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Original Article

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Self-reported Drowsiness and Safety Outcomes While Driving After an Extended Duration Work Shift in Trainee Physicians

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Abstract

Study Objectives: Extended duration (≥24 hours) work shifts (EDWSs) are associated with increased risk of motor vehicle crashes, and awareness of any impairment has important implications on legal accountability for any adverse driving outcome. The extent to which adverse driving events were preceded by predrive self-reported sleepiness was evaluated in medical residents after an EDWS.

Methods: Sixteen resident physicians (10 females; 29.2 ± 2.0 years) working EDWS were monitored when driving on their commute to and from the hospital (438 drives). Sleep and work hours were obtained from daily logs, and adverse driving outcomes were captured from a driving log completed at the end of each drive. Self-reported sleepiness (Karolinska Sleepiness Scale; KSS) and objective drowsiness were captured using a time-stamped, hand-held device and infra-red reflectance oculography.

Results: Self-reported sleepiness and objective indices of drowsiness were positively correlated, and both were elevated following EDWSs. Compared with the commute to work, EDWSs were associated with more than double the self-reported adverse outcomes when driving home, significantly higher than drives to or from the day shift at comparable times of day. EDWSs more than tripled the odds of reporting sleep-related, inattentive, hazardous, or violation-driving events. The number and type of adverse event was predicted by the predrive KSS level and in a dose-dependent manner.

Conclusions: Driving after an EDWS puts resident physicians/drivers and other road users at avoidable and unnecessary risk. Demonstrating self-reported sleepiness at the beginning of the drive is associated with adverse outcomes has serious implications on the legal accountability for driving when drowsy.

Statement of Significance

Driving while drowsy represents a significant risk to fatal or serious car crashes and is attributed to approximately 20% of motor vehicle crashes. One strategy for minimizing the risk of drowsy driving is for drivers to acknowledge their level of drowsiness and to take evasive action. The extent to which drivers can accurately self-assess their drowsiness has been of continued debate in the field, however. Our study provides clear evidence that, before driving home from a 24-hour shift, drivers are aware of their drowsiness level which predicts subsequent on-road adverse driving events. Drivers should therefore proactively evaluate their drowsiness level prior to driving and not expose themselves and others to the significant, and avoidable, risk of drowsy driving.

Key words: drowsiness; sleepiness; driving; safety; residents; shift work

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Introduction

In the United States, medical and surgical trainee physicians beyond their first year of residency are permitted to work for up to 28 hours continuously and are routinely scheduled to work extended duration work shifts (EDWSs) of 24 hours or more twice per week [1]. Since 2011, such marathon shifts were not permitted for first-year residents ("interns"), but the Accreditation Council for Graduate Medical Education (ACGME) proposes to reintroduce them in 2017 [2].

Although these EDWSs present a significant risk to patient safety due to increased attentional failures [3], risk of errors on clinical task [4], and higher rates of serious medical errors [5, 6], they also negatively affect the health and safety of the trainee physicians themselves [7]. Although physician risk may involve increased rates of depression [8] or needle stick injury [9], the most documented risk for trainee physicians is the risk of a motor vehicle crash [10–13].

It is well documented that these EDWSs negatively affect the safety of trainee physicians by increasing the risk of motor vehicle crashes on the commute home [10–13]. For instance, trainee physicians working a heavy call schedule exhibit deficits on a simulated driving task comparable to performance at 0.04%–0.05% blood alcohol concentration [14] due to a combination of excessive time awake, overnight work, and chronic sleep deficiency. Notably, the odds of a trainee physician being involved in a motor vehicle crash or near-crash after an EDWS are increased by 2.3 and 5.9, respectively, compared with a non-extended shift [10]. These motor vehicle (near) crashes may not be directly attributed to having fallen asleep (although previous studies suggest 49% of trainee physicians admitted to having falling asleep while driving [11], compared with 11%–31% of the nonmedical drivers [see Ref. 15]). Instead, and based on laboratory-evidence, other causal factors for drowsy crashes may include enhanced distractibility [16, 17], reduced vigilance [18], and poor decision making [19]. Despite the prevalence of driving while drowsy in trainee physicians, little is known about the impact of EDWSs on safety outcomes while driving.

Alleviating crash risk in resident physicians (and all road users) requires a multifaceted approach. Firstly, understanding causal factors of drowsy driving crashes is essential to informing intervention strategies for reducing crash risk. Secondly, and perhaps most importantly, drivers should be able to determine when they have reached a level of drowsiness associated with increased risk of adverse driving outcomes. Although it is now largely accepted that drivers are typically aware when they have reached a level of sleepiness that is dangerous for driving [20–24], they often continue to drive [25]. Ideally then, drivers should actively evaluate whether they are safe to drive before commencing the journey. To the best of our knowledge, no study has examined self-reported sleepiness at the onset of the drive and the utility of this approach to predict the risk of adverse events on the subsequent drive.

Our study objective was therefore to first characterize adverse driving outcomes and examine the prevalence of objective drowsiness and self-reported sleepiness in trainee physicians driving to and from the hospital, and secondly to examine the extent to which a predrive self-assessment of sleepiness accurately predicts adverse driving outcomes.

Methods

Participants

Sixteen resident physicians (10 females; 29.2 ± 2.0 years; range 24.5–33.4 years; Table 1) from seven hospitals in the Boston metropolitan area, and who were experienced drivers (licenced >2 years; drove >50 miles per week) driving >15 minutes alone to and from work, provided a total of 438 driving sessions (Figure 1). Trainee physicians were recruited from four clinical disciplines including internal medicine, surgery, anaesthesiology, and pediatric medicine. Advertisements were placed around the main teaching hospitals in the Boston metropolitan region and emailed to interns and residents via the Committee of Interns and Residents. Interested individuals (n = 192) contacted the study coordinator (CA) and were provided with additional information about the study. For those interested in the study (n = 69), an initial phone interview determined work and driving commitments to ensure that they were within the limits for inclusion criteria. Participants, who commuted to and from the hospital, worked EDWSs, and with a roster that was consistent with the requirements of the study (i.e., a period of noncall plus six consecutive EDWSs), were invited to take part in the full study. Participant demographic, driving experience, residency experience, and presence of sleep or medical problems are reported in Table 1. The study was approved by the Human Research Committee of Partners Healthcare and all participants provided written informed consent and were remunerated for their involvement.

Design

We monitored trainee residents during the commute to and from work, for six consecutive EDWSs and all intervening non-EDWSs. Using a repeated measures design, we compared self-reported sleepiness, objective drowsiness, and self-reported driving outcomes when driving to and from an EDWS and non-EDWS.

Shift Schedules

In the United States, a trainee physician (beyond their second year of residency) can be scheduled to work EDWSs of 24–28 consecutive hours (24 + 4) within a 80 to 88–hour work week, averaged over 4 weeks [26]. Our study included trainee physicians working EDWSs every third (Q3), fourth (Q4), or fifth (Q5) shift. In between individuals were scheduled to work a "noncall" shift (~06:00 am until ~03:00–05:00 pm) or have a day off. The study ended after six EDWSs, which were completed over 3 to 5 weeks.

Methods

During baseline assessments, we obtained information on participants' demographics, shift schedules, driving experience, and trait levels of daytime sleepiness using the Epworth Sleepiness Scale [27]. For 1 week prior to study, participants worked on a noncall rotation without night duty or EDWS (n = 11) or were on a scheduled week of vacation (n = 5). This ensured adequate opportunity for rest prior to taking part in the study. During this prestudy phase, hours of work and rest, and sleep outcomes were monitored via actigraphy (Motionlogger, Ambulatory Monitoring, Inc., Ardsley, NY) and daily sleep and work logs.

Table 1. Demographics and Work/Sleep Parameters in Trainee Physicians

Variable				Range
N			16	—
Males		*n* (%)	6 (37.5%)	—
Age (y)		Mean ± SD	29.2 ± 2.0	24.6–33.4 y
Year of residency		*n* (%)		
First			9 (56.3%)	
Second			4 (25%)	
Third			1 (6.3%)	
Fourth			2 (12.5%)	
Clinical disciplines		*n* (%)		
Internal medicine			12 (75%)	
Surgery			2 (12.5%)	
Anaesthesiology			1 (6.25%)	
Pediatric medicine			1 (6.25%)	
Body mass index (kg m^{-2})		Mean ± SD	24.2 ± 3.0	18.3–30.8
Body mass index >30		*n* (%)	1 (6.25%)	—
Diagnosed illness/disorder		*n* (%)[a]	6 (37.5%)	—
Epworth Sleepiness Score		Mean ± SD	10.8 ± 4.8	3–18
Sleep need		Mean ± SD	7.5 ± 1.0	6–10 h
Fall asleep events	Telephone	Mean ± SD (%)[b]	1.4 ± 1.8 (62.5%)	0–6
in past month,	Meeting	Mean ± SD (%)[b]	0.07 ± 0.25 (12.5%)	0–1
when	Traffic	Mean ± SD (%)[b]	0.33 ± 0.49 (37.5%)	0–1
	Driving	Mean ± SD (%)[b]	0.87 ± 1.77 (31.25%)	0–5
Driving experience (y)		Mean ± SD	11.6 ± 2.3	6-14 y
Miles driven per week		Mean ± SD	105.8 ± 56.0	50–250 miles
Commute time		Mean ± SD	26.7 ± 10.3	15.8–56.8 min
Duration of residency training (mo)		Mean ± SD	18.6 ± 19.5	5–80 mo
Extended work shift duration		Mean ± SD (*d.h*)	28.3 ± 1.85	
Day shift duration		Mean ± SD (*d.h*)	9.62 ± 2.6	
Sleep duration/24-h period				
Prestudy (with naps[c])		Mean ± SD (*d.h*)	9.11 ± 0.81	
Prestudy (without naps)		Mean ± SD (*d.h*)	7.9 ± 0.86	
Preday shift (with naps)		Mean ± SD (*d.h*)	8.43 ± 2.17	
Preday shift (without naps)		Mean ± SD (*d.h*)	6.67 ± 0.79	
Pre-extended shift (with naps)		Mean ± SD (*d.h*)	6.97 ± 1.33	
Pre-extended shift (without naps)		Mean ± SD (*d.h*)	7.45 ± 1.42	
During extended shift (with naps)		Mean ± SD (*d.h*)	1.88 ± 1.99	
During extended shift (without naps)		Mean ± SD (*d.h*)	2.32 ± 1.96	

[a]Current illnesses reported included high blood pressure (unmedicated), depression (medicated), gastrointestinal problems (medicated [*n* = 2] and unmedicated [*n* = 1]), and insomnia (unmedicated).
[b]% with an affirmative response for OSA or fall asleep event in the last month.
[c]nap defined as sleep <20 minutes in duration.

During the main study, we obtained data relating to sleep, work hours, and driving outcomes over six consecutive EDWSs and all intermediary day shifts (as per our previous studies [3, 5, 28]), using validated daily sleep [3] and work logs and driving logs completed after each commute to and from the hospital (Supplementary Material 1). Sleep diaries comprised 14 questions on sleep timing, duration, disturbance, and alcohol or medication use. Participants also completed the start and end dates and times of any shift worked in the last 24 hours. The driving log contained 18 items including information on the type and duration of commute, incidence and information of near-crashes or actual crash events, adverse driving events, countermeasure to sleepiness actions, and other information relating to the drive (i.e., traffic density, weather, and consumption of caffeine/alcohol). Participants selected as many driving events and/or countermeasure actions as applicable. The diary is available in Supplementary Material. From the driving log, self-reported driving events were categorized according to criteria adapted from the work of Reason [21, 29]: (1) sleep-related (i.e., "falling asleep at a stop light"), (2) inattention (i.e., "being distracted"), (iii) hazardous (i.e., "swerving violently"), and (iv) violation (i.e., "driving through a stop light").

Objective measures of drowsiness (Johns Drowsiness Score; JDS) were recorded while driving using infrared reflectance oculography (Optalert™ Drowsiness Measurement System, Sleep Diagnostics Pty Ltd., Melbourne, Australia [30, 31]). This approach captures information from involuntary eye blinks, such as amplitude/velocity ratio, long eye closures, and blink duration. The ocular parameters are then combined via a proprietary algorithm to derive the JDS, which compared with other ocular parameters from which the composite JDS is derived, is a more sensitive marker of drowsiness [32], and has been previously associated with driving performance in real on road driving [21]. Participants completed an electronic, time-stamped Karolinska Sleepiness Scale (KSS) [33] at the beginnng and end of each commute.

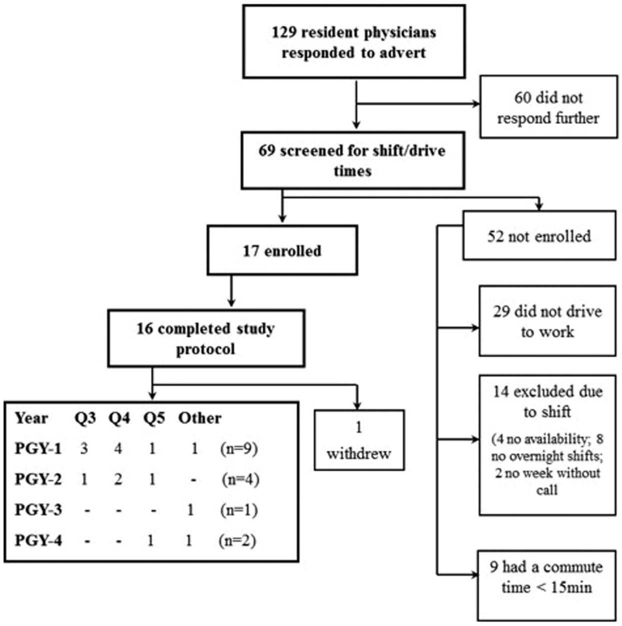

Figure 1. Flow chart of physicians' participation. For those screened to fit within our shift and drive requirements, 75% were not eligible for the study largely due to not driving and/or living too close to the hospital (55%). Of those screened, 25% consented to take part, resulting in 23% completing the study.

Data Analysis

We categorized all data to either a "day shift"—for shifts starting at 06:00–07:00 am of <16 hours duration—or an "EDWS"—for shifts ≥24 hours duration (referred to as EDWS throughout). Commutes to the hospital are referred to as "preshift drive" and the commute home as "postshift drive."

We averaged data within an individual for each pre- and postshift drive for day shifts and extended shifts separately, and compared using repeated measures two-way ANOVA (shift*commute). To examine the likelihood of reporting each of the four driving event categories ((1) sleep-related, (2) inattention, (3) hazardous, and (4) violation events) during preshift drives compared with postshift drives, we employed a chi square relative risk test using a within-subject comparison for day shift and EDWSs separately. We obtained KSS scores from PDA (Personal Digital Assistants) devices logged at the beginning and end of each commute. Where there were missing KSS data on the PDA devices, these were replaced with scores reported in the driving log at the beginning and end of each drive. A total of 56 (13%) KSS scores were derived from driving logs. Taking all data, driving log and PDA-derived KSS scores were highly similar (KSS start of drive, $r = 0.84$, $p < .001$; KSS end of drive, $r = 0.86$, $p < .001$). To examine the impact of shift, we averaged KSS within subject and then within-shift (day shifts and extended work shifts) for pre- and postshift drives and compared using a two-way (2 × 2) ANOVA (shift*commute).

For objective drowsiness, we first removed any commute without 10 consecutive data points (minutes) from the analysis due to reduced reliability of the output. We then visually inspected all data for artifact. Each EDWS was paired with a preceding or subsequent day shift within each individual for comparison and removed any participant without a matching day and EDWS ($n = 8$ remaining). We then used a two-way (2*2) ANOVA (shift*commute) to examine the impact of shift on ocular-derived drowsiness outcomes.

To verify self-reported outcomes, we examined the association between self-reported sleepiness and objective markers of drowsiness using Pearson correlations. To evaluate the predictive capacity of predrive KSS, we performed binary logistic regression where KSS was the predictor variable (continuous) and self-reported adverse driving event the outcome variable. This analysis was conducted separately for each event category. Goodness of fit was determined by Omnibus Tests of Model Coefficients. In addition, to assess predictive capacity of KSS for subsequent adverse events, we constructed receiver–operator characteristic (ROC) curves and performed area under the curve (AUC) analyses. Pretest probability was estimated empirically from the data, which was $p = .41$ for all events, $p = .23$ for sleep-related events, and $p = .17$ for inattentive events. All cost-ratios were set at 1.0. These values were used to determine optimal cutoff points.

Results

Data Obtained

Fourteen trainee physicians completed the full study (six EDWSs) and two physicians completed only four EDWSs (study finished early due to sick leave [$n = 1$] and poor weather conditions [$n = 1$]). We obtained data from 438 drives: 218 (49.8%) commuting to the hospital and 220 (50.2%) commuting home after the work shift and 241 (55.0%) for day shifts and 197 (45.0%) for EDWSs. Of the 438 drives monitored with driving logs, 289 were also monitored with the objective drowsiness detection system (67%). Although individual reasons for lost oculography data were not reported by participants, these included a failure of the technology to record, a loss of battery power, or participants not recording the drive. Following visual quality checks of the data, only 182/289 (63%) were deemed of sufficient quality for analysis. Although the majority of drives were rejected for multiple signal artifact, individual reasons for rejection included a biphasic signal ($n = 54$), clipping of the signal ($n = 14$), blinks not clearly identifiable ($n = 95$), noise in the signal ($n = 42$), an inverted signal ($n = 10$), and a small signal ($n = 93$). We then omitted a further 20 drives due to failing to meet the criteria of at least 10 consecutive minutes of monitoring (6.9%). The final number of drives containing objective drowsiness data was 162 (56%) and was equally distributed across day and EDWS (87/46.3% vs. 75/53.7%, respectively; $z = 0.858$, $p = .39$) and pre- and postshift drives (73/45.1% vs. 89/54.9%, respectively; $z = 1.109$, $p = .27$).

Sleep and Work Scheduling

Sleep and work-scheduling data can be seen in Table 1. For an EDWS, the proportion of individuals with an average KSS score of 6 or more (some signs of sleepiness) on the drive home was 75%, compared with 12% of the drive to work. The proportion of individuals with an average score of 7+ (moderate-severe sleepiness) was 44% on the drive home, compared with 12% on the drive to work. Self-reported sleepiness was elevated by 46% on the commute home after an EDWS ($p < .0001$), compared with only 1.26% after a day shift. Likewise, objective measures of drowsiness were also elevated on the drive home, but only after an EDWS ($p = .012$). Here, JDS increased by 48% when driving home after an EDWS, compared with a 25% decrease after a day shift. Predrive self-reported sleepiness assessments and subsequent objective drowsiness levels were highly correlated ($r = 0.81$, $p = .003$) (Figure 2).

There was a three-fold increase in the average number of self-reported adverse driving events on the drive home from an EDWS compared with driving to work (1.1 ± 0.78 versus 0.37 ± 0.49 events/drive, $p < .005$, respectively), much more than the increase associated with driving to and from a day shift (0.35 ± 0.53 versus 0.59 ± 0.63 events/drive, respectively; Figure 3). Compared with driving to work, the odds (odds ratio [OR], 95% confidence interval [CI]) of reporting an adverse event on the drive from an EDWS was 3.90 (1.73–8.80, $p = .001$) for sleep-related events, 3.58 (1.72–7.47, $p < .0001$) for inattention events, 3.32 (1.16–9.53, $p = .02$) for hazardous events, and 5.39 (1.15–25.29, $p = .018$) for violation events. In comparison, after working a day shift, there were no increased odds of self-reporting an adverse event ($p > .1$) (Table 2).

Although no crashes occurred, 10 near-crash events were reported (2.3% of total drives) from 6/16 trainee physicians (38%): one from a day shift, one while commuting to an EDWS, and eight while driving home after an EDWS (8.2% of commutes from EDWSs). Descriptive evaluation of these near-crash events can be seen in Table 3.

Predrive KSS was a significant predictor of subsequent driving events in a dose-dependent manner (Figure 3). For each one-point increase in predrive KSS, there was a 2.39 times increase in the odds of reporting a sleep-related adverse event during the subsequent drive (95% CI: 1.98–2.89, $p < .0001$). The odds of reporting an inattention or hazardous event also increased per each single-point KSS rise [1.33 (1.13–1.56) and 1.20 (1.06–1.36), respectively] (Table 4). Receiver–operator curves demonstrated that a predrive KSS rating of ≥6 ("some signs of sleepiness") had 91% sensitivity and 69% specificity for predicting a sleep-related adverse driving event (AUC = 0.86; $p < .001$).

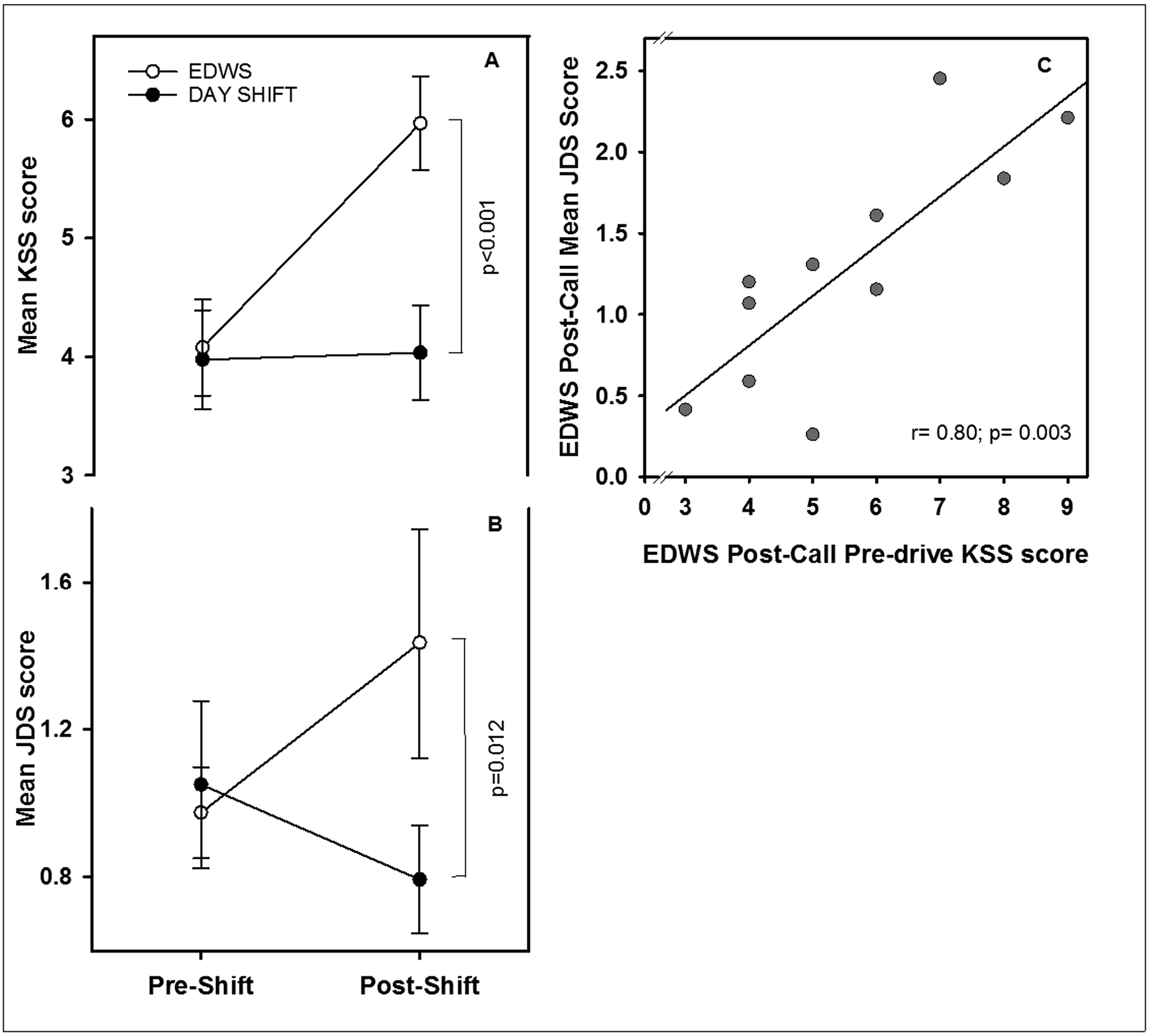

Figure 2. Self-reported sleepiness and objective drowsiness while driving to and from the hospital on day versus EDWSs: self-reported ratings of sleepiness [(A) Day shift: 3.98 ± 0.42 to 4.03 ± 0.40; EDWS: 4.08 ± 0.41 to 5.97 ± 0.40] and objective ocular-derived measures of drowsiness [(B) 1.05 ± 0.23 to 0.79 ± 0.15; EDWS: 0.97 ± 0.12 to 1.43 ± 0.31] were elevated when driving home after an EDWS. Self-reported sleepiness prior to the drive was positive associated with subsequent objective measures of drowsiness (C).

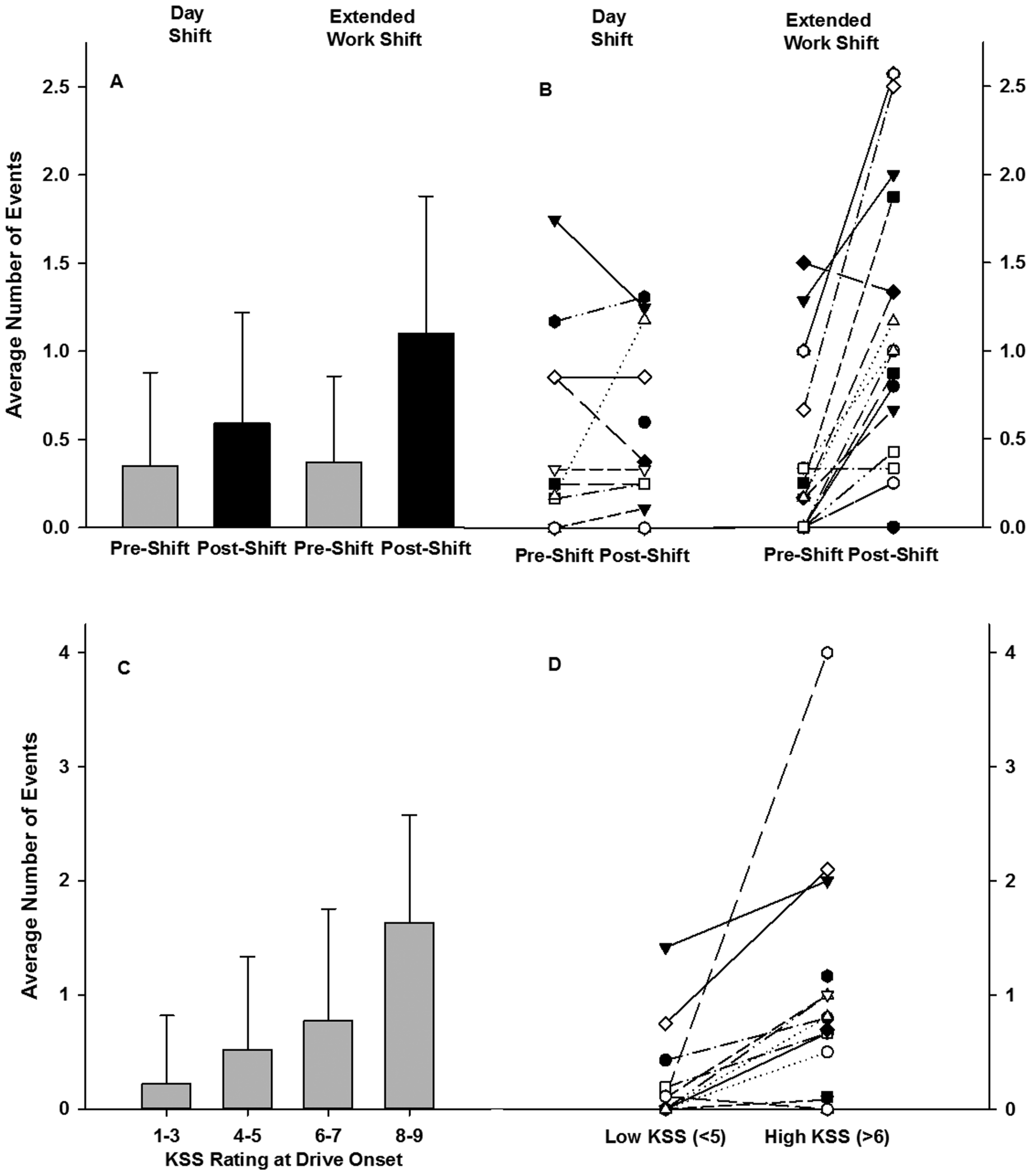

Figure 3. Adverse drive events while driving to and from the hospital on day shifts versus EDWSs. Compared with preshift, more adverse events were reported post-shift for the EDWS (0.37 ± 0.49 and 1.1 ± 0.78). This was less evident for day shift (0.35 ± 0.53 and 0.59 ± 0.63), despite being at a comparable time of day. Refer (A) and (B) for group and individual level data, respectively. Importantly, increasing KSS was associated with an increased average number of adverse driving events in a dose response manner, at the group (C) and individual level (D).

Discussion

We examined self-reported and objective measures of drowsiness in US trainee physicians when driving to and from the hospital after day shifts (<12 hours) and EDWSs (>24 hours). In our study, driving home after working an EDWS was associated with an approximately 40% increase in self-reported sleepiness at the start of the drive home, elevated levels of objectively measured drowsiness while driving, and a greater number of adverse driving events. Self-reported sleepiness at the beginning of the drive was associated with objective drowsiness during the drive, and both the number and type of adverse driving events reported.

Table 2. The Odds Ratio of a Drive Postshift Containing a Specific Driving Event Compared With the Drive Preshift: Day Shifts and EDWSs

		Day shift						Extended work shift					
		Preshift[a]	Postshift[b]	χ^2	OR	95% CI	*p*	Preshift[c]	Postshift[d]	χ^2	OR	95% CI	*p*
Sleep-related	Resting the eyes Asleep stop light	31 (25.8%)	31 (25.6%)	0.00	0.99	0.56–1.76	.97	9 (9.2%)	28 (28.3%)	11.78	3.9	1.73–8.8	.001
Inattention	Fixation Lack awareness Distracted Missed turn	11 (9.2%)	16 (13.2%)	1.00	1.51	0.67–3.41	.32	12 (12.2%)	34 (33.3%)	12.43	3.58	1.72–7.47	<.0001
Hazardous	Braked sharply Hit rumble strip Swerved violently Near Miss	9 (7.5%)	13 (10.7%)	0.76	1.49	0.61–3.62	.38	5 (5.1%)	15 (15.2%)	5.45	3.32	1.16–9.53	.02
Violation	Shouting Driving through stop light	1 (0.8%)	5 (4.1%)	2.7e	5.13	0.59–44.58	.10	2 (2.0%)	10 (10.1%)	5.59e	5.39	1.15–25.29	.018

[a]Data are based on 120 drives.
[b]Data are based on 121 drives.
[c]Data are based on 98 drives.
[d]Data are based on 99 drives.
[e]Fishers exact test reported when number of events falls below 5.

Table 3. Descriptive Data for Near-Crash Events

Shift	Pre- or post shift	Time of day	Amount of sleep in previous 24 h	Time since awake (h)	Description
Day	Postshift	17:25	6	10	"Other car went through a red light"
Extended	Preshift	06:25	8	1	"Fast moving car in left lane, tried to change lanes but nearly rear-ended"
Extended	Postshift	14:30	2	9	"I was merging into traffic and dozed off and almost hit another car"
Extended	Postshift	12:50	0	30	"Eyes closed on freeway, veared 1/4 way into adjacent lane, had it been a busier time of day would have probably hit someone"
Extended	Postshift	12:25	0.5	36	"Other than 30 min, been awake 36 h…Clear day, someone ran a red light in Boston and I had to slam on brakes to avoid"
Extended[a]	Postshift	13:45	0	30	"Had four near misses involving nodding off while driving"
Extended	Postshift	12:45	8	7	"Driving in wet but then another car crossed over into the lane without signaling I was able to slow down in time"

[a]Description of four events in one commute home.

Currently, resident and attending physicians are permitted to work >24-hour shifts [1], which have adverse implications for the physician's safety while driving [10]. Half of trainee physicians admit to having fallen asleep while driving [11], compared with 11%–31% of typical drivers not working EDWS [15]; this is consistent with our observation of nearly four times greater odds of reporting a sleep-related adverse driving event on the drive home after an EDWS. Sleep deficiency also manifests in other behaviors, such as increased distractibility [16, 17], aggression and irritability [34], and poor decision making [19]. Consistent with this wider scope of drowsy driving symptomology, trainee physicians driving home after an EDWS in the current study had 3–5 times greater odds of reporting an inattentive, hazardous, or violation-driving event. Although inattention was comprised of drivers reporting being fixated, missing the turn, being distracted, and having a lack of awareness, our findings of increased inattention were largely due to being distracted and having a lack of awareness. These data are in agreement with our previous simulated driving study that showed drivers were more distracted when drowsy. Importantly, this inattentive behavior was associated with an increased likelihood of the car leaving the driving lane [17].

Three quarters of trainee physicians reported a KSS of 6+ ("some signs of sleepiness"), whereas 44% reported a KSS of 7+ (moderate–severe sleepiness), prior to driving home after an EDWS. Given that the levels of sleepiness reported by the interns and residents in our study was similar to that reported elsewhere for studies of comparable demographic [35] and design [23], there is no evidence to suggest that our sample represents an unusual population. Our data revealed a strong dose-dependent association between the predrive KSS and the incidence of sleep-related adverse events reported during the subsequent drive home after an EDWS. These data suggest that trainee physicians' self-assessment of their sleepiness before driving can be a powerful and reliable warning indicator of driving impairment. This is consistent with our previous study assessing on-road driving impairment following a night shift; although night shift workers reported an average KSS of 6 at the onset of the drive, the drive was associated with increasing KSS, use of emergency braking manoeuvres (on 38% of postnight shift drives, PNSD), a failure to adequately remain in control over the vehicle (44% of PNSD), and the potential for falling asleep at the wheel [23]. A KSS score of 6 or more should therefore be considered a warning indicator for high risk of drowsy driving and should prompt

Table 4. Binary Logistic Regression Examining the Predictive Capacity of Predrive KSS on Subsequent Adverse Driving Events

	Goodness of fit		Binary logistic regression parameters					
	χ^2	Sig.	B(S.E.)	Wald	*df*	Exp(B)	Sig.	Upper
Sleep-related	145.5	<.0001	0.87 (0.10)	82.06	1	2.39	<.0001	1.98–2.89
Inattention	8.8	.003	0.18 (0.06)	8.53	1	1.20	.003	1.06–1.36
Hazardous	12.87	<.0001	0.28 (0.08)	11.57	1	1.33	.001	1.13–1.56
Violation	0.01	.92	−0.01 (0.11)	0.01	1	0.99	.025	0.80–1.23

individuals to avail themselves of alternative transportation or to deploy appropriate countermeasures such as sleep at the hospital before driving home (with adequate time upon waking to dissipate any sleep inertia [36]), or caffeine [37]. Although alternative transport was available to the physicians in the current study through hospital-funded taxi-cab schemes, only two participants reported taking a taxi during the study suggesting as follows: (1) despite being aware of feeling sleepy, there was a failure to associate this with the risk of adverse safety outcomes while driving, similar to the impairment of risk assessment under the influence of alcohol [38] or (2) inadequate education or reinforcement/encouragement to use the service.

Despite trainee physicians reporting elevated levels of sleepiness after an EDWS, they continue to drive with adverse safety outcomes for themselves and other road users. Much debate exists on the utility of self-reported sleepiness in reducing motor vehicle crash risk. Previous studies showing a lack of agreement between self-reported and objective indices of sleepiness have focused on either individuals in a laboratory-based, nondriving scenarios (e.g., Ref. 39) or examined sleepiness levels just prior to a driving event (when introspection into sleepiness is likely to be low) [40]. Laboratory-based simulator studies have consistently argued that self-reported sleepiness is associated with either objective indices of drowsiness [22, 41–44] or impaired driving performance [22, 44]. Although driving simulator studies have provided much evidence for the agreement between self-reported and objective measures, real on-road studies provide the most ecological valid evidence for evaluating the association between self-reported sleepiness and objective physiological (e.g., slow eye closures) and behavioral (e.g., adverse driving event) indices of drowsiness. These studies have demonstrated consistently that drivers are aware of increasing sleepiness while driving, which occurs in parallel with increased adverse outcomes [20, 21, 23, 45, 46].. Of relevance to our study, self-reported ratings prior to the drive has been associated with subsequent driving events previously. For instance, in sleep-restricted individuals driving at night on a French highway, increasing self-reported sleepiness prior to the drive was associated with more lane crossing in the subsequent drive [46], our study of night shift workers found a predrive KSS of 6 at was associated with adverse driving outcomes (emergency braking manoeuvres required, failure to adequately remain in control over the vehicle, and falling asleep at the wheel) [23], and our study of Australian nurses driving home after a night shift revealed a higher reported pre-drive KSS was associated with an increased risk of a sleep-related event (e.g., falling asleep at a stop light) during the subsequent drive [21].

Despite this awareness, drivers often start, or continue to, drive [25], possibly due to a desire to reach the destination or not being able to find a suitable and safe place to stop and rest if the drive has already commenced. Ideally then, drivers should evaluate their sleepiness prior to commencing the journey. Our study is informative in that it examines sleepiness ratings prior to starting the drive and thus provides an opportunity for evasive action. Habitually reflecting on sleepiness prior to driving a motor vehicle may therefore provide an opportunity to take action and ultimately alleviate accident risk.

Our study has a number of limitations. Firstly, as participants were not selected, randomly prior concerns about sleepiness and work hours may have motivated individuals to volunteer. Although our study data were collected from 2009–2011 when the ACGME were working toward their recommendation to abolish EDWS for PGY-1 residents, enquiring about attitudes toward shifts and sleepiness may have helped us to understand whether individuals felt strongly about work hours and driving, and to understand if our participants were motivated to participate by those feelings. It should be noted however that of those who expressed an interest to participate (i.e., phone interview), 42% did not drive and 12% did not work overnight or have extended work shifts, suggesting that strong attitudes toward "marathon shifts" or drowsy driving was not a major factor in choosing to volunteer. Furthermore, as described above, self-reported sleepiness ratings were very similar to a recent independent study of 124 interns and residents, suggesting that our samples was not dominated by interns with higher-than-normal levels of sleepiness [35]. Secondly, the self-report nature of the adverse driving outcomes may not reflect actual adverse events due to report bias. It is unlikely, however, that this would have affected the objective infrared reflectance oculography which was correlated with the self-reported data. Furthermore, although self-reported outcomes may be perceived as unreliable, previous studies have shown self-reported measures of driver performance to be associated with actual driver performance as assessed by objective methods (i.e., speed) or a trained assessor [47] and, of significance, crash risk [48]. Thirdly, our sample size was small and was not powered to detect crash or near-crash events. Rather, this study was designed to examine associations between sleepiness and adverse driving events. Fourthly, we lost a large amount of data from the infrared oculography device due to missing or reduced quality data. Given the nature of the study, and the work commitments and priorities of the study physicians, it is not unexpected that data loss may occur. As the study took place in built-up areas which require more movement and monitoring than that associated with highway driving (i.e., long stretches of straight road, largely comprised of looking ahead), signals can be lost due to excess head movements affecting the ocular signal. The importance of cleaning the data when using these types of devices in field settings is high. Finally, our "control" drives likely involved high levels of drowsiness, thus reflecting lower odds ratios for adverse driving events. For instance, odds ratios for adverse driving events on the commute home were lower in our study compared with those reported in the study of night shift working Australian nurses [21]. This is likely due to (1) the preshift drives in our study (which serve as a comparative baseline for odds ratio) occurred during an adverse circadian phase (~06:00 am), whereas the Australian nurses drove to work during the wake maintenance zone (~07:00 pm), and (2) the resident physicians in our study probably had higher levels of chronic sleep restriction due to repeated shifts, which subsequently affects sleep-related outcomes [28], whereas the Australian nurses worked a maximum of three night shifts.

Although EDWSs were originally designed for residents working, sleeping and residing in the hospital [34], modern day trainees commuting to and from the hospital are exposing themselves and others to an elevated risk of drowsy driving. Higher levels of predrive sleepiness, the objective confirmation of drowsiness while driving, and the high rate of self-reported adverse events measured during the drive home from EDWS suggest that those working these shifts may knowingly place themselves and other road users at an unnecessary risk of drowsy driving crashes. Our data confirm that these risks are predictable—drivers were able to recognize their own elevated sleepiness levels before driving home and those assessments predicted the risk of a subsequent adverse driving event with relatively high sensitivity and specificity. This has serious implications on the legal accountability of the driver for adverse outcomes on the drive [49]. It is essential, therefore, that larger-scale studies in real, on-road environments should examine this wider issue in physicians and other shift worker populations. Our data are newly relevant, given that the ACGME have recently reinstated EWDS for postgraduate year 1 (PGY-1) resident physicians [2]. Although EDWSs are permitted, our data suggest that trainee physicians, and all other road users driving during this period considered at risk for drowsiness, should consciously evaluate their sleepiness level prior to each and every drive and, if they suspect that they are impaired, seek alternative transportation and not expose themselves and others to the significant, and avoidable, risk of drowsy driving.

Ethical Approval

The study was approved by the Human Research Committee of Partners Healthcare and all participants provided written informed consent and were remunerated for their involvement.

Supplementary Material

Supplementary material is available at *SLEEP* online.

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Author Contributions

All authors have made substantial contributions to the work presented and have approved the final version of the manuscript. CA, CAC, and SWL designed the study; CA conducted the study, analyzed and interpreted the data, and wrote the manuscript; SF assisted in the analysis and interpretation of the data; JMR provided technological oversight of the Optalert™ measurements and data output; SWR, CAC, and SWL contributed to data analysis, interpretation of data, and edited the manuscript. All authors approved the final manuscript.

Disclosure Statement

CA has no conflicts of interests related to the results reported in this paper report. In the interest of full disclosure, she has received a research award/prize from Sanofi-Aventis; contract research support from VicRoads, Rio Tinto Coal Australia, and Tontine/Pacific Brands; and lecturing fees from Brown Medical School/Rhode Island Hospital, Ausmed, Healthmed, and TEVA. In addition, she has served as a consultant through her institution to the Rail, Bus, and Tram Union, the Transport Accident Commission (TAC), and the National Transportation Committee (NTC). She has also served as an expert witness and/or consultant in relation to fatigue and drowsy driving. CA is a Theme Leader in the Cooperative Research Centre for Alertness, Safety, and Productivity. SF serves as a Project Leader in the Cooperative Research Centre for Alertness, Safety, and Productivity. JMR reports that he has served as a consultant through his institution to Takeda Pharmaceuticals North America and Cephalon and has received consulting fees from Vanda Pharmaceuticals. SMWR reports that he has served as a consultant through his institution to Vanda Pharmaceuticals, Philips Respironics, EdanSafe, The Australian Workers' Union, National Transport Commission, Transport Accident Commission, and New South Wales Department of Education and Communities; has through his institution received research grants and/or unrestricted educational grants from Vanda Pharmaceuticals, Shell, Teva Pharmaceuticals, Rio Tinto, Seeing Machines, Takeda Pharmaceuticals North America, Philips Lighting, Philips Respironics, Cephalon, and ResMed Foundation; and reimbursements for conference travel expenses from Vanda Pharmaceuticals. His institution has received equipment donations or other support from Optalert™, Compumedics, and Tyco Healthcare. He has served as an expert witness and/

or consultant to shift work organizations. SMWR also serves as a Program Leader in the Cooperative Research Centre for Alertness, Safety, and Productivity. CAC has received consulting fees from or served as a paid member of scientific advisory boards for Bose Corporation, Boston Celtics, Columbia River Bar Pilots, Institute of Digital Media and Child Development, Klarman Family Foundation, Quest Diagnostics, Inc., Vanda Pharmaceuticals, and V-Watch/PPRS. He has also received education/research support from Cephalon Inc., Mary Ann & Stanley Snider via Combined Jewish Philanthropies, Optum, Philips Respironics, Inc., ResMed Foundation, San Francisco Bar Pilots, Schneider Inc., and Sysco. He has received lecture fees from American Academy of Sleep Medicine (AADSM), CurtCo Media Labs LLC, Global Council on Brain Health/AARP, Hawaii Sleep Health and Wellness Foundation, National Sleep Foundation, University of Michigan, University of Washington, and Zurich Insurance Company, Ltd. The Sleep and Health Education Program of the Harvard Medical School Division of Sleep Medicine (which CAC directs) has received Educational Grant funding from Cephalon, Inc., Jazz Pharmaceuticals, Takeda Pharmaceuticals, Teva Pharmaceuticals Industries Ltd., Sanofi-Aventis, Inc., Sepracor, Inc., and Wake Up Narcolepsy. CAC is the incumbent of an endowed professorship provided to Harvard University by Cephalon, Inc. and holds a number of process patents in the field of sleep/circadian rhythms (e.g., photic resetting of the human circadian pacemaker). Since 1985, he has served as an expert on various legal and technical cases related to sleep and/or circadian rhythms including those involving the following commercial entities: Bombardier, Inc., Continental Airlines, FedEx, Greyhound, and United Parcel Service (UPS). CAC owns or owned an equity interest in Somnus Therapeutics, Inc. and Vanda Pharmaceuticals. He received royalties from McGraw Hill and Koninklijke Philips Electronics, N.V. for the Actiwatch-2 and Actiwatch-Spectrum devices. CAC's interests were reviewed and managed by Brigham and Women's Hospital and Partners HealthCare in accordance with their conflict of interest policies. SWL has no conflicts of interests related to the research or results reported in this paper. In the interests of full disclosure, commercial interests from the last 3 years (2014–2017) are listed below. SWL has received consulting fees from the Atlanta Falcons, Atlanta Hawks, Carbon Limiting Technologies Ltd. on behalf of PhotoStar LED, Perceptive Advisors, Serrado Capital, and SlingshOT Insights and has current consulting contracts with Akili Interactive, Consumer Sleep Solutions, Delos Living LLC, Headwaters Inc., Hintsa Performance AG, Light Cognitive, Mental Workout, Pegasus Capital Advisors LP, PlanLED, OpTerra Energy Services, Inc., and Wyle Integrated Science and Engineering. SWL has received unrestricted equipment gifts from Biological Illuminations LLC, Bionetics Corporation, and F.LUX Software LLC; has equity in iSLEEP, Pty; advance author payment and/or royalties from Oxford University Press; honoraria plus travel, accommodation, and/or meals for invited seminars, conference presentations or teaching from BHP Billiton, Estee Lauder, Lightfair, Informa Exhibitions (USGBC), Teague; and travel, accommodation, and/or meals only (no honoraria) for invited seminars, conference presentations, or teaching from FASEB, Hintsa Performance AG, Lightfair, and USGBC. SWL has completed investigator-initiated research grants from Biological Illumination LLC and Vanda Pharmaceuticals, Inc. and has an ongoing investigator initiated grant from F. Lux Software LLC; completed service agreements from Rio Tinto Iron Ore and Vanda Pharmaceuticals Inc.; and completed three sponsor-initiated clinical research contracts from Vanda Pharmaceuticals, Inc. SWL holds a process patent for "Systems and methods for determining and/or controlling sleep quality," which is assigned to the Brigham and Women's Hospital per Hospital policy. SWL has also served as a paid expert on behalf of several public bodies on arbitrations related to sleep, light, circadian rhythms, and/or work hours for City of Brantford, Canada, and legal proceedings related to light, sleep, and health. SWL is also a Program Leader for the CRC for Alertness, Safety, and Productivity, Australia.

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