Accident Analysis and Prevention 50 (2013) 44–50

Contents lists available at SciVerse ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Sleepy driving on the real road and in the simulator—A comparison

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ARTICLE INFO

Article history:
Received 14 March 2011
Received in revised form 28 August 2012
Accepted 27 September 2012

Keywords:
EEG
EOG
KSS
Driving performance
Lateral deviation
Speed
Lateral position
Night
Shift work

ABSTRACT

Sleepiness has been identified as one of the most important factors contributing to road crashes. However, almost all work on the detailed changes in behavior and physiology leading up to sleep related crashes has been carried out in driving simulators. It is not clear, however, to what extent simulator results can be generalized to real driving. This study compared real driving with driving in a high fidelity, moving base, driving simulator with respect to driving performance, sleep related physiology (using electroencephalography and electrooculography) and subjective sleepiness during night and day driving for 10 participants. The real road was emulated in the simulator. The results show that the simulator was associated with higher levels of subjective and physiological sleepiness than real driving. However, both for real and simulated driving, the *response* to night driving appears to be rather similar for subjective sleepiness and sleep physiology. Lateral variability was more responsive to night driving in the simulator, while real driving at night involved a movement to the left in the lane and a reduction of speed, both of which effects were absent in the simulator. It was concluded that the relative validity of simulators is acceptable for many variables, but that in absolute terms simulators cause higher sleepiness levels than real driving. Thus, generalizations from simulators to real driving must be made with great caution.

1. Introduction

The National Transportation Safety Board (US) has identified driver sleepiness as one of the most important factors contributing to road crashes (Ntsb, 1999). The risk of road crashes due to sleepiness is higher at night (Horne and Reyner, 1995; Åkerstedt et al., 2001; Connor et al., 2002), after reduced prior sleep (Connor et al., 2002), and with increased duration of driving (Hamelin, 1987). The effects of the latter, however, are confounded with other factors like time of day, time awake, and prior sleep, which often covary with the duration of driving. These observations of a temporal pattern of crashes fit well with studies showing time of day, sleep duration, and time awake as major determinants of sleepiness (Dijk and Czeisler, 1995; Jewett et al., 1999).

Studies of sleepiness indicators during driving have shown sleep intrusions in the waking EEG or EOG during driving in relation to mainly night driving or sleep loss (Kecklund and Åkerstedt, 1993; Mitler et al., 1997), as well as subjective sleepiness (Kecklund and Åkerstedt, 1993). However, most research concerning the physiological and behavioral aspects of sleepy driving has been carried out using driving simulators instead of real driving on public roads. A main reason is that one may study driving conditions which would be unethical on a real road. Control and general safety issues are also important. The results show essentially that prior sleep loss or night driving is associated with increased EEG alpha and theta activity (O'hanlon and Kelly, 1974; Horne and Reyner, 1996; Otmani et al., 2005; Anund et al., 2008b), increased eye blink duration (Wierwille and Ellsworth, 1994; Akerstedt et al., 2005), and increased subjective sleepiness (Reyner and Horne, 1998; Akerstedt et al., 2005). Among the behavioral indicators of driver sleepiness lateral variability (the standard deviation of lateral position – SDlat) of the vehicle is increased by sleep loss/night driving (Contardi et al., 2004; Akerstedt et al., 2005; Otmani et al., 2005; Anund et al., 2008a, b) as is lane crossings (Reyner and Horne, 1998; Ingre et al., 2006; Anund et al., 2008c), and driving off the road (Reyner and Horne, 1998; Anund et al., 2008b). Speed, or speed variability (from the posted limit), has been shown to have some relation with sleep loss (Fairclough and Graham, 1999; Arnedt et al., 2000, 2001; Campagne et al., 2005).

While the simulator results usually are quite clear cut in terms of effects of sleep loss on sleepiness indicators, it is not clear to

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http://dx.doi.org/10.1016/j.aap.2012.09.033

what extent generalizations to real driving are justified. With the exception of the study performed by Philip et al. (2005) in which a rather simple, table-top simulator, was compared (without physiological indicators) to real driving, there seems to be no validation studies that involve sleepy driving. The study by Philip et al. (2005) could not compare the simulated and real driving in absolute terms, but noted that subjective sleepiness and line crossings responded to sleep loss in a similar way, that is, there was a relative validity (validity in behavioral response). Other types of validations have been carried out, for example, by Tornros (1998), who found that driving in a tunnel was associated with a lateral position further to the left in the lane in real tunnel driving and the speed was lower than in the (moving base) simulator. Thus, absolute validity of the simulator was not optimal. In another study (Godley et al., 2002), the avoidance response to a rumble strip was similar in simulated and real driving, indicating a relative validity of the simulator, but speed was higher during real driving, indicating less absolute validity of the simulator. In a study on left and right turns, Shechtman et al. (2009) found both relative and absolute validity to be high for a table-top simulator.

A validation study of driver sleepiness during real road driving compared to simulated driving would require a comparison of different levels of sleepiness, using the road characteristics of a real road in the simulator and running the same subjects under simulated and real driving conditions. Such a comparison was made possible in the present study through the use of two studies of real (Sandberg et al., 2011a) and simulated (Akerstedt et al., 2010) driving with similar day/night drive designs, with the same participants and with the real road being implemented in a high fidelity, moving base, simulator scenario. The purpose of the present study was to compare real driving with simulated driving under conditions of extended time awake (day versus night time driving), using some key indicators of sleepy driving. The latter included EEG measures, subjective ratings, eye blink duration, SDlat, lateral position and speed. Absolute validity was investigated through testing for a significant difference between the two studies and relative validity was established through testing the interaction between study and condition (or segment).

2. Method

2.1. The participants (common for both studies)

Subjects were randomly recruited from the national register of vehicle owners (in the Linköping area). The simulator study was carried out a year before the real driving study and 10 of the 14 subjects that participated in that study also participated in the real driving study. Only data corresponding to these 10 test subjects have been included in this analysis. Each subject received a monetary compensation of €400 for the simulator study and €500 for the real driving study. The criteria for participation included good reported health (questionnaire), absence of sleep disturbances (including sleep apnea and restless legs) as indicated in the Karolinska Sleep Questionnaire (Akerstedt et al., 2008), not having irregular work hours (i.e. being a shift worker), being able to abstain from smoking for 24 h (only one participant smoked – 3–4 cigarettes/day), ability to abstain from caffeine for 24 h (average cups of coffee per day = 2.2 ± 0.5), a BMI within the range 22–30 (mean: 24.3 ± 1), no medication, no glasses needed for driving (to permit camera monitoring of eye movements), a minimum of 5000 km of driving per year, and no problems with motion sickness (for the simulator). Before participation, the subjects received detailed information about the study and signed an informed consent form. The menstrual cycle was not controlled for in the study. The mean age of the 10 individuals that participated in both studies were 40 ± 11 years and 5 of participants were women. They were experienced drivers and had held a driving license for an average of 21 ± 11 years. The mean self-reported sleep duration did not significantly differ between the studies (simulator: 7.5 ± 0.2 h, field study: 7.7 ± 0.7 h). The mean Epworth Sleepiness Score was 7.4 ± 3.1 before the simulator study and none of the participants reported symptoms of excessive daytime sleepiness in the questionnaire that was filled in prior to both studies.

Table 1
The starting time of the driving sessions included in the analysis from both data sets.

Condition	Simulator		Real road	
	Session	Time of day	Session	Time of day
Day	1	09:30 or 11:00	1	09:00 or 11:00
Night	6	03:00 or 04:10	5	01:00 or 03:00

2.2. Overall design

The simulator study was preceded by a practice run some days before the experiment proper. The real driving study was preceded by a practice run on the way out to the test road used during the experiment. For both experiments the test subjects were required to sleep between 23:00 and 07:00 during the three nights before the experiment. This was monitored via wrist actigraphs and sleep diaries. Subjects arrived at the laboratory around 08:00 h, then electrodes were applied and the test subjects filled out questionnaires. Both experiments had several driving sessions scheduled from around 9 in the morning to late night.

The *real* driving condition had one group (early) scheduled at 09:00, 13:00, 17:00, 21:00 and 01:00. The late group started at 11:00, 15:00, 19:00, 23:00 and 03:00. The *simulated* driving study had one group starting at 09:30, 13:00, 16:30, 20:00, 23:20, and 03:00. The late group started 10:40, 14:10, 17:40, 21:10, 00:30 and 04:10. For the statistical analyses one morning drive and one night drive were selected (see Table 1 below for the driving session times).

The duration of the driving sessions in the real driving experiment was 90 min, but only the first half of each driving sessions has been used here since the second half involved experiments with sleepiness warning systems. The duration of the drive in the simulator experiment was 60 min. After each drive the participants filled out debriefing questionnaires. The studies were carried out at the Swedish Road and Transport Research Institute, Linköping, Sweden.

The studies were approved by the regional ethical committee in Linköping, Sweden. In addition, a government approval was obtained permitting studying sleepy drivers on public roads. No driving was allowed after 05:00. The local police was informed about each drive, but did not monitor drives and were not visible in any way during driving.

2.3. Scenario and vehicle

For *real driving* the experiment took place on a rural road (Road 34) in south-east Sweden during October through December 2007. The vehicle used in the experiments was a Volvo S80, model year 2000, equipped with dual command. Each driving session began at the same spot along the road, just outside the city of Linköping, and then proceeded along Road 34 to south of the town of Kisa, situated about 55 km south of Linköping. Here, the drivers turned back toward the starting point in Linköping. For the most part, the road stretches of Riksväg 34 (considered in this work) are 9 m wide with a driving lane width of 3.75 m and have a speed limit of 90 km/h. During the second half of each driving session (i.e. after the turn in Kisa and on the way back to Linköping), a driver sleepiness