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# Reliability of a driving simulation task for evaluation of sleepiness

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**Abstract**

Driving Simulators reproduce situations that require tracking and visual searching, the main features of real driving. This study measured the reliability of a monotonous driving scenario to detect the circadian variations of alertness in healthy subjects.

Five men and five women underwent a monotonous 30 min driving simulation task every 2 h. Before each driving task subjects completed the Stanford Sleepiness Scale (SSS) and the Visual Analogue Scale (VAS) to correlate the subjective measurements of sleepiness to the objective data of the simulator. Driving performances deteriorated or improved according to the circadian variation of alertness.

The scenario is suitable to detect the consequences of sleepiness related to the circadian variations of alertness. The standard deviation of lane position, comparing the differences among the 10 min blocks in each task is the parameter most significant for the evaluation of sleepiness.


*Keywords:* Sleep deprivation; Sleepiness; Circadian variation of alertness; Driving performance; Driving Simulator

## 1. Introduction

Driving Simulators reproduce situations, requiring tracking and visual searching, the main features of real driving. Driving Simulators allow to analyze the consequences of different kinds of simulation tasks in conditions of excessive daytime sleepiness, when the alertness is decreased, without any risk for the subjects involved in the study [1–5,7–13]. Relative to these tasks, the major consequence of sleep deprivation is a decrement of driving performance, such as an interaction of the duration of sleep deprivation and the time of day.

The aim of this study was to measure the reliability of a monotonous driving scenario to detect the circadian variations of alertness in healthy subjects. We tried to identify the most important driving parameter for evaluation of sleepiness.

## 2. Materials and methods

We evaluated 10 healthy subjects (5M/5F), mean age ± S.D. = 25.2 ± 1.6 years, with a valid driver license. Exclusion criteria were: symptoms of a medical or sleep disorder, including excessive daytime sleepiness tested with the Epworth Sleepiness Scale (score >10) [6], alcohol, coffee or nicotine abuse, use of drugs which can interfere with the circadian variation of alertness (barbiturates, benzodiazepines, antidepressants, antihistamines, antiepileptics, neuroleptics). All subjects gave their written informed consent to the study.

### 2.1. Protocol

Subjects underwent a monotonous 30 min driving simulation task (STISIM 300, Systems Technology Incorporated, Hawthorne, USA) every 2 h, from 10 a.m. to 12 a.m. of the following day without sleeping or taking stimulants (coffee, tea, chocolate) during the study.

The Driving Simulator was equipped with steering wheel, gas and brake pedals, 17 in. display, and sound.

The night before the test and during the test, the subjects underwent Actigraphy (Sleepwatch v2.22, Cambridge Neurotechnology Ltd.).

Before each driving task subjects completed the Stanford Sleepiness Scale (SSS) and the Visual Analogue Scale (VAS) for subjective measurements of sleepiness.

### 2.2. Driving scenario

We projected a very monotonous driving scenario to unmask hidden drowsiness. The simulation lasted 30 min. It

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showed a cross-country highway, with two lanes in each direction. There were a few curves, intersections and many oncoming and approaching vehicles, but there were no obstacle that forced the driver to brake or change direction if the subject kept driving to the right hand lane. At the top corner of the driver's display there were two gray squares with a red diamond inside that changed into a red triangle or a horn symbol. When the diamond changed, the subject had to push the corresponding traffic indicator or the horn immediately, to record the Reaction Times (RT) (Divided Attention Driving Task, DADT). If they did not push, after 5 s the symbol became a diamond again and the DADT was missed. There were 35 DADTs in pre-specified points along the track, but during the 30 min simulation task the subject met 22–26 DADTs, according to the speed maintained.

During a trial simulation, the subjects were instructed in the targets of the test: (1) drive in the right hand lane; (2) maintain a speed between 80 and 120 km/h; (3) respect the variable speed limits; (4) attend to the DADTs to measure the Reaction Times while driving.

### 2.3. Statistical analysis

We analyzed mean and standard deviation of lane position (distance from the vehicle to the Midline), speed and Reaction Times to DA, number of correct and incorrect DA, exceeding the speed limit and crash frequency data. Driving performance data were grouped in three 10 min blocks and we analyzed the differences between the blocks of data. Non parametric tests (Wilcoxon test and Kruskal–Wallis test)

Table 1
Mean of each parameter and statistical analysis with Kruskall–Wallis test

| Time | Crashes (*n*) | Corr DA (*n*) | Incorr DA (*n*) | M DA (s) | M1 DA | M2 DA | M3 DA | DS DA (s) | DS1 DA | DS 2DA | DS 3DA | M Mid (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.00 | 0.00 | 22.60 | 0.80 | 1.58 | 1.66 | 1.37 | 1.41 | 0.68 | 0.81 | 0.56 | 0.57 | 4.79 |
| 12.00 | 0.00 | 22.80 | 0.80 | 1.42 | 1.37 | 1.34 | 1.43 | 0.46 | 0.55 | 0.50 | 0.60 | 4.82 |
| 14.00 | 1.00 | 22.90 | 0.50 | 1.33 | 1.31 | 1.31 | 1.30 | 0.50 | 0.60 | 0.42 | 0.47 | 4.83 |
| 16.00 | 0.00 | 23.00 | 0.50 | 1.31 | 1.33 | 1.21 | 1.32 | 0.60 | 0.62 | 0.42 | 0.64 | 4.83 |
| 18.00 | 0.00 | 23.30 | 0.10 | 1.23 | 1.23 | 1.19 | 1.32 | 0.48 | 0.49 | 0.38 | 0.53 | 4.81 |
| 20.00 | 0.00 | 23.20 | 0.30 | 1.22 | 1.20 | 1.19 | 1.28 | 0.53 | 0.49 | 0.40 | 0.49 | 4.84 |
| 22.00 | 0.00 | 23.30 | 0.10 | 1.20 | 1.14 | 1.21 | 1.27 | 0.40 | 0.30 | 0.38 | 0.41 | 4.83 |
| 24.00 | 0.00 | 22.90 | 0.30 | 1.27 | 1.25 | 1.23 | 1.29 | 0.41 | 0.49 | 0.25 | 0.41 | 4.79 |
| 2.00 | 2.00 | 22.90 | 0.20 | 1.34 | 1.26 | 1.25 | 1.51 | 0.55 | 0.59 | 0.29 | 0.58 | 4.84 |
| 4.00 | 3.00 | 23.00 | 0.20 | 1.36 | 1.30 | 1.29 | 1.53 | 0.61 | 0.58 | 0.35 | 0.68 | 4.80 |
| 6.00 | 8.00 | 22.80 | 0.20 | 1.60 | 1.44 | 1.47 | 1.86 | 0.66 | 0.58 | 0.37 | 0.83 | 4.83 |
| 8.00 | 7.00 | 22.70 | 0.40 | 1.52 | 1.35 | 1.56 | 1.60 | 0.62 | 0.48 | 0.67 | 0.63 | 4.80 |
| 10.00 | 5.00 | 22.80 | 0.40 | 1.44 | 1.33 | 1.41 | 1.56 | 0.58 | 0.47 | 0.44 | 0.64 | 4.80 |
| 12.00 | 2.00 | 23.40 | 0.20 | 1.32 | 1.25 | 1.28 | 1.42 | 0.46 | 0.42 | 0.42 | 0.53 | 4.83 |
| K–W test | 0.00* | 1.000 | 0.711 | 0.127 | 0.468 | 0.454 | 0.066 | 0.311 | 0.545 | 0.53 | 0.411 | 0.998 |

| Time | M1 Mid | M2 Mid | M3 Mid | DS Mid (m) | DS1 Mid | DS2 Mid | DS3 Mid | M Speed (km/h) | DS Speed (km/h) | Speed exc (*n*) | SSS | VAS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.00 | 4.75 | 4.82 | 4.83 | 0.28 | 0.26 | 0.26 | 0.28 | 101.15 | 9.34 | 2.60 | 1.90 | 8.43 |
| 12.00 | 4.78 | 4.83 | 4.85 | 0.27 | 0.26 | 0.26 | 0.27 | 101.57 | 9.02 | 1.80 | 1.60 | 8.71 |
| 14.00 | 4.79 | 4.86 | 4.85 | 0.28 | 0.28 | 0.27 | 0.28 | 101.42 | 8.45 | 1.30 | 1.70 | 8.35 |
| 16.00 | 4.77 | 4.86 | 4.85 | 0.31 | 0.33 | 0.41 | 0.40 | 101.86 | 9.86 | 3.50 | 2.00 | 8.16 |
| 18.00 | 4.77 | 4.84 | 4.85 | 0.29 | 0.27 | 0.27 | 0.30 | 101.66 | 8.73 | 1.90 | 2.00 | 8.16 |
| 20.00 | 4.79 | 4.86 | 4.87 | 0.30 | 0.27 | 0.30 | 0.30 | 101.31 | 8.50 | 1.70 | 2.20 | 7.76 |
| 22.00 | 4.79 | 4.85 | 4.86 | 0.30 | 0.28 | 0.30 | 0.30 | 100.41 | 8.85 | 2.50 | 2.60 | 7.31 |
| 24.00 | 4.80 | 4.86 | 4.86 | 0.31 | 0.29 | 0.30 | 0.32 | 100.03 | 8.66 | 2.10 | 3.50 | 6.08 |
| 2.00 | 4.79 | 4.89 | 4.87 | 0.34 | 0.31 | 0.33 | 0.34 | 99.83 | 9.23 | 1.80 | 3.50 | 5.92 |
| 4.00 | 4.76 | 4.82 | 4.84 | 0.44 | 0.44 | 0.42 | 0.44 | 100.34 | 9.25 | 3.20 | 4.20 | 4.63 |
| 6.00 | 4.80 | 4.84 | 4.83 | 0.46 | 0.39 | 0.45 | 0.51 | 100.06 | 10.56 | 6.30 | 4.10 | 4.48 |
| 8.00 | 4.77 | 4.82 | 4.81 | 0.49 | 0.39 | 0.55 | 0.49 | 100.25 | 10.46 | 4.30 | 4.40 | 4.65 |
| 10.00 | 4.78 | 4.84 | 4.78 | 0.50 | 0.38 | 0.47 | 0.59 | 99.66 | 9.47 | 4.60 | 4.30 | 4.54 |
| 12.00 | 4.84 | 4.83 | 4.83 | 0.38 | 0.34 | 0.40 | 0.39 | 101.87 | 9.33 | 3.50 | 3.56 | 5.88 |
| K–W test | 0.910 | 0.998 | 0.999 | 0.00* | 0.00* | 0.00* | 0.00* | 1.000 | 0.431 | 0.096 | | |

Crashes: number of crashes; Corr DA: number of correct DA; Incorr DA: number of incorrect and missed DA; M DA: Mean Reaction Time; M1 DA: Mean Reaction Time in the first 10 min; M2 DA: Mean Reaction Time in the second 10 min; M3 DA: Mean Reaction Time in the third 10 min; DS DA: standard deviation of Reaction Time DS1 DA: standard deviation of Reaction Time in the first 10 min DS2 DA: standard deviation of Reaction Time in the second 10 min; DS3 DA: standard deviation of Reaction Time in the third 10 min; M Mid: mean of lane position; M1 Mid: mean of lane position in the first 10 min; M2 Mid: mean of lane position in the second 10 min; M3 Mid: mean of lane position in the third 10 min; DS Mid: S.D. of lane position in the first 10 min; DS1 Mid: S.D. of lane position in the first 10 min; DS2 Mid: S.D. of lane position in the second 10 min; DS3 Mid: S.D. of lane position in the third 10 min; M Speed: mean of the speed; DS Speed: standard deviation of speed; Speed exc: mean of the number of exceeding the speed limits; SSS: Stanford Sleepiness Scale; VAS: Visual Analogue Scale.

* Significant results.

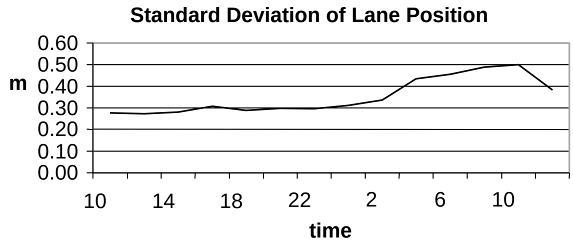


Fig. 1. Lane Position Variability.

with $\alpha < 0.05$ set and Pearson's correlations ($P < 0.05$) were used for statistical analysis (non c'è una chiara spiegazione di quello che questi valori vogliono dire: la deviazione standard della posizione della linea può rappresentare una misura della vigilanza, ma non ci sono elementi connotativi).

## 3. Results

Driving performances deteriorated or improved according to the circadian variation of alertness.

Standard deviation of lane position, Reaction Times to DA, exceeding the speed limit and crash frequency data deteriorated at 4 p.m. and during the night, from 2 a.m. to 8 a.m., when alertness is at lowest levels (Fig. 1). This variability (which variability ???) was significant for crashes and standard deviation of lane position (Kruskal–Wallis test: $\alpha < 0.01$, Table 1). Mean lane position and speed did not show significant differences.

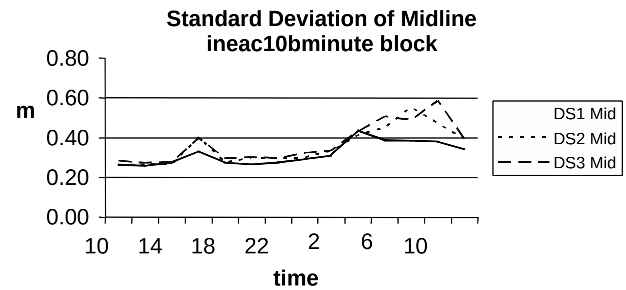


Fig. 4. Lane Position Variability in each 10 min block.

The most significant parameter for evaluation of sleepiness was standard deviation of (from ?) lane position. The analysis of Lane Position Variability every 0.5 s showed difficulties in maintaining the vehicle in the middle of the right hand lane when alertness was lowest, mostly after the night of sleep deprivation (Figs. 2 and 3).

The Mean Reaction Times and Lane Position Variability comparison between the first 10 min and the last block of data in each task showed differences when vigilance was lowest (Fig. 4). Standard deviation of lane position showed significant differences from midnight to 12 a.m. of the second day (Wilcoxon test: $\alpha < 0.05$) (Table 2).

Pearson's analysis showed significant correlations of the most important driving parameters (mean and standard deviation of Reaction Time, standard deviation of lane position, number of crashes, standard deviation of speed, number of exceeding the speed limits) with Stanford Sleepiness Scale and Visual Analogue Scale (Table 3).

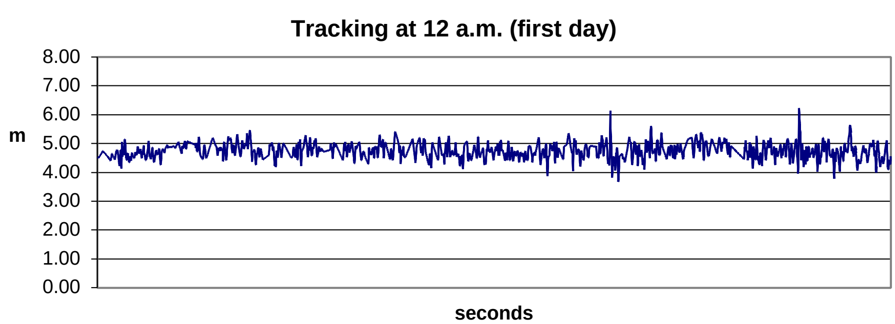


Fig. 2. Tracking at maximum alertness.

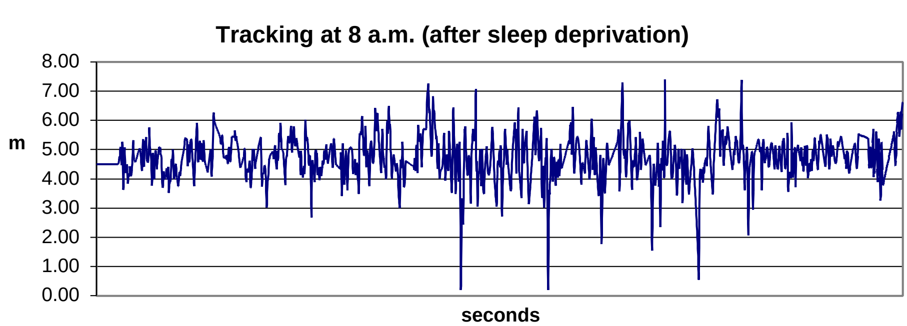


Fig. 3. Tracking at minimum alertness.

Table 2
Difference in the driving performance between blocks according to sleep deprivation and to the time of day

| Time | M1–M3DA | M1–M2DA | M2–M3DA | DSl–DS3Mid | DSl–DS2Mid | DS2–DS3Mid |
|---|---|---|---|---|---|---|
| 10 | 0.139 | 0.028* | 0.575 | 0.241 | 0.959 | 0.059 |
| 12 | 0.445 | 0.508 | 0.386 | 0.139 | 0.241 | 0.445 |
| 14 | 0.799 | 0.959 | 0.721 | 0.575 | 0.799 | 0.169 |
| 16 | 0.721 | 0.241 | 0.445 | 0.093 | 0.203 | 0.575 |
| 18 | 0.139 | 0.721 | 0.059 | 0.203 | 0.508 | 0.037* |
| 20 | 0.575 | 0.799 | 0.203 | 0.022* | 0.074 | 0.721 |
| 22 | 0.047* | 0.333 | 0.878 | 0.114 | 0.028* | 0.028* |
| 24 | 0.646 | 0.575 | 0.646 | 0.037* | 0.386 | 0.03* |
| 2 | 0.047* | 0.508 | 0.037* | 0.049* | 0.114 | 0.959 |
| 4 | 0.059 | 0.575 | 0.093 | 0.045* | 0.169 | 0.959 |
| 6 | 0.013* | 0.646 | 0.028* | 0.013* | 0.093 | 0.028* |
| 8 | 0.013* | 0.059 | 0.575 | 0.047* | 0.05* | 0.139 |
| 10 | 0.11 | 0.508 | 0.203 | 0.09* | 0.05* | 0.139 |
| 12 | 0.169 | 0.386 | 0.028* | 0.028* | 0.037* | 0.646 |

* Wilcoxon test significant results.

Table 3
Correlations between driving parameters and subjective evaluation of sleepiness (Pearson's correlations)

| Correlations | SSS | $\alpha$ | VAS | $\alpha$ |
|---|---|---|---|---|
| MDA | 0.27 | 0.002* | −0.35 | 0.00* |
| Ml DA | 0.13 | 0.120 | −0.23 | 0.006* |
| M2 DA | 0.28 | 0.001* | −0.37 | 0.00* |
| M3 DA | 0.36 | 0.00* | −0.45 | 0.00* |
| DS DA | 0.17 | 0.038* | −0.26 | 0.002* |
| DS1 DA | 0.02 | 0.856 | −0.10 | 0.221 |
| DS2 DA | 0.09 | 0.291 | −0.10 | 0.234 |
| DS3 DA | 0.19 | 0.022* | −0.27 | 0.001* |
| M Mid | −0.07 | 0.393 | −0.04 | 0.678 |
| M Mid l | 0.02 | 0.818 | −0.09 | 0.241 |
| M Mid 2 | −0.09 | 0.264 | −0.02 | 0.811 |
| M Mid 3 | −0.11 | 0.157 | 0.03 | 0.737 |
| DS Mid | 0.49 | 0.00* | −0.48 | 0.00* |
| DS Mid | 0.32 | 0.00* | −0.32 | 0.00* |
| DS Mid 2 | 0.46 | 0.00* | −0.42 | 0.00* |
| DS Mid 3 | 0.39 | 0.00* | −0.38 | 0.00* |
| Crashes | 0.40 | 0.00* | −0.36 | 0.00* |
| Corr DA | −0.05 | 0.536 | 0.09 | 0.285 |
| Incorr DA | 0.01 | 0.663 | −0.02 | 0.562 |
| M Speed | −0.02 | 0.826 | 0.07 | 0.434 |
| DS Speed | 0.30 | 0.00* | −0.19 | 0.024* |
| Speed exc | 0.38 | 0.00* | −0.29 | 0.00* |

* Significant results.

## 4. Discussion

A long and monotonous scenario characterizes the Driving Simulation Test we designed.

The parameter highly significant for evaluation of sleepiness is the standard deviation of lane position: it indicates the subject's oscillations in maintaining the right hand lane. These oscillations could depend on light alterations of alertness, while a crash is the consequence of heavy sleepiness or a sleep attack.

The continuous variations of standard deviation of lane position show that when awake the subject does not move from his starting position, but has difficulties in maintaining the vehicle in the middle of the right hand lane when alertness is reduced, mostly after the night of sleep deprivation.

In particular, an important index of sleepiness seems to be the difference between the driving parameters in the first and third 10 min block: this is the "time on task" effect, the progressive deterioration of performances during each driving session.

We demonstrated that this scenario is suitable to detect the consequences of sleepiness related to the circadian variations of alertness and to unmask hidden sleepiness.

## References


[1] L.J. Findley, P.M. Suratt, D.F. Dinges, Time-on-task decrements in "Steer Clear" performances of patients with sleep apnoea and narcolepsy, Sleep 22 (6) (1999) 804–809.

[2] C.F.P. George, A.C. Boudreau, A. Smiley, Simulated driving performance in patients with obstructive sleep apnoea, Am. J. Respir. Crit. Care Med. 154 (1996) 175–181.

[3] M. Gillberg, G. Kecklund, T. Akerstedt, Sleepiness and performance of professional drivers in a truck simulator comparisons between day and night driving, J. Sleep. Res. 5 (1996) 12–15.

[4] M. Hack, R.J.O. Davies, R. Mullins, S.J. Choi, S. Ramdassingh-Dow, C. Jenkinson, J.R. Stradling, Randomised prospective parallel trial of therapeutic versus subtherapeutic nasal continuous positive airway pressure on simulated steering performance in patients with obstructive sleep apnoea, Thorax 55 (2000) 224–231.

[5] A. Iudice, E. Bonanni, M. Maestri, B. Nucciarone, S. Brotini, L. Manca, G. Iudice, L. Murri, Lormetazepam effects on daytime vigilance, psychomotor performance and simulated driving in young adult healthy volunteers, Int. J. Clin. Pharmacol. Ther. 40 (7) (2002) 304–309.

[6] M.W. Johns, A new method for measuring daytime sleepiness: the Epworth Sleepiness Scale, Sleep 14 (6) (1991) 540–545.

[7] M.G. Lenné, T.J. Triggs, J.R. Redman, Time of day variations in driving performance, Acc. Anal. Prev. 29 (4) (1997) 431–437.

[8] M.G. Lenné, T.J. Triggs, J.R. Redman, Interactive effects of sleep deprivation, time of day and driving experience on a driving task, Sleep 21 (1) (1998) 38–43.

[9] M.R. Risser, C. Ware, F.G. Freeman, V.D. Wooten, S. Billmann, Driving simulation performance and EEG evaluation associated with obstructive sleep apnoea, Sleep 22 (Suppl.) (2000) 119.

[10] M.R. Risser, J.C. Ware, F.G. Freeman, Driving simulation with EEG monitoring in normal and obstructive sleep apnoea patients, Sleep 23 (3) (2000) 393–398.
[11] M.B. Russo, D. Thorne, M. Thomas, H. Sing, D. Redmond, T. Balkin, N. Wesensten, G. Belenky, Sleep deprivation induced peripheral visual neglect identified in a driving simulator study, Sleep 23 (Suppl. 2) (2000) A248.
[12] D.R. Thorne, M.L. Thomas, M.B. Russo, H.C. Sing, T.J. Balkin, N.J. Wesensten, D.P. Redmond, D.E. Johnson, A. Welsh, L. Rowland, R. Cephus, S.W. Hall, G. Belenky, Performance on a driving simulator divided attention task during one week of restricted nightly sleep, Sleep 22 (Suppl.) (1999) 301.
[13] W.B. Verwey, D.M. Zaidel, Preventing drowsiness accidents by an alertness maintenance device, Acc. Anal. Prev. 31 (1999) 199–211.