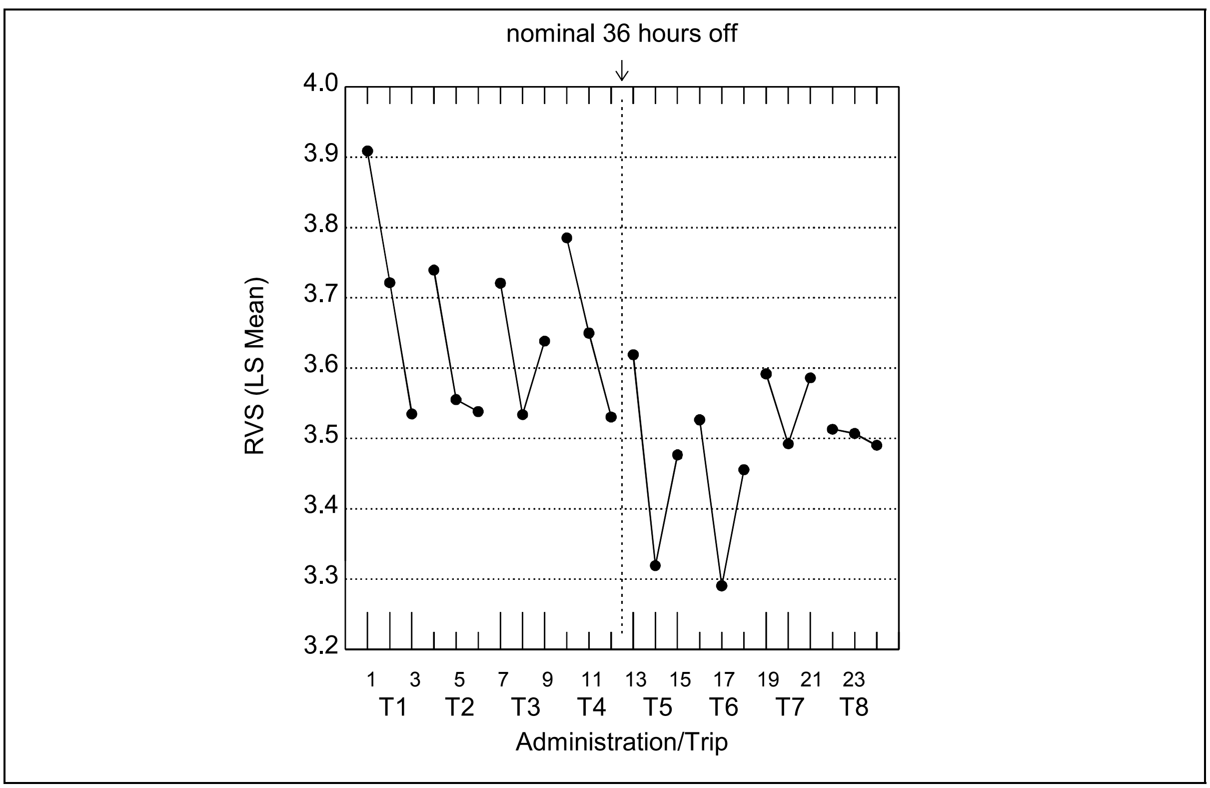

Figure 19. RVS scores on each test administration in Condition 3-5 (nightstart) trips, grouped by trip number.

Table 4. Surrogate performance test changes between Trips 4 and 5 of Condition 4-6 (daystart), with no workdays off. (Only three drivers participated in this condition, making reliable estimates of change difficult.)

Measure	F-ratio	df1	df2	Probability	Trip 5 - 4 scores
CS	0.455	1	2	0.570	no significant change
CTT	0.044	1	2	0.854	no significant change
Lapses	0.002	1	2	0.967	no significant change
RVS	0.563	1	2	0.531	no significant change

One workday (36 hours) off, Conditions 3-5, 4-7, and 4-9

Sixteen drivers drove four 13-hour trips, took 36 hours off, then drove a fifth trip. The group included five nightstart drivers (Condition 3-5) and eleven daystart drivers (Condition 4-7 and 4-9). There were a greater number of observations for this group than in Condition 4-6, permitting estimates with reliability approaching that of the DFAS (which used 20 drivers). The only statistically significant result was a marginal improvement in CS which, in this context, cannot be interpreted as recovery. The results of contrasting the fourth with the fifth trip in this 36-hour off-duty group are shown in Table 5.

Table 5. Surrogate performance test changes between Trips 4 and 5 of Condition 3-5 (nightstart), 4-7 (daystart), and 4-9 (daystart) with one intervening workday (36 hours) off. (The data of 16 drivers was used in these analyses.)

Measure	F-ratio	df1	df2	Probability	Trip 5 performance
CS	0.831	3	13	0.018	better than Trip 4
CTT	0.041	1	15	0.842	no significant change
Lapses	0.023	1	13	0.881	no significant change
RVS	4.345	1	13	0.057	no significant change

Two workdays (48 hours) off, Condition 4-8

Six drivers participated in Condition 4-8 (daystart). Having driven the four 13-hour daystart trips of the base Condition 4, they took 48 hours off, then drove an additional trip. There were no statistically significant improvements in scores between the fourth and fifth trips. The results of contrasting the fourth and fifth trips are shown in Table 6. Only six drivers participated in this observational condition, making reliable estimates of change difficult.

Table 6. Surrogate performance test changes between Trips 4 and 5 of Condition 4-8 (daystart), with two intervening workdays (48 hours) off. (Six drivers participated in this observational condition.)

Measure	F-ratio	df1	df2	Probability	Trip 5 performance
CS	1.411	1	5	0.288	no significant change
CTT	0.514	1	5	0.506	no significant change
Lapses	0.975	1	4	0.379	no significant change
RVS	2.847	1	4	0.167	no significant change

SUMMARY OF SURROGATE PERFORMANCE TEST RESULTS

Comparisons between two sets of four trips with one intervening workday off

In the comparisons of the first set of four trips with the second set of four trips after one workday off (Conditions 3-5 and 4-9), CS showed ongoing improvement with practice throughout the duration of the study (see Figure 11). Although CTT scores were lower on the last trip of each 4-trip set (see Figure 14), the effect was not statistically significant. The measures derived from the SRVT (Lapses and RVS) showed a trend of ongoing performance decrement across the eight trips (see Figures 17, 18, 19), with no recovery across the 36-hour off-duty period. The decrease in RVS (indicating increasing reaction time) was statistically significant, $F(7,49) = 3.57$, $p = 0.003$. The correlation of the RVS and SSS (driver self-ratings of sleepiness) measures was -0.29 ($p < .005$), which is quite small, but it is possible that drivers were to a certain extent aware of degraded functioning in those abilities measured by the SRVT.

The effect of 0, 1, and 2 workdays off on performance the following trip

There were no statistically significant performance test score changes between Trips 4 and 5 (Condition 4-6) when drivers did not take an intervening workday off. The number of subjects in this Condition (driver N=3) would make it difficult to obtain statistically reliable estimates of even rather large effects.

The larger number of drivers (driver N=16) who took one workday (36 hours) off between Trips 4 and 5 (Conditions 3-5, 4-9, 4-7) afforded better statistical reliability in estimating level of change over the recovery period, with reliability approaching that of the DFAS (which used 20 drivers). However, the only statistically significant change in scoring was in CS, which showed ongoing improvement with practice in all conditions. CS was better on Trip 5 than on Trip 4 but one could hardly call this performance recovery since, because of practice effects, there was no degradation of performance across the first set of four trips. Recovery implies prior degradation.

In the case of two intervening workdays (48 hours) off (Condition 4-8; driver N = 6), no statistically significant changes were noted between Trip 4 and Trip 5 performance test scores. As was the case with the condition without a workday off (Condition 4-6; driver N = 3), the number of subjects in Condition 4-8 would make it difficult to obtain statistically reliable estimates of even rather large effects.

SECTION 4. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

ONE WORKDAY (36 HOURS) OFF

Prevalence of drowsiness

The Mann-Whitney U-test was used to compare the average proportion of analysis epochs judged "drowsy" for all the recovery study Conditions (i.e., 3-5, 4-6, 4-7, 4-8, 4-9) aggregated by Condition and half trip. The test failed to reveal statistically significant differences in prevalence of drowsiness between the first four trips completed by each driver and subsequent trips taken after the prescribed recovery periods.

In the symmetrical Conditions 3-5 (nightstart) and 4-9 (daystart), drivers completed four trips, then took 36 hours off, then completed an additional four trips. The repeated-measures analysis of covariance of the arcsine transform of the proportion of analysis epochs judged "drowsy," with between-subjects factors "Condition" (= 3-5, 4-9) and "Age" (covariate) and within-subjects factors "Trip" (= 1st, 2nd, 3rd, 4th) and "Set" (= first set of four trips, second set of four trips) showed no significant effect of Condition or Set, although it did show a significant interaction of Set by Trip by Condition, $F(3,21)=5.0$, $p<.009$. Contrasting the trip preceding the 36-hour time-off period with the trip following it revealed no difference in both conditions 3-5 and 4-9.

In summary, recovery effects of the 36 hours off-duty were not apparent for the prevalence of drowsiness measure.

Lane tracking

In Condition 4-9 (daytstart), the lane tracking standard deviation (LTSD) performance measure trended upward (indicating worse performance) throughout the first 4 trips, then leveled off and remained at a relatively high level during the second 4 trips following the 36 hours of time off.

In Condition 3-5 (nightstart), drivers commenced with a relatively high level of LTSD which remained essentially the same throughout the 8 trips, with an exceptionally high value on the trip after the one workday (36 hours) off.

In summary, there was no evidence that one workday (36 hours) off brought about any improvement in driving performance as measured by LTSD.

Surrogate performance tests

The measures derived from the SRVT (Lapses and RVS) showed a trend of ongoing performance decrement across all eight trips, with no recovery over the 36-hour off-duty period. The decrease in RVS (indicating increasing reaction time) was statistically significant. CS and CTT did not show any statistically significant recovery effects associated with the time off.

Driver self rating

Drivers' self-ratings showed some improvement from the 36-hour off-duty period whereas objective performance measures did not. The drivers may have genuinely felt better, or they may have been reacting to an expectation that the correct response was to show improvement in sleepiness rating.

Sleep duration

For drivers starting their shift by day, some increase was observed in the amount of sleep obtained during the 36 hours of time off. On the other hand, the one workday (36 hours) off appears to have resulted in less sleep for drivers starting their shifts at night. In all likelihood, these drivers resumed day shift sleep-wake patterns on their time off, even though the time off was insufficient for accommodation.

Overall conclusion

For sixteen drivers taking one workday (36 hours) off, there was no objective evidence of driver recovery of performance.

ZERO AND TWO WORKDAYS OFF

These conditions had fewer drivers in them and the results are therefore more subject to random variation. For six drivers taking two workdays (48 hours) off, Condition 4-8 (daystart), there was no objective evidence of driver recovery. LTSD went "up-down-up," possibly representing random variation. In any event, LTSD on the day after the break is at a high level relative to the other trips. Surrogate performance test scores did not show recovery effects. For three drivers taking no workday off, Condition 4-6 (daystart), LTSD trended upward across the five workdays. There were no statistically significant surrogate performance test score changes between Trips 4 and 5. Because of the few drivers in these conditions, the prevalence of drowsiness measure was not examined.

RECOMMENDATIONS

Because of the smaller numbers of drivers who participated in the recovery study conditions compared with the DFAS, the statistical tests did not have the same power to detect effects. The methodology having been proven, this study could be repeated with a larger number of subjects, to improve the sensitivity of the tests. The effect of longer off-duty periods than examined in this study should also be investigated to establish the duration required for complete driver recovery during day, night, rotating, and irregular schedules.

APPENDIX 1

DRIVER SLEEP RELATED DATA FOR OBSERVATIONAL CONDITIONS 3-5, 4-6, 4-7, 4-8, 4-9

(Not available in electronic format)