Final Report
Diagnostic Tools for Identifying Sleepy Drivers in the Field

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16. Abstract

The overarching goal of this project was to identify and evaluate cognitive and behavioral indices that are sensitive to sleep deprivation and may help identify commercial motor vehicle drivers (CMV) who are at-risk for driving in a sleep deprived state and may prove useful in field tests administered by officers. To that end, we evaluated indices of driver physiognomy (e.g., yawning, droopy eyelids, etc.) and driver behavioral/cognitive state (e.g. distracted driving) and the sensitivity of these indices to objective measures of sleep deprivation. The measures of sleep deprivation were sampled on repeated occasions over a period of 3.5-months in each of 44 drivers diagnosed with Obstructive Sleep Apnea (OSA) and 22 controls (matched for gender, age within 5 years, education within 2 years, and county of residence for rural vs. urban driving). Comprehensive analyses showed that specific dimensions of driver physiognomy associated with sleepiness in previous research and face-valid composite scores of sleepiness did not: 1) distinguish participants with OSA from matched controls; 2) distinguish participants before and after PAP treatment including those who were compliant with their treatment; 3) predict levels of sleep deprivation acquired objectively from actigraphy watches, not even among those chronically sleep deprived. Those findings are consistent with large individual differences in driver physiognomy. In other words, when individuals were sleep deprived as confirmed by actigraphy watch output they did not show consistently reliable behavioral markers of being sleep deprived. This finding held whether each driver was compared to him/herself with adequate and inadequate sleep, and even among chronically sleep deprived drivers. The scientific evidence from this research study does not support the use of driver physiognomy as a valid measure of sleep deprivation or as a basis to judge whether a CMV driver is too fatigued to drive, as on the current Fatigued Driving Evaluation Checklist.. Fair and accurate determinations of CMV driver sleepiness in the field will likely require further research on alternative strategies that make use of a combination of information sources besides driver physiognomy, including work logs, actigraphy, in vehicle data recordings, GPS data on vehicle use, and performance tests.

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Title Page

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Diagnostic Tools for Identifying Sleepy Drivers in the Field- Phase II

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Executive Summary

Significance and overarching goal

Excessive daytime sleepiness underpins many motor vehicle crashes. Fair and accurate field measures are needed to identify commercial motor vehicle drivers (CMV) who are at-risk for driving in a sleep deprived state. Consequently, the overarching goal of this project is to identify and evaluate cognitive and behavioral indices that are sensitive to sleep deprivation and may prove useful in field tests administered by officers.

Background

Extensive scientific evidence links sleep deprivation with impaired performance in many tasks that are essential for safely operating a motor vehicle. These include maintaining wakefulness and alertness, vigilance and selective attention, processing speed, and a range of cognitive functions such as working-memory, decision-making and other executive functions, detection of safety threats, problem solving, communication and mood (Dement, 1997; Dinges, 1995; Engelman et al., 1997; Van Dongen et al., 2006). Sleepiness is not an all or none condition where a driver is either rested with no negative effects or sleepy with severe negative effects on performance. There are degrees of sleepiness, and the negative effects of sleepiness on performance can vary widely from one driver to another. Currently no gold standard test exists to judge sleepiness in the field.

Phase I goals and outcomes

Previous research has shown that Psychomotor Vigilance Task (PVT) is sensitive to sleep deprivation (Loh et al., 2004). The first goal of Phase I of this 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 Phase I 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. PVT was the only task that showed a consistent slowing of both ‘best’, i.e. minimum, and ‘typical’, i.e. median reaction time, responses, due to sleepiness. However, PVT failed to show significant associations with objective measures of sleep deprivation (number of hours awake). Also, PVT had an (“unfair”) advantage over other tests because it is a longer test (providing greater opportunity to probe flagging abilities) and perhaps even too lengthy for feasible deployment in operational (field) settings. The findings indicated that sleepiness tests in the field have significant limitations and that it will not be possible to set absolute performance thresholds to identify sleep-impaired drivers based on cognitive performance on any single test, PVT included. And that any inclusion of cognitive tests will require baseline measure of performance specified individually for CMV drivers to judge decrements in cognitive functioning due to extended duty cycles, sleep deprivation, medication use, and/or disease (DOT final report SPR 90-00-SLDR-010).

Phase II Goals

Given the limitations of relying on cognitive performance indices to judge sleep deprivation, phase II of this project attempted to refine the existing Fatigued Driving Evaluation Checklist. To that end, we evaluated indices of driver physiognomy (e.g., yawning, droopy eyelids, etc.) and driver behavioral/cognitive state (e.g. distracted driving) with respect to their sensitivity to objective measures of sleep deprivation sampled on repeated occasions over a period of 3.5-months.

Existing field evaluations of fatigue among CMV drivers (such as the Fatigued Driving Evaluation Checklist) sample officer observations in four domains: a) condition of the truck, b) condition of the sleeper, c) condition of the cab, and d) trucker’s physical condition. The specific items that are evaluated in the first three domains include cleanliness observations (for example ‘dirty/unkempt interior’ in the Truck Condition and ‘empty caffeinated drink cans’ in the Cab Condition). Items in the Sleeper condition domain concern whether the berth is actually used for sleep or storage, as well as sources of distraction such as video games and reading materials. The items in those three domains (a-c) tap evidence that may be associated with uninterrupted driving for long stretches of time (e.g., weeks to months) and failure to comply with duty and sleep cycle regulations. The items in the fourth domain, d) trucker’s physical condition, tap physiognomy such as yawning, droopy eyelids, head bobbing, watery/tearing eyes which may be more direct but not necessarily specific indicators of sleepiness.

While the items selected for inclusion in the checklist are based on a systematic review of literature (e.g., Klauer et al., 2006; Neale et al., 2005; Wierville & Elsworth, 1994), the sensitivity and relevance of physiognomy and behavioral/cognitive state variables observed in the driving context to degree of sleep deprivation is not known. A better understanding of the magnitude of associations between sleep deprivation and indicators of both physiognomy and behavioral/cognitive state, both separately and in combination is a necessary first-step in helping refine the Fatigued Driving Evaluation Checklist in use by officers in the field.

Any research endeavor that aims to assess the sensitivity (i.e., magnitude of association) of physiognomy and behavioral/cognitive state indicators to sleep deprivation in the context of driving performance must meet three criteria: 1) a relevant population must be studied, 2) sleepiness related physiognomy and behavioral/cognitive state indicators must be observed in driving-relevant contexts, and 3) the variables of interest, sleep deprivation, physiognomy, and behavioral/cognitive state must be sampled over an extended time frame to capture adequate within-person and between-person variability in each.

Ongoing research at the UIHC—Neuroergonomics Laboratory fulfills the three research criteria listed above and is relevant to the needs of the IA-DOT. This research was designed to examine the dose-response relationship between Positive Airway Pressure (PAP), the standard treatment for Obstructive Sleep Apnea (OSA) (a relatively prevalent condition among at-risk sleepy CMV drivers), upon real-world driving performance. We are collecting objective measures of sleep deprivation, as well video samples of cognitive/behavioral state and physiognomy in drivers with OSA and matched controls, driving their own vehicles amid the contingencies and risks of the real world. These unique samples of behavior are being collected over an extended time frame (3.5-months) which permits capture of within-person variability in the domains sampled. Further, the study of drivers with OSA permits an examination of poor quality of sleep, due to a disease process, in relation to both physiognomy and cognitive/behavioral state variables in the driving context. Hence, the protocol of the study is appropriate to address questions of interest to IA-DOT in phase II: assessing the sensitivity of physiognomy and cognitive/behavioral state to sleep deprivation and based on that sensitivity make recommendations to improve Fatigued Driving Evaluation checklist.

Specific Analytic Tasks of Phase II included coding the physiognomy and the cognitive/behavioral state (driver distraction) of 15 drivers with OSA and 10 matched controls from video clips and relating those evaluations to objective measures of sleep quality over a 3.5-month period. There were three specific analytic tasks or aims.

Aim 1. Quantify extent of sleepiness and cognitive/behavioral state (driver distraction) behind the wheel at the composite level using calibration methods. Specifically,

> a1) a face-valid composite of sleepiness (a composite is an index that pools information from several discrete indicators of sleepiness such as yawning, droopy eyelids, etc.) must be sensitive enough to statistically distinguish participants with OSA from matched controls before the OSA participants begin using PAP at an alpha-level of .10;
>
> a2) a face-valid composite of sleepiness must be sensitive enough to statistically distinguish participants with OSA before and after they begin their PAP treatment at an alpha-level of .10;
>
> a3) a face-valid composite of cognitive/behavioral state (driver distraction) must obtain smaller differences in the comparisons that will be tested for a1 and a2 using the sleepiness composite.

Aim 2. Assess the associations between both composite-level and individual indicators from each domain (i.e. physiognomy and cognitive/behavioral state) and extent of sleep deprivation using objective sources (e.g., actigraphy watches). Correlations were examined for hours slept at less than 5.5, 5.5-7, more than 7hours over several days to quantify within-subject variability in the strength of the association.

Aim 3. Based on findings in Aim1 and Aim 2, select those physiognomy and cognitive/behavioral state indicators with the highest inter-rater reliability coefficients to make recommendations to improve the items included in the Fatigued Driver Evaluation Checklist. Selection of indicators on the basis of both sensitivity and inter-rater reliability permits recommendations that would be useful for officers who conduct the evaluations and who will need to attend to matters other than driver’s physiognomy and state.

Executive Summary

Methods

Sample

Data in this report was based on 44 drivers with diagnosed OSA and 22 matched controls. Control participants were matched with OSA drivers on gender, age within 5 years, education within 2 years, and county of residence for rural vs. urban driving. OSA participants were recruited from UIHC, VA-Iowa City, and private sleep clinics in the area. Patients met ICSD-2 clinical criteria for OSA and had a Respiratory Distress Index > 15, while controls had no sleep complaints and an RDI < 5. PAP (20-CPAP, 1-BPAP) was titrated to a minimum “adequate” level according to AASM guidelines (Kushida et al, 2005).

Procedures

Participants were observed driving their own vehicles using an instrumented vehicle data acquisition system (IV-DAS), similar to “black-box recorders” (Blanchard et al., 2010; Blanchard & Myers, 2010; Crizzle et al., 2011; Huebner et al., 2007; Marshall et al., 2007; Myers et al., 2011). There were two periods of observation: a) a two-week period prior to beginning PAP, pre-PAP phase, and b) a period of three-months after beginning PAP-use, post-PAP phase. IV-DAS contains three devices: an internal camera cluster (ICC), a GPS, and a central processing unit obtaining data from OBD-II and accelerometers. The cameras are located underneath the rear view mirror, with one pointing towards the road and the other at the face and upper body of the driver. The participants were asked to wear actigraphy watches that collected objective measures of daily sleep quality during the entire 3.5-month period. The video samples from the IV-DAS were coded for indicators of sleepines based on prior research (Klauer et al., 2006; Neale et al., 2005; Wierville & Elsworth, 1994).

Measures

Objective measures of sleep. Actigraphy watches yield several pieces of information including total minutes slept, number of awakenings, and sleep efficiency (% time spent in sleep corrected for minutes awake) on a daily basis. Note that actigraphy data could not be manipulated by participants as they were not provided with the software and hardware to extract stored data on its microchips. Furthermore, the participants had no incentive to manipulate the watch output. This daily objective sleep data were available for the entire 3.5 month-period.

Cognitive/ Behavioral State. Variables characterizing driver cognitive and behavioral state performance were evaluated in 20-second segments based on previous research (Klauer et al., 2006; Neale et al., 2005; Wierville & Elsworth, 1994). Coders were trained on example clips illustrating the range of behaviors in each of the dimensions listed in Table 1 until they showed acceptable levels of inter-rater reliability (e.g. on categorical scales a Kappa of .61 or on continuously distributed composite scales an intra-class correlation of .71). Presence and absence of sleepiness and discrete indicators of distraction (e.g. cell-phone, eating, talking etc.) were divided by the number of 20-second segments within a day and thus transformed into rates. Table 1 shows the specific list of indices and their definitions that were coded in each video clip. The bolded indices were pooled into a face-valid composite of score of overall sleepiness to create a robust face-valid measure of sleepiness.

Results

Descriptive Data. We examined all available data from the project exceeding the promised 15 OSA and 10 matched controls to increase statistical power in our inferences. As can be seen from Table 2, we had 3194 days of data on objective indices of sleep including total sleep time, sleep efficiency, and number of awakenings, an index of disrupted sleep from among OSA participants. We had 1590 days of data on objective indices of sleep from matched control participants. Also shown in Table 2, is amount of coded video data for these drivers behind the wheel. We have 1167 days of driving data for OSAs and 379 days of driving data for matched controls. In general, we had an average 362 clips per OSA participant and 267 per control participant which were evaluated for sleepiness behind the wheel and distraction.

As can be seen from Table 3, participants with OSA had lower overall quality of sleep compared to matched controls. For example, their sleep efficiency was lower and they slept fewer minutes compared to matched controls prior to beginning pap treatment. When the data were pooled across three months of post-pap data, those with OSA showed improvements. For example, sleep efficiency, total sleep time improved and number awakenings, an indication of disrupted sleep, declined. Those analyses showed that sleep efficiency and total sleep time was lower for OSAs compared to matched controls and improved over the course of pap-treatment for OSAs.

Analyses Addressing Aim 1. Table 4 shows the average relative frequency of specific indicators of sleepiness (e.g. fixed eyes, slow eyelid closure, etc.) from video clips. These statistics are provided for three sets of comparisons: a) between OSA and matched controls prior to pap-treatment, b) within OSAs before and after pap treatment, and c) before and after treatment differences for the subset of OSAs who were compliant with the minimum treatment of at least 4 hours of pap use per night.

The data show that indicators of sleepiness are generally observed infrequently. For example, on average only 4% of daily clip samples from OSAs prior to treatment showed fixed gaze compared to 5% of daily clips from matched controls. This was in general true for all indicators of sleepiness as well as overall sleepiness. In contrast, distraction occurred far more frequently. For example, on average 42% daily clip samples from OSAs indicated at least one distraction compared to 48% of daily clip samples from controls all prior to treatment.

Table 4 also shows that there were three specific indicators of sleepiness, fixed gaze, face rubbing, and low energy body movements, that showed changes from before to after pap-treatment among OSA participants. Importantly and contrary to expectations, however, following pap treatment these indicators of sleepiness increased and did not decrease, suggesting sleepiness increases after pap treatment compared to before treatment. This pattern of findings contrary to expectations was also true among those OSA participants who were generally compliant with pap-treatment.

Analyses Addressing Aim 2. We examined the associations among objective measures of sleep obtained from actigraphy watches in relation to video clip data. The output from the watches yields information on total minutes of sleep, number of awakenings, and sleep efficiency. Table 3 illustrated that the actigraphy watch output yielded expected pattern of differences among those with OSA compared to controls prior to pap treatment, and expected pattern of differences among OSAs before and after treatment. Those findings validate the actigraphy watch data.

We examined the distribution of total sleep time in the sample and classified each day into one of three levels of total sleep time for each participant: 1) slept less than 5.5 hours, 2) slept between 5.5 to 7 hours and 3) slept more than 7 hours. If total hours slept is systematically related to driver physiognomy we would expect features indicative of sleepiness (e.g. yawning, slow lid closure, fixed gaze, etc.) to occur at a greater rate when the participant sleeps 7 hours or more compared to sleeping less than 5.5 hours. Table 5 shows those comparisons for specific indicators of sleepiness, distraction as well as the face-valid composite index of sleepiness. As can be seen from Table 5, the average daily rate of specific indicators of sleepiness, overall sleepiness, and distraction did not differ as a function of total amount of sleep.

We also examined whether each of these indicators were significant predictors of total hours slept in participant specific regressions. Table 6 shows the number of times specific indicators of the face-valid composite of sleepiness emerged as a significant predictor of objective measures of sleep across 30 participants. To ensure within-particpant regressions yielded reliable inferences, participants had to have a minimum of 15 days of both objective sleep data and driver physiognomy data from video clips. 30 participants met this criterion to be included in the regressions. At an alpha of .10 we could expect an indicator to emerge as a significant predictor by chance 3 times in 30 regressions for each sleep quality metric. Those indicators that emerged more than 3 times or more across 30 participants are bolded. The table indicates that fixed gaze, yawning, rubbing eyes, face, low facial muscle tone, low energy body movements, and bodily muscle tone emerged as significant predictors of at least one out of three sleep metrics. However, the statistics in this table do not indicate whether the prediction was in the expected direction.

Figures 1 and 2 indicate whether the face-valid overall sleepiness composite predicted each of two objective seep metrics in the expected direction. In each of these figures, the y-axis depicts the standardized beta coefficient from within-person regressions, indicating whether the prediction was in the expected direction. The x-axis shows the participant ID#. For the prediction of total sleep time (Figure 1), we would expect majority of the beta’s to be less than zero, consistent with a negative correlation so that less a person slept more sleepy s/he appeared behind the wheel from the video clips. For the prediction of number awakenings (Figure 2), we would expect majority of the beta’s to be greater than zero, consistent with a positive correlation so that the more disrupted the sleep was the more sleepy s/he appeared behind the wheel from video clips.

As can be seen from Figure 1 and 2, the within-person regressions were in a direction opposite the predictions. The less a driver slept the less sleepy s/he appeared behind the wheel (Figure 1), and the more disrupted the driver’s sleep as measured by number of awakenings the less sleepy s/he appeared behind the wheel (Figure 2).

Tables 5 and 6, Figures 1 and 2 indicate that patterns of driver physiognomy associated with sleep deprivation or generally poor quality sleep vary widely across individuals. It is also possible that large individual differences in the ability to tolerate sleep deprivation and resulting performance differences could be constrained by examining physiognomy for those individuals who had chronically low amounts of sleep. To that end, we isolated those individuals who slept less than 5.5 hours on 30% or more days of observation as chronically sleep deprived. There were 19 individuals with OSA and 4 matched controls who met this criteria. Table 7 presents the number of days that meet the criterion of sleep deprived days and number of OSAs and matched controls who had 30% or more days of observations when they slept less than 5.5 hrs. Table 7 shows that we had 1066 days of data when OSA participants had less than 5.5 hours of sleeps and 391 days when matched controls had less than 5.5 hours of sleep. 19 OSA participants had 30% or more of their observed days characterized as sleep deprived whereas there were 4 matched controls who had 30% or more of their days characterized as sleep deprived.

Table 8 shows average daily rates of specific indicators of sleepiness, overall sleepiness, and distraction among the 23 (19 OSA + 4 Control) chronically sleep deprived participant. The average daily rates were obtained on days when the participants were sleep deprived (less than 5.5 hours of sleep) compared to the corresponding data when the participants were not sleep deprived (i.e. they slept more than 7 hours). This comparison, which further reduces individual difference variability by isolating those individuals who are chronically sleep deprived indicates that only rates of eye rubbing were larger and none of the other specific or overall indicators showed significant differences on driving days with sleep deprivation versus days without sleep deprivation.

Analyses Addressing Aim 3. Aim 3 called for picking those indicators with the greatest inter-rater reliability to include in the checklist for fatigued driver sheet The analyses conducted for Aim 1 and Aim 2 indicated that there is a large amount of individual difference variation in manifest indicators of sleep deprivation in both sleep-disordered and non-sleep disordered populations. Not even one indicator of sleepiness emerged consistently across various comparisons to show systematic and reliable differences to support statements such as the following: ‘sleep deprived individuals (either due to a sleep-disorder or treatment of a sleep disorder or sleep-deprivation without a sleep disorder or chronic sleep deprivation) are more likely to manifest specified behaviors more often on days sleep deprived than not.’

The specific indicators listed in Table 1 vary in the ease with which they can be identified consistently and reliably from video clips by trained observers. However, they do not appear to be systematically or consistently associated with sleep deprivation. This finding indicates that no scientific evidence would support the inclusion of these specific behaviors as valid measures of sleep deprivation among CMV drivers. Hence, we recommend that indicators of driver physiognomy be removed from the Fatigued Driving Evaluation Checklist.

Executive Summary

We examined specific dimensions of driver physiognomy associated with sleepiness or fatigue and face-valid composite scores of sleepiness in relation to objective measures of sleep deprivation over 3.5 month period and in relation to systematic differences between a sleep-disordered population, OSA, and matched controls as well as differences in OSAs before and after PAP treatment. Our goal was to identify those indicators that reliably and consistently sensitive to amount of sleep deprivation in unselected populations and distinguished different populations and then to identify a subset of indicators that could be recommended for inclusion into the Fatigued Driving Evaluation Checklist to be used by officers in field evaluations of CMV drivers.

The findings showed specific dimensions of driver physiognomy associated with sleepiness in previous research and face-valid composite scores of sleepiness failed to: 1) distinguish participants with OSA from matched controls; 2) distinguish participants before and after PAP treatment including those who were compliant with their treatment; 3) predict levels of sleep deprivation acquired objectively from actigraphy watches, not even among those chronically sleep deprived.

Those findings are consistent with large individual differences in driver physiognomy. In other words, when individuals were sleep deprived as confirmed by actigraphy watch output they did not show consistently reliable behavioral markers of being sleep deprived. This finding was true whether each driver was compared to him/herself after adequate sleep (Table 5) and after inadequate sleep and whether drivers were examined in the aggregate. In fact, predictions were often in the opposite direction (Figures 1 and 2).

Recall that none of the individuals we sampled here had a cause to manipulate their total sleep times unlike field evaluations of CMV drivers. For example, the participants were not paid more or penalized for sleeping a certain number of hours, for not using their pap a designated/ recommended amount of time very night. Furthermore, we were successful in demonstrating that populations could be distinguished based on the quality of their sleep before treatment, and those with OSA showed the expected improvements in sleep quality from before to after PAP treatment.

Because we found no scientific evidence to support the inference that driver physiognomy provides a valid measure of sleep deprivation, our findings do not support use of driver physiognomy as a basis to judge whether a CMV driver is too fatigued to drive. Use of driver physiognomy to support field based judgments of *whether a CMV driver is complying with mandated duty cycles* is likely to be unreliable.

Recommendations

Given the evidence from this study and others, our recommendations inform broader policy and incentives that encourage compliance with mandated duty cycles. In terms of monitoring compliance with sleep –duty cycles, we would recommend that CMV drivers wear actigraphy watches to monitor their sleep cycles. Watch data can be downloaded quickly and efficiently in a field evaluation to examine whether a CMV driver had adequate amount of sleep. Based on Phase I of this study, we would also recommend inclusion of cognitive testing during field evaluations only if CMV drivers' baseline performance on PVT collected when they are well-rested and motivated to perform at their best is kept on record and available to DOT officers.

Technical Report Table 1

Table 1. Definitions of driver physiognomy behind the wheel relevant to sleepiness.

Variable	Definition
Fixed gaze	Gaze movements are sluggish/ fixed for extended time frames, indicating lack of focus
Squinting eyes	Squinting eye muscles especially when there is no concurrent effort to focus on a difficult to identify object (e.g. no effort to read too small print or look for a small object, etc.)
Slow eyelid closure	Slow blinks, heavy drooping eyelids
Fast/hard blinking	Excessive (fast & hard) blinking (e.g. excludes instances when person is trying to remove an eyelash, dust)
Eye rubbing	Rubbing, scratching, touching the eye region (e.g. eye lid, corner of the eyes, etc)
Yawning	Yawning
Face Rubbing	Touching face, jaw, mouth region
Low facial muscle tone	Muscle tone in the cheeks, mouth region is low
Low energy body movements	Sinking/ slumping of the upper body/ trunk
High energy body movements	Repositioning body in seat, fidgety,
Neck/Head low energy movements	Difficulty holding head weight erect (e.g. leaning to the side, resting head on hands, door frame)
Distraction	Any distraction while driving (e.g. eating, drinking, cellphone, reading/ talking, etc.)

Note. The bolded indices were pooled into a face-valid composite of score of overall sleepiness.

Technical Report Table 2

Table 2. Density of observations in terms of days of objective sleep data and driving related clips per person and across two populations.

	N	Sleep quality				Driving related clips			
		Min	Max	Mean	SD	Min	Max	Mean	SD
OSA	44	7	126	77.3	28.14	7	1363	361.7	293.1
		3194 days of sleep data				1167 days of driving data			
Control	22	19	105	76.3	24.9	10	564	261.8	151.8
		1590 days of sleep data				379 days of driving data			

Technical Report Table 3

Table 3. Sleep metrics speaking to differences in sleep quality as a function of disease, and differences before and after treatment.

	Pre-treatment (pre-pap)			OSA		
	OSA	vs.	Control	Pre-pap	vs.	Post-pap
Efficiency	**73.8 (18.5)**		**82 (11.0)**	73.8 (18.5)		75.5 (16.1)
Total Sleep Time	**361.7 (91.6)**		**384.6 (74.3)**	361.7 (91.6)		366.8 (88.3)
# of awakenings	34 (17.3)		33.2 (14.2)	**34 (17.3)**		**31.1 (15.9)**

Technical Report Table 4

Table 4. Sensitivity of specific physiognomy indicators to differences in population characteristics.

	Pre-treatment		OSA[c]		OSA (compliant)[d]	
	OSA[a] vs.	Control[b]	Pre-pap vs.	Post-pap	Pre-pap	Post-pap
Fixed gaze	.04 (.06)	.05 (.05)	**.03 (.04)**	**.06 (.07)***	**.02 (.03)**	**.05 (.06)***
Squinting eyes	.02 (.03)	.01 (.01)	.02 (.03)	.03 (.05)	.01 (.02)	.03 (.05)
Slow eyelid closure	.03 (.06)	.02 (.02)	.02 (.02)	.03 (.02)	.01 (.02)	.02 (.03)
Fast/hard blinking	.02 (.04)	.03 (.08)	.02 (.04)	.02 (.04)	.03 (.05)	.02 (.05)
Eye rubbing	.02 (.02)	.01 (.01)	.02 (.02)	.02 (.02)	.01 (.02)	.02 (.02)
Yawning	.03 (.06)	.02 (.03)	.03 (.06)	.02 (.02)	.02 (.02)	.01 (.01)
Face Rubbing	.14 (.08)	.13 (.06)	.13 (.08)	.14 (.07)	**.12 (.07)**	**.16 (.08)***
Low facial muscle tone	.07 (.11)	.08 (.10)	.06 (.12)	.09 (10)	.03 (.05)	.05 (.05)
Low energy body movements	.07 (.10)	.03 (.04)	.05 (.09)	.07 (.07)	.03 (.06)	.04 (.06)
High energy body movements	.08 (.07)	.07 (.04)	**.06 (.07)**	**.09 (.08)***	**.06 (.08)**	**.08 (.07)***
Neck/Head low energy	.01 (.02)	.01 (.01)	.01 (.02)	.01 (.02)	.00 (.01)	.00 (.01)
Distraction	.42 (.18)	.48 (.20)	.42 (.18)	.43 (.16)	.33 (.12)	.40 (.15)
Overall Sleepiness	.03 (.04)	.04 (.04)	.04 (.04)	.04 (.03)	**.02 (.03)**	**.03 (.03)***

* p < .10 ** p <.05 [a] N = 40; [b] N = 23; [c] N = 43; [d] N = 18

Note. The bolded variables highlight those physiognomy indicators that show significant differences within populations.

Technical Report Table 5

Table 5. Differences in driver physiognomy as a function of total hours slept.

	Less than 5.5 hours of sleep	5.5-7 hours of sleep	>=7 hours of sleep
Fixed gaze	.06 (.11)	.07 (.09)	.06 (.07)
Squinting eyes	.03 (.05)	.03 (.08)	.02 (.03)
Slow eyelid closure	.02 (.04)	.03 (.04)	.02 (.04)
Fast/hard blinking	.03 (.07)	.03 (.06)	.03 (.06)
Eye rubbing	.02 (.03)	.02 (.02)	.01 (.01)
Yawning	.02 (.02)	.02 (.03)	.02 (.03)
Face Rubbing	.15 (.10)	.15 (.09)	.15 (.09)
Low facial muscle tone	.08 (.11)	.08 (.11)	.07 (.11)
Low energy body movements	.04 (.10)	.05 (.07)	.04 (.06)
High energy body movements	.07 (.07)	.08 (.08)	.08 (.07)
Neck/Head low energy	.01 (.01)	.01 (.03)	.01 (.02)
Distraction	.42 (.17)	.42 (.15)	.44 (.17)
Overall Sleepiness	.03 (.03)	.04 (.03)	.03 (.03)

* p < .10 ** p <.05 N = 28 OSAs N = 14 Controls

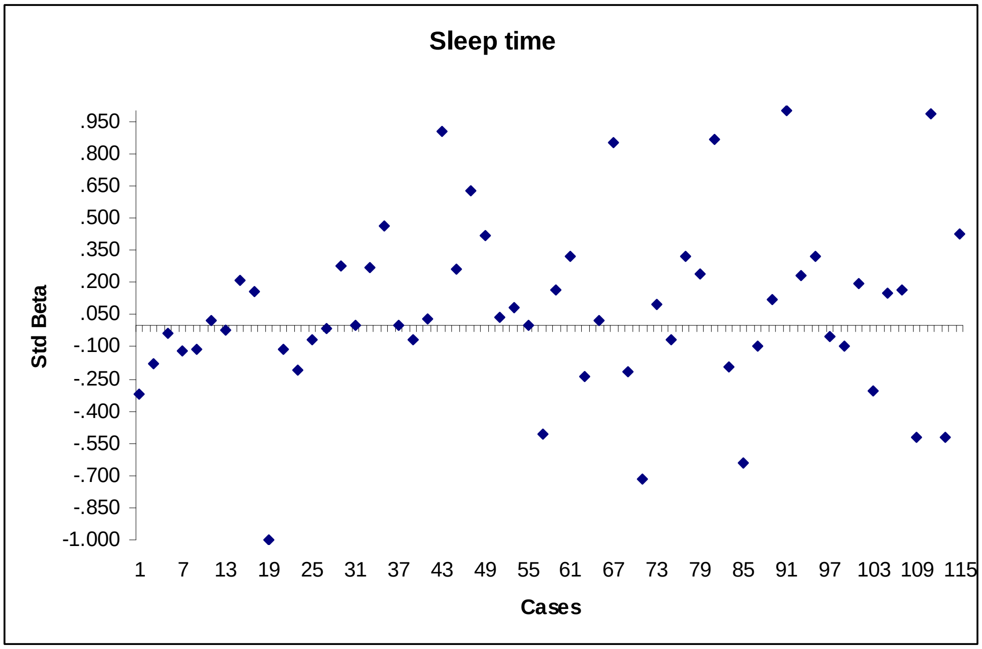
Technical Report Table 6

Table 6. Robust predictors of objective sleep quality in 30 within-participant regressions.

	Objective measures of sleep deprivation & quality		
	Sleep Time	Sleep Efficiency	# of awakenings
Fixed gaze	**4**	**2**	**5**
Squinting eyes	1	**4**	2
Slow eyelid closure	2	1	1
Fast/hard blinking	3	1	2
Eye rubbing	**5**	**5**	**3**
Yawning	**6**	**2**	**4**
Face Rubbing	**3**	**4**	**3**
Low facial muscle tone	**3**	**5**	**2**
Low energy body movements	**3**	**2**	**5**
Neck/Head low energy movements	3	3	1

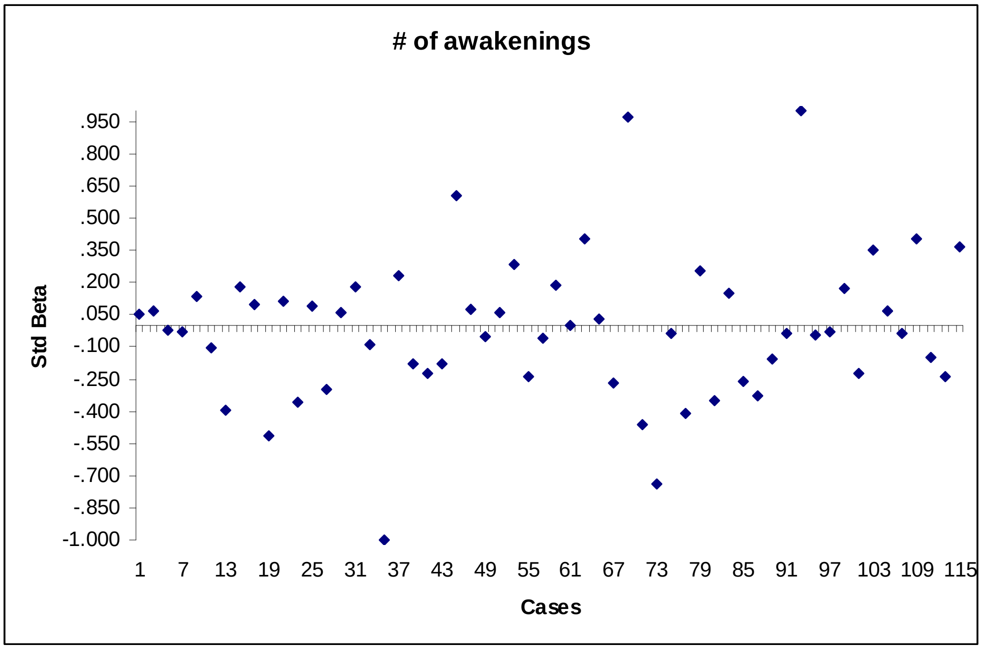
Technical Report Figure 1

Figure 1. Predictions of sleep time from face-valid overall sleepiness composite



Technical Report Figure 2

Figure 2. Predictions of number of awakenings from face-valid overall sleepiness composite



Technical Report Table 7

Table 7. Total number of days OSA & matched control individuals had various levels of sleep.

	< 5.5 hrs	5.5-7hrs	>= 7hrs	# chronically deprived
OSA	1066	1217	1118	19
Control	391	726	561	4

Technical Report Table 8

Table 8. Mean differences in the average daily rate of specific behaviors on sleep deprived days (less than 5.5 hours of sleep) versus on adequate sleep days (more than 7 hours of sleep) among chronically sleep deprived participants.

	Less than 5.5 hrs of sleep	>=7 hrs of sleep
Fixed gaze	.03 (.03)	.07 (.10)
Squinting eyes	.01 (.01)	.01 (.02)
Slow eyelid closure	.01 (.01)	.01 (.02)
Fast/hard blinking	.01 (.01)	.02 (.04)
Eye rubbing	**.02 (.02)**	**.01 (.01)***
Yawning	.02 (.03)	.03 (.06)
Face Rubbing	.16 (.07)	.17 (.12)
Low facial muscle tone	.04 (.07)	.06 (.09)
Low energy body movements	.01 (.02)	.02 (.03)
High energy body movements	.07 (.07)	.08 (.07)
Neck/Head low energy	.01 (.02)	.00 (.002)
Distraction	.42 (.14)	.37 (.19)
Overall Sleepiness	.02 (.01)	.03 (.02)

* p < .10 ** p <.05 N = 11

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