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Fatigue, sleep restriction and driving performance

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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

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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