Fatigue, Sleep Restriction, and Performance in Automobile Drivers: A Controlled Study in a Natural Environment

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Objectives: To test the neurobehavioral consequences of sleep restriction combined with fatigue from long-distance driving (1000 Km/600 miles).

Design: Counterbalanced study involving 3 experimental conditions: laboratory after controlled habitual sleep (8.5 hours), driving after controlled habitual sleep (8.5 hours) (Road 1), and driving after reduced sleep (2 hours) (Road 2).

Setting: Sleep laboratory and open French highway.

Participants: 10 male participants (mean age 22 years, range 18-24 years, mean driving distance per year 15000 Km/9000 miles) free of sleep disorders.

Measurements: Simple reaction time, prospective self-assessment of performance, and instantaneous fatigue and sleepiness ratings measured at 2-hour intervals.

Results: A two-way repeated ANOVA with time of day and condition indicated a significant main effect for time of day (p<0.05). The interaction between the two factors (condition * time of day) was also significant (p<0.05). The effects of time of day were significant only in the condition of driving after sleep restriction, (p<0.05). Under sleep restriction, some drivers presented an increase of 650 milliseconds compared to the laboratory condition, representing an increase of 23 meters in breaking distance at a speed of 75 miles per hour. Correlation analyses showed a significant linear correlation between self-assessment and reaction time in the laboratory condition (r = -0.58, p<0.01) but not in the road conditions. Self-ratings during the breaks showed a significant increase in instantaneous self-rated fatigue and sleepiness between Road 1 and Road 2 conditions (Wilcoxon’s test, Z = -6.47, p < 0.0001 and Z = -6.26, p < 0.0001).

Conclusions: Sleep restriction combined with fatigue significantly affects reaction time. The lack of correspondence between reaction time and prospective self-evaluation of performance suggests that self-monitoring in real conditions is poorly reliable.

Key Words: driving, sleep restriction, simple reaction time, sleepiness scale, young adult, fatigue.


INTRODUCTION

ALTHOUGH FATIGUE AND SLEEPINESS1-2 AT THE WHEEL ARE MAJOR RISK FACTORS FOR TRAFFIC ACCIDENTS, many drivers combine sleep deprivation and extensive driving 3,4 for economic 5 or socio-cultural reasons.6 In fact, sleep restriction is now a well-identified factor for traffic accidents.7 Due to the high frequency of conflicts between physiologic needs and social or professional activities,8 understanding the human effects of fatigue and sleep deprivation are becoming key issues in accident prevention.

Fatigue is defined by a gradual and cumulative process associated with a disinclination toward effort, eventually resulting in reduced performance efficiency.9 It has been described in driving episodes that require sustained attention for long periods of time.10 Philip et al,11 for example, showed in a study on automobile drivers an increase of 3.4 milliseconds on a reaction time (RT) test per additional hour of driving. Sleepiness is defined by difficulty in remaining awake even while carrying out activity.12 This symptom is related to circadian and homeostatic influences. During the daytime, human rhythms cause a drop in alertness in the mid-afternoon and a period of high alertness toward the end of the afternoon.13 Extended wakefulness or sleep restriction increases sleep pressure and generates cumulative sleepiness,14,15 which is known to impair neurobehavioral functioning.16,17 Dawson et al showed that every extra hour of wake would decrease the mean relative performance on a tracking task by 0.74%.18 Nevertheless, until now, no controlled trials have looked at the combined effects of fatigue (generated by extensive driving) and sleep deprivation on RT.

Of the many tests for cognitive functioning, RT testing is a highly sensitive measure of sustained attention, which is a fundamental prerequisite for safe driving.18 Several epidemiologic studies have shown that impaired RT is associated with traffic accidents.19-23 Since RT is sensitive to sleep loss and fatigue,15,16,22 we chose this function as a measure of the neurobehavioral consequences of sleep restriction combined with daytime long-distance driving. We also considered the subjects’ self-perception of their performance, fatigue, and sleepiness in 3 test conditions: in the laboratory and during driving breaks on the road after 8.5 hours of nocturnal sleep and after 2 hours of sleep.

METHODS

Subjects

Ten healthy male subjects (mean age 22 years; range 18-24 years, mean driving distance per year 15000 Km) were recruited. All the subjects provided written informed consent, approved by the local ethics committee.

Inclusion Criteria

Subjects underwent a clinical evaluation, an interview with a sleep specialist, and 1 nocturnal polysomnogram to eliminate subjects with sleep disorders. We used actimetry recordings to quantify the sleep duration and to eliminate any subjects with sleep-wake schedule disor-
bers. Each individual had 7 days of actimetry prior to inclusion. The selected participants were instructed to maintain a regular sleep-wake schedule (controlled by actimetry) for 3 days before the study periods. No stimulant use of any kind was allowed during study.

Protocol

Subjects were tested in 3 different conditions: in the laboratory after controlled usual sleep (8.5 hours), in a driving condition after controlled usual sleep (8.5 hours) (Road 1), and in a driving condition after reduced sleep (2 hours) (Road 2). Half of the subjects started the experiment with the laboratory condition, and the other half started with the driving conditions. A minimum of 3 days was allowed between each testing day in order to let the subjects rest.

For the tests in rested conditions (laboratory and Road 1), subjects were monitored in the laboratory from 2100 to 0830 and were in bed from 2300 to 0730. For the tests in the sleep-restricted conditions (Road 2), subjects were monitored in the laboratory from 2100 to 0830 and were in bed from 2300 to 0100. Sleep duration was monitored by actimetry during the 3 conditions (Actiwatch and Actiwatch sleep analysis software, Cambridge Neurotechnology).

Once awake, in the laboratory condition, subjects were tested every 2 hours (0900, 1100, 1300, 1500, 1700, 2100). Subjects were asked, “How well do you think you are going to perform on the RT test?” They rated their subjective assessment on a visual-analogue scale (VAS) from “excellent” to “very poor.” Then they performed a 10-minute simple RT test on a Palm™ personal organizer.11,24 After a 1-minute training period, 176 black squares were displayed on the screen at randomized (2-7 s) intervals, over 10 minutes. 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 second, a new interval was started. Pressing the key before the square was displayed, or within 100 milliseconds, caused the response to be discarded and a warning to be displayed. The software that controls this protocol includes a 1/RT program that calculates the mean of the 10% slowest trials (RT) during the 10-minute task. This value was used as the dependent variable of our study.

In order to minimize the differences between the laboratory and freeway testing conditions, subjects performed RT tests in 2 rooms (1 in the laboratory and 1 in a rest stop building of the freeway company) of equal size, same level of light, and same level of noise.

For the road conditions (Road 1 and Road 2), subjects drove five 200-kilometer (120 miles) segments on a 2-lane highway, starting at 0900. They were instructed to maintain a constant speed (130 Km/h-75 miles/h). During the whole experiment a copilot was ready to take control of the car if the subject fell asleep. Every 105 minutes (at 0900, 1045, 1245, 1500, 1700, 1900) subjects were asked to stop for a 15-minute break for performance testing. In addition to the tests used in the laboratory condition (RT test and self-assessment of performance), subjects were asked to rate their instantaneous fatigue (“describe how fatigued you are now”) on a VAS and sleepiness on the Karolinska Sleepiness Scale (KSS).24 At 1245 subjects had a 15-minute lunch break after the test. Standardized meals were provided in all conditions.

Statistical Analysis

The effect of the condition (Laboratory, Road 1, and Road 2) and time of testing on RT were evaluated by analysis of variance for repeated measurements (ANOVA). As previously described,11 we transformed RT values to 1/RT to perform the ANOVAs to normalize data. To correct for sphericity, all p values derived from ANOVA were based on Huynh-Feldt corrected degrees of freedom. Posthoc LSD tests for repeated measurements were performed to compare pairs of RT means. Correlation between self-assessment of performance and RT was calculated using the Pearson correlation coefficient.

Since the data regarding fatigue and sleepiness were non-normally distributed, they were analyzed non-parametrically.25 The Friedman non-parametric “analysis of variance” for repeated measures was used to test variation across time for each condition separately. Wilcoxon matched-pairs signed-ranks test was used to identify if these variables differed between the 2 conditions (Road 1 vs. Road 2). This was done at each separate point in time.

RESULTS

During the full sleep nights, actimetric recordings indicated a mean total sleep time of 495 ± 14 minutes in the laboratory condition and 493 ± 17 minutes in the Road 1 condition. In the Road 2 condition, actimetric recordings indicated a mean total sleep time of 112 ± 12 minutes.

For RT, a two-way repeated ANOVA with time of day and condition indicated a significant main effect for time of day (F=2.66, p<0.05) but not for condition. The interaction between the two factors (condition and time of day) was also significant (F=2.44, p<0.05).

One-way repeated ANOVAs, with the time of day separated for each experimental condition, revealed that the effects of time of day were significant only in the condition of driving after sleep restriction (F=2.90, p<0.05) (Table 1). Posthoc tests for repeated measurements showed that RT was significantly slower at 1700 than at 1100. (p<0.05) (Figure 1). The difference in the 10% slowest RTs between the 2 conditions could reach 650 milliseconds.

In the rested condition, the experimenter never had to take control of the car. In the sleep-restricted condition, 7 subjects out of 10 had to be assisted by the experimenter during their driving (Wilcoxon test, Z = -2.53, p < 0.0001).

Correlation analysis showed a significant linear correlation between self-assessment and RT in the laboratory condition (r= -0.58, p<0.01) but not in either of the 2 road conditions. (Figure 2).

Table 1—Median KSS and fatigue VAS scores (minimum/maximum values)

<table>
<thead>
<tr>
<th>Condition</th>
<th>0900</th>
<th>1100</th>
<th>1300</th>
<th>1500</th>
<th>1700</th>
<th>1900</th>
<th>1/RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSS in Road 1</td>
<td>2.5 (1/4)</td>
<td>3.0 (1/5)</td>
<td>3.0 (1/7)</td>
<td>3.0 (1/7)</td>
<td>3.0 (1/6)</td>
<td>2.0 (1/5)</td>
<td>p = 0.05</td>
</tr>
<tr>
<td>KSS in Road 2</td>
<td>3.5 (1/8)</td>
<td>5.0 (3/9)</td>
<td>5.0 (3/9)</td>
<td>6.5 (3/8)</td>
<td>7.5 (5/9)</td>
<td>5.0 (1/9)</td>
<td>p = 0.01</td>
</tr>
<tr>
<td>Fatigue in Road 1</td>
<td>20.6 (5/4)</td>
<td>20.7 (5/5)</td>
<td>20.5 (11/49)</td>
<td>19.5 (7/54)</td>
<td>33.5 (8/59)</td>
<td>18.5 (6/59)</td>
<td>p = 0.01</td>
</tr>
<tr>
<td>Fatigue in Road 2</td>
<td>40.5 (15/80)</td>
<td>58.5 (22/98)</td>
<td>62.5 (36/81)</td>
<td>67.5 (20/82)</td>
<td>68.5 (43/100)</td>
<td>66.0 (25/100)</td>
<td>p = 0.02</td>
</tr>
</tbody>
</table>

KSS, Karolinska Sleepiness Scale; VAS, visual-analog scale.
Instantaneous self-rated fatigue (as measured during the breaks) and sleepiness (KSS) increased significantly between Road 1 and Road 2 conditions (median ± standard error, respectively) 20 ± 2.1 versus 62 ± 2.7 (Wilcoxon test, Z = -6.47, p ≤ 0.0001) and 3 ± 0.19 versus 5 ± 0.27 (Wilcoxon test, Z = -6.26, p ≤ 0.0001), showing a similar temporal trend to the RT. The difference was significant at all times of measurement (Table 1).

There was no significant variation across time of instantaneous self-rated fatigue (as measured during the breaks) or of sleepiness during the 9-hour drive in the Road 1 condition (Friedman test, chi square = 7.02 and chi square = 8.3, p = NS). In the Road 2 condition, however, instantaneous self-rated fatigue (Friedman test, chi square = 18.34, p ≤ 0.01) and sleepiness (Friedman test, chi square = 10.8, p = 0.05) increased during the drive.

DISCUSSION

Fatigue and extensive duration of driving are identified causes of accidents. We chose to use the RT as the dependant variable because previous studies showed a good sensitivity of this test to extensive duration of driving and sleep deprivation.

We found that 9 hours of extensive driving after a full night of sleep did not significantly affect RT performance in the laboratory condition. This result could be explained by the presence of 15-minute driving breaks every 1 hour and 45 minutes, which may have reduced the extent of fatigue. Another possible explanation is that 9 hours of driving in one 24-hour period is tolerable for a nonprofessional driver. European driving regulations recommend less than 10 hours of driving in a 24-hour period and less than 4.5 hours of nonstop driving, and our study confirms that when drivers are not sleep deprived, performance is not affected by that duration of driving.

In contrast, our study shows a time-dependent effect on the RT of fatigue combined with sleep restriction. On the road, some of our sleep-restricted subjects increased their RT by 650 milliseconds, compared to the laboratory testing. Driving at 75 miles per hour (French speed limit on the highway), this represents an increase for stopping a car of 23 meters.

Changes in RT across time were significant only in the condition of driving after sleep restriction. As shown in Figure 1, the RT worsens as a function of hours of driving, with a different time-of-day effect between the 2 conditions. This could be explained by the additive effect of fatigue to sleepiness. A slight upward nonsignificant trend is observed at 1900, which could be attributed to the “end-spurt effect” reported in other studies. Subjects were aware that they were at the end of the experimental condition, which might have increased their motivation to quickly finish the test.

It is interesting to note that the subjects’ self-assessment of performance accurately predicted results in the RT test in the laboratory condition. This is globally true for our group, but the scatter plot shows some outliers in this condition. On the road, such correlation is absent, although subjects clearly report fatigue and sleepiness during the sleep-restricted condition (Road 2). The absence of correlation suggests that sleep restriction and fatigue can impair performance awareness, as it has been shown for alcohol. It is possible that the freeway’s environment may have enhanced the motivation of the subjects and helped them to fight against fatigue, while at the same time altering the self-perception of their performances.

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