Effect of fatigue on performance measured by a driving simulator in automobile drivers

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Abstract

Objective: To identify risk factors of performance decrement in automobile drivers. Methods: 114 drivers (age < 30 years, n = 57; age ≥ 30 years, n = 57) who stopped at a rest stop area on a freeway were recruited for the study. They filled out a questionnaire on their journey, sleep/wake patterns and performed a 30-min test on a driving simulator. The test evaluates, by computerized analysis, the lateral deviation of a virtual car from an appropriate trajectory on a virtual road. A sex/age matched control group was recruited in the community. Control subjects were studied at the same time of day as the index case driver. Controls had normal sleep wake schedule, absence of long driving and performed the same driving test. Results: Drivers performed significantly worse than controls on the driving test. Age and duration of driving were the main factors associated with decreased performance. Conclusion: Our driving simulator can identify fatigue generated by driving but results must be considered in relation with age of subjects.

Keywords: Age; Automobile drivers; Driving duration; Driving simulator

Introduction

Automobile accidents are one of the major causes of death in modern society and fatigue is identified as one major risk factor [1–13]. There is anecdotal evidence that “voluntary” sleep curtailment before long drives may be another hazard. This issue has not yet been studied, and a research program was therefore initiated to investigate the occurrence of sleepiness in relation to the duration of sleep and driving as well as other variables. The program uses an approach in which drivers turning into a rest stop on a motorway are asked to participate in experimental testing. The motorway is the European E4, which links Sweden to Portugal, via France, and which, in certain regions, involves a high level of suspected sleep-related accidents and long driving distances. We have already shown that driver-curtailed total sleep time prior to departure for summer vacation [14,15]. In a second study, we used simple reaction time tests to measure drivers’ performances. We found a strong relationship between duration of driving and fatigue, especially in young drivers [16]. Nevertheless, our last study used a simple reaction time test and did not include a control group to evaluate the effects of driving fatigue. We therefore initiated a new controlled study using a driving simulator to test the response of automobile drivers involved in long-distance journeys.

Method

The study was conducted from 8:00 a.m. until 8:00 p.m., during three-peak vacation week ends in the summer. As soon as a car stopped in a rest area located on the E4 Freeway, drivers were asked if they were involved in a long-
distance journey and, if so, if they would participate in a research protocol. All subjects giving informed consent were included in the study. They completed questionnaires and performed a test on a driving simulator located near the rest stop.

The questionnaires included the Basic Nordic Sleep Questionnaire [17], which explores habitual total sleep time, sleep latency, sleep quality and sleepiness, and the Epworth Sleepiness Scale [18], which quantifies behavioral sleepiness and logs of sleep/wake behavior during the year, just prior to departure and during the journey. A measure of sleep debt was derived by subtracting the habitual 24-h total sleep time during the year from the total sleep time in the 24 h before the interview. A second questionnaire explored the duration of driving, the number and duration of stops and the number of changes of drivers during the journey.

A sex/age matched control group was recruited in the community. Control subjects were studied at the same time of day as the index case driver. Control subjects were screened using the Basic Nordic Sleep Questionnaire to exclude from sleep disorders (maximum score on each item = 2 on 0–5 scale). Other medical disorders and treatment interfering with daytime vigilance and cognitive performances were screened to exclude volunteers, which could bias the results. They were also instructed to keep regular sleep hygiene for 3 days before testing (monitored by sleep logs) and to avoid driving and caffeinated beverages in the 24 h before testing. All control group drivers had to drive a minimum of 10,000 km/year and have at least 2 years of driving experience.

Driving simulator

We used the Divided Attention Steering Simulator (DASS; Stowood Scientific Instruments) based on a tracking task and visual detection of digits located at the four points near the sides of a computer screen (see Fig. 1). The software reproduces a winding road shown as lines on the screen, and the objective is that the driver must keep the front of the car central between the two sides of the road. To steer, subjects use a computer game steering wheel modified to full size (Grandprix 1, Thrustmaster) fixed to a table. The steering wheel is equipped with buttons on both right and left sides.

The computer program records 10 times per second the lateral deviation of the virtual car from the centre of the virtual road. If the driver is unable to maintain the car between the lines on the road for a period of longer than 15 s, the test stops automatically.

In addition to the tracking test, subjects are asked to monitor four digits located at the sides of the computer screen. These digits change every 8–10 s in a pseudorandom order and the subject must click on the appropriate (left or right) button every time he sees the number “2” appear on that side of the screen.

The software calculates the mean deviation from the centre of the road and the standard deviation of this difference. This standard deviation from the centre of the road (SDS) is one of the studied variables. The standard deviation of the car steering error from the ideal curve (SDC) is another measure, which represents the ability of the driver to follow perfectly the curve with the car.

The time taken to identify and respond to the digits, i.e., “reaction time,” is measured from the presentation of the digit to the screen display driver to the signal being received from the button. The slope of this ‘reaction time’ during the test is also calculated. If the subjects maintain a similar time to respond to the digits during the whole duration of the test, the slope of the reaction time equals zero. If the performance get worse during the test, the slope becomes positive. As previously defined [19], in order to reduce any learning effect, each subject first performed two 5-min training sessions. After training, subjects had to complete a 30-min test during which there were 39 appearances of the number “2.”

Statistical analysis

The demographic information between experimental and control groups was analyzed using nonparametric tests (Mann–Whitney test). Spearman correlations were then performed to investigate relationships between test results, sex, age and driving and sleeping behaviours among the experimental group. The steering error from the ideal curve on the driving simulator and its relation to the above other factors was then studied through a stepwise logistic regression analysis.

Results

Population of drivers

Seventy percent of the drivers approached agreed to participate in the study. There were 114 participants (100 men) with mean age 32 ± 10 years (min 17 and max 56 years, \( n = 57 < 30 \) years and \( n = 57 > 30 \) years of age).
The mean annual duration of driving of the drivers was 28,000 ± 22,000 km, 14 subjects driving more than 50,000 km/year. Eleven subjects were usually under medical treatment. Four subjects were taking antihistaminic drugs, one subject was taking an antidiabetic drug, five subjects were taking antihypertensive drugs and one subject was taking an antidepressive drug.

The mean Epworth Sleepiness Score of the drivers was 6 ± 3 (0–16), 67 subjects (58.8%) reported no daytime somnolence during the present trip. Eighteen subjects (15.8%) had to stop during the trip because of a severe daytime somnolence. During the trip, drivers drank a mean of 2.3 ± 2 cups of coffee.

There was no statistical difference (Mann–Whitney, \( P=\text{NS} \)) in terms of chronic daytime somnolence (ESS scores) or sleepiness at the wheel during the trip between drivers taking or not taking medication.

Control group

There were 114 control subjects (100 men) with mean age 32 ± 10 years (min 17 and max 56 years, \( n=57 < 30 \) years and \( n=57 > 30 \) years of age). The mean annual duration of driving of the controls was 20,000 ± 14,000 km, seven subjects driving more than 50,000 km/year.

The mean Epworth Sleepiness Score of the drivers was 5 ± 2 (0–10).

Driving distances and driving time

The mean distance driven before subjects reached the study site was 631 ± 229 km. The average amount of time spent driving since departure was 352 ± 158 min and the mean estimated total duration of rest period since departure was 182 ± 245 min.

Sleep prior to departure versus reported “regular” sleep

From the subjects’ logs, we compared the total sleep time in the 24 h before the interview with the reported “usual” sleep/wake schedule during the year. 76.3% of all subjects experienced a reduction in their total sleep time in the 24 h before the interview. Sleep restriction was significantly correlated with duration of driving (Spearman test, \( \rho=.22, P<.019 \)).

Table 1 presents sleep data in experimental and control groups.

Driving simulator

Out of a population of 114 drivers, 99 subjects (86.8%) performed the 30-min test. Four subjects (3.5%) stopped performing after 10 min of testing. Out of a population of 114 controls, 106 subjects (93%) performed the 30-min test. Two subjects (1.8%) stopped performing after 10 min of testing.

Drivers performed significantly worse than controls on the driving simulator. The main factor affected was the standard deviation steering error from the ideal curve (see Table 1). There was no significant difference between the two groups in steering error from the centre (see Table 1) or in the time necessary to identify the selected digit (a measure of reaction time).

We then looked at the drivers group and investigated factors that might influence the steering error from the ideal curve. We tested the following variables — age, sex, duration of sleep in the 24 h before the interview, duration of driving in the 24 h before the interview and usual yearly kilometers driven — against steering errors using the Spearman rank correlation test.

Only age and duration of driving before the interview were correlated to steering error from the ideal curve: The longer the duration of the driving before the interview, the larger the SDC (Spearman test, \( \rho=.23, P<.008 \)), and the younger drivers, the smaller the SDC (Spearman test, \( \rho=.23, P<.011 \)).

We then subdivided SDC results. We grouped subjects based on the SDC, using the median data and taking as cutpoint the 75th percentile, with a group formed by subjects in the 25th higher percentile against the rest. We performed a logistic regression, with age and duration of driving before the interview, as independent variables. Only duration of driving remained in the model (\( \rho=.13, P<.05 \)).

Discussion

As we already reported [14], many of our vacation drivers had driven for long times with acute sleep loss. The differences observed between drivers and matched controls confirm that fatigue affects long-distance drivers. The amount of driving performed before testing was the major predictor of SDC. These findings suggest that steering error on a driving simulator could be used to measure fatigue. The fact that drivers have a harder time than controls to maintain a perfect angle in curves could be explained by the fact that this procedure requires good coordination, which is affected by fatigue. Reaction time, measured with our divided attention task, did not discriminate subjects, but we cannot completely eliminate the role
of instruction given to the subjects in this negative result, which was primarily to maintain the car central on the road. Therefore, subjects may have prioritized the driving task before the attention task.

The fact that the duration of the drive before testing was the major predictor of SDC, was intuitively expected, although not much data is available, except for the accident studies reported by Hamelin [5] and Harris [2]. These studies, however, did not control for other factors.

The negative effect of age was also expected from previous studies [20]. Indeed, our present results replicate previous findings.

The fact that neither sleep debt nor any of the variables related to sleep duration entered the regression confirms findings obtained using reaction time tests [16]. There again, duration of driving was the major determinant for performance decrement. Finally, long duration of driving was associated with sleep restriction and cumulative factors may play a role in masking the effects of sleep deprivation, as this factor was almost never observed “alone” in our drivers.

References