Final Report on the Portable Computerized Assessments of Sleepy Drivers in Operational Environments

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1. Report No. # SPR 90-00-SLDR-010	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Portable Computerized Assessments of Sleepy Drivers in Operational Environments		**5. Report Date** 6/29/2011 **6. Performing Organization Code**
7. Author(s) Rizzo, Matthew, MD; Tippin, Jon, MD; Aksan, Nazan, PhD		**8. Performing Organization Report No.**
9. Performing Organization Name and Address University of Iowa Hospitals & Clinics, Dept of Neurology 200 Hawkins Drive Iowa City IA 52242		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Organization Name and Address Iowa Department of Transportation 800 Lincoln Way Ames, IA 50010		**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code** IA-DOT
15. Supplementary Notes		

16. Abstract

Excessive daytime sleepiness underpins a large number of the reported motor vehicle crashes. Fair and accurate field measures are needed to identify at-risk drivers who have been identified as potentially driving in a sleep deprived state on the basis of erratic driving behavior. The purpose of this research study was to evaluate a set of cognitive tests that can assist Motor Vehicle Enforcement Officers on duty in identifying drivers who may be engaged in sleep impaired driving. Currently no gold standard test exists to judge sleepiness in the field. Previous research has shown that Psychomotor Vigilance Task (PVT) is sensitive to sleep deprivation. The first goal of the current study was to evaluate whether computerized tests of attention and memory, more brief than PVT, would be as sensitive to sleepiness effects. The second goal of the study was to evaluate whether objective and subjective indices of acute and cumulative sleepiness predicted cognitive performance. Findings showed that sleepiness effects were detected in three out of six tasks. Furthermore, PVT was the only task that showed a consistent slowing of both 'best', i.e. minimum, and 'typical' responses, median RT due to sleepiness. However, PVT failed to show significant associations with objective measures of sleep deprivation (number of hours awake). The findings indicate that sleepiness tests in the field have significant limitations. The findings clearly show that it will not be possible to set absolute performance thresholds to identify sleep-impaired drivers based on cognitive performance on any test. Cooperation with industry to adjust work and rest cycles, and incentives to comply with those regulations will be critical components of a broad policy to prevent sleepy truck drivers from getting on the road.

17. Key Words —1) Sleepiness 2) Cognitive Field Tests		**18. Distribution Statement** No restrictions.	
19. Security Classification (of this report) Unclassified.	**20. Security Classification (of this page)** Unclassified.	**21. No. of Pages** 21	**22. Price** NA

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Title Page

Final Report on the Portable Computerized Assessments of Sleepy Drivers in Operational Environments

May 26, 2011

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Acknowledgments

We would like to thank research team members Kelsey Thompson, Katherine Read, and Mark Schall who twisted their circadian rhythms to follow our participants around their shifts. We would like to thank the participants who went to the trouble of remembering to show up at odd hours to take the tests despite being exhausted. We would like to thank the IA-DOT for giving us the opportunity to appreciate the difficulty of coming up with objective and fair field assessments of sleepiness.

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Background and Purpose

Excessive daytime sleepiness underpins a large number of the reported motor vehicle crashes (MVC) (35 - 42%: Dingus et al., 1987; Leger, 1995), and may be second only to alcohol as the most frequent cause of MVCs. Evidence shows that sleepy individuals are not always aware of their impaired status (Chin et al, 2004; Dement 1997; Engleman et al, 1997; Furuta et al, 1999; Chin, 2004), which may unwittingly lead some to engage in unsafe driving behavior. For example, Furuta et al (1999) demonstrated a disconnect between how sleepy patients perceived themselves compared to how sleepy they actually were with more objective markers of sleepiness that can only be administered in laboratory settings. Hence, lack of sleepiness awareness and resulting impairment in cognitive functioning is not likely to be sufficient to motivate drivers' self-regulatory resources to reduce crash risk.

Measures to counteract sleep impaired driving may include preventing sleepy drivers from ever getting on the road, through mandated duty cycles, driver logs, and other tools. Fair and accurate measures are also needed to identify at-risk drivers who have been identified as potentially driving in a sleep deprived state by Motor Vehicle Enforcement Officers on the basis of erratic driving behavior. The purpose of this research study was to evaluate a set of tests that can assist Motor Vehicle Enforcement Officers on duty in identifying drivers who may be engaged in sleep impaired driving. In practice, an officer who stops a driver for erratic driving behavior will not know why the driver is impaired. Consequently, any sleepiness diagnostic tool would have to be used alongside existing alcohol and substance related screens, and feasibly administered by troopers in the field.

Currently no gold standard test exists to judge sleepiness in the field. Previous research has shown that Psychomotor Vigilance Task (PVT) is sensitive to sleep deprivation (Dingus & Powell, 1985). The PVT is a relatively simple task that requires a participant to respond to a randomly presented light by pressing a button. The main outcome measures are lapses in attention, or number of times the participant fails to respond to the random presentation of light, along with reaction time. This test, however, takes about 10-11 minutes to administer and reducing the length of the test also reduces the sensitivity of the test to sleep deprivation (Loh et al., 2004).

Goals and Design

The first goal of the current study was to evaluate whether computerized tests of attention and memory, more brief than PVT, would be as sensitive to sleepiness effects. The second goal of the study was to evalute whether objective and subjective indices of acute and cumulative sleepiness predicted cognitive performance.

With those goals in mind, night and rotating shift workers were asked to complete computerized tests of attention and memory along with PVT twice, once prior to their shift and once immediately after their shift. In addition, the participants were asked to complete sleep diaries for a period of two weeks prior to their cognitive testing visits. The sleep diaries were used to quantify both objective and subjective indices of cumulative sleep deprivation. Magnitude of objective acute sleepiness was measured in number of hours the participant had stayed awake prior to each cognitive testing session.

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Methods

Participants

Fifty-six healthy night or rotating work shift adults participated in this study. Eight of those individuals dropped out for various reasons, (not showing up to cognitive testing sessions, failure to return calls, etc.) leaving 46 participants with complete data (13 males). The participants ranged in age from 22 to 56 years with a mean age of 32 years. The educational attainment ranged from high school graduate to post-graduate or professional degree, with an average of 16 years corresponding to college level education.

Procedure

This study was conducted over a series of three visits: an introductory session and two experimental sessions. During the first visit, each participant received an explanation of the purpose of the study and provided consent, completed general health / demographic questionnaires, and was given a sleep diary that was used to collect sleep habit information for at least one week prior to the two testing sessions. Each participant was instructed on how to use the sleep diary.

The two experimental sessions were conducted at the beginning and at the conclusion of a full work shift for each participant. Half of the participants completed the first experimental session prior to their work shift and the second session immediately after completing that same shift. The remaining participants completed the first experimental session after completion of a work shift and the second experimental session directly before the next work shift that the participant would work. This counterbalancing of pre- versus post-shift visits permitted estimation of sleepiness effects without confounding it with practice effects.

Each participant made an assessment of personal sleepiness using the Stanford Sleepiness Scale (SSS) prior to and after completion of cognitive testing at each session. The seven computerized cognitive tests were administered in a warm and comfortable environment with low ambient light levels to simulate the back seat of a trooper's vehicle. The order of the cognitive tests was randomized and administered serially without interruption or break.

Measures

Sleepiness/ Fatigue

Both acute and cumulative measures of objective and subjective sleepiness/fatigue were collected.

Objective measure of acute sleepiness was the number of hours participants had been awake prior to each cognitive testing session. Objective measure of cumulative sleepiness was measured with sleep diaries, during the two weeks prior to the cognitive testing sessions. Participants indicated the times they went to bed and awakened in addition to number of minutes they stayed awake unable to sleep. This information was used to derive number of hours slept adjusting for insomnia for each dairy day. To derive an objective cumulative sleepiness index, the minimum and average number of hours slept during the course of the two week period and percentage of nights when the participant slept for less than 4 hours were transformed to z-scores and averaged. This index had high internal consistency, alpha = .84.

Subjective acute sleepiness was measured with the *Stanford Sleepiness Scale.* This scale measures sleepiness with a Likert scale ranging from 1 (very alert) to 7 (extremely sleepy). Participants completed this scale at the beginning and end of each cognitive testing session.

The average of the two ratings was used to index acute subjective sleepiness. Data on subjective measures of cumulative sleepiness was collected from sleep diaries as well. Upon waking, participants were also asked to rate the quality of their sleep and alertness with a Likert scale from 1 to 5 (1 =poor and 5 =very good) every day. The minimum, average and percentage of nights when sleep quality and alertness ratings were equal to or less than 2 were standardized and averaged into composite score. This index had high internal consistency, alpha = .90.

Finally, the participants were asked to complete the *Epworth Sleepiness Scale* (Johns 1991). This scale measures cumulative daytime sleepiness. The participants rated how likely they would be to fall asleep in eight situations with a scale from 0 to 3. Sum of the ratings across eight situations is used in analyses.

Cognitive functioning

The cognitive assessments included seven standard computerized attention tasks. Tasks tapped various domains of functioning. Two psychomotor tasks tapped speed and vigilance (PMS and PVT); working memory tasks tapped both visual and spatial memory; two tasks captured attention with visual search and spatial cueing of attention, and one task, digit symbol substitution, captured general neurological impairment.

PVT – Psychomotor Vigilance Task is a simple task that requires a participant to respond to a randomly presented light by pressing a button. The main outcome measures of this task are lapses in attention, or number of times the participant fails to respond to the random presentation of light, and reaction time. The task lasts 10 minutes.

PMS – Psychomotor speed. The PMS task measures a subject's psychomotor speed and impulsivity. Based on the Continuous Performance Test (Conners, 1992; Rosvold et al., 1956), PMS presents subjects with a smiling or frowning face schematic, with eyes and mouth only. Subjects are instructed to respond as quickly as possible to the face by pressing a button when he/she detects a smiling face. Conversely, subjects are instructed to inhibit responding when a frowning face is presented. Measures include reaction time to smiling faces and successful response inhibition to frowning faces.

Visual Search task measures the ability to actively scan a visual environment for a target object presented among distractors (Triesman & Gelade, 1980). The test has four trial types of increasing difficulty. The first two involve feature search (green square with a gap in the bottom) under both low clutter and high clutter conditions. The last two involve conjunctive search (same feature among many green squares) under both low clutter and high clutter conditions. In low clutter conditions there were a total of four squares and in high clutter conditions there were a total of 12 squares.

Posner – Spatial cueing task measures efficiency of attentional orienting (Carrasco & Yeshurun, 1998; Posner, Snyder, & Davidson, 1980; Yeshurun & Carrasco, 1999). It provides an objective reaction-time measure of orienting to targets when alerts appear in spatially congruous and non-congruous locations relative to the target. Measures include reaction time and accuracy.

Digit-Symbol Substitution is a simple but sensitive test to neurological impairment. The participant is asked to match a set of 9 symbols to digits between 1 and 9. Number of correct substitutions is the main outcome measure (Smith, 1982).

VSTM – Visual working memory task presents the participant with four colored squares, and following a brief delay the participant is presented with a fifth test square. The participant is asked to judge whether the test square matches any in the initial sample of four. Reaction time and accuracy are recorded.

SPWM – spatial working memory task measures an individual's ability to detect changes in spatial location of an item. The test briefly presents either two (low clutter) or three dots (high clutter) in space. Following a delay a red dot is presented at either the same or a different location. The participant is asked to judge whether the red dot's location exactly matches the placement of at least one of the sample dots. Reaction time and accuracy are recorded.

Statistical Analysis

Following an examination of sleepiness effects from pre to post-shift using repeated measure ANOVAs, correlations of post-shift cognitive performance scores were examined in relation to objective and subjective markers of sleepiness.

Results

Table 1 presents the F-values from repeated measure ANOVAs testing sleepiness effects, post- and pre-shift differences. The outcome measures included the best responses, i.e. minimum RTs and typical responses, i.e. median RTs, and accuracy, i.e. percentage of correct responses. Because none of the accuracy measures other than lapses in PVT showed sleepiness effects, only findings pertinent to RTs are presented in Table 1. Because of repeated testing, participants would be expected to show improved performance from the first to the second testing session. However, because session order was counterbalanced, practice and sleepiness effects were not confounded. The table provides F values associated with both practice and sleepiness effects.

Table 1 demonstrates that practice effects were common to all tasks, detected both for typical responses, median RT, as well as best responses, minimum RT. Practice effects typically decreased RTs about 50 milliseconds from first to second administration.

Sleepiness effects, on the other hand, were detected in three out of six tasks. Furthermore, PVT was the only task that showed a consistent slowing of both 'best', i.e. minimum, and 'typical' responses, median RT due to sleepiness. Visual search task and spatial short-term memory tasks showed sleepiness effects in high clutter trials. For example, median RTs slowed in high clutter featural visual search trials of the Visual Search Task and in high clutter matching trials of the spatial short-term memory task. In addition, a slowing in the minimum RT was also noted in high clutter conjunctive search trials.

Table 2 gives the size of the observed sleepiness effects in each of those three tasks. As can be seen from Table 2, RTs slowed by 26 to 54 milliseconds in the brief cognitive tests. This magnitude of RT slow-down is comparable to the 30 millisecond slow-down in median RTs for the PVT. However, because the slow down in RTs were more variable across trials in the brief cognitive battery, the sleepiness effects were not as consistent in these tests compared with the PVT.

Table 3 shows the correlations of post-shift RTs in tasks that showed statistically significant sleepiness effects, shown in Table 2, and subjective and objective markers of acute and cumulative sleepiness. For these analyses, minimum and median RTs were pooled into a composite score to derive more robust measures of performance in each task.

Post-shift cognitive performance showed, at best, weak correlations with both objective and subjective measures of sleepiness. Interestingly, PVT which was the most robust test to sleepiness effects from pre- to post-shift visits, failed to show significant associations with objective measures of sleep deprivation (number of hours awake). In contrast, RTs in featural and conjunctive search trials with high degrees of clutter tended to increase the more acutely sleep deprived the participants were. Objective measures of cumulative sleep deprivation were not associated with cognitive test scores. Only performance on the PVT appeared to be correlated with subjective ratings of acute and cumulative sleeplessness.

Conclusions & Recommendations

PVT was the only task sensitive enough to show statistically significant decrements in performance from pre- to post-shift sessions in all measures including best and typical RTs as well as accuracy. Interestingly, the objective index of acute sleep deprivation magnitude, number of hours the participant had been awake at the time the test was taken, was not correlated with PVT performance metrics. While visual search and spatial working memory tasks indicated statistically significant decrements in performance from pre- to post-shift sessions, those differences were not consistently noted across all performance metrics. However, unlike the PVT, RTs in the visual search task were correlated with objective indices of sleep deprivation in the expected direction. Finally, PVT was the only cognitive test to show meaningful associations with subjective ratings of acute and cumulative sleepiness.

It is important to note that the study had sufficient statistical power to detect a difference of 30milliseconds, a small difference. Lack of pervasive sleepiness effects across several cognitive tests indicates that it will be difficult to develop accurate and reliable tests that can be deployed in the field to detect sleep impaired drivers. Furthermore, even when tests are sensitive to sleep impairment, cognitive tests will not permit a trooper to infer that reason for impairment is specific to sleep deprivation versus another causal agent, e.g. intoxication.

The findings from this and other studies (Loh et al., 2004) would suggest, however, that any tests that are deployed in the field to detect sleep impaired drivers will need to be lengthy. Furthermore, it is not clear whether the stress of being pulled over would alter alertness levels in ways that decrease or alter the sensitivity of the tests to sleepiness.

Fatigue Risk Management Systems (FRMS) can be developed that benefit from a large body of existing research on sleep and duty cycle and education and policy plans that take advantage of the latest developments in sleep science.

We note that risks of sleepiness-related errors and crashes stem from multiple interrelated and interacting aspects of work, rest, and sleep. These include: 1. Duration of work periods within a single day and over time, 2. Time of day at which work occurs, 3. Variation in the timing of work within and between weeks, 4. Duration of sleep obtained on work days and on non-work days, 5. Frequency and duration of days off from work, 6. Different vulnerabilities of workers to sleepiness from these factors, and 7. Volume and intensity of work. (see Institute of Medicine, 2009, pp. 218-219, Dinges, 1995), Drake et al., 2004; Folkard et al., 2005; Rosa, 2001; and Van Dongen, 2006; and extensive References provided below).

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To inform the development of industry best practices and policies relevant to driver sleepiness, the DOT should study to determine the effect of several primary sleepiness risk factors: (1) sleep quantity 48 hours prior to the end of duty on each day of the trip; (2) sleep quality 48 hours prior to the end of duty on each day of the trip; (3) time awake in the 48 hours prior to the end of duty on each day of the trip; (4) cumulative sleep time in the 72 hours prior to the end of a duty period; and (5) circadian phase at which sleep is obtained and at which duty is undertaken (relevant to drivers making cross country trips). To be maximally useful, the study should include a large random sample of drivers from multiple companies as well as driver owned operations. The study should provide objective data on sleepiness risk antecedents by using a well-validated technology that provides reliable information on sleep and wake periods, such as wrist actigraphy and a sleep-wake diary.

Executive Summary

Extensive scientific evidence exists on the negative effects of sleepiness in performance of many cognitive tasks including those essential for safely operating a commercial motor vehicle. These include adverse effects of sleepiness induced by sleep loss on maintaining wakefulness and alertness, vigilance and selective attention, psychomotor and cognitive speed, accuracy in performing a wide range of cognitive tasks, working and executive memory, and on higher cognitive functions such as decision-making, detection of safety threats, and problem solving, as well as communication and mood. Sleepiness is not, however, an all or none condition where a driver is either rested with no negative effects on performance or sleepy with resultant severe negative effects on performance. There are degrees of sleepiness and degrees of negative effects on performance. Likewise the effects of sleepiness on performance can vary substantially from one driver to another without differing effects on driving performance and safety.

There are no valid and reliable tools and techniques feasible to reach the goals of detecting excessive sleepiness and fitness for duty in truckers in an operational setting. Current research tools can measure critical driver abilities in operational settings, however there are large inter-individual differences in individual baseline abilities and performance, and it is not known what is "normal" for an individual driver encountered for the first time. It is not possible to determine if a poor performance is due to sleepiness alone or if there are other factors (e.g., educational, drugs). There are no clear thresholds based on available tests to diagnose drivers as excessively sleepy or not for purposes of evaluation in the field. What is more, there are large interindividual differences in ability to cope with sleepiness. The encounter with a tester (e.g. an officer) in the field can be "activating", such that a driver might temporarily perform well despite being excessively sleepy. There are also learning effects of subjects on tests so that drivers may actually improve with repeated tests based on practice with the test, despite being excessively sleepy.

More work is needed to develop tools and techniques capable of detecting sleepiness and fitness for duty in truckers in an operational setting. To achieve these goals, further research would be needed to scientifically validate the tools and techniques, demonstrate that they are technically feasible in an operational environment, and evaluate their relationship to operational safety and the extent to which they can be integrated into an operational context. Meanwhile, there are several feasible tacks that the IDOT can take to mitigate drowsy driving that take advantage of existing knowledge and resources.

We note that risks of sleepiness-related errors and crashes stem from multiple interrelated and interacting aspects of work, rest, and sleep. These include: 1. Duration of work periods within a single day and over time, 2. Time of day at which work occurs, 3. Variation in the timing of work within and between weeks, 4. Duration of sleep obtained on work days and on non-work days, 5. Frequency and duration of days off from work, 6. Different vulnerabilities of workers to sleepiness from these factors, and 7. Volume and intensity of work. (see Institute of Medicine, 2009, pp. 218-219, Dinges, 1995), Drake et al., 2004; Folkard et al., 2005; Rosa, 2001; and Van Dongen, 2006; and extensive References provided below).

Recommendation 1: Truckers should avoid pre-duty activities that result in being awake beyond approximately 16 hours before the end of duty and endeavor to sleep at least 6 hours prior to reporting for duty. Truckers should also consider the amount of sleep and time awake in decision making about calling in sleepy or deciding to drive.

Recommendation 2: Sleepiness in commercial drivers should be addressed as part of an industry-wide strategy to manage the risk of sleepy driving. Fatigue Risk Management Systems (FRMS) should gather information about pre-duty sleep and wake time relative to duty cycle. FRMS should provide a mechanism for identifying problematic patterns and addressing them. FRMS can offer both the industry and the DOT an improved assessment of driver alertness during normal operations and thereby provide some information on whether fatigue is or is not within an acceptable level.

Recommendation 3: Sleepiness education and awareness training should be considered as part of the industry Fatigue Risk Management Plan. Training should include guidelines regarding the effects of inadequate or disturbed sleep or prolonged wakefulness on sleepiness and performance. Furthermore, sleepiness education and awareness training should be annually updated and particular attention should be paid to incorporating relevant new developments in sleep science into this training.

Recommendation 4: The DOT should commission efforts to develop protocols and materials for training drivers to make decisions regarding driving easily and effectively and to ensure that they are informed by current science.

Recommendation 5: To inform the development of industry best practices and policies relative driver sleepiness, the DOT should study to determine the effect of several primary sleepiness risk factors: (1) sleep quantity 48 hours prior to the end of duty on each day of the trip; (2) sleep quality 48 hours prior to the end of duty on each day of the trip; (3) time awake in the 48 hours prior to the end of duty on each day of the trip; (4) cumulative sleep time in the 72 hours prior to the end of a duty period; and (5) circadian phase at which sleep is obtained and at which duty is undertaken (relevant to drivers making cross country trips). To be maximally useful, the study should include a large random sample of drivers from multiple companies as well as driver owned operations. The study should provide objective data on sleepiness risk antecedents by using a well-validated technology that provides reliable information on sleep and wake periods, such as wrist actigraphy and a sleep-wake diary.

Technical Report Table 1

Table 1. F-values for practice and sleepiness effects among cognitive tests administered pre and post-shift.

Tasks	Trial Type	Measure	Practice	Sleepiness
Psychomotor Tests				
PMS-speed		min RT	7.95**	1.66
		Mdn RT	17.37**	<1
PVT-vigilance		**min RT**	4.98*	**4.72***
		Mdn RT	4.93*	**13.53****
		Lapses	< 1	**6.04***
Visual Attention for Targets				
Featural	low clutter	min RT	4.75*	<1
		Mdn RT	24.36**	<1
	high clutter	min RT	6.29*	<1
		Mdn RT	10.81**	**4.59***
Conjunctive	low clutter	min RT	14.09**	4.05+
		Mdn RT	40.17**	1.18
	high clutter	**min RT**	9.38**	**7.79****
		Mdn RT	6.76*	<1
Posner Cueing	Congruous	min RT	7.87*	<1
		Mdn RT	11.20**	<1
	Incongruous	min RT	<1	<1
		Mdn RT	22.14**	<1
Digit Symbol Substitution		# correct	7.76**	<1
Short-term Memory				
Visual	match	min RT	13.70**	<1
		Mdn RT	22.22**	<1
	No match	Min RT	8.88**	<1
		Mdn RT	11.92**	<1
Spatial				
	Low clutter match	min RT	14.42**	<1
		Mdn RT	20.21**	<1
	No match	Min RT	2.77	<1
		Mdn RT	8.59*	<1
	High clutter match	min RT	10.97**	<1
		Mdn RT	6.58*	**4.53***
	No match	Min RT	7.15*	1.57
		Mdn RT	13.13**	<1

Abbrv. PMS = Psychomotor Speed; PVT=Psychomotor Vigilance Task.

Technical Report Table 2

Table 2. Means and standard deviations for pre and post-shift RTs in those tasks that showed significant sleepiness effects.

		Pre-shift		Post-shift	
Task & trial type	Measure	Mean	SD	Mean	SD
Featural high clutter	min RT	540.93	61.73	542.24	66.72
	Mdn RT	**693.7283**	**82.69**	**720.6522**	**105.77**
Conjunctive high clutter	**min RT**	**740.17**	**116.65**	**795.11**	**137.76**
	Mdn RT	1355.99	318.90	1382.40	291.41
SPWM high clutter match	min RT	569.26	112.45	583.57	123.19
	Mdn RT	**750.52**	**114.37**	**791.48**	**134.88**
PVT	**min RT**	**182.18**	**20.27**	**190.55**	**28.40**
	Mdn RT	**253.70**	**31.78**	**283.80**	**64.54**
	Lapses	**.87**	**1.69**	**4.20**	**10.13**

Technical Report Table 3

Table 3 Correlations of post-shift cognitive performance with subjective and objective indices of acute and cumulative fatigue/ sleepiness.

	Subjective sleepiness		Objective sleepiness	
	Acute SSS	Cumulative Sleep quality past 2 wks	Acute Hours Awake	Cumulative Sleep quantity past 2 wks
PVT	.30*	-.28*	.15	-.18
Attention: Visual Search				
Featural high clutter	.02	.35*	.29+	-.11
Conjunctive high clutter	.04	.02	.29+	-.14
Spatial Working Memory				
Match high clutter	.05	.04	-.15	-.04

Note. Correlations in the expected direction are underlined. * p < .05; + p < .10

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