MICROSLEEP EPISODES, ATTENTION LAPSES AND CIRCADIAN VARIATION IN PSYCHOMOTOR PERFORMANCE IN A DRIVING SIMULATION PARADIGM

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Summary: Numerous studies document circadian changes in sleepiness, with biphasic peaks in the early morning and late afternoon. Driving performance has also been demonstrated to be subject to time-of-day variation. This study investigated circadian variation in driving performance, attention lapses (AL) and/or frequency of microsleep (MS) episodes across the day. Sixteen healthy adults with valid driver's licenses participated in the study. Using the York Driving Simulator, subjects performed four intentionally soporific 30-minute driving simulations at two-hour intervals (i.e., at 10:00, 12:00, 14:00, and 16:00). During each session, individuals had EEG monitoring for MS episodes (defined as 15 to 30 seconds of any sleep stage by polysomnographic criteria) and AL episodes (defined as intrusion of alpha- or theta-EEG activity lasting 4-14 seconds). Measured variables included: lane accuracy, average speed, speed deviation, mean reaction time (RT) to "virtual" wind gusts and off-road events. Mean values of each variable at every time were analyzed using a general linear model and paired sample *t*-tests. RT displayed significant within-group variation, with paired samples tests at df=15 showing RT at 10:00 significantly faster than at other times of the day, but no significant within-group variation between other times of the day. All other variables and EEG-defined AL episodes failed to exhibit any statistically significant variation across the day. However, MS episodes were found to occur more often at 16:00 in comparison to all other times. As RT was optimal before noon, it appears that psychomotor performance and therefore driving ability is subject to circadian variation. Coincident with the demonstrated circadian pattern of diminished alertness, this may partially explain the high incidence of motor vehicle accidents during the mid- to late-afternoon. By better understanding circadian fluctuations in driver sleepiness and psychomotor performance, human performance researchers may be in a position to better educate the public about cautionary measures to prevent accidents.

INTRODUCTION

Trends in sociodemographic population distribution, health patterns and technological advances are converging to create a challenge in human transportation safety (*1*). Medical professionals are placed in the difficult role of making objective assessments of driving safety in their patients, with decisions often carrying medicolegal weight (*2*). Yet much of the act of driving competency

relates to a patient's subjective wellbeing, sensorimotor functioning, cognitive functioning and level of insight into any deficits. Selected medical and psychological tests are available, which can indirectly assess aspects of physical or mental functioning relevant to driving. Alternately, *in vivo* testing centres exist that can perform on-road testing. This method, while more ecologically valid, is often more costly, and more difficult to standardize. Our pilot research has aimed to evaluate the utility of a standardized computerized driving assessment device that is able to collect driving-related data in real-time during a standardized driving task. The aim of this device would be to balance ecological validity and cost-efficiency, essentially acting as a 'red-flag' for potential driving impairment, warranting more thorough naturalistic testing and/or licensing restrictions. While it is known that a wide variety of mental and physical conditions may affect fitness to drive, the chief focus will be from the perspective of a medical practitioner/researcher in the field of sleep disorders.

The adverse effect of sleepiness on driving ability has been well-documented, with some research suggesting that driving while excessively sleepy may make the driver more impaired than being under the influence of alcohol (*3*). Numerous sleep researchers have documented that circadian variations in sleepiness and alertness occur throughout the 24-hour period, with greatest proneness towards sleepiness occurring in the early AM morning period, as well as during the mid-afternoon 'siesta period' (*4,5,6*). Similarly, epidemiological reviews of traffic accidents have noted peaks in crashes thought to be related to sleepiness that occur at corresponding times of day and night (*7,8*). However, this issue has not been investigated in a controlled prospective manner, i.e., by investigating driving performance in correlation to neurophysiologically documented sleep proneness. Concurrent to testing subjects' driving performance, we have used polysomnography measures including electroencephalography, (EEG) electromyography (EMG) and electro-oculography (EOG) to record actual changes in levels of consciousness, ranging from fully alert wakefulness to impairments due to attention lapses, drowsiness and actual brief episodes of sleep intrusions into consciousness.

RESEARCH PROTOCOL

Recruitment took place via advertisements in local newspapers and/or on hospital bulletin boards. Interested subjects were mailed a series of baseline questionnaires to assess study eligibility prior to a clinical screening interview. The questionnaire included the CES-D Depression Scale rating scores, Epworth Sleepiness Scale, Berlin Sleep Apnea Questionnaires, and ZOGIM Alertness Scale scores. A self-report sleep log assessing sleep latency, wakefulness and typical bed- and rise-times over the past two weeks was also completed. During the clinical interview, subjects were screened for eligibility and informed consent by a physician with expertise in sleep medicine. Informed consent was obtained from all participating subjects.

On the day of the clinical screening interview, patients undertook a 30-minute driving test in the driving simulator to become familiarized with the simulator and to control for possible learning effects. Subsequent testing for the purpose of the study took place in the form of four separate 30-minute standardized and supervised driving sessions occurring at 10:00, 12:00, 14:00 and 16:00.

Inclusion criteria: (screened for via sleep logs, questionnaires and clinical screening interview)

(1) Age 18-65, male and female

(2) Good physical and mental health

(3) Valid Driver's License (verified by sleep lab staff)

(4) Self-report of mean sleep onset latency of no more than 30 minutes (as defined by sleep logs) within the past two weeks.

(5) Self-report of a mean sleep duration of no less than 6.5 hours (as defined by sleep logs) within the past two weeks.

(6) Self-report of wakefulness, after initial sleep onset, of not more than 30 minutes.

(7) Self-report of normal bedtime between 22:00-24:00, and normal sleep time between, and rise time between 7:00-9:00.

Exclusion criteria:

(1) history of alcohol or substance abuse

(2) major neurologic and psychiatric disorders

(3) recent history (during the past 6 weeks) of medications likely to influence cognition or vigilance, such as sedatives, antipsychotics, stimulants.

(4) history of past major medical condition

(5) complaints of sleep disruption, excessive daytime sleepiness or impaired alertness within past 6 weeks.

Driving Simulation:

A 'virtual driving environment' was used, consisting of a monotonous highway scenario, intended to provoke lapses in alertness, in combination with standard polysomnographic EEG/EMG/EOG set-up.

The York Driving Simulator (York Computer Technologies, Kingston, Ontario, Canada) was used to assess driving performance (see Figure 1). The driving simulator consists of a personal computer, 15" monitor and peripheral steering wheel, accelerator and brake accessories. The simulator has been validated (*9,10,11*) as an effective and naturalistic research tool to measure psychomotor performance. The simulator presents a forward view from the driver's seat of a motorway road scene, with standard lane markings and signs signals appropriate to the road environment. The four-lane route has few turns, no stops signs or traffic lights, and posted speeds ranging from 70 to100 km/h. Subjects will be driving for 30 minutes following instructions to stay in the right hand lane to avoid passing cars in the left lane. Patients are instructed to obey all lane markings and speed signs and to keep both hands on steering wheel, while operating the pedals with the right foot only.

The simulator program samples a number of performance variables 10 times per second. These include reaction time for corrective steering maneuvers in response to "virtual wind gusts," mean velocity, mean variability road position, and a variable called "safe zone time," which is defined as the percentage of time the vehicle is traveling within 10 km/h of the posted speed limit, and

within 1.3 meters of the centre of the right lane. Thus, at the end of a simulation run, a wide range of driving performance variables is available for the researcher. Other variables of interest—for example, mean ratio of accelerations versus decelerations—can be retrospectively accessed from the stored performance file.

The **primary dependent performance outcome measures** included:

1) road position (expressed as a percentile, with the centre of the right lane being 25%, the centre lane 50%, and the centre of the left lane 75%);
2) mean speed over the four 30-minute driving sessions;
3) mean speed deviation, calculated as the difference in km/h of the speed of the vehicle from the posted speed limit;
4) mean reaction time by driver to 'virtual windgusts' generated in standardized randomized fashion by the simulator;
5) off-road incidents, i.e., the number of times per testing session that the vehicle crashed; and
6) Occurrence of microsleep episodes and attention lapses was monitored using EEG/EMG/EOG.

Polygraphic data was continuously recorded during repeat driving task performance: recording involved a ground lead, two frontal leads (EEG), a right-sided para-ocular lead (EOG), and a submental lead (EMG).

Primary Polygraphic Outcome Measures were:

a) **Microsleep:** defined as occurrence of 15 to 30 seconds of any sleep stage by EEG/EMG/EOG criteria.
b) **Attention Lapse:** defined as intrusion of alpha- or theta EEG activity lasting more than 3 seconds but less than 15 seconds (see Figure 2)

Figure 1. A subject's brainwave activity is monitored via EEG while using simulator
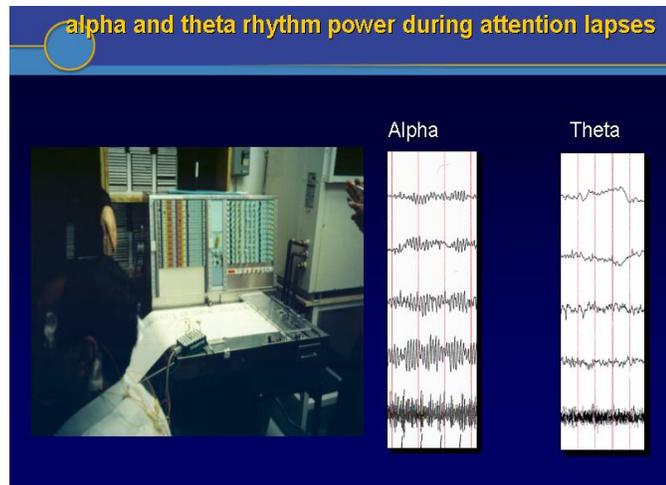
**Figure 2. Electrophysiological correlates of distraction
and sleepiness are recorded**

Statistical Analysis

To study varying levels of driving performance during the course of a day a repeated measure analysis was performed. Mean scores on the primary dependent variables will be measured for each individual 30-minute testing period, and a composite mean score was calculated using the mean of the four testing sessions during the day and night.

If any difference was detected, we investigated at which point in time the difference occurred by using a paired *t*-test for the continuous variables and McNemar's test for the categorical variable. The data were analyzed and stored using the SPSS program.

RESULTS

Sixteen individuals (11 male, 5 female) were included in the study with an average age of 30.8 +/- 7.5. Mean values of each variable at every time of simulation were attained and analyzed using a general linear model and paired sample *t* testing.

Performance Measures

Reaction time to virtual wind gusts was found to be quickest at 10:00 with no significant variation between other times of the day [RT10:00 - RT12:00 (*p = 0.04*) / RT10:00 – RT14:00 (*p = 0.01*) / RT10:00 – RT16:00 (*p = 0.01*)]. All other variables—lane accuracy, average speed, speed deviation, off-road events, attention lapses, and subjective ratings—failed to exhibit any statistically significant variation across the day.

Polygraphic/EEG Measures

While the occurrence of Attention Lapses failed to show a circadian variation of significance (F=0.5, df=3, **p=.58**), there was a significant within-group variation throughout the day of testing for the occurrence of Microsleep episodes (F=4.4, df=3, **p=0.2**). Specifically, Microsleep

episodes were found to occur more often at 16:00 in comparison to all other times, which between them did not vary significantly [MS10:00 – MS16:00 (*p = 0.01*) / MS12:00 – MS16:00 (*p = 0.02*) / MS14:00 – MS16:00 *(p = 0.00)*].

DISCUSSION

The capacity for human attention and cognitive capacity in relation to bandwidth has been described as one of the most important economic commodities of the 21st century (12). If this is true, then perhaps the effects of sleepiness and attention lapses on driving would seem appropriate phenomena to study using a computer simulation paradigm. Excessive sleepiness is essentially a phenomenon that arises more readily due to a low level of external cues. This phenomenon is well recognized in the sleep disorders literature; some examples of conditions that lead to excessive daytime sleepiness include sleep apnea, narcolepsy and chronic sleep deprivation. In disorders causing excessive sleepiness, sleep-related brain activity begins to intrude into wakeful consciousness; in the case of narcolepsy this may even include episodes of hallucinatory dreams. Thus, the well-defined patterns of being awake and alert vs. drowsy and asleep start to become more blurred (*6,7*). Traffic accidents due to impaired alertness are among the most dramatic adverse consequences of excessive daytime sleepiness.

Traditionally, sleep specialists have used neurophysiological methodologies to assess daytime sleepiness (*13*). In one test, the Mean Sleep Latency Test (MSLT), the subject is asked to take a nap during a 30-minute testing interval at four separate times of the day, analogous to our experimental protocol. EEG and EMG monitoring is used to document sleep onset. This test has been criticized as being a better measure of someone's ability to be able to go to sleep, rather than to try to stay awake. Thus, the Maintenance of Wakefulness Test (MWT) was developed (*13*), in which the subject is asked to sit down in a comfortable lounge-chair in a darkened room for four similar 30-minute intervals and asked to attempt to resist drifting off to sleep under such soporific conditions.

While it can be argued that a test that assesses an individual's ability to resist sleep in a boring situation like a darkened room (i.e., the MWT) would be a better way to assess risk of sleep-related car crashes, it still appears to lack some ecological validity. After all, driving a car is a complex task of information processing, requiring a variety of cognitive and psychomotor performance abilities (alertness, attention, multitasking, memory, co-ordination and visuospatial perception, to name a few) to be intact. However, there is a trade-off: the more realistic and behaviourally oriented a task becomes, the more difficult it becomes to standardize the task and control for individual differences (*14*). This makes sense in the case of a test to assess driving abilities; after all, there are a multitude of cognitive or behavioural factors that could potentially cause impairment in the real world. Thus, the challenge becomes one of designing a highly standardized screening tool for a fairly variable range of behaviours. Yet for assessing driving impairment due to excessive sleepiness, the standardized soporific driving task seems to enjoy good face validity, as it mimics real-world circumstances where a sleepy driver might be prone to lose consciousness and nod off.

In our subject group, reaction time was the one performance variable that showed significant diurnal variation throughout the day. While it remains possible that the 'novelty effect' of the first testing session of the day played as important a role as circadian factors, we attempted to

control for this by giving subjects a practice session. On polysomnographic/ EEG testing, microsleeps showed a clear tendency to occur more readily on the last testing session. Although we would postulate primarily a circadian explanation for this phenomenon, it might also be argued that an element of 'task fatigue' played a role.

It is our belief that deficits in both task performance and alertness would be accentuated in a more broad-based fashion.

Our work with the simulator thus far has focused on the gathering of normative data from healthy individuals. This has allowed us to correlate changes in driving performance with brain-activity patterns associated with sleepiness. We believe that if this methodology is applied to patients with actual sleep disorders such as sleep apnea or sleep deprivation, the occurrence of microsleep episodes and attention lapses will be further provoked, and will show corresponding impairments on driving performance measures. Clinically, subjects usually perceive these types of episodes as brief periods of 'nodding off' or 'phasing out,' often without even being aware of these lapses in consciousness. A previous pilot study by our group has found our driving simulator system more sensitive than MWT testing in assessing impairments in alertness relevant to driving in patients with clinically significant sleepiness (*11*).

There is clearly a significant medicolegal onus on the physician of the potential driver; in fact, physicians have been found negligent for failing to report medically impaired drivers causing harm in Canada, with courts emphasizing the doctor's responsibility not just to the individual patient, but to protect society at large as well. Not only does this responsibility put physicians in an awkward position towards the patient whom they often have known for years, but the actual task of detecting driving impairment in the office checkup is technically more difficult than law and policymakers might like to admit. From a clinician's perspective, the frustrating issue at hand is that there is no one clearly defined symptom or physical exam maneuver that can reliably screen for subtle impairments in the variety of facilities required to be intact for safe driving. While the ultimate 'red flag' would be a failed road test, this is more costly and time-consuming than our current health-care system allows for. The idea of an 'off-road' computerized screening test for medical fitness might serve as a cost-effective 'red flag' system that could be performed in a hospital laboratory, while still giving information relevant to performance on the road. The gold standard of driving assessment will likely always be a live driving assessment. In defense of simulated tests, one can make the valid argument that the actual *in vivo* road-test used to make licensing decisions is also only a 30-minute snapshot which can never truly test a potential driver under the variety of driving conditions he will eventually face.

There are broader sociopolitical issues that need to be considered in the context of computerized driving assessment methodologies. Are such tests perhaps best used in forensic circumstances, i.e., after an accident has already occurred, or to make a final determination of culpability? If this type of data was automatically collected by the vehicle (in a dashboard-camera 'black-box' paradigm) during routine driving, would this partially obviate the need for roadside human law-enforcement? What would be the role of government agencies and/or automotive industry in this process? For now, it would appear that the detection of the distracted and sleepy drivers is to be a feasible long-term goal to aim for, requiring continued collaborative input from researchers from the medical, human factors and automotive industry.

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