Accident Analysis and Prevention 37 (2005) 473–478

ACCIDENT ANALYSIS & PREVENTION

www.elsevier.com/locate/aap

Fatigue, sleep restriction and driving performance

Pierre Philip [a,*], Patricia Sagaspe [b], Nicholas Moore [c], Jacques Taillard [a], André Charles [b], Christian Guilleminault [d], Bernard Bioulac [a]

[a] Clinique du Sommeil, CHU Pellegrin, Place Amelie Raba Leon, 33076 Bordeaux Cedex, France
[b] Laboratoire de Psychologie, EA 3662, Université Bordeaux II, 33076 Bordeaux Cedex, France
[c] Département de Pharmacologie, Université Bordeaux II, 33076 Bordeaux Cedex, France
[d] Sleep Research Center, Stanford Medical School, Stanford, CA, USA

Received 1 December 2003; received in revised form 1 May 2004; accepted 28 July 2004

Abstract

We ran a randomized cross-over design study under sleep-deprived and non-sleep-deprived driving conditions to test the effects of sleep restriction on real driving performance. The study was performed in a sleep laboratory and on an open French highway. Twenty-two healthy male subjects (age = 21.5 ± 2 years; distance driven per year = 12,225 ± 4739 km (7641 ± 2962 miles) [mean ± S.D.]) drove 1000 km (625 miles) over 10 h during five 105 min sessions on an open highway.

Self-rated fatigue and sleepiness before each session, number of inappropriate line crossings from video recordings and simple reaction time (RT) were measured.

Total crossings increased after sleep restriction (535 crossings in the sleep-restricted condition versus 66 after non-restricted sleep (incidence rate ratio (IRR): 8.1; 95% confidence interval (95% CI): 3.2–20.5; $p < 0.001$)), from the first driving session. The interaction between the two factors (condition × time of day) was also significant ($F(5, 105) = 3.229$; $p < 0.05$). Increasing sleepiness score was associated with increasing crossings during the next driving session in the sleep-restricted (IRR: 1.9; 95% CI: 1.4–2.4) but not in the non-restricted condition (IRR: 1.0; 95% CI: 0.8–1.3). Increasing self-perceived fatigue was not associated with increasing crossings in either condition (IRR: 0.95; 95% CI: 0.93–0.98 and IRR: 1.0; 95% CI: 0.98–1.02).

Rested subjects drove 1000 km with four shorts breaks with only a minor performance decrease. Sleep restriction induced important performance degradation even though time awake (8 h) and session driving times (105 min) were relatively short. Major inter-individual differences were observed under sleep restriction. Performance degradation was associated with sleepiness and not fatigue. Sleepiness combined with fatigue significantly affected RT.

Road safety campaigns should encourage drivers to avoid driving after sleep restriction, even on relatively short trips especially if they feel sleepy.

Keywords: Sleep restriction; Fatigue; Sleepiness; Performances; Driving; Line crossings

1. Introduction

Though fatigue and sleepiness at the wheel are well-known risk factors for traffic accidents (Horne and Reyner, 1995; Philip et al., 2001; Connor et al., 2002), many drivers combine sleep deprivation and driving (Mitler et al., 1997; Philip et al., 1999). This dangerous behaviour can be related to economic rewards (Arnold et al., 1997) in professional drivers or to socio-cultural factors (Philip et al., 1996, 1999) in vacationers. Nurses or physicians, who also have to stay awake for very long hours face a similar challenge (Lamberg, 2002; Veasey et al., 2002). Working under sleep deprivation increases fatigue and risk of professional errors (Gaba and Howard, 2002). However, in these populations, alertness is not only a major concern for work

* Corresponding author. Tel.: +33 5 56 79 55 13; fax: +33 5 56 79 48 06.
E-mail address: pierrephilip@compuserve.com (P. Philip).

0001-4575/$ – see front matter
doi:10.1016/j.aap.2004.07.007

safety but also for traffic safety. Traffic accidents from work to home is one of the major causes of injury and deaths among workers (Harrison et al., 1993; Personick and Mushinski, 1997) and residents and house staff are particularly exposed to this risk (Marcus and Loughlin, 1996; Steele et al., 1999).

Because of these conflicts between physiological needs and social or professional activities (Rajaratnam and Arendt, 2001; Gaba and Howard, 2002), understanding the human limits of fatigue and sleep deprivation are becoming key issues in accident prevention.

Fatigue is a gradual and cumulative process associated with a disinclination towards effort, eventually resulting in reduced performance efficiency (Grandjean, 1979). It has been described in driving episodes which require sustained attention for long periods of time (Lal and Craig, 2001). Fatigue resolves after a period of rest.

Sleepiness is a difficulty in remaining awake even while carrying out activities (Dement and Carskadon, 1982). This symptom is related to circadian and homeostatic influences. The biological clock generates and maintains chronobiological rhythms which control sleep and wakefulness. During daytime, human rhythms generate a drop of vigilance in the mid-afternoon and a very alert period towards the end of the afternoon (Lavie, 1986).

Extended time awake and/or sleep restriction increase sleep pressure and generate cumulative sleepiness (Carskadon and Dement, 1979, 1981) which is known to impair neurobehavioral functioning (Froberg, 1977; Powell et al., 2001). Interaction between these two regulatory processes induces a non-linear evolution of sleepiness over time. Sleepiness resolves after sleep.

In the public, fatigue and sleepiness are very frequently confused. Even if their causes (heavy workload versus sleep deprivation) and counter-measures (rest versus sleep) are very different, people do not necessarily discriminate the effects and remedies to the two conditions. For instance, sleep-deprived drivers will stop more frequently but will not necessarily sleep during their breaks (Philip et al., 1996, 1999).

Fatigue and sleepiness are both thought to impair driving abilities but the cumulative effects of sleepiness on fatigue-related decrements of performance have never been quantified. For this reason, we designed a controlled cross-over study of real long-distance driving under normal and sleep-restricted conditions, to study the effects of fatigue alone or associated with sleepiness on performance. Several studies have shown that impaired daytime alertness induces lateral deviations during driving (O'Hanlon and Volkerts, 1986; O'Hanlon et al., 1995; Ramaekers and O'Hanlon, 1994) and sleep-related accidents frequently happen with a single car driving off the road and hitting an obstacle with no reaction from the driver (Horne and Reyner, 1995). Therefore, we selected inappropriate line crossings as our main outcome criterion to quantify driving impairment after sleep restriction.

2. Methods

2.1. Subjects

The study was approved by the local ethics committee (consultative committee for the protection of persons participating in biomedical research, CCPPRB Bordeaux A). Twenty-two healthy male subjects (mean age = 21.5 years; range = 18–24 years; mean yearly driving distance = 12,225 ± 4739 km (7641 ± 2962 miles)) participated after providing written informed consent.

2.2. Inclusion criteria

All subjects underwent a clinical interview with a sleep specialist and a nocturnal polygraphy to rule out any sleep disorder. Because sleep duration and sleep efficiency are crucial in sleep restriction protocols, we used actimeters (Actiwatch®, Cambridge Neurotechnology) (Delafosse et al., 2000) to quantify our volunteers' sleep duration. This device monitors body movements and allows calculation of mean nocturnal sleep episodes and of nocturnal awakenings.

Total time in bed was recorded with a click button by the subject when getting into and out of bed. Sleep efficiency was then calculated by dividing the total time in bed by the total sleep time estimated by the software (Kushida et al., 2001).

To rule out any sleep–wake schedule disorders, each subject had 7 days of actimetry before being included in the study. Subjects were included if they had a mean sleep efficiency equal or superior to 85% during the 7 days of recordings.

This was a randomized open cross-over study, with all subjects having two driving periods, one after normal sleep, and one after restricted sleep. The order in which these were performed was randomly attributed to each subject in a balanced design, using a random permutations sequence.

2.3. Sleep schedules

The subjects were instructed to maintain a regular sleep–wake schedule and were monitored by actimetry during the 3 days preceding each experimental session. No stimulant of any kind was allowed during the study.

For the tests obtained in the normally rested condition, subjects were monitored in the laboratory from 21:00 to 08:30 the next day morning and were allowed to go to bed from 23:00 to 07:30. In the sleep restriction condition, subjects were also monitored in the laboratory from 21:00 to 08:30 the next day but were allowed to sleep only from 23:00 to 01:00. The duration of sleep was monitored by actimetry during both conditions. Each subject was tested after a normal sleep night and after a restricted sleep night in random order, with at least 3 days of normal sleep between each experimental period.

2.4. Driving sessions

After the controlled sleep, subjects drove five identical 200 km (125 miles) sessions on a separated lanes motorway

(100 km (62.5 miles) one way and 100 km the other), starting at 9:00 a.m.

Each driving session lasted 105 min. The session times were: 9:00–10:45, 11:00–12:45, 13:15–15:00, 15:15–17:00 and 17:15–19:00. Driving conditions were on a straight highway, on weekdays with usually light traffic conditions, in fair weather. So, individual drivers were exposed to precisely the same conditions, or even broadly equivalent condition. Subjects were instructed to maintain a constant speed (130 kph or 80 mph) and not to cross the painted lines separating the lanes except to pass a slower vehicle. During the whole experiment, a professional driving instructor monitored the driving speed and was ready to take control of the car (equipped with dual controls) if the subject started losing control of the vehicle. If a subject was no longer able to drive during a session, he was driven back to the rest area. After completing the self-assessment of fatigue and sleepiness and a cognitive test at the next scheduled time (see below) and if the subject felt OK, he started a new driving session. The car used for the experiment was equipped with a video camera which filmed and recorded the road (Ramaekers et al., 1992).

At the end of each driving session during the test day (at 10:45, 12:45, 15:00 and 17:00), subjects had a 15 min break in order to complete testing. Before the first driving session, and during each of these breaks, subjects were asked to rate their instantaneous fatigue (“describe how fatigued you are now”) on a 100 mm visual analogue scale and their sleepiness on the Karolinska Sleepiness Scale (KSS) (Gillberg et al., 1994) and to perform a 10 min cognitive test. At the end of this 15 min break, driving was resumed. At 13:00, subjects had an additional 15 min break for a quick lunch, after the tests.

2.5. Reaction time performances

At 08:45, 10:45, 12:45, 15:00, 17:00 and 19:00, subjects were tested for reaction time (RT). Subjects performed a 10 min simple reaction time test on a PALM personal organizer. After a 1 min training period, 176 black squares were displayed on the screen at randomized (2–7 s) intervals, over 10 min. The subject’s task was to respond to the stimuli by pressing a key to turn the square off. If no response was given within 1 s, a new interval was started. Pressing the key before the square was displayed or within 100 ms, caused the response to be discarded and a warning to be displayed. The software that controls the internal clock yields data with at least 0.01 ms resolution (the keyboard is sampled at CPU frequency divided by the number of instructions needed for sampling). Another part of the program calculates the mean of the 10% slowest trials (slowest RT) during the 10 min task. This value was used as a dependent variable of our study.

2.6. Data processing and analysis

An inappropriate line crossing was counted each time the car crossed one of the lateral highway lane markers, as evidenced by video recording analysis, except during a passing maneuver or some other necessary driving action. Effectively, all deviations related to traffic interference were excluded from the counting to concentrate on line crossings related to drivers’ status. The scorer of video recordings was blind to the study condition.

The results were analyzed using negative binomial regression in Stata 8 (Stata Corporation, USA), using number of crossings per driving session per subject as dependent variable and driving session and sleep condition (group) as determinants, clustered on subjects. Driving sessions were tested compared to the first morning driving session within each sleep condition. In addition, the negative binomial regression model was repeated with instant self-rated fatigue and sleepiness as determinants to study the association between self-rated fatigue or sleepiness and line crossings during the subsequent driving session, overall and for each sleep condition.

The effect of the condition and time of testing on RT, fatigue and sleepiness were evaluated by analysis of variance for repeated measurements (ANOVA). As previously described (Philip et al., 1999, 2003) to normalize data, we transformed RT values to 1/RT to perform the ANOVAs. To correct for sphericity, all p-values derived from ANOVA were based on Huynh–Feldt’s corrected degrees of freedom.

Results are given as total number of crossings per session, per subject and overall per sleep condition. Comparisons between conditions and sessions are given as incidence rate ratios (IRR) with their 95% confidence intervals (95% CI). The associations between fatigue or sleepiness and line crossings are given as IRR per point on the respective scales. Results for fatigue and sleepiness are given as means and standard deviation.

3. Results

3.1. Actimetry

During the usual sleep night, actimetric recordings indicated an estimated mean total sleep time of 477 min (S.D. = 21 min). During the restricted sleep night, actimetric recordings indicated a mean total sleep time of 108 min (S.D. = 16 min). Sleep efficiency for the usual sleep night was 90% (S.D. = 4%) and 80% (S.D. = 16%) for the restricted sleep night (see Table 1).

3.2. Driving sessions

In the rested condition, co-pilots never interfered with driving. In the sleep-restricted condition, co-pilots interfered 61 times with the driving of our subjects. No subjects had to stop driving during the rested condition.

In the sleep-restricted condition, one subject had to be driven back to the rest area by the co-pilot because of exhaustion during the 15:00–17:00 driving session, after 63 min of driving. Another subject had to be driven back to the rest area

Table 1
Actimetric results

	Minimum	Maximum	Mean	S.D.
Rested, time in bed	472	510	490.82	15.990
Sleep-deprived, time in bed	106	140	122.09	8.059
Rested, total sleep time	436	508	476.50	21.084
Sleep-deprived, total sleep time	75	139	107.64	16.238
Rested, sleep efficiency	78.8	96.9	89.905	4.0703
Sleep-deprived, sleep efficiency	40.0	94.9	79.773	15.5570

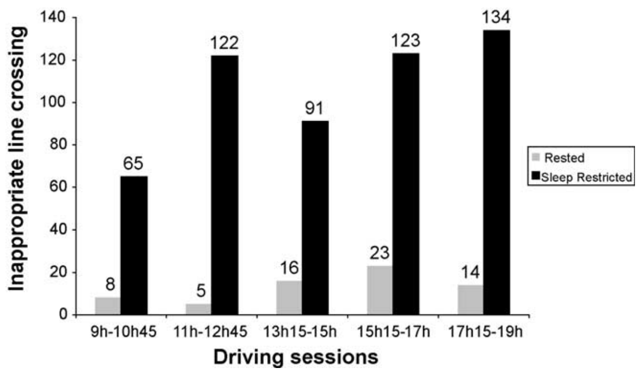

Fig. 1. Cumulative number of inappropriate line crossings per subject and driving session, in the rested (8 h sleep) and sleep-restricted (2 h sleep) conditions.

by the co-pilot because of exhaustion during the 11:00–13:00 session after 90 min of driving and during the 15:00–17:00 session after 64 min of driving. Nevertheless, both subjects finished the day of testing. There was no correction in the analysis for these incomplete driving sessions. On the other hand, four subjects did not do even one line crossing over the whole study day in the sleep-restricted condition (Fig. 1).

The video recording of driving performance showed a significant increase in inappropriate line crossings between the usual and restricted sleep conditions, with a total of 535 line crossings in the sleep-restricted condition, versus 66 after normal sleep (Fig. 1).

Overall, sleep restriction increased by 8.1 times (95% CI: 3.5–20.5) the risk of inappropriate line crossings. The relative risk of inappropriate line crossing between the normal sleep and restricted sleep conditions was increased during all driving sessions, from the very first session in the morning (Table 1).

Between sessions, compared to the first morning session, the risk of line crossing increased significantly in the fourth session (15:15–17:00) in the non-restricted condition, and in the second session (11:00–12:45) in the restricted condition (Table 2).

We found no relationship between the number of miles driven per year and the total number of inappropriate line crossings in either conditions. We also found no correlation between the driver's age, sleep duration within each condition (rested and sleep-restricted) and the number of inappropriate line crossings in either conditions.

3.3. Reaction time performances

A two-way repeated ANOVA with time of day and condition indicated a significant main effect for time of day ($F(5, 105) = 4.868$; $p < 0.01$) and condition ($F(1, 21) = 20.447$; $p < 0.001$). The interaction between the two factors also reached significance ($F(5, 105) = 3.229$; $p < 0.05$).

3.4. Self-perception of fatigue and sleepiness

Self-ratings during the breaks showed a significant increase in perception of instantaneous fatigue between rested and sleep-restricted conditions (mean ± S.D., respectively, 31.9 ± 15.5 versus 60.5 ± 18.4; $F(1, 21) = 67.791$; $p < 0.0001$). Fatigue increased over the driving sessions (Table 2) in the rested condition (fatigue score = 24.7 (S.E. = 2.4) + 2.1 (1.0) times session number from 1 to 5; $r = 0.19$; $p = 0.045$) and sleep-restricted condition (fatigue score = 49.5 (3.9) + 3.7 (1.2) times session number from 1 to 5; $r = 0.28$; $p = 0.0028$). The group by driving session interaction was not significant ($F(5, 105) = 0.896$; $p > 0.05$).

There was a correlation between VAS fatigue and KSS in rested condition (Spearman's $\rho = 0.665$; $p < 0.001$) and in sleep-restricted condition (Spearman's $\rho = 0.698$; $p < 0.001$).

There was no association between the scores of instantaneous self-rated fatigue and the subsequent number of inappropriate line crossings overall (IRR: 0.98; 95% CI: 0.96–1.001) or in the rested condition (IRR: 1.0; 95% CI: 0.98–1.02). In the restricted condition, there was a slight negative association (IRR: 0.95; 95% CI: 0.93–0.98).

Self-ratings during the breaks showed a significant increase in perception of sleepiness (KSS) between rested

Table 2
Overall and per period total number of deviations in 22 subjects driving after normal or restricted sleep

Driving session	Normal sleep, *N* [IRR (95% CI)]	Restricted sleep, *N* [IRR (95% CI)]	Normal vs. restricted sleep, IRR (95% CI)
All (mean ± S.D.)	66 (3 ± 5)	535 (24 ± 30)	8.1 (3.2–20.5)
9:00–10:45	8 [Reference]	65 [Reference]	8.1 (1.9–34.3)
11:00–12:45	5 [0.6 (0.3–1.2)]	122 [1.9 (1.3–2.8)]	24.4 (7.9–75.0)
13:15–15:00	16 [2.0 (0.7–5.6)]	91 [1.4 (0.6–3.1)]	5.7 (2.3–13.8)
15:15–17:00	23 [2.9 (1.8–4.7)]	123 [1.9 (0.8–4.7)]	5.3 (1.6–17.3)
17:15–19:00	14 [1.8 (0.7–4.1)]	134 [2.1 (0.9–4.6)]	9.6 (3.3–27.7)

IRR: incidence rate ratio (negative binomial regression, random effects model, clustered on subject).

Table 3
Mean self-rated fatigue scores (±S.D.) and mean self-rated sleepiness (KSS: Karolinska Sleepiness Scale) scores (±S.D.) for each point of measurement in the rested and sleep-restricted (SR) conditions

Condition	Time					
	8:45	10:45	12:45	15:00	17:00	19:00
KSS in rested condition	2.9 ± 1.2	2.9 ± 1.0	3.3 ± 1.6	3.3 ± 1.5	3.4 ± 1.5	3.5 ± 1.7
KSS in SR condition	4.9 ± 2.1	6.0 ± 2.0	6.1 ± 1.9	5.8 ± 2.0	6.9 ± 1.9	6.0 ± 2.6
Fatigue in rested condition	26.8 ± 14.5	29.9 ± 16.5	30.1 ± 14.4	30.8 ± 14	36.6 ± 17.2	36.0 ± 19.11
Fatigue in SR condition	51.0 ± 19.6	60.6 ± 19.9	61.4 ± 13.6	59.8 ± 19.5	69.7 ± 15.15	63.0 ± 22.1

and sleep-restricted conditions (mean ± S.D., respectively, 3.2 ± 1.1 versus 5.9 ± 1.6; $F(1, 21) = 84.449$; $p < 0.0001$). Sleepiness increased insignificantly over the driving sessions (Table 3) in the rested condition (KSS = 2.7 (S.E. = 0.3) + 0.15 (0.09) times session number from 1 to 5; $r = 0.16$; $p = 0.099$) and significantly in the sleep-restricted condition (KSS = 4.8 (0.45) + 0.37 (0.13) times session number from 1 to 5; $r = 0.25$; $p = 0.008$). The group by driving session interaction was not significant ($F(5, 105) = 1.986$; $p > 0.05$).

There was a significant association between the sleepiness as self-rated on the Karolinska Sleepiness Scale and subsequent line crossings overall (global IRR: 1.40; 95% CI: 1.18–1.66), which was related to an association in the sleep-restricted condition (IRR: 1.9; 95% CI: 1.4–2.4) but not in the rested condition (IRR: 1.0; 95% CI: 0.8–1.3).

4. Discussion

Our study shows that rested non-professional drivers can drive from 9:00 to 19:00 (625 miles) with three 15 min breaks and one 30 min break without experiencing noticeable performance decrement, during mildly demanding (fair weather, light traffic) long-distance driving. This demonstrates that fatigue generated by extensive driving has a limited impact on driving skills in normally rested drivers. This can very probably be explained by the fact that we designed our driving tests with four breaks. These breaks were used to change co-pilots, evaluate the subjects' levels of fatigue and sleepiness and test their performances. The 1 p.m. break allowed our subjects to restore themselves.

Accident studies have shown that breaks are associated with a reduction of traffic accident risk (Cummings et al., 2001).

When our subjects were sleep-restricted a clear impact on driving skills was noted, from the first driving session in the morning. Our study, therefore, highlights the fact that even for short duration of driving (1–2 h) and moderate time awake (8 h) sleep restriction can impair driving. This sleep pattern is very frequent in shift workers or on call workers like residents or house staff and driving should be as much as possible avoided after sleep restriction.

Since no overall performance decrement was observed during the rested condition we believe that sleep pressure could account for most or all of the driving alteration in our protocol. The only moderate impairment observed in the rested session occurring in the mid afternoon session (3:15 p.m.) a possible role of the circadian system could be suspected to explain this variation.

It is interesting to note that a great inter subject variability was observed between subjects (four individuals having 0 line crossings when two other had 93 and 94 line crossings). This differences could be explained by a variability in the activation of waking systems. Further research is needed to identify who will be the most or least vulnerable to sleep restriction.

Fatigue perception significantly increased with driving and extended wakefulness. This increase occurred in the sleep-restricted condition even before the first driving session, but there was no significant association of increasing fatigue with alteration of driving performance. The poor correspondence between the perception of fatigue during the breaks and driving performance could be explained by the fact that instantaneous fatigue may not be representative of prior or future fatigue due to masking by the stimuli involved in driving on the road and interacting with others. A closer relation may possibly have been obtained if ratings had been done during driving.

Sleepiness also increased across the day after sleep deprivation. A previous study (Reyner and Horne, 1998) performed in a driving simulator showed that when subjects were regularly questioned about their sleepiness during the drive, there was a relationship between instantaneous level of sleepiness and driving impairment. These results match very well with previous experiments showing a link between subjective sleepiness and performance decrement (Dinges et al., 1997).

In our study, the goal of our measurements was to evaluate if a self-perception during a break was reasonably related to future driving skills.

As shown in previous studies, driving performance is correlated to self-perceived sleepiness during the breaks but self-assessment of fatigue is not an accurate predictor of subsequent driving performances. We found this same discordance between fatigue assessment and reaction time in similar circumstances (Philip et al., 2003).

Our findings show that duration of driving is not the main factor to explain driving impairment and that time awake and previous sleep duration have a much bigger impact. Professional regulations and work schedules should integrate sleep schedules before and during the work period as an essential dimension for safe driving.

In addition to recommending that drivers stop driving when they are sleepy, and not only fatigued, road safety campaigns should encourage drivers to respect their sleep needs and avoid sleep restriction before driving even for commuting distances.

Acknowledgements

This research was supported by a special grant from Matmut®, Norauto® and Direction Générale des Armées. Special thanks to Autoroutes du Sud de la France for allowing us to use their motorway for our research, to the French Sleep Research Society and its past president Patrick Levy, and to the ministry of transportation (DISR) for promoting this research, to Olivia Danet and Cédric Valtat for collecting data, to Abdelilah Abouelfath for his help in the statistical analysis.

References

Arnold, P.K., Hartley, L.R., Corry, A., Hochstadt, D., Penna, F., Feyer, A.M., 1997. Hours of work, and perceptions of fatigue among truck drivers. Accid. Anal. Prev. 29 (4), 471–477.

Carskadon, M.A., Dement, W.C., 1979. Effects of total sleep loss on sleep tendency. Percept. Mot. Skills 48 (2), 495–506.

Carskadon, M.A., Dement, W.C., 1981. Cumulative effects of sleep restriction on daytime sleepiness. Psychophysiology 18 (2), 107–113.

Connor, J., Norton, R., Ameratunga, S., et al., 2002. Driver sleepiness and risk of serious injury to car occupants: population based case control study. Br. Med. J. 324 (7346), 1125.

Cummings, P., Koepsell, T.D., Moffat, J.M., Rivara, F.P., 2001. Drowsiness, counter-measures to drowsiness, and the risk of a motor vehicle crash. Inj. Prev. 7 (3), 194–199.

Delafosse, J.Y., Leger, D., Quera-Salva, M.A., Samson, O., Adrien, J., 2000. Comparative study of actigraphy and ambulatory polysomnography in the assessment of adaptation to night shift work in nurses. Rev. Neurol. (Paris) 156 (6–7), 641–645.

Dement, W.C., Carskadon, M.A., 1982. Current perspectives on daytime sleepiness: the issues. Sleep 5 (Suppl. 2), S56–S66.

Dinges, D.F., Pack, F., Williams, K., et al., 1997. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 h per night. Sleep 20 (4), 267.

Froberg, J.E., 1977. Twenty-four-hour patterns in human performance, subjective and physiological variables and differences between morning and evening active subjects. Biol. Psychol. 5 (2), 119–134.

Gaba, D.M., Howard, S.K., 2002. Fatigue among clinicians and the safety of patients. N. Engl. J. Med. 347 (16), 1249–1255.

Gillberg, M., Kecklund, G., Akerstedt, T., 1994. Relations between performance and subjective ratings of sleepiness during a night awake. Sleep 17 (3), 236–241.

Grandjean, E., 1979. Fatigue in industry. Br. J. Ind. Med. 36 (3), 175–186.

Harrison, J.E., Mandryk, J.A., Frommer, M.S., 1993. Work-related road fatalities in Australia, 1982–1984. Accid. Anal. Prev. 25 (4), 443–451.

Horne, J.A., Reyner, L.A., 1995. Sleep related vehicle accidents. Br. Med. J. 310 (6979), 565–567.

Kushida, C.A., Chang, A., Gadkary, C., Guilleminault, C., Carrillo, O., Dement, W.C., 2001. Comparison of actigraphic, polysomnographic and subjective assessment of sleep parameters in sleep-disordered patients. Sleep Med. 2, 389–396.

Lal, S.K., Craig, A., 2001. A critical review of the psychophysiology of driver fatigue. Biol. Psychol. 55 (3), 173–194.

Lamberg, L., 2002. Long hours, little sleep: bad medicine for physicians-in-training? J. Am. Med. Assoc. 287 (3), 303–306.

Lavie, P., 1986. Ultrashort sleep-waking schedule. III. ‘Gates’ and ‘forbidden zones’ for sleep. Electroencephalogr. Clin. Neurophysiol. 63 (5), 414–425.

Marcus, C.L., Loughlin, G.M., 1996. Effect of sleep deprivation on driving safety in housestaff. Sleep 19 (10), 763–766.

Mitler, M.M., Miller, J.C., Lipsitz, J.J., Walsh, J.K., Wylie, C.D., 1997. The sleep of long-haul truck drivers. N. Engl. J. Med. 337 (11), 755–761.

O’Hanlon, J.F., Volkerts, E.R., 1986. Hypnotics and actual driving performance. Acta Psychiatr. Scand. Suppl. 332, 95–104.

O’Hanlon, J.F., Vermeeren, A., Uiterwijk, M.M., van Veggel, L.M., Swijgman, H.F., 1995. Anxiolytics’ effects on the actual driving performance of patients and healthy volunteers in a standardized test. An integration of three studies. Neuropsychobiology 31 (2), 81–88.

Personick, M., Mushinski, M., 1997. Highway fatalities: leading cause of work-related deaths. Stat. Bull. Metrop. Insur. Co. 78 (2), 19–25.

Philip, P., Ghorayeb, I., Stoohs, R., et al., 1996. Determinants of sleepiness in automobile drivers. J. Psychosom. Res. 41 (3), 279–288.

Philip, P., Taillard, J., Guilleminault, C., Quera Salva, M.A., Bioulac, B., Ohayon, M., 1999. Long distance driving and self-induced sleep deprivation among automobile drivers. Sleep 22 (4), 475–480.

Philip, P., Vervialle, F., Le Breton, P., Taillard, J., Horne, J.A., 2001. Fatigue, alcohol, and serious road crashes in France: factorial study of national data. Br. Med. J. 322 (7290), 829–830.

Philip, P., Sagaspe, P., Taillard, J., et al., 2003. Fatigue, sleep restriction, and performance in automobile drivers: a controlled study in a natural environment. Sleep 26 (3), 277–280.

Powell, N.B., Schechtman, K.B., Riley, R.W., Li, K., Troell, R., Guilleminault, C., 2001. The road to danger: the comparative risks of driving while sleepy. Laryngoscope 111 (5), 887–893.

Rajaratnam, S.M., Arendt, J., 2001. Health in a 24-h society. Lancet 358 (9286), 999–1005.

Ramaekers, J.G., O’Hanlon, J.F., 1994. Acrivastine, terfenadine and diphenhydramine effects on driving performance as a function of dose and time after dosing. Eur. J. Clin. Pharmacol. 47 (3), 261–266.

Ramaekers, J.G., Uiterwijk, M.M., O’Hanlon, J.F., 1992. Effects of loratadine and cetirizine on actual driving and psychometric test performance, and EEG during driving. Eur. J. Clin. Pharmacol. 42 (4), 363–369.

Reyner, L.A., Horne, J.A., 1998. Falling asleep whilst driving: are drivers aware of prior sleepiness? Int. J. Legal Med. 111 (3), 120–123.

Steele, M.T., Ma, O.J., Watson, W.A., Thomas Jr., H.A., Muelleman, R.L., 1999. The occupational risk of motor vehicle collisions for emergency medicine residents. Acad. Emerg. Med. 6 (10), 1050–1053.

Veasey, S., Rosen, R., Barzansky, B., Rosen, I., Owens, J., 2002. Sleep loss and fatigue in residency training: a reappraisal. J. Am. Med. Assoc. 288 (9), 1116–1124.