A REVIEW OF DRIVING UNDER THE INFLUENCE OF FATIGUE

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ABSTRACT

Driving under the influence of fatigue and drowsiness is one of the leading causes of accidents throughout the world. The United States Department of Transportation (USDOT) estimates that every year driver fatigue causes close to 100,000 crashes in the United States. These accidents results in1,544 fatalities, 71,000 injuries, and $12.5 billion in monetary losses in the US alone. Around the world, thousands of lives are lost each day due to road accidents. The National Road Safety Secretariat (NRSS) Pakistan estimates, the annual economic cost of highway crashes over rupees one hundred billion (over US$ 1.6 billion) for Pakistan. This paper provides a comprehensive review of the previous literature regarding driver fatigue and drowsiness research, the present state of research and the future trends. Various factors that may contribute to driver fatigue and drowsiness, Fatigue related countermeasures from various sources along with their merits are discussed. The Center for Intelligent Systems Research (CISR) of the George Washington University conducted an experiment at their Vehicle Simulator Laboratory to study driver drowsiness. Results of this study and description of the algorithm are provided. A comprehensive list of references is provided at the end.

Key words: *driver fatigue, road transport, driver drowsiness, highway accidents*

INTRODUCTION

NHTSA estimates 100,000 drowsiness and fatigue related crashes annually that, according to Fatality Analysis Reporting System (FARS), results in more than 1500 fatalities. It is estimated that 15% of single vehicle fatal truck crashes are fatigue or drowsiness related. Driver fatigue is particularly significant in commercial vehicle operations because truck drivers stay on the road for extended period of time, which often involves driving at night. Surveys conducted by Tilley,[1] in 1973 at Duke university, Seko[2] in 1984 in Japan, and Planque[3] in 1991 in France all indicate driver drowsiness as a serious problem and major cause of fatal accidents. According to a survey by the American Automobile Association (AAA) Foundation in 2004, Ninety percent of the North American police officers have stopped a driver who they believed was drunk, but turned out to be drowsy. According to a recent CBS report drowsy driving costs the North American consumer $16.4 billion in terms of property damages, health claims, lost time and productivity. Another $60.4 billion/year are spent by US Government and businesses on accidents related to drowsy driving.

This paper provides a comprehensive review of the previous literature regarding driver fatigue/drowsiness research, the present state of research and technologies being developed, and the future trends. Fatigue related factors that play important role in affecting driver performance are being discussed. Driver fatigue related countermeasures are discussed along with their merits and demerits.

FACTORS CONTRIBUTING TO FATIGUE RELATED ACCIDENTS

Researchers have identified many factors that can be attributed to the causes of drowsiness related accidents. Factors that influence driver fatigue/drowsiness include Greater Daytime Sleepiness, Less Sleep, More Difficult Schedules, More Hours of Work, Driver's Age, Driver Experience, Cumulative Sleep Debt, Presence of a Sleep Disorder, and Time of Day[4,5].

Loss of Sleep: The most common cause of drowsiness is lack of sleep. The effect of sleep is cumulative and loosing one or two hours of sleep a night can accumulate to cause serious sleep deprivation overtime,[6]. Sleep disruptions or fragmented sleep causes loss of sleep and will result in sleep deprivation,[7]. Sleeping less then 4 hours per night severely impairs driving performance and the loss of one night of sleep can result in extreme sleepiness. Drivers averaging less then 5 hours of sleep per night increased their risk of

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being in a sleep related crash nearly five times[8]. Loss of sleep increases the tendency of falling asleep and reduces driving performance[9,10]. A 1995 NTSB report identified the duration of the driver's last sleep period, the total sleep obtained during the 24 hours preceding the crash, and fragmented sleep patterns as the most contributing factors towards a drowsiness related single vehicle large truck crash. According to Sweeney[11] et al. (1995) the two most contributing factors are the duration of the last sleep period and the amount of sleep in the last 24 hours. Cumulative sleep debt, duration of continuous wakefulness, and acute sleep loss also highly contribute to fatigue related accidents.

Work Schedule: Researchers like Lin et al[12] have reported that total driving time has a greater effect on crash risk among truck drivers. According to a study by Mackie and Miller[13] driving performance among truck drivers start declining after 5 hours of driving for drivers with irregular schedules as compared to 8 hours for drivers with regular schedules. Harris et al.[14] found that the driver risk of being involved in a crash increases after 4 hours of continuous driving. Tractor-trailer drivers who violated the hour of service rule are more likely to fall asleep at the wheel,[15] Truck drivers who split there 8 hours of required off duty time into two shifts are at increased risk of being involved in a fatal crash[16], Hertz (1988). Lavie[17] (1986) argues that truck drivers, who work irregular night shifts and are compelled to sleep during the day time, may not be getting the restorative quality of night time sleep. Factors associated with sleep related crashes include working two or more jobs, working night shifts and working more then 60 hours per week,[8].

Sleep Disorder/Quality of Sleep: Individuals with sleep apnea and other sleep disorders that cause excessive daytime sleepiness are at high risk for accidents[18,19]. Drivers involved in sleep crashes are more likely to report that they often or always had problem falling or staying asleep. They are also more likely to report that the overall quality of their sleep is poor[8].

Time of Day: Due to circadian rhythms people feel sleepy during the afternoon and evening hours, even among people who are not sleep deprived[7]. Sleep accidents are more likely to occur during the early morning hours from 2:00 AM to 6:00 AM and to a lesser extent during the afternoon from 2:00 PM to 4:00 PM. Driver schedules that interfere with natural circadian sleep patterns can disturb sleep. Truck drivers who drive during night time are at higher risk of being involved in a crash[16,20]. According to Miller[13] and Harris[14] there exist a correlation between time of day and level of fatigue. Reimer,[21] analyzed data from a driving simulation experiment and argued that time of day effects has a significant role in assessing performance in a simulated driving environment. They suggested that it should be considered for testing driver performance in simulated driving. Otmani[22] studied the effect of time of day and age of drivers in a simulated driving environment. The most interesting findings of this study was that the performance of young drivers is more affected by the time of day and are more prone to falling asleep as compared to middle aged. Chipman and Lin[23] analyzed actual crash data to study the effect of light and circadian rhythm on occurrence of crash for drowsy driving conditions and partially concluded that lack of light may exacerbate the effect of other factors at times of low alertness.

Monotony of Road/Driving Conditions: A situation is said to be monotonous when the stimuli remain unchanged or change in a predictable manner[24]. Highway night drivers are particularly vulnerable to sleep related accidents[25]. Sleep related accidents may be more common on long stretches of interstate highways and may account for 40% of fatal accidents[26]. Driving performance degrades at a faster rate on straight road sections than on curves[27]. 40% of sleep related accidents occur on highways[28]. According to an estimate by Fell[29] in 1994 30% of accidents on rural roads are due to driver drowsiness. In a self reported driver fatigue/drowsiness study by Sagberg in 1999[30] US drivers were found to be more susceptible to drowsy driving as compared to Norwegian drivers. Sagberg argues that it may be due to the geometry and environment of US highways. He further argues that the risk of falling asleep is higher on straight, monotonous roads with low traffic, where boredom is more likely to occur. From a simulator study Thiffault and Bergeron[31] suggested that fatigue is likely to occur much earlier when driving in a monotonous low demanding road environment[32]. Studied the effect of different outside environments and the changes in these environments on the driving behavior of fatigued drivers. The most interesting finding of this study was that the performance of fatigued drivers is more affected by changes in road environment than by the length of driving time. The drivers felt more fatigued when the road environment was changed from complex to monotonous

Driver Personality and Age: There are large individual differences in the susceptibility to become drowsy while driving[33] Zaidel (2000). Other studies on driver drowsiness by Wyli[34] observed the same phenomenon. They all argue that some drivers are more affected, by study conditions, than others. Thiffault and Bergeron[35] found that drivers who are more sensation seekers may be more sensitive to road monotony and thus more prone to fatigue related driver errors on monotonous, low demanding roads. Campagne[36] compared the performance of three age groups in a driving simulator study and found that deterioration of vigilance is correlated with driving errors for drivers aged 60 and above.

CHARACTERISTICS OF DROWSINESS/FATIGUE RELATED ACCIDENTS

Horne and Reyner[37] in 1995 mentioned the criteria by which sleep related vehicle accidents could be identified these include: Vehicle running off the road, No sign of braking, No mechanical defect, Good weather, and Elimination of speeding. According to NHTSA statistics the highest numbers of crashes occur during the period from midnight to early morning. More than 40% crashes occur between 1 a.m. and 7 am. About 70% of crashes occur on rural highways with 55-65 mph speed limits. This generally provides a monotonous and calm atmosphere, which is just right for falling asleep. The first events that occur in the accident are: 64% are collisions with fixed objects (trees, guardrail, highway sign etc.), 17% are collisions with another moving vehicle. 7% are rollovers. 6% are collisions with parked vehicles. Hamouda and Saccomono[38] developed an Artificial Neural Network (ANN) model for identifying fatigue related accidents. The ANN was trained on data from police reports database of the province of Ontario.

COUNTER MEASURES AGAINST DRIVER FATIGUE/DROWSINESS

Legislation/Enforcement: In 1938 the United States congress in-acted the federal hours-of-service (HOS) regulations[39] applied to interstate commercial motor vehicles (CMV). These regulations limit the CMV driver's driving to 10 consecutive hours. Drivers are permitted to begin driving again for another ten hours after having 8 h off-duty. In this way driver actually can drive a total of 16 hours in a 24 hours period. These rules were amended on January 1 2004 and these new rules reduced the permissible hours of driving in each 24-hour period from 16 to 14. These require 10 hours of off-duty time, which provides two hours more for sleep and other hygiene functions. CMV drivers are required to complete their Record of Duty Status (RODS) also known as driver’s log. However, according to many researchers the HOS regulations are regularly flouted by a larger proportion of drivers particularly owner operators. One solution to this is the use of automatic recording of driver log using GPS, smart cards and onboard monitoring[40]. After analyzing data collected in a naturalistic driving study Rich Hanowski[41] concluded that the drivers are getting significantly more sleep after the implementation of the revised 2003 HOS rules.

In October 2002, the first bill regarding drowsy driving was introduced in the United States House of Representatives. The main feature of his bill is that it provides incentives to states and local communities for taking measures to enhance traffic safety related to driver fatigue. The bill calls for training of police officers, the creation of driver’s education curriculum, standardized reporting of fatigue-related crashes on police report forms, and the promotion of countermeasures such as continuous shoulder rumble strips and rest areas.

In 2003 the state of New Jersey passed legislation that established driving while fatigued as recklessness under the state’s vehicular homicide statute. The legislation allow judges to consider drivers on trial for vehicular homicide as having driven recklessly, provided the driver had fallen asleep or had not slept for more then 24 consecutive hours before the accident occurred. Radun[42] reviewed the cases of fatigued or sleepy drivers who were convicted for drowsy driving offence in Finland. Despite the fact that it is difficult to prove the charges relating to drowsy driving, Finish police and prosecutors were able to convict a significant number of drivers.

Driver Education: Educating drivers and creating awareness among general population about drowsy driving is key to the solution of this problem. Introducing material regarding fatigue/drowsy driving and its countermeasures into driver training curriculum and driver licensing examination will be very effective in combating drowsy driving. The findings of Gander[43] suggest that fatigue management education is very useful for developing a fatigue management culture among CMV operators and further argues that knowledge gained at the time of training is mostly retained and drivers implement the strategies against fatigue

Rumble strips: Anund[44] studied the alerting effect of rumble strip on fatigued or drowsy drivers in a simulator experiment. Hitting the rumble strip did produce an alerting effect on sleepy drivers but it did not last for more than five minutes. There was no difference between the alerting affect of various types of rumble strips.

Other Strategies: many researchers have argued that lake of external stimuli has a negative effect on driver fatigue. Secondary task stimuli can increase the mental demand and thus help reduce deterioration of alertness. According to Verwey and Zaidel[45] drivers were able to counteract deterioration of their alertness by using a speech controlled game box, as a devise for increasing mental activity in monotonous driving conditions. Wierwille[46] suggest that a secondary task requiring a simple yes/no response every 15 sec might may reduce drowsiness. Gershon[47] studied the effect of various fatigue encountering measures in a driving simulator experiment. It was found that drinking an energy drink can have significant positive effect on counteracting fatigue. These strategies or countermeasures can only delay, to a lesser extent, the onset of drowsiness but may not increase alertness when drowsiness has already been detected. Fairbanks[48] also reported that secondary task stimuli showed disappointing results when used as an alertness device.

DRIVER DROWSINESS DETECTION TECHNIQUES

Based on the scientific literature these techniques can be broadly classified into two categories. In the first category are techniques based on sensing of driver physical and physiological phenomenon such as eye movements, Electro Encephalogram (EEG), facial features, and body posture. The second category is based on sensing performance output of the vehicle hardware such as steering, braking, velocity, lane position etc.

Eye closure: Monitoring driver eyes is one of the most successful techniques for detecting drowsiness as studied by many researchers. Eyelid closure is one of the most reliable predictor of the onset of sleep[49,50,51]. Dingus[52] in1987 developed the PERCLOSE algorithm, which is a measure of the proportion of time that the eyes of a subject are closed over a certain time period. Different techniques have been used to track the eyelid closures. Ueno[53] in 1994 used a method based on the ferit's diameter of the eye to track the eyelid closures. Torsvall and Akerstedt[54] in1990 used Electrooculography (EOG) to detect eye movements. Ogawa[51] in 1997 used the angle of inclination of eye corners to track the eyelid closures. Seki[55] in 1998 used reflection from the retina for capturing eye closing. Kurt[56] in 2009 developed an Artificial Neural Network model to detect drowsy and sleep stages, using EEG, EOG, and EMG as input. Although the model was not tested in a driving environment the high accuracy rate (over 98%) makes it a good candidate for such use. Morad[57] in 2009 studied two ocular parameters, papillary activity and saccade velocity using a commercially available product to screen truck drivers for fatigue. They reported that ocular parameters are an efficient tool for measuring fatigue in drivers. Shuyan[58] developed a model based on eye lid data obtained from EOG electrodes in a simulator study. This model uses support vector machine (SVM) to detect fatigue or sleepiness**.** Wu[59] developed a drowsiness detection model based on changes in facial expressions and used fuzzy logic and expert system to analyze the images obtained through a CCD camera. Eye position and eye closures were the two variables that play major role in there detection algorithm. Eye closure activity can provide good detection accuracy but changes in light conditions, correction glasses, angle of face, and other conditions can seriously affect the performance of image processing systems.

Electro encephalogram (EEG): EEG recorded from the human scalp is the most important physiological indicator of the central nervous system activation and alertness. In time domain commonly used EEG measures include: average value, standard deviation, and sum of squares of EEG amplitude while in frequency domain energy content of each band (β, α, γ, Δ), mean frequency, and center of gravity of the EEG spectrum are commonly used[60,61,54,62,63,64,65] all used EEG as a measure of driver fatigue/drowsiness. Subhasi[66] and Vuckovic[67] used ANN to extract features from the raw EEG. Changes in EEG patterns during the alert, transitional, and post transitional phases of fatigue were observed by Lal and Craig[63]. These changes were used to develop a detection algorithm for detecting a set of programmed changes that occur during the observed phases of fatigue. Yang[68] in 2010 used dynamic Bayesian Network, information fusion and multiple contextual and physiological features to develop a driver fatigue detection model. They employed first order Hidden Markov Model (HMM) to compute the dynamics of a Bayesian Network at two different time slots and reported that ECG and EEG are the two important fatigue recognition features. Generally EEG is considered suitable for making accurate and quantitative judgments of alertness levels. EEG based detection is very impractical as it requires electrode to be fixed to human skin, which makes it very intrusive.

Facial expressions and body posture: According to Wierwille and Ellsworth in 1994[46] trained observers could rate the drowsiness level of drivers based on video images of driver faces. Bergasa in 2003[69] and others have developed vision-based systems to extract facial expressions automatically. There is little evidence about the accuracy and robustness of such systems. Andreeva[70] studied changes in body postures by attaching triple-axial accelerometers to upper body but the results reported are inconclusive.

Vehicle Speed, Yaw, Brake, and Acceleration: Generally, variability in speed, Yaw, Brake and acceleration has not shown any significant results that can be used to predict drowsiness as reported by[71,72,73]. Dingus,[52] found little evidence of any relation between accelerator activity and time or drowsiness.

Vehicle lateral position: Mast[74] in 1966 first found that the lane tracking ability decreases as the time on task increases. Skipper[50], Stein[75] and Piluti[76] all reported that measures related to vehicle lane position could be used to detect drowsiness. From practicality point this variable is a very weak candidate because it is not only difficult to capture vehicle lane position but it may also be too late for a warning if the vehicle had already crossed into other lane.

Vehicle Steering Activity: Researchers have carried out many experiments to determine the physical vehicle parameters characterizing driving that could be correlated with physiological parameters for predicting driver drowsiness. Hulbert[77], Mast[74], Dureman[78], Ryder[79] found that the frequency of steering reversals decreases with time on task. Mackie[34] Planque[3], Elling[80] reported that variations in steering wheel movements are correlated with time on task and drowsiness. Fukuda,[81] developed a detection technique at Toyota motor company using steering adjustment time to detect drowsiness.

Liu[82] concluded in a review paper that no single measure can reliably predict drowsiness and therefore, further research is necessary to examine more complex functions, and individual differences between drivers. They also argued that a successful countermeasure for prediction of driver drowsiness will require the use of multiple measures and setting of multiple criteria.

In 2001 Sayed and Eskandarian[83] developed an algorithm, which is based on Artificial Neural Network (ANN) learning of driver steering. To enhance the detection accuracy and robustness of this detection system an experiment was conducted at the CISR Vehicle Simulator Laboratory using a patented state of the art eye tracking system for recording eye closures data and a combined ANN model, using both eye closures and vehicle steering angle, is developed.

Twelve subjects between the ages of 25 to 45 years participated in the experiment. During the experiment drivers (subjects) were asked to drive the vehicle simulator. Drivers were required to complete two experimental driving sessions, each under different level of sleep deprivation.

To normalize the effect of curvature, it was subtracted from the steering angle in the curve sections. The one dimensional steering angle data was discretized and coded into an eight dimensional vector. The eye closure data was recorded at 60 Hz but was reduced to 1 Hz, to match with the steering angle data. The eye closure data was discretized into a four dimensional vector. These two vectors are then combined to form the twelve dimension vector. After coding, this vector was summed over an interval of n seconds to get the input vectors for the ANN model, each input vector then represents n seconds of driving interval. The desired output, required for ANN training, is a two dimensional vector representing sleep or wake state.

The network correctly identified 191 out of a total of 207 sleep intervals i.e. an accuracy of 92.4 %. There were 14 “false alarms” i.e. these intervals were in wake class but were misclassified as sleep. 16 intervals that were in the sleep class but the network misclassified them as wake.

To further test the model and to have a more clear visualization of the network performance, data from all the subjects (both morning and night sessions) was presented to the ANN one subject at a time. Figure 1 shows the ANN output for two subjects, all of the remaining subjects showed similar results. It can be seen from Figure 1 that in the morning driving session, with the exception of few falls alarms, the model consistently classified the driving as wake. During the night driving session, when the drivers were sleep deprived, the model detected large number of sleep intervals indicating driver drowsiness. During the night driving session, drivers fell asleep and crashed the vehicle. Figure 1 shows the time interval in which the crash occurred. It can be seen that in almost all the cases the model detected drowsy driving much before the actual crash occurred. The top portion of Figure 1 is a bar graph of the eye closure data, each bar represents the fraction of time eye was closed for that particular 15 sec time interval. The output of the model correlates very well with the eye closures

Commercially Available Driver Drowsiness Detection Systems

For any drowsy detection system to be commercially successful, it has to be non-driver specific, non-intrusive, work in real time, be unobtrusive and have no physical contact with the driver. It should also cause no harmful emissions or include any moving parts. The only commercially available devise that is partially validated is the PERCLOS based camera by Attention Technologies. Nissan, Ford and Toyota all developed systems based on steering activity but are never implemented and still in research stage. Devices based on head dropping/nodding

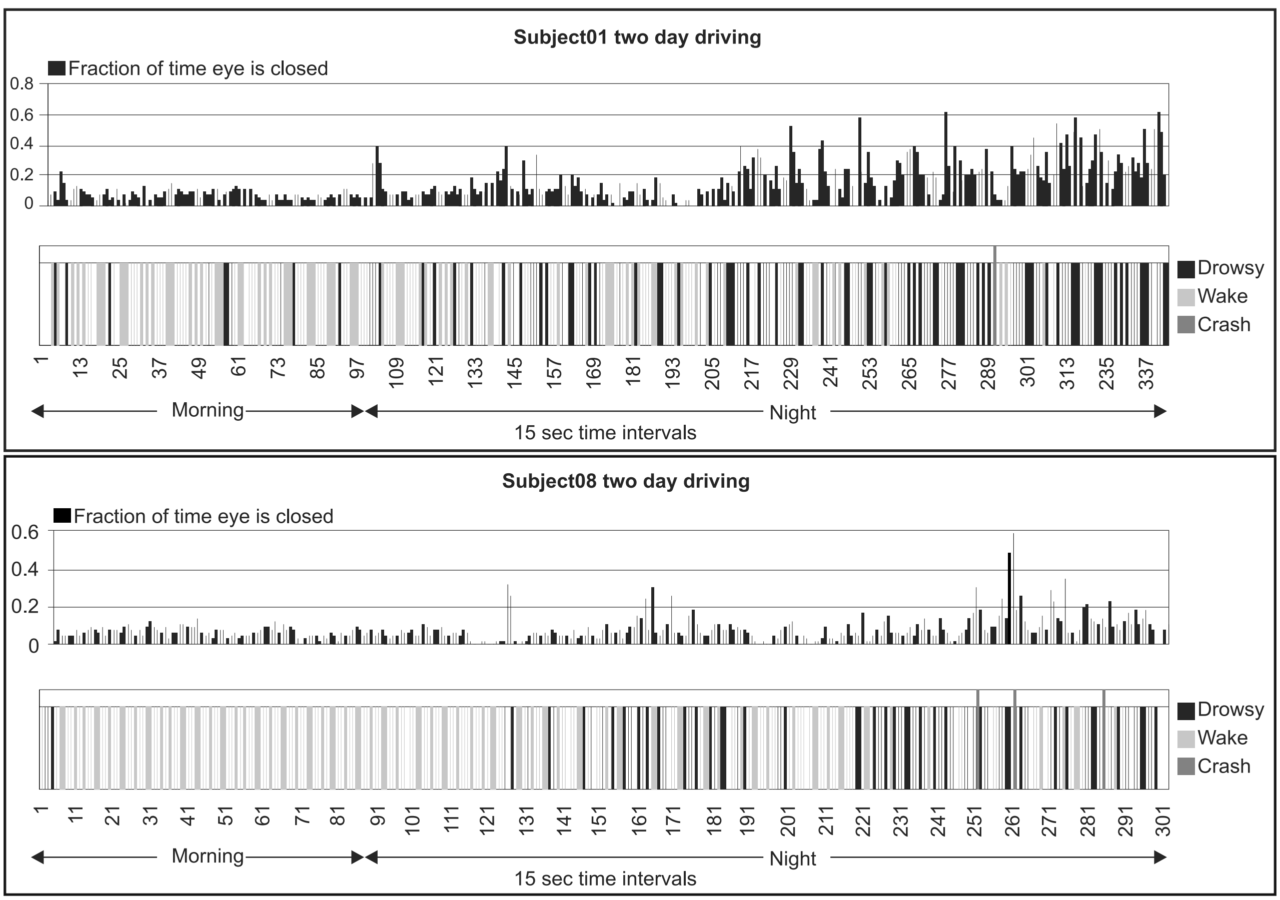

Figure 1: Results for Two Subjects

are also available from many vendors but are not validated.

DISCUSSIONS AND CONCLUSIONS

The scope and gravity of the problem of driver fatigue and drowsiness have been discussed. Various factors that contribute to the problem of driver fatigue have been identified and countermeasures to combat fatigue have also been discussed. Technological countermeasures for detecting driver fatigue and their merits/demerits are discussed. A method for detecting drowsy driving behavior using both steering angle and eye closures has been presented.

It is the opinion of this author that no single measure will solve the problem of driver fatigue. To combat this problem every one has to act together, the legislation, the law enforcement, the technology, the educators, and above all the responsibility lies on the individual driver. The fundamental cause of drowsiness is loss of sleep and there is no cure but to get the required amount of sleep. The detection technologies are still in their early stage of infancy the validity of their inputs remains somewhat uncertain, and their reliability in real traffic on the road is still unproven. Moreover they may create a false sense of security, and the driver may keep on going beyond his/her impairment. These technologies are not a substitute for the required amount of sleep.

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